MODELING THE IMPACTS OF CLIMATE VARIABILITY ON DISCHARGE OF THE UPPER RIVER YALA BASIN, KENYA

Miima Winstone Atamba

A thesis submitted in partial fulfilment of the requirements for the award of Master of Science degree in Climate Change Mitigation and Adaptation of Masinde Muliro University of Science and Technology

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DECLARATION

This thesis is my original work prepared with no other than the indicated sources and support and has not been presented elsewhere for a degree or any other award.

Sign………………………………… Date……………………………………

Miima Winstone Atamba

CCA/G/01-53990/2019

CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance of Masinde Muliro University of Science and Technology proposal entitled ''**Modeling the Impacts of Climate Variability on Discharge of the Upper River Yala Basin, Kenya**."

Sign………………………………… Date……………………………………

Dr. Veronica Kiluva Mwikali (PhD)

Department of Disaster Preparedness and Engineering Management

School of Disaster Management and Humanitarian Assistance

Masinde Muliro University of Science and Technology

Sign………………………………… Date……………………………………

Dr. Wekulo Saidi Fwamba (PhD)

Department of Disaster Preparedness and Engineering Management

School of Disaster Management and Humanitarian Assistance

Masinde Muliro University of Science and Technology

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DEDICATION

This thesis is dedicated to my mother, the late Rev. Lydia Miima for her love, sacrifice and guidance.

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Miima W. A.

ABSTRACT

The Upper River Yala, which is a very important tributary of Lake Victoria, has been subjected to a lot of discharge variation owing to the high intensity rains and the growing climate variability. Extreme weathers have changed the streamflow patterns, and there is a high association between tributary inflows and precipitation. In spite of the forecasts of the inter-annual discharge variation, a uniform trend was not yet determined about when the peak or the minimum flow occurs. Past research has looked at rainfall runoff relations but has not estimated the combined effects that climate variability and land use alterations have on discharge especially in the upper Yala catchment. The primary aim of this research was to model the effects of climatic variability on the discharge in the Upper River Yala Basin, Kenya. These objectives were to: simulate the effect of temperature variability on discharge; simulate the effect of rainfall variability on discharge; and to determine the effect of simulated climate variability on discharge in different land use and land cover cases. Based on historical daily temperatures and precipitation records (19902019), the Soil and Water Assessment Tool (SWAT) was installed to model the hydrological responses when different climatic and land cover conditions occurred. River gauging station data was used to calibrate and validate the model (19902006 and 20072019 respectively). It was found that discharge is highly dependent on the temperature and variability of rainfall. Rises in temperature correlated with higher river flows (coefficient = 11.264) and the effect of the maximum temperature was heavy compared to the effect of the minimum temperature. Rainfall became the most dominant factor and it contributed to 94.2% of the discharge variation (correlation coefficient = 0.963). High discharges were seen to occur with high rainfalls and low discharges during dry seasons. Changes in land use especially agricultural development and deforestation were noted to cause a reduction in river flow during the dry season and increase in river flow during the wet season. Dry season discharge decreased at 2.1 m 3 /s and 1.68 m 3 /s and wet season discharge climbed at 1.18 m 3 /s and 5.69 m 3 /s which signifies less water availability and more flows and risk of flood. These results indicate that climatic variability and altered land use have amplified seasonal variations on river discharge, lessening dry season flows and amplifying wet season flows. The temperature change had a major influence on the river flow, and an increase in the temperatures led to a decrease in the dry season discharge and the change in seasonal water supply. Times of change in discharge were also due to rainfall variability where low rainfall caused a decrease in dry season flows and high rainfall events causing a rise in the wet season flows indicating that the basin is sensitive to rainfall variability. Temperature and rainfall fluctuation together with land use alterations like agricultural growth and deforestation aggravated seasonal discharge distributions. This highlights the interactive action of climate and human activities on the dynamics of the rivers. The literature finds that climate variability, especially, rainfall and temperature changes, and land use processes have a significant influence on the pattern of discharges in rivers. It suggests that hydrological models need to be incorporated with temperature and rainfall variability, sustainable land use is needed, and the adoption of an Integrated Water Resources Management (IWRM) framework should be used. Future research should incorporate additional environmental variables, long-term climate scenarios, and ecological impacts, while integrated climate–land use–hydrology models can improve prediction and support sustainable management of the Upper Yala Basin.

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LIST OF ABBREVIATIONS AND ACRONYMS

AMS	Annual Mean Stream-flow
CMIP:	Coupled Model Intercomparison Project Phase
DHAs:	Direct Human Activities
ET:	Evapotranspiration
FAO:	Food and Agricultural Organization
GCMs:	Global climate models
GIS:	Geographic Information System
GLEAM:	Global Land surface Evaporation Amsterdam Methodology
GWAVA:	Global Water Availability Assessment
HRU:	Hydrologic Response Unit
LULC:	Land Use/Cover Change
MATLAB:	Matrix Laboratory
NSE:	Nash Sutcliffe model efficiency
PBIAS:	Percentage Bias
RCP:	Representative Concentrated Pathways
SWAT:	Soil Water Assessment Tool
TWS:	Terrestrial Water Storage
UNESCO:	United Nations Educational Scientific and Cultural Organization
USGS:	United States Geological Survey

DEFINITION OF OPERATIONAL TERMS

Annual Low Flow:	The average amount of water in a river during times of low flow
Annual Maximum Flow:	The highest observed flow in each water year.
Annual Mean Flow:	The average flow for the individual year or multi-year period of interest.
Catchment:	The area of land bounded by watersheds draining into a river. The water enters via precipitation and then moves across the surface or subsurface until it drains into a stream or river.
Calibration:	Calibration is the process of adjusting the parameters of a model so that its outputs closely match observed data. It ensures that the model accurately represents the real system during a specific period.
Climate Variability:	Temporal changes in climate as measured by temperature and precipitation deviations (anomalies) over a given period of time.
Duration of Flow:	How long flow exceeds or is below a given magnitude.
Frequency of Flow:	How often flow exceeds or is below a given magnitude.
Modelling:	Modelling is the creation of a simplified representation (mathematical, physical, or computational) of a real-world system or process to analyze, understand, or predict its behavior.
Magnitude of Flow:	The total amount of flow at any given time.
Rate of Change of Flow:	How quickly flow changes from one magnitude to another.

River Flow Regime:	The temporal patterns of high and low flows (changes to river discharge over a year) as influenced by temperature, precipitation and catchment properties.
Rainfall Variability:	Refers to the degree to which rainfall amounts fluctuate over time and space. It describes how inconsistent or unpredictable precipitation can be in a particular area or period.
Temperature variability:	Refers to the degree to which temperature fluctuate over time and space.
Socio-economic Impacts:	Effects arising from climate variability including health, water, livelihood security, forced displacement, loss of cultural identity, and other related risks.
Simulation:	Simulation is the use of a model to imitate or reproduce the behavior of a real-world system over time or under different conditions. It involves running the model to generate predictions or understand system dynamics.
Validation:	Validation is the process of testing a calibrated model against an independent dataset (different from the calibration data) to evaluate how well the model predicts real-world outcomes. It checks the model's reliability and accuracy.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

At the global-scale, the likelihood of high risks of significant ecological change in both high and low flows increase with global warming: across all basins there is a medium to high risk of change in high (low) flows in 21.4% (22.4%) of ensemble members for 1.0°C warming, increasing to 61.5% (63.2%) for 3.0°C. Risks are particularly pronounced for low flows at 3.0°C for many rivers in South America, southern Africa, Australia, southern Europe and central and eastern USA (Thompson *et.al*, 2021). Climate change and variability is presenting new challenges in management of water resources across the globe with key challenges including water availability, appropriate allocation and adaptation strategies to best equip basins and their stakeholders for any possible future change (Rickards, 2020). Global climate models (GCMs) have projected future changes in stream flow and watershed hydrology, observations that are in agreement with the global evidence of a warming world (Tessema *et.al*, 2021).

The impacts of climate change on future river flows are of global concern, not just because of possible increases in the frequency and magnitude of floods and droughts, but also the impact of changes in the flow regime on river water quality, erosion, morphology and ecology (Kay *et.al*, 2020). According to Gulakhmadov *et.al*, (2020), Vakhsh River basin in central Asia is projected by the end of 2099 to increase its median and high flows but the low flow might decrease. Results from simulated hydrological model reported an increasing tendency of average annual stream flow, from 17.5% to 52.3% under various representative concentration pathways.

In Thailand, stream flow change in Mun River in response to future climate change may affect agricultural water demand, which would increase hydrological uncertainty and increase the challenges faced by local water assets management (Li & Fang, 2021). In the Upper Indus River Basin, climate change has an overall increasing trend on future stream flow (Khan *et.al,* 2020). Using a SWAT Model in a Semi-Arid Basin of El Kalb River, Lebanon, the average annual discharge in the near future (2021–2040) projects decrease by around 28–29% (Saade *et.al*, 2021). Simulation of river flow analysis in Britain of seasonal mean flow changes for two future time-slices (2020–2050 and 2050–2080) suggests large decreases in summer flows across the country (median−45% by 2050–2080), but possible increases in winter flows (median 9% by 2050–2080), especially in the north and west (Kay, 2021). Uncertain climate change impacts on high flows across Great Britain with regional variations in flow projections attributed to increased heavy-precipitation events although did not always result in increased flood flows for catchments with low runoff coefficients, highlighting the varying factors leading to changes in high flows (Lane *et.al*, 2022).

New Zealand River Hydrology revealed mean annual flood increases more in the south, while mean annual low flows show both increases and decrease. Changes that are likely to have important long-term implications for New Zealand's societal, cultural, economic, and environmental well-being (Collins, 2020). Majority of the projections suggest a dryer future of the USA-Mexico Trans boundary Santa Cruz River Basin. The declines in average precipitation from 1955–2000 to 2001–2020 of 50% in the winter and 17% in the summer were accentuated by reductions in stream flow on the Santa Cruz River of 87.6% and 63%, respectively (Shamir *et.al*, 2021).

For the near-term, the medians of the global climate models (GCMs) using the RCP 4.5 and RCP 8.5 suggest 2.9%–8.1% increases in the 100-year, 24-h flow event in the Connecticut and an increase of 9.9%–13.7% in the Merrimack River providing useful guidance for the long-term management of infrastructures on the Connecticut and Merrimack River floodplains (Siddique & Palmer, 2021). In different parts of Canada, the average precipitation increased since 1950s from under 500 to around 600 mm/year, with up to a 10% reduction in Prairies and up to a 35% increase in northern and southern parts. Annual stream flow patterns mostly exhibit stability, with changed temporal distribution, due to the complex interplay of different hydrological components. Massive investment for water management would be required to adapt to the impacts of climate change for agriculture in Canada (Bhatti *et.al*, 2021).

In the Upper Tekeze basin, Ethiopia, a scenario-based approach using Soil and Water Assessment Tool (SWAT) model that, during 1986–2015, low-flow duration decreased by 5.0 days/year, and the magnitude and occurrence of high flow increased by 5.23 m3/s/yr. and 5.11 days/year, respectively. The expansion in rock area increased runoff and high flow, which may lead to significant land deterioration and loss of water storage capacity in the mountainous basin (Reda, 2022). There is little information about the hydrological impacts of climate change in Burundi. An increase in mean and extreme stream flow has been found in the northern and central part of Burundi (Ruvubu basin), while in the south a reduction of discharge along the year, with exception of an increment in some rainy months (Rivas-López *et.al*, 2022). A study on

River Mpanga flows in Uganda showed that from 2000 to 2011 revealed that 70.46% of the total variance in river flows was attributed to climate variability (Onyutha *et.al*, 2021).

Simulated stream flow for base simulation (1985-2013) and two climate change periods of Kakia-Esamburmbur sub-catchment revealed an increase in floods under climate change will be between 6.7% and 8.2% for floods in 2016-2035 period and between 18.5% and 24.3% in 2046-2065 period under RCP 4.5 scenario (Tchouateu *et.al*, 2020). The change in hydrologic response of the Kaptagat catchment in Uasin Gishu County, Kenya over time for the period of 1989–2019 is largely attributed to the change in forest cover. Decreased forest cover from 1989–2009 led to a reduction in precipitation, an increased proportion of the rainfall converted to runoff, and decreased groundwater recharge (Kibii *et.al*, 2021). A study on the rainfall-runoff nexus in mid-block of river Yala catchment revealed a direct relationship of rainfall and runoff in the three watersheds namely Edzava River watershed, Zaaba River Watershed and Garagoli River watershed all located in the mid-block section of Yala catchment. High runoff generated in river Yala basin is caused by intense storms upstream. The study recommended that rainfall-runoff model was suitable for predicting future possible scenarios in the water shed (Odiero *et.al*, 2018). Most of the previous studies on river Yala basin have focused on the lower Yala basin and ecosystem services with almost none focusing on climate variability. It's against this background this study seeks to examine the effects of climate variability on upper Yala basin.

1.2 Problem statement

River Yala, which is a major tributary of Lake Victoria, has a high variation in discharge between wet and dry seasons and this is mainly caused by the increase in intensity of rain seasons and extended dry seasons. Extreme weather events are rising, which also contributed to the variability of streamflows, which partially supports the high correlation between precipitation and tributary inflows in Lake Victoria (Paul & Oppelstrup, 2020). Although future projections of discharges indicate a high inter-annual variability, it does not appear that there is a systematic trend among the various Representative Concentration Pathway (RCP) scenarios. Such forecasts are primarily changes in when and how large discharge highs and lows are (Osaka et al., 2019). Although the previous simulations have shown that there are strong correlations between the rainfall and surface runoff in some of the parts of the Yala catchment, the effects of climate variability on the overall hydrological behaviour of the river especially in the upper catchment have not been well studied (Odiero, 2019). The hills, wetlands, and floodplains of the upper River Yala catchment are medium-gradient slopes having soils with textures of silty clay to clay (Olale et al., 2019). All these are physical characteristics that affect the response of the basin to the events of rain and climate variables. The Kenyan government has also suggested the development of Keben Dam at the junction of Kimondi and Mokong' tributaries in the upper river Yala catchment as a solution to increased water requirements. The dam also seeks to provide treated water to various towns and provide a source of small-scale hydropower generation. The sustainability and feasibility of this project, however, greatly depend on a good insight into the hydrological responses of the catchment to new climatic conditions (Jared, 2018). Up to date, little is known of the impacts of changes in temperature and precipitation, which are major signs of climate changes, on river discharge of the Upper River Yala Basin. This lack of knowledge is a barrier to proper water resource planning, development of infrastructure and the development of climate adaptation strategies. Thus, the hydrological processes of the basin in various climate and land use conditions should be urgently simulated and analyzed. This will help to make evidence-based water management and policy decisions about the region that are sustainable.

1.3 Study Objectives

The main objective of the study was to simulate the impacts of climate variability on discharge of the upper river Yala basin, Kenya.

Specific Objectives

The study was guided by the following specific objectives;

i. To simulate the influence of temperature variability on discharge in the Upper River Yala Basin, Kenya.
ii. To model the influence of rainfall variability on discharge in the Upper River Yala Basin, Kenya.
iii. To establish the influence of simulated climate variability on discharge under different land use and land cover scenarios in Upper River Yala Basin, Kenya;

1.4 Research Questions

The study was be guided by the following research questions;

i. How does simulated temperature variability influence river discharge in the Upper River Yala Basin, Kenya?
ii. How does simulated rainfall variability influence river discharge in the Upper River Yala Basin, Kenya?
iii. How does simulated climate variability under different land use land cover scenarios Influence River discharge in the upper River Yala Basin, Kenya?

1.5 Justification of the study

Temperature is the most widely used climate variable in climate variability and change (trend) analyses. The mean global temperature has increased by nearly 1.1°C since 1880 and from 0.15°C–0.20°C. Likewise, the average global surface temperature in 2022 was 0.86°C above the average of the 20th century (13.9°C), and it was the sixth-warmest among all years between 1880 and 2022. The mean precipitation responses to global warming are both positive (increase) and negative (decrease). Reviewed literature indicates that the extent of temperature variability and change differs with locations, months, seasons, investigation periods and considered scenarios or representative concentration pathways (RCPs), (Chinasho *et.al*., 2025). Observational evidence demonstrated that significant streamflow changes have occurred in one-third of 200 major worldwide rivers since the 1950s', attributed to the rising global temperatures, (Xu *et.al*., 2024).

Climate change has had a significant impact on precipitation and streamflow's across the river basins, regionally and worldwide. Understanding these hydroclimatic variables regardless of whether a change is statistically significant or not and detecting trends in changes due to the future impact of climate change is necessary to assess both long-term and short-term trends in precipitation and streamflow data, (Orkodjo *et.al*., 2022). Rainfall is one of the most important in the world, which influences both the spatial and temporal trends of streamflow availability. The amount and frequency of rainfall changes have a direct impact on streamflow patterns and availability of water in the watershed, (Malede, *et.al*., 2022).

Land use/cover change (LUCC) and climate change (CC) affect water resource availability as they alter important hydrological processes. Mentioned factors modify the magnitude of surface runoff, groundwater recharge, and river flow among other parameters, (Martínez-Retureta *et.al.,* 2022). Many researchers have modeled climate change impacts under the assumption of constant LULC types. This is unrealistic in areas typified by the impacts of human factors such as growing population, rapid urbanization and industrialization on hydrology. Thus, it is recommended that future hydrological conditions should be analyzed while using forecasted or projected or future LULC types, (Onyutha, 2024). Even though the effects of climate change on the hydrology and water quality of the catchment have been effectively assessed, future research should concentrate on determining which factor between land use and climate change has a greater influence on changes in hydrology and water quality in order to prioritize mitigation and adaptation measures (Gule *et.al*., (2024).

1.6 Significance of the study

In the face of climatic variability, measures should be developed and implemented to mitigate its impacts and maintain eco-environmental integrity and water supplies (Pirnia *et.al,* 2019). Estimation of the magnitude of future flows in a river catchment is always required for efficient design, planning, and management of projects that deal with conservation and utilization of water for various purposes (Osman *et.al,* 2019). The impacts of anthropogenic climate variability on river discharge are already apparent with changes in annual river stream flow, shifts in both flood peak magnitude and timing, alterations in flow duration curves and changes in magnitude of low-flow periods. Hydrological modeling provides a basis for future water development and management, which requires an understanding of the impact of climatic and environmental change on future hydrological conditions (Hakala *et.al,* 2019).

Africa depends on its water resources for hydroelectricity, inland fisheries, and water supply for domestic, industrial, and agricultural operations. Anthropogenic climate changes have implications on agriculture and energy sectors and hence the livelihood of people on the continent (Chawanda *et.al,* 2023). To develop adaptation and mitigation strategies to climate change it is urgently necessary to evaluate the impacts of climate change on the quantity of water in the rivers that drain into Lake Victoria (Shinhu *et.al,* 2023). A better understanding of the hydrological regime of the sub-region would be very instrumental in helping policy makers and water resource managers to make important decisions on investment, development and management. The insufficient sampling of African watersheds, and more generally of watersheds on the tropical belt, is a real issue for understanding climate change (CC) impacts on fresh waters and ensuring a safe, conscientious and shared use of inland waters (Tarpanelli *et.al.,* 2023).

Understanding and predicting inter-annual and multi-decadal variations and changes in climate and the resultant impacts has become a critical and active area of research globally over the decades. In developing countries particularly in Africa, expanding knowledge in this domain has become more pertinent hence the steady developments in research therein (Maviza & Ahmed, 2021). There is need for researchers in government institutes, universities, and other academic institutions should take the opportunity to utilize SWAT and their various research works (Akoko *et.al,* 2021).

1.7 Scope and limitations of the study

The study was conducted in the upper river Yala basin utilizing temporal and spatial data captured between the years 1990 to 2020. The study conducted trend analysis of temporal data across the wet and dry seasons. The study was limited to the accuracy of spatial, climate and observed river flow data used and to the time period used for validation. The study was also limited to utilizing temperature and rainfall from Kenya Meteorological Department and observed stream flow data from Water Resources Authority. Spatial data (for digital elevation model & land use land cover) were downloaded from USGS portal while soil data was obtained from the Food and Agricultural Organization (FAO) world digital soil map. The study was limited to using SWAT model to project future Upper River Yala discharge under different future climatic and land use scenarios.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter presents the empirical literature review on climate variability, response of stream flow to climate variability, hydrological models, SWAT model and climate models. The chapter also presents the conceptual and modelling frameworks underpinning the study. The chapter highlights the knowledge gaps by context of the studies, study variables and methodology.

2.2 Climate Variability and Hydrology

Pörtner *et.al*, (2022) asserts that currently, roughly half of the world's population is experiencing severe water scarcity for at least one month in a year due to climatic change and other factors. Climate change and changes in land use and water pollution are key drivers of ecosystem loss and degradation with negative impacts observed on culturally significant terrestrial and freshwater species and ecosystems in the Arctic, mountain regions and other biodiversity hotspots. Climate trends and extreme events have had major impacts on many natural systems. Away from these general observations, the current study was more specific in assessing the effects climate variability on tropical river catchments using the case of upper river Yala upper catchment in Kenya.

A literature review by (Abbas *et.al,* 2022), on the effects of climate variability on hydrology revealed water resources were more adversely affected than any other deteriorating factors. They observed that climate variability influenced the regional hydrology of watersheds, particularly surface runoff both at present and in the future. In the future, climate change would have a significant impact on stream flow systems worldwide. The impact of climate change on river-flow systems will vary from region to region. Building on these findings, the current study explored the past influence and modelled influence of climate variability on the discharge of upper river Yala catchment, bringing in a more local perspective of the effect of climate variability on water sheds. According to the Brief, U. W. P. (2019), water is the medium through which many of the impacts of the climate crisis are felt by society – for example, through diverse risks to the energy, agriculture, health and transport sectors.

Climate change negatively affects freshwater ecosystems by altering stream flow and water quality, posing risks to drinking water even with conventional treatment. While these are relevant observations and projections, in many countries, there is a gap in knowledge in terms of observational data and understanding how climate change will affect the hydrological cycle and water-dependent services at the appropriate temporal and spatial scales relevant to decision-making. This study sought to fill the above knowledge gap by establishing the past impacts and modeling future scenarios of climate change on river discharge of upper river Yala catchment in Kenya.

Pokhrel *et.al,* (2021), conducted a study on global Terrestrial Water Storage and Drought Severity under Climate Change. Results revealed that by the mid- (2030-2059) and late- (2070-2099) twenty-first century, Terrestrial Water Storage (TWS) is projected to substantially decline in the majority of the Southern Hemisphere, the conterminous U.S., most of Europe and the Mediterranean, but increase in eastern Africa, south Asia and northern high latitudes, especially northern Asia. Changes in

TWS are driven primarily by climate forcing, as opposed to land and water management and/or socioeconomic drivers. While their study was broader, covering terrestrial water storage, the current study specifically focused on effect of climate variability on river discharge using a case of one tropical river basin in Eastern Africa.

2.3 Specific Objective 1: Influence of Temperature Variability on River Discharge

Xu *et.al*., (2024) observes that each 1 ℃ rise in temperature corresponds to a 4% increase in streamflow. In cold and mountain regions, rising temperatures tend to affect streamflow through changes in evapotranspiration and the accumulation/ablation of snow and ice. For instance, in China's western Tianshan and Kunlun Mountains, about 42–64% of streamflow derived from meltwater. While this study links temperature variability to streamflow changes, it relies on evidence from cold, snowmelt-dominated basins that differ significantly from the tropical hydrology of the Upper Yala Basin.

Wang et.al., (2025), analyzed and compared how hourly extreme precipitation and streamflow in the Yangtze River Basin and its tributaries respond to temperature changes using scaling analysis. Their findings revealed a consistent temperature response across different spatial scales in the basins: hourly extreme precipitation increased at approximately 1.75 times the rate of daily precipitation. Furthermore, floods showed a positive response to rising temperatures, but the degree of this response was more consistent in the mainstem than it was in the tributaries. Both daily and hourly extreme streamflow in the mainstem increased by about 7 % (7.47 % and 6.18 % respectively) for every 1 °C increase in temperature. Although conducted in a large Asian basin, these results highlight the broader importance of examining temperature–

discharge dynamics, which remain underexplored in tropical catchments such as the Upper Yala Basin in Kenya.

Patterson et.al., (2022) applied a functional flows method to determine the ecological impact of modifying streamflow patterns in snowmelt-dominated watershed of the Sierra Nevada mountains in California. Their approach in climate change models was a combination of ensemble Global Climate Models (GCMs) and decision scaling approaches to include the impact of GCM-projections of the changes in precipitation variability on the streamflows patterns. Among the parameters of climate studied, the air temperature had the strongest influence on the functional flows. Although their setting is not comparable to tropical basins, the paper emphasizes the importance of temperature in hydrological responses, and this is why the study needs to test the impact of temperature on streamflow variability in the Upper Yala Basin.

Akhundzadah (2024) examined trends in mean annual temperature, river discharge across five river basins of Afghanistan (1980-2022) with an innovative trend analysis (ITA) trend analysis, Mann-Kendall (MK) and Sen slope (SS) estimator. These findings indicated drastic conclusions about the climatic changes such as an increase in mean annual temperature by 1.5 °C, which is significantly higher than the global rate of 1.3 o C and a decrease in river discharge of -128m 3/s in all the basins since 1980. The results highlight the need to evaluate temperature–discharge relationships in other susceptible basins such as Kenya Upper Yala where comparable long-term studies have been constrained.

Chakilu et.al, (2022), conducted a study on climate change and reaction of streamflow of watersheds in the high emission scenario in Lake Tana sub-basin, upper Blue Nile basin, Ethiopia. The research was used to assess how climate is changing in the area, and the effect on stream flow of watershed simulated using Soil Water Assessment Tool (SWAT) under Representative Concentration Pathway (RCP8.5) by comparing the past three decades of the last century (19712000) to this century (20712100). It found that change of temperature and precipitation did not exhibit consistent variation in the outputs of all the climate models used particularly temperature depicted an upward trend in the top emission scenario (RCP 8.5) across the past thirty years of this century. Therefore, the increase in potential evapotranspiration and the decrease of rainfall is bound to result in a decline of stream flow during the dry seasons. This paper illustrates that variations in temperature, as well as changes in precipitation, can greatly change the discharge pattern of tropical African basins- a fact that supports the significance of studying these processes in Kenya in the Upper Yala Basin.

2.4 Specific Objective 2: Influence of Rainfall Variability on River Discharge

As Xu et.al., (2024) observes, alterations of meteorological factors, especially variation of precipitation over a period of time is the first risk factor of world surface water resources, with the contribution of 83 percent of the variation. They examined the associations among meteorological factors/ocean and streamflow in the Yellow River, between 1960 and 2018 using the wavelet analysis. Meteorology was found to be more closely correlated to streamflow than ocean signals and accounted 79.3% of the variability in streamflow which is way more than ocean signals (0.1%). Precipitation was the most significant direct influence of the meteorological factors on streamflow (P

< 0.01). These findings bring rainfall to the forefront of the discharge variability and this connection is vital to evaluate in the rainfall reliant tropical basin like that found in Kenya, in the Upper Yala.

Hrour et.al., (2022), explored the effects in a Mediterranean catchment on precipitation and discharge in response to the climate change and human activity. Trends in the discharges and precipitations time series between the years 1960 and 2018 were examined using MannKendall, Pettitt and Buishand tests which identified the breakpoints. The analyses drew a downward trend of the precipitation whereby the mean annual precipitation declined by 16 to 26 percent since 1970. The reduction in discharge of about 35% started in the late 1970s/early 1980s. This research found out that there might be already an effect of climate changes where the discharge is reduced in catchments. The present research highlights the need to examine rainfall/discharge relationships in other susceptible areas like the Upper Yala Basin where the hydrological factor that influences the changes in precipitation is the most dominant..

Orkodjo et.al., (2022), estimated the purposes of climate change on the quantity of the precipitation, seasonal pattern, and streamflow of the Omo-gibe basin in Ethiopia. In the near future (20252050), medium future (20512075), and far future (20762100) projections of climate and streamflow using a mean ensemble of RCMs were compared to the reference (19892019). Mann-Kendall (MK) trend testing was employed to identify whether a change is statistically significant; the trend of temperature, precipitation and streamflow. To estimate the effect of climate change on the streamflow, the hydrological model that was applied was the Soil and Water Assessment Tool (SWAT). The decrease in annual average precipitation in the projected precipitation is 10.77-13.11 in the RCP 4.5 emission scenario and 11.10-13.86 in the rainy summer season (June-August) and irregular rain season (March-May). These are estimated to reduce an average annual streamflow by between 7.08-10.99% in the RCP 4.5 emission scenarios and 10.98-12.88% in the RCP 8.5 emission scenarios. These findings demonstrate that streamflow within tropical basins is very sensitive to fluctuation of rainfall, which supports the significance of the research of the same processes in the Upper Yala Basin in Kenya.

Odwori, (2022), assessed the effects of the change in rainfall and temperature on the streamflow of Nzoia river basin Kenya. The statistical test done on the data to determine statistically significant trends in streamflow, rain and temperature was carried out using Mann-Kendall statistical test. The correlation between the streamflow and the rainfall is positive meaning that the streamflow varies with the rainfall. This paper discovered a positive relationship between rainfall and streamflow, which proves that discharge patterns are closely related to the variability of rainfall. This local evidence supports the significance of rainfall as the major control of the streamflow in tropical basins like the Upper Yala.

2.5 Specific Objective 3: Climate Variability, Land Use/Land Cover (LULC), and Hydrological Response

Ahmed et.al., (2022), ranged the effects of land use/ landcover change and climate change on the runoff in the upstream region of Yangtze River, China. They have used statistical methods along with Soil and Water Assessment Tool (SWAT). The key landuse/landcover change between 1990 and 2005 is low grassland to medium grassland (2%), wetlands (0.9), bare land to medium grassland (0.2), glaciers to wetland (16.8) and high grassland to medium grassland (5.8). The results indicate that the average annual runoff at the Zhimenda station in UAYR is increasing, with 15 mm of it being due to climate change and the remaining 2% of it due to landuse/landcover change. Although this paper shows that although land cover transitions affect hydrology, climate variability has a much more influential effect on runoff, which might be interesting to examine in the Upper Yala Basin of Kenya where the two interact to produce discharge.

To comprehend the impact of LULC change on the run off of Rur basin, Germany, Shukla et.al., (2023), used the example of Soil and water Assessment Tool (SWAT). As it turned out, it was observed that the data of the stream flow and runoff was adjusted to the SWAT model between the years 2000 and 2010 and proved between 2011 and 2015. The numerical values that were used to compute the performance of the hydrological model were the coefficient of determination, p-value, r-value and percent bias (PBAIS). The average R 2 of the calibration and validation of the model were 0.68 and 0.67 (n= 3) as will be seen. The authors show that LULC change of the deciduous forest to urban settlements, agricultural land and grasslands increased the total basin runoff by 43, 14 and 4 percent respectively. These results indicate the high levels of hydrology of the LULC change that points to the need to test equivalent procedures in tropical basins like the Upper Yala where land conversion forces are working today.

Govender et.al., (2022), undertook a literature review on the remote sensing of land use-land cover variation and climate variability on hydrological process in Sub-Saharan Africa: scientific advances and limitations in the field. This study has shown that the remote sensed data application has been a widely accepted effective method of estimating the total evaporation. It has been however identified that little focus has been put on the impact of the LULC change and climate variability on the total evaporation. Ayalew et.al., (2023), examined the hydrological response to the process of change by land use and land cover and climate dynamics in the Rift Valley Lakes Basin Ethiopia. To evaluate the change in spatio-temporal water fluxes, the hydrologic model SWAT+ was used by utilizing five watersheds that were selected in the basin. This difference in the elements of the water balance implied that the watersheds had a wide spatial dissimilarity of the water flux. The average decrease in precipitation and evapotranspiration and infiltration and increase in surface runoff have been high during the period of interference compared to the period of the base. The change in land use and land cover in particular due to the high population growth rate and the fluctuation of the climate play a big role in the hydrologic system altersations within the basin. These findings describe that the changes in LULC, along with climate variability, are the critical issues that affect the hydrological changes in African basins and this must be considered in the Upper Yala Basin in Kenya.

In a study by Mangi et.al., (2022), the authors evaluated how the land-use in the Upper Pangani Sub catchment changed the water flow characteristics by using the hydrologic model Soil and Water Assessment Tool (SWAT). The QGIS was used to determine land use and alteration of cover within the Upper Pangani Sub catchment between 1987 and 2017. The outcome revealed that there was an increase in agriculture expansion in terms of 96,737 ha to 314,871ha between the year 1987 and 2017. The land cover of the basin has been influenced by changes in land usage. Forest has reduced in 196558 ha to

106839 ha in 1987 to 2017. The bush land cover has been lost by 83445 ha over this period. This research determined that the land cover conversion had caused a change in the hydrology nature of this catchment creating rapid surface run-off, rapid soil erosion and low infiltration rate of the soil. These changes in land cover changed hydrology of the basin that caused rapid surface runoff, soil erosion, and low infiltrations. The paper demonstrates that massive agricultural development and forest cover loss can severely interfere with the flow of catchment water, which explains why similar LULC-driven hydrological responses in the Upper Yala Basin of Kenya should be assessed.

2.6 Hydrological Modeling in Climate Variability Studies

As it is observed by Chathuranika et.al, (2022), the majority of hydrologic models were developed in various settings and subsequently applied to watersheds that had other climatic and watershed features other than what they were developed to apply to. The individual watershed should have been identified as suitable in terms of hydrological performance of models. The stream flow estimates made by various computation models may include certain differences with the stream flows measured on the ground. Consequently, it is significant that identification of the most appropriate hydrologic model to use in a specific watershed is vital when it comes to stream flows.

As Horton et.al, (2022) point out, since hydrological modeling was introduced the various models continue to multiply at an accelerated rate. In fact, no one good model can be applied to all purposes. Two generally accepted properties that models ought to have are parsimony and suitability to the problem under consideration i.e., a model is not permitted to be more intricate than required and also capable of being fit-purpose.

Certain models are specific to a specific set of processes, e.g. snow glaciers and hence are disproportionately applied in those areas. The most spread models, i.e. PREVAH, HBV-light, WaSiM, and SWAT are general models and applied to different subjects, including studies on the impact of climate change, floods, droughts, processes with cryosphere and operational forecasting.

Hakala et.al, (2019) notes that the models based on buckets are typically employed to model the effect of climate change on stream flow since they are typically thought to be complex enough to represent the most important hydrological processes, although their data needs are relatively low. These models are usually a catchment expressed lumpedly or semi-distributedly. In lumped models the catchment is assumed to be spatially homogeneous and in semi-distributed models the heterogeneity of the catchment is assumed by means of subunits generally referred to as Hydrological Response Units (HRUs). These models require data in terms of precipitation, temperature and evapotranspiration that are generally adequate in discharge modeling. In this case, a bucket-type hydrological model should be used when beginning with the production of stream flow projections. These models are simpler to establish and implement than process-based models as they require less data and are less costly to run allowing a greater collection of projections.

Ahmed et.al, (2020) notes that distributed physically based models are useful when either there are spatial conditions in the study or where there are measured data that are towards the hydrological aspects at the local interior points in the watershed. In this way, the spatial representation of the physical processes and physical inputs in the physically based models, are not being utilized efficiently, since the performance of the model is measured by the stream flow of output only. Moreover, distributed models that are based on physics are associated with their own modelling issues including nonlinearity, scale, equifinality, and the high number of input data and model parameters. The lumped models are potentially capable of capturing the watershed response of the watershed at its outlet.

The parameters of conceptual model are efficient and can model the temporal variation effectively. The conceptual models, when captured in a simplistic way result in a low cost of computation and a stronger model, which would be applicable to certain working situations. A good alternative option can be the conceptual model where the data available is limited and the watershed response is the primary interest. The availability of the forcing data, watershed scale, driving processes, and model application should be used to select the model that is used. This may lead to more simplified and more correct a model of watershed stream flow simulation.

2.7 Soil and Water Assessment Tool (SWAT)

2.7.1 Model application

As noted by Shrestha et.al, (2021), SWAT model is one of the most popular models particularly in the US and Canadian watersheds. The presence of custom-made datasets, including the US STATSGO soil database, the US First order weather generator database, and other datasets, is among the numerous factors that have predetermined the large-scale use of SWAT model in the watersheds of the US. In the Canadian watersheds, some of the significant SWAT applications have been; hydrology, water quality management including best management practices of water quality assessment,

assessment of the effects of climate change on hydrology or water quality, water security assessment, identification of variables source area. As compared to this model which has been mostly used in water sheds in the US and Canada, the present study increased its application through the modelling of the impact of climate change on the Upper River Yala Catchment in Africa.

The reviewed SWAT applications in the Mediterranean region by Aloui et.al, (2023) primarily focus on the evaluation of water resources quantity and quality and hydrologic and environmental impacts of land use and changes in climate. Various works conducted positive comparisons of responses of the Mediterranean watersheds or SWAT to other models or techniques. A considerable percentage of articles cited challenges in terms of availability of data since they are either low, poorly resolved or they are not available freely. They recommend that to maximize the performance of the SWAT, they should identify and develop correct model inputs and testing data. Based on their results and considering their shortcomings, the present research modeled the climate change impacts on the Upper River Yala catchment on the SWAT framework.

Akoko et.al, (2021) summarized the critical findings of SWAT applications in various studies in Africa, examined the existing challenges related to the application of SWAT model in the African continent, and established possible SWAT model improvements that could be implemented in future studies using the model in Africa. As they discovered, data on local sources can be used to model relatively low; and a significant number of researchers prefers to use global data in their analysis. They suggested that scholars in government institutes, universities and other academic institutions should use the available opportunity to apply SWAT and the newly developed SWAT+ in their different researches to plan and manage the broader ecosystem, and formulation of policies. Based on these suggestions, this work applied SWOT model to engage the impacts of variability of climate on the release of Upper River Yala catchment in Kenya.

In Kenya, Kibii et.al, (2021) used Soil and Water Assessment Tool (SWAT) to analyze the Effect of the Land Use and Climate Variability on the Kaptagat Catchment River Discharge. The findings indicated variation of the catchment hydologic response, which was provoked by more surface runoff, reduced base flow and groundwater recharge, and thus the high fluctuations in water levels in the catchment in the dry and wet seasons as it was simulated in the model. A discrepancy between the observed results and the model output by them was identified to be due to poor observed data, which curtails the model usage in the prospective day to day management judgment despite having the potential to hypothetically investigate the effects of land use and climate on river discharge. Following the same model and considering the results of the present study, the present study modelled the impacts of the climate variability on upper River Yala catchment discharge in Kenya.

2.7.2 Model accuracy

Nauman et.al, (2019) discovered it to be difficult to calibrate and validate the model due to inadequate records of the regular river discharge. Nevertheless, when these cases applied the calibrated parameter ranges to an independent validation time series the results of the parameter displayed good model performance. They advised that data on such daily discharge should be captured so as to get to know the hydrological processes taking place in the watershed better. The present research was done on a gauged river, and thus data is accessible.

Makumbura et.al, (2022), calibrated a SWAT model in five stream flow gauging stations with three different strategies of calibration. The employed strategies were (1) downstream data, (2) upstream data, both under the single-site calibration category, and (3) downstream and upstream (multi-site calibration) data. The model was now very good with the multi-site calibration technique as compared to good. This technique can be used to enhance the accuracy of the results and enables the hydrological modelers to take into account the spatial difference in the characteristics of watershed and minimise the uncertainty in the hydrologic forecasts. The same method was followed in the current study where several calibration technique was used to enhance the accuracy of the results.

According to Jin and Jin, (2020), in most cases, site-based stream flow data are the ones employed to calibrate and verify a hydrological model since it is hard to observe other variables. Other watersheds have heterogeneously located hydrological stations in some watersheds. Consequently, an auto calibrated model with site based stream flow data gives very generalized values of all model parameters and hydrological processes of the watershed. Thus, the site-based stream flow and other spatially heterogeneous observations data should also be combined with the model auto-calibration procedure to achieve reasonable model parameters and enhance the ability of the model to simulate hydrological processes of watersheds. The stream flow, Global Land Surface Evaporation Amsterdam Methodology (GLEAM) and satellite-based evapotranspiration

(ET) data combination proved beneficial to the performance of the SWAT model in simulating the stream flow and the water balance..

2.7 Climate Models

Pandey et.al, (2019) confirmed that to achieve sustainable development and gain an understanding of the availability of water; climatic projection should be combined with hydrological models. Coupled Model Intercomparison Project Phase 5 (CMIP5) climate models output was used in their research to combine the result with a calibrated hydrological model, Soil and Water Assessment Tools (SWAT) to assess the possible impact of climate change on green and blue water over Upper Narmada River Basin (UNB). Representative Concentration Pathways (RCPs) 4.5 and 8.5 were used in calibration of model to represent the baseline period (19702000) and three futuristic period P1 (20112040), P2 (20412070) and P3 (20712100).

Sensitivity of the Upper Narmada River Basin to climatic changes in the future was stipulated by them using projections of CMIP5 climate models and their methodology involved the operation of several climate model results in estimating the possible change across the river basin. Following the same line of thought, the present study relied on global climate models especially Coupled Model Intercomparison Project Phase 5 (CMIP5) climate models to model the effects of future climate variation on the discharge of upper river Yala Catchment in Kenya.

In assessing the adaptability of the current Global Circulation Models (GCMs) to Miami River watershed, Ohio, USA watershed using stream flow regimes, Shrestha et.al, (2019), determined the adaptability of the prevailing Global Circulation Model. The climate change scenarios, comprising of ten downscaled Coupled Model Inter-comparison Project Phase 5 (CMIP5) climate models in combination with two Representative Concentration Pathways (RCP 4.5 and RCP 8.5) were chosen through the correlation of observed records and model outputs. The flows 2 simulated by SWAT reacting to most climate models forecasts reflected uniform enhancement in low flow tendency. In any case, the low flow ensemble of all the 10 climate models in the 21 st century, appeared to be slightly higher in comparison with historical low flows. This research paper has added to this literature as far as it used Coupled Model Intercomparison Project Phase 5 (CMIP5) climate model outputs in simulating the Yala River upper catchment, Kenya discharge.

Satriagasa et.al, (2023), found out the impacts of future climate change on the rainfall, stream flow as well as flooding of the Upper Nan Watershed. To determine the stream flow and flooding prospects in this region, SWAT and HEC-RAS were used. Three GCMs were used to make predictions on the effect of future climate change, under RCP4.5 and RCP8.5. The results showed that the rainfall in the Upper Nan Watershed which had a trend towards increase was expected to escalate further with the climate change. This will result in a wetter Upper Nan Watershed in future in both the dry and wet seasons. Contrary to this study, the current study attempted to determine the impact of the precipitation, temperature and land use changes on future stream flow in the upper river Yala catchment, in Kenya, despite the adoption of the same climate modeling scenarios.

2.8 Conceptual Model

The previous climate change context studies have adopted the soil and water assessment tool (SWAT) model in an attempt to show how the stream flows are sensitive to weather changes (Akoko et.al, 2021). SWAT is a semi-distributed continuous-time process-based river basin modeling that has the ability to simulate the hydrology, and other environmental processes like identifying how climatic variability affects the hydrology of a basin (Marahatta et.al, 2021). Land use land cover change, soil map, and a Digital Elevation Map (DEM) are the necessary inputs data to be used with SWAT. The model setup consists of five steps, i.e. data preparation, (2) the sub-basin discretization, (3) defining the hydro-logic response unit (HRU), (4) parameter sensitivity analysis and (5) calibration and validation (Ngo et.al, 2020). The SWOT model acquires the topographic data and the water system information on the Geographic Information System (GIS) and divides the target basin into sub-basins, and the sub-basin further divides into hydrologic response units (HRU), all of which have the same land-use condition and soil characteristics as the target basin (Lee et.al, 2020).

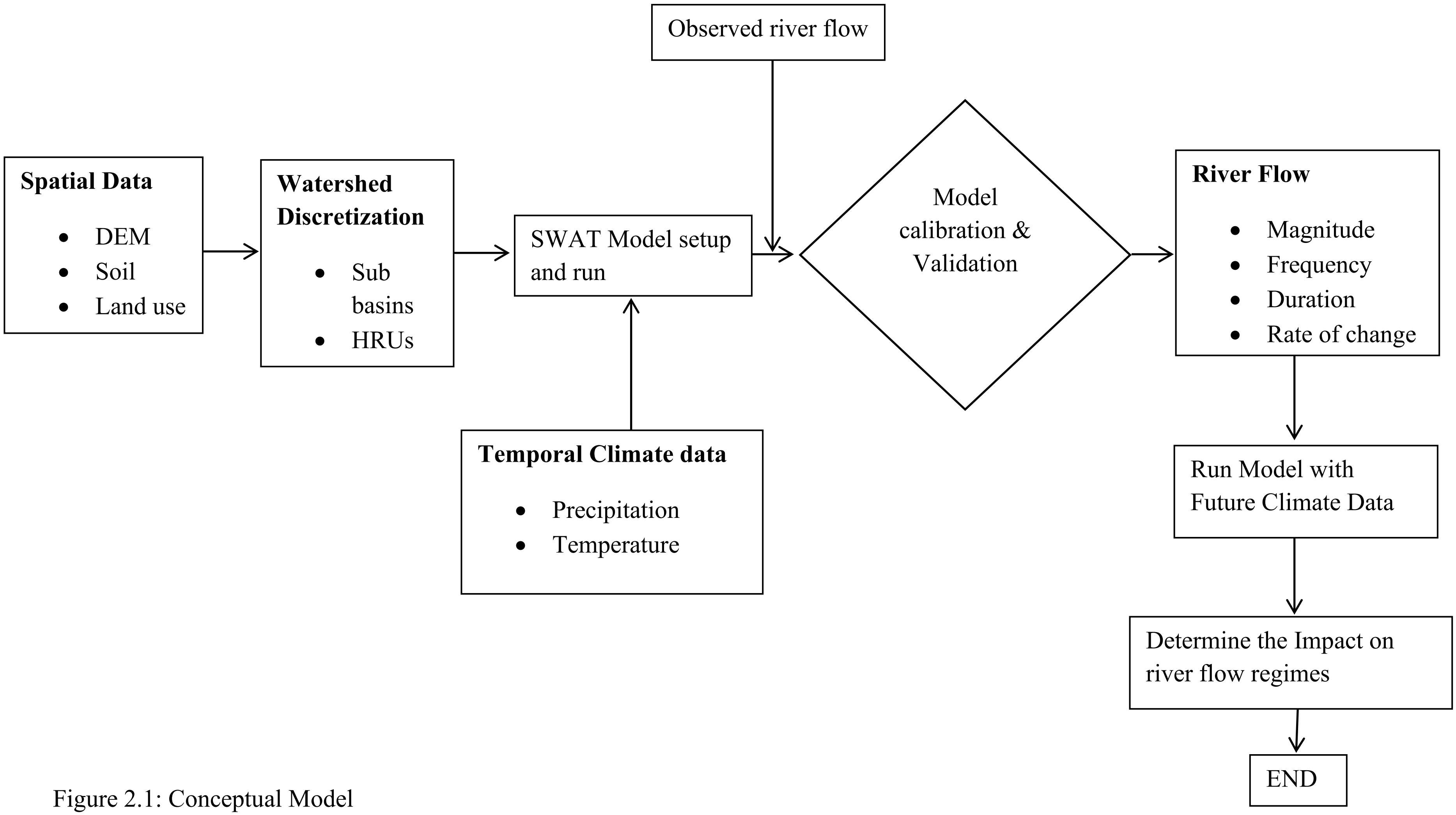


Figure 2.1: Conceptual Model

Source: Author, 2023

2.10 Conceptual Framework

Changes of LULC have both long-term and short-term temporal and spatial impacts on watershed hydrology. Topography and soil properties are more likely to result in short-term hydrologic variations (Leta *et.al*, 2021). Factors like demography, institutions, technology, biophysical, national and local policies and macroeconomic activities result in an extensive alteration of LULC which affect the hydrological systems both at the basin and regional scales.

On the other hand, climate change affects the hydrological cycle by changing runoff over watersheds, disturbing the transformation and transport characteristics of the catchment hydrology. Therefore, scientific investigations to understand the interactions between LULC, topography, soil characteristics and climate change, and their effect, is required to manage the water resource and environment in the face of future changes (Dibaba *et.al,* 2020).

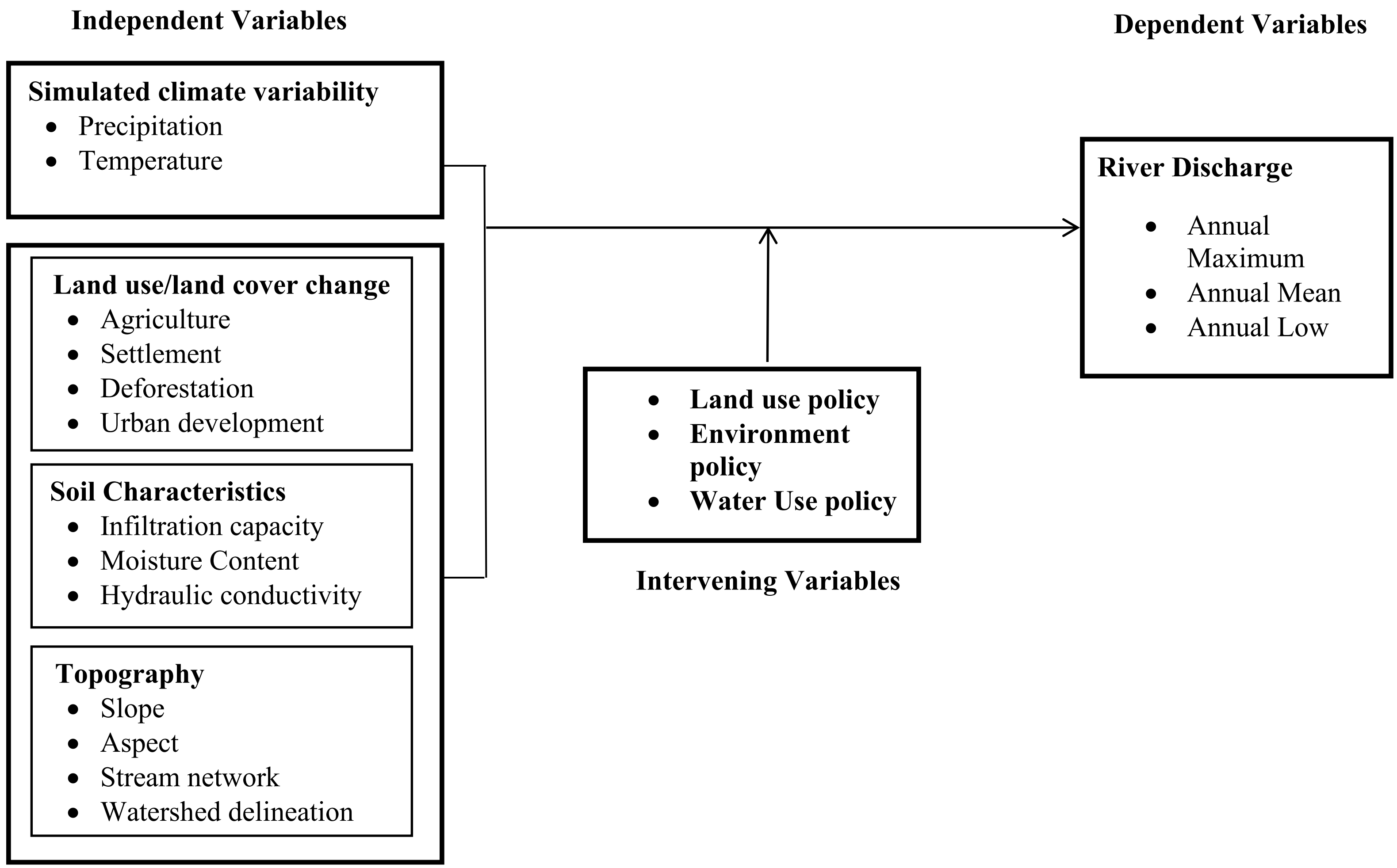


Figure 2.2: Conceptual Framework

Source: Author, 2023

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the methodology of the study. The chapter describes the area of study, data collection, trend analysis of climate data, SWAT modelling, estimating spatial and temporal impacts of Climate variability on Stream flow, forecasting of climate variability Impact on Stream flow, Ethical Considerations and Study limitations.

3.2 Research Design

A retrospective observational modeling design was used in this study as a way of simulating the effect of climate variability and land use/land cover (LULC) change on discharge in the Upper River Yala Basin, as per the objectives of the study. Daily and monthly historical time-series of streamflow, rainfall and temperature were summarized and digital elevation models (DEMs), soil and data on multi-date LULC maps were added. A semi-distributed hydrological model was created to be used on the sub-catchment level to enable the spatial representation of the processes within catchments.

To provide the answer to Objective One (temperature variability), the model considered both past and present records of temperatures to model its impacts on discharge. To achieve Objective Two (rainfall variability), precipitation records were examined and put in the model to assess the effects of the rainfall patterns on the streamflow variability. Objective Three (combined climate variability and LULC change) entailed the development and experimentation of alternative land use/ land cover scenarios with climate experiments to determine the combined and individual role of each alternative in achieving variations in both the mean and extreme occurrence of discharge.

To ascertain reliability of simulations, model calibration and validation was done using split sample based on observed discharge data. The use of minimum 30 years of climatic data as the climatological baseline to make the data more robust was supplemented with statistical tests of association, which were backed up by power analysis to guarantee adequate explanatory power.

3.3 Study Area

The river Yala basin covers an area of 3,351 Km^2 with an elevation ranging from 1200 meters above sea level (m.a.s.l.) in the lowlands to 2200 m.a.s.l. in the highlands. The 219 km long Yala River originates from Nandi Escarpment water tower and traverses Kakamega and Siaya counties before discharging into Lake Victoria at Winam Gulf. Based on data from 1950 to 2000, the river has a long-term average annual discharge of 37.6 m^3 per second, accounting for about 4.8% of the surface inflow into Lake Victoria. Common land use types within the upper river Yala basin are human settlements, agriculture that mainly entails tea and coffee plantations and other assorted crops with pockets of individual grazing plots. Soil type in the upland and midland catchment are well drained, deep, dark-reddish-brown humic Nitisols (Dida *et.al*, 2020). Average annual rainfall is about 850 mm in the large flat area near Lake Victoria and up to 2,000 mm in the highlands.

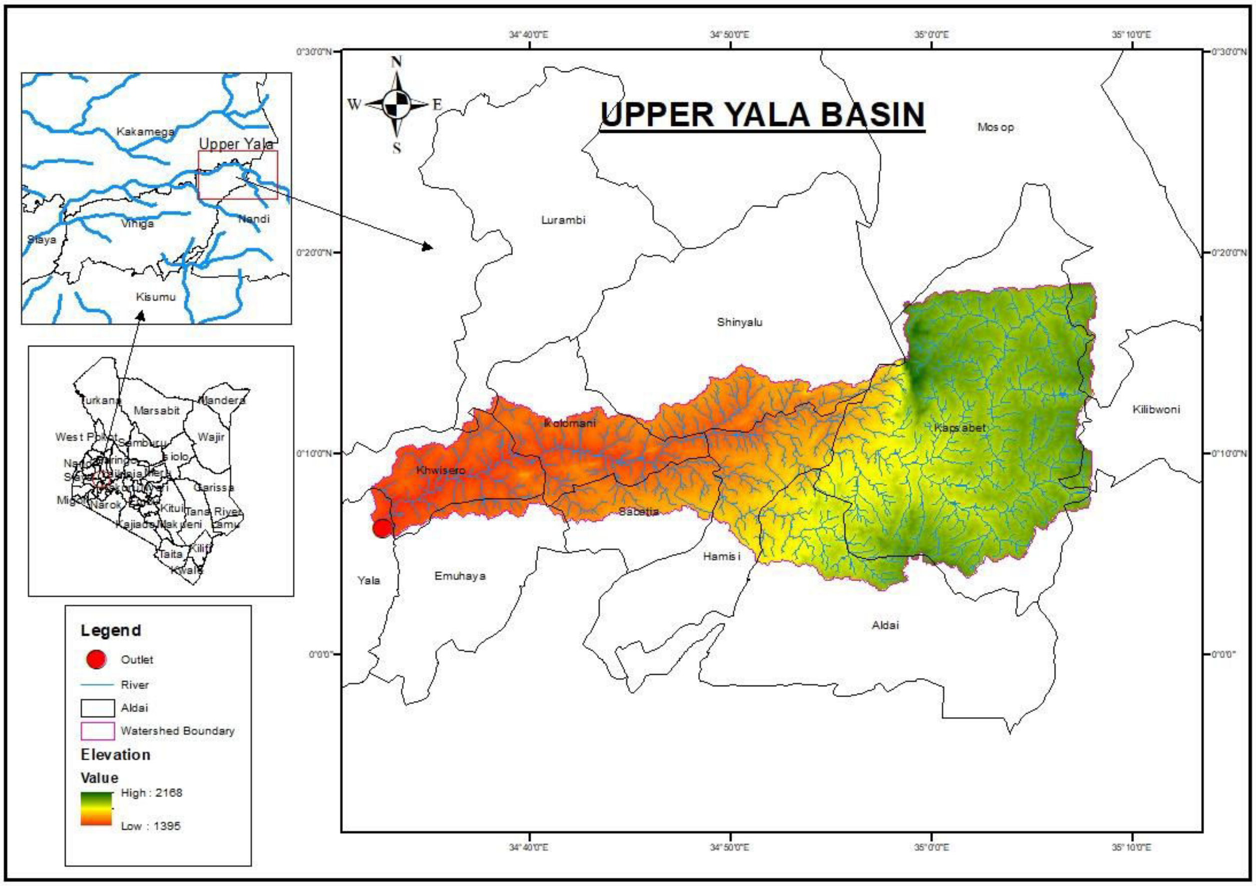


Figure 3.1: Map of the study Area, (Source Author 2023)

3.4 Data Collection

3.4.1 Temporal Data

The study utilized two temporal datasets, capturing climate variables and observed streamflow values in the Upper River Yala catchment. Temporal data observed between the months January, 1990 to December, 2020 was utilized.

3.4.1.1 Climate Data

The study utilized climate data observed by the Kenya Meteorological Department. Data on only two climate variables; temperature and precipitation were utilized in the study. The two-climate variables were preferred due to their data availability and completeness during the period of study. In addition, precipitation and temperature have more direct influence on river discharge.

3.4.1.2 Hydrological Data

This study utilized observed stream flow data from a river gauging station at the outlet of the upper river Yala basin. The data was used in calibration and validation phases of the SWAT model.

3.4.2 Spatial Data

The study utilized spatial data in developing digital elevation model, soil map and land use land cover for the study area. DEM data with a resolution of 30m were downloaded from United States Geological Survey (USGS). Land use Land Cover images were down loaded from the USGS. Image selection was guided by the driest month of the year as well as low cloud cover less than 10 percent. Soil database of the world from Food and Agricultural Organization was utilized to calibrate the MWSWAT database to the study area.

3.5 Trend Analysis of Climate Variables

The trend analysis of the monthly and annual values of climate variables based on the datasets of 2000 2020 year was conducted using non-parametric Mann-Kendall trend test. Mann-Kendall trend test was the favorite one as it has less conditions of validity and can handle missing values and outliers. The climate variables (air temperature, precipitation) were listed by the order of measuring (the month/year). A S positive (S) value is taken to be an increasing trend and a negative value is taken to be a decreasing trend. In order to statistically measure the significance of the rising and falling trends in the climate variables, two tailed test was done at the level of 5 percent..

3.6 Modeling Stream flow Response to Climate Variability using SWAT

The analysis involved the examination of the regimes of the streams in space and time with respect to the various climatic conditions. The SWOT modeling system was employed because it is a semi-distributed system, it is computationally efficient and less input data is required.

3.6.1 Preparation of Digital Elevation Model (DEM)

The topographic attributes of the catchment were parameterized by Digital Elevation Model (DEM) in regards to the size of the sub-catchment area and the stream length, stream width, stream depth, stream flow direction, the average slope, stream network and stream outlets. The Yala River Watershed was downloaded at the USGS site as a 30m resolution DEM based on elevation data of the Shuttle Radar Topography Mission (SRTM). The DEM gave description of the land on the catchment and hence it was crucial to the watershed model. The Arc-Swat was used to process the DEM in order to extract the path of streams, water shed boundary and the slope of basin as indicated in Figure 4.3. Division into a few sub-basins was then done depending on the topography and direction of flow.

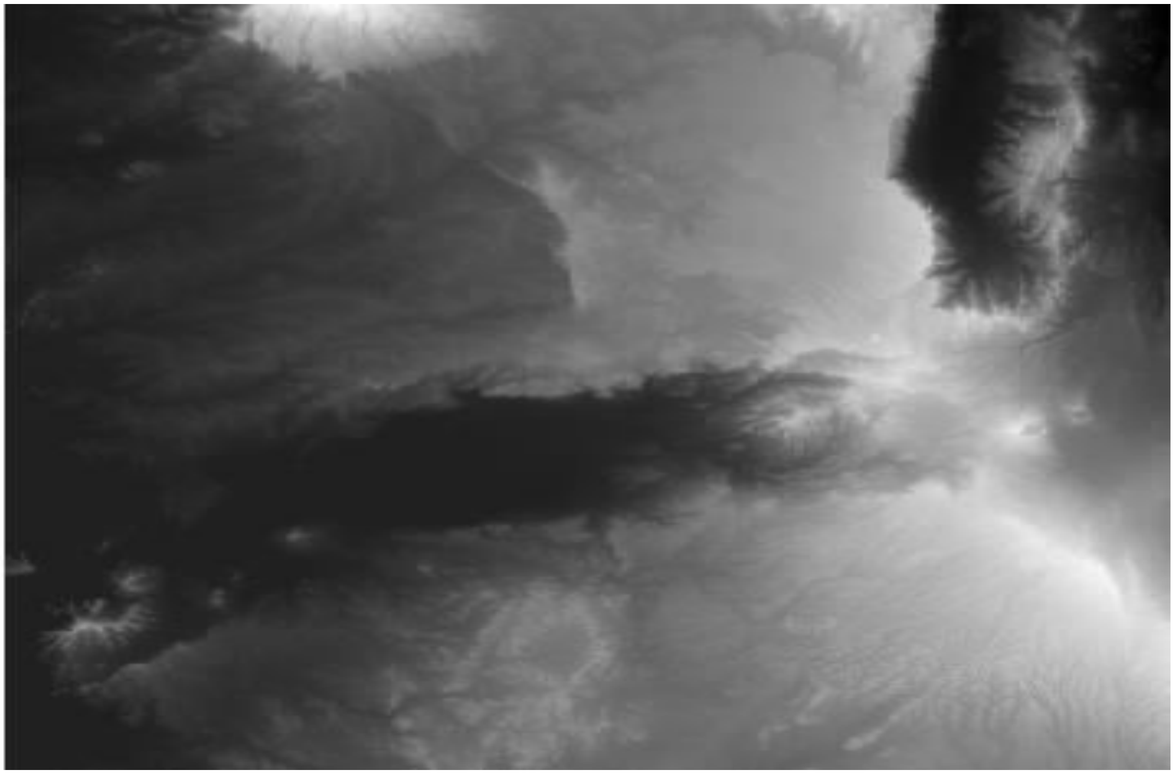


Figure 3.2 Digital Elevation Map for the Upper River Yala Basin

3.6.2 Preparation of Land Use-Land Cover Map

The parameters of hydro-logic response units were obtained based on the land use- land cover in order to be used in the SWAT modeling system. The land use/cover map provides the spatial area and grouping of different classes of land use/cover of the study area. This data of land use/cover combined with the cover of soil forms the hydrologic characteristics of the basin (the study area) which consequently forms the excess precipitation, recharge to the ground water system and storage in the soil layers. The elevation data of Radar Topography Mission (SRTM) was downloaded on the USGS site and served as the land use/cover data.

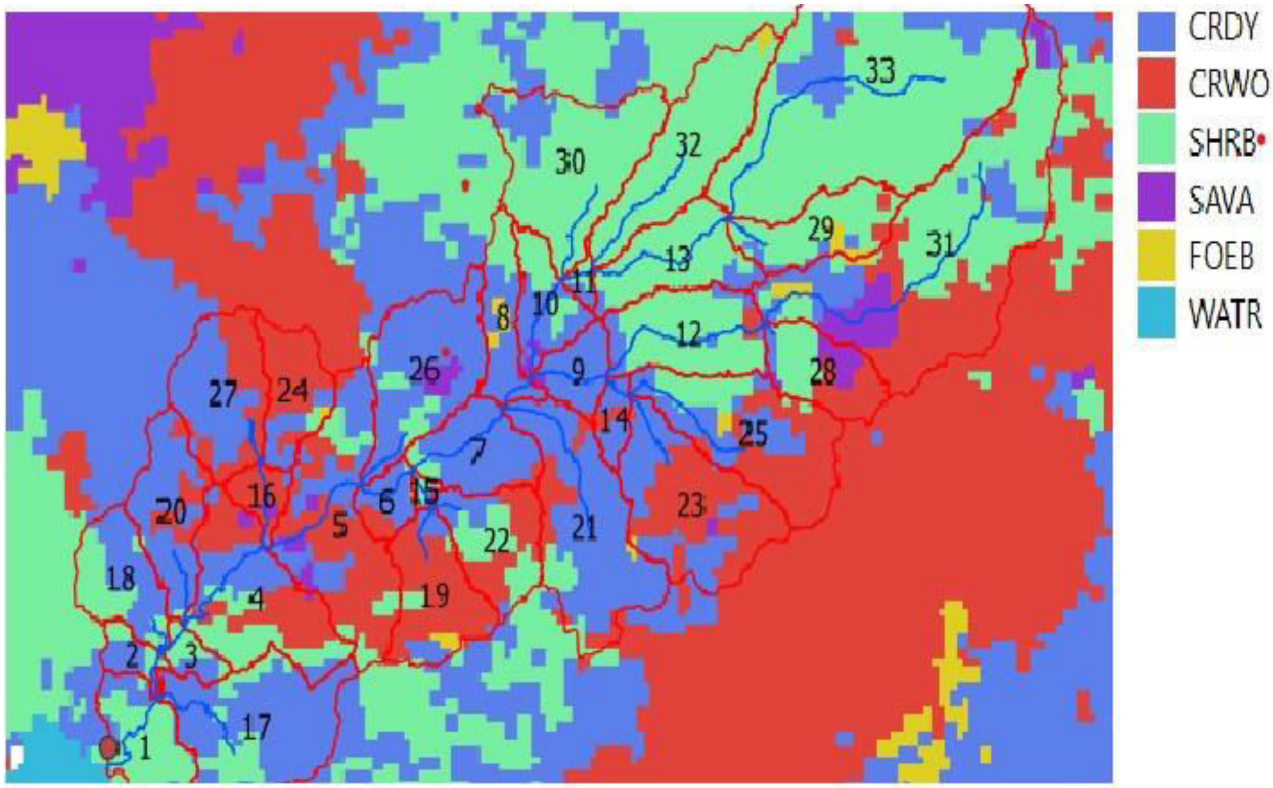


Figure 3.3: Land cover map for the Upper River Yala Basin

3.6.3 Preparation of Soil Data

In this research, FAO/UNESCO map of world soil classification was used. The data of the soil was used to obtain soil characteristics like moisture content, infiltration capacity, bulk density, texture, chemical composition, porosity, organic carbon content, water repellence and hydraulic conductivity of each unit of hydrologic response. The ready soil maps were the input to the SWAT database. The Soil data map of Yala River Watershed was downloaded at Soil and Terrain (SOTER) database of Upper Yala Catchment based on the scale of 1:250,000. The obtained data was then used to categorize the soil groups into 6 hydrologic groups of A, B, C based on their slowest rates of infiltration. This is due to the fact that the rate of infiltrating a soil and surface intake rates and the permeability of the soil below the surface (SCS, 1986). Then a GIS layer with hydrologic soil groups distribution within the basin was drawn.

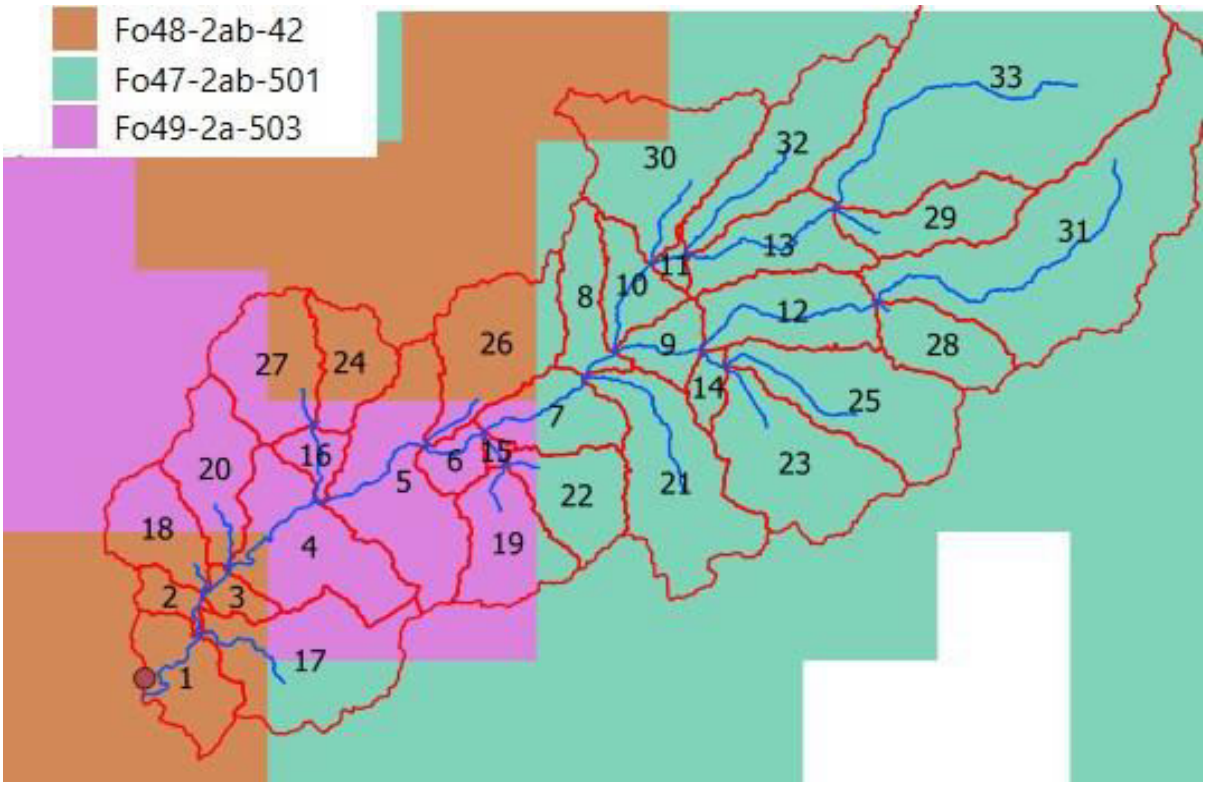


Figure 3.4: Soil map for the Upper River Yala Catchment Area

3.6.4 Preparation of Climate Data

Values for precipitation and temperature for the years 2000 to 2020 were obtained from records of observed data. Data was aggregated at daily interval and all missing data filled. The aggregated daily data was transformed to a format compatible with the weather generator. Weather generator database was developed for input into the SWAT database. Weather generator database comprised of the statistical data required to approximate missing weather data and simulate representative daily climate data for the sub-catchments.

3.6.5 Catchment Delineation

The topographic and river network information was used to delimit sub-catchments using GIS algorithm. Some of the steps used in this process were filling of pits of depression by increasing the elevation of the pit, calculating the direction of flow in each of the cells, determining the flow accumulation in each of the cells and delimiting the actual streams by a threshold of flow accumulation. DEM loading in the Arc SWAT 2012 model to do delineation was done by loading the DEM (12.5 m × 12.5 m). To obtain the stream network, a threshold area that determines the origin of a stream was applied. To delineate watersheds, the positions of the streamflow gaugings were introduced manually in form of sub basin outlets. This makes sure that, the calibration of the models was performed at the specific site. According to this, the total size of the watershed was 3,364.6km ^{2}.

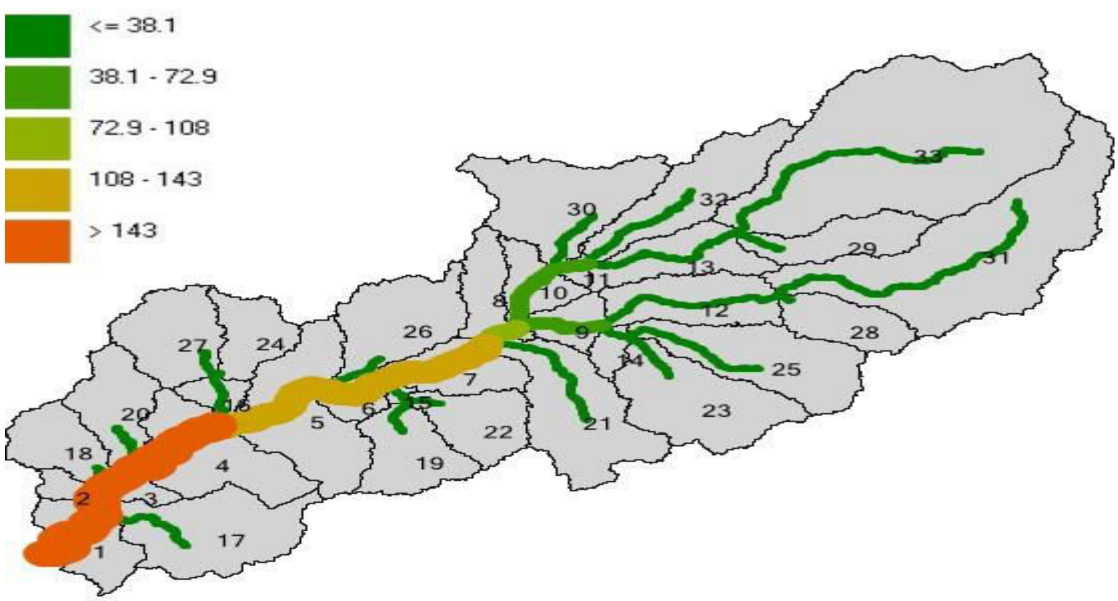


Figure 3.5: Upper Yala River Watershed

3.6.6 Hydrologic Response Unit Analysis

The reclassification of LULC, Soil spatial data, and slope basing on the DEM attributes was necessary to obtain the hydrologic response unit analysis because the study area does not belong to the USA. The hydrologic response units of each sub-catchment were outlined using the overlaid layers. Every HRU was regarded as a hydro-logically homogeneous unit comprising of a discrete combination of land-use and slope and soil in a sub-watershed. In order to enhance the efficiency of the model, small HRUs have been eliminated in the model set-up and their areas divided among the other HRUs.

Arc SWAT loaded the prepared land use and soil map into the delineated watershed and the slope was classified. Multiple slope as an option was chosen i.e., six classes (0-10, 10-20, 20-30, 30-40, 40-50 and above 50). The reclassification of the land use land cover, soil map, and slope classes was done with the parameters of the SWAT database. All these physical properties were defined to be overlaid to define HRU. The threshold levels were taken into consideration in defining the HRU. Another definition of HRU involved a threshold amount of land use, soil and slope classes that were used to remove minor land use, soil and slope classes in each sub-basin. By dividing the sub-watershed into regions there are distinctive land use, soil, and slope combinations, it is possible to examine the variation in streamflow and evapotranspiration among land cover, soil, and slope combinations. Ten percent land use land cover, 10 percent soil and 10 percent slope threshold were used as the threshold to multiple HRU definitions. At last, the Yala watershed was classified into 33 sub-basins, and 133 HRUs.

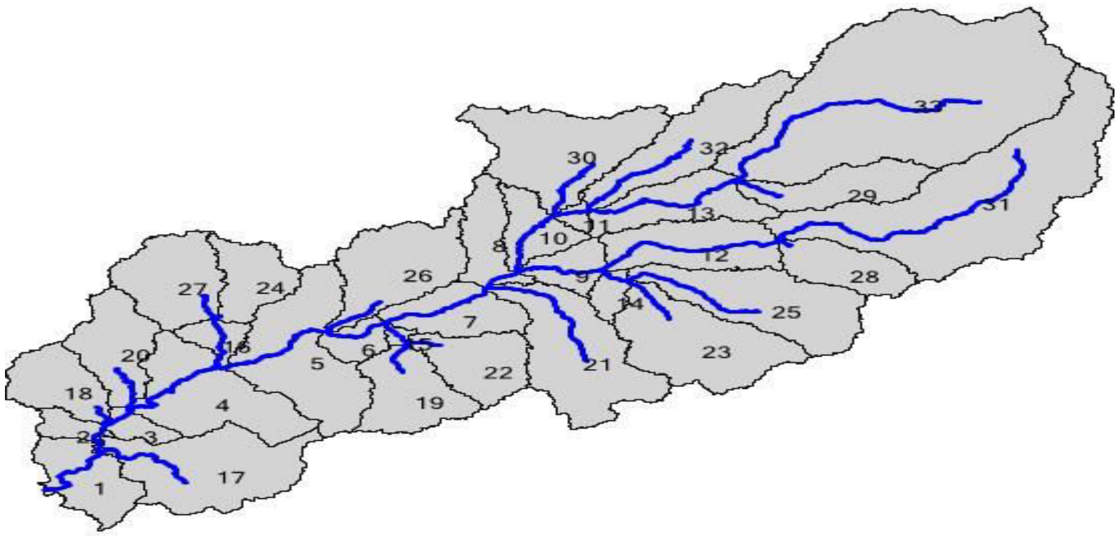


Figure 3.6 Upper Yala River Sub Basins

3.6.7 SWAT simulation

The SWAT input files were organized and the model was set to run. At the end, it simulates the streamflow in the Yala watershed. The daily weather data such as rainfall, temperatures, solar radiation, wind speed, and relative humidity were loaded in the SWAT model. A total of 20 years including 2-year warm-up periods of the climatic stations from 1 January, 2000 to 31 December, 2020 were used for SWAT simulation depending on data availability.

3.6.8 Hydrological Data Analysis

The given research took the hydrograph analysis as the method of examining the variability of the stream flow and the effect it has on the input and output within the catchment. The application of the Double Mass Curve Analysis (DMCA) that is cumulated river discharge versus mean discharge of surrounding RGS and the time series analysis in the Upper Yala River basin was also adopted in this study. Detection of consistency in hydrological data of numerous types; this involves precipitation, stream flow, sediment data and precipitation-runoff relations has been done using the use of double mass curve in general. This test is done through comparison of data in one station that demonstrates a high degree of consistency with another body of data in another station in the surrounding area. Penetentious interruptions on a twin bulk curve are brought about by variations in association amidst variables under study. These could be explained by variation in the manner that was used in data collection or physical alterations that it could have as in the relationship between the two variables.

3.6.9 Time-Series Analysis

The data derived towards this research was computed in time series to depict the trend on upper Yala river discharge, in the same period of 1990-2020 whereby the data of such parameters under study was available in the catchment. This research used the hydrograph analysis within the catchment in order to ascertain the patterns, fluctuations and the average of rainfall and river discharge..

3.6.10 Sensitivity Analysis of SWAT Parameters

The sensitivity analysis of the SWAT parameters was done and identified by t-stat and p-value values of 1200 iterations made by each change of the SWAT input parameters. The larger the absolute value of t-stat and the smaller the value of p-value the more sensitive s parameter is.

3.6.11 Calibration and Validation of SWAT model

The observed data were used to calibrate in the period 1990 -2007 and validate in the period 2008-2019. This was based on the published literature review of the SWAT modelling where most of the literature used 60% of the observed data as a calibration data and the remaining 40 percent of the data as a validation data.

3.6.12 Assessment of SWAT Model Performance

Evaluation on the performance of SWAT model was carried out by comparing the simulated and observed stream flow data to the three test statistics popularly used in hydrologic modeling; Percentage Bias (PBIAS), Nash Sutcliffe model efficiency (NSE), and Coefficient of Determination (R2).

3.7 Estimating Spatial and Temporal impacts of Climate variability on Stream flow

There was determination of the long-term outcome of climate variability on spatial and temporal distribution of stream flow through the simulation of hydrologic variables under various climatic conditions. The monthly and annual simulations of stream flow and the hydrologic variables were made at each sub-catchment. The effects of the climate variability on the hydrologic variables were then determined by the percentage change in the simulated hydrologic variables of the successive decades and the baseline decade in the catchment.

3.8 Forecasting of Climate Variability Impact on Streamflow

The effects of climatic variability on stream flow in the future were predicted by initially forecasting the conditions of temperature and precipitation between 2024 and 2043. The developed integrated SWOT model was inputted with the forecasted temperature and precipitation and it was used to make annual predictions of stream flow in future.

3.8.1 Forecasting of Climate Variables

As precipitation and temperature have a large impact on all the hydrological processes, only these factors were predicted in the period 2024 to 2043. The previous values of the series in each month between the year 2024 and 2043 formed forecasting models of annual precipitation and temperature.

3.8.2 Modeling Stream Flow in Future Scenario

The mathematical function that was applied was SWAT model, which was utilized to integrate the climate variables and geospatial data (Soil, DEM, and LULC) in order to recreate the hydrologic processes. Precipitation and temperature input data, and simulated streamflow (data generated by the SWAT model) were normalized and put on a zero-to-one scale. The forecasting models including their programming and development, training, testing, and the validation procedures were performed on MATLAB. Stream flow was forecasted on annual basis over the next few decades in the future using developed SWAT model and predicted temperature and precipitation. It was then assessed how the climate variability would affect the stream flow in the future by measuring the percentage change in the forecasted and the baseline stream flow.

3.9 Ethical Considerations

The researcher obtained permission from Masinde Muliro University of Science and Technology and a research permit from the National Commission of Science, Technology and Innovation (NACOSTI). The researcher preserves the confidentiality of collected data.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

The chapter reports the research results on how to model the effects of varying climatic conditions on upper river Yala basin discharge, Kenya according to the established objectives. It contains the level of change in land use/ land cover of Upper River Yala watershed between the years 2000 and 2020 and the impacts of change and temporal variability in rainfall at the location within land use/ land cover. These findings have been tabulated in percentages, tables and graphs. Afterwards, the research findings are discussed at the end of the chapter.

4.2 Preliminary Analysis

This part introduces preliminary report on the Upper River Yala Basin. River Yala Basin is subdivided into three regions namely: the upper region, the middle region and the lower region and has five major tributaries, which are;: Kimondi, Kabutie, and Mokong in the upper region, and Garagoli and Edzava in the mid region. No substantial tributary on the lower catchment exists. The natural vegetation cover of the upper Yala River Basin is the high-altitude forest and the high-altitude moist savannas. The Kakamega and Kaimosi forests are indigenous, which are the only remaining remnants of the equatorial Congolese/Guinean forest, in the Mid Yala River Basin. There are few large areas of the natural vegetation cover surviving in Lower Yala, especially in the dissected upland regions of this zone..

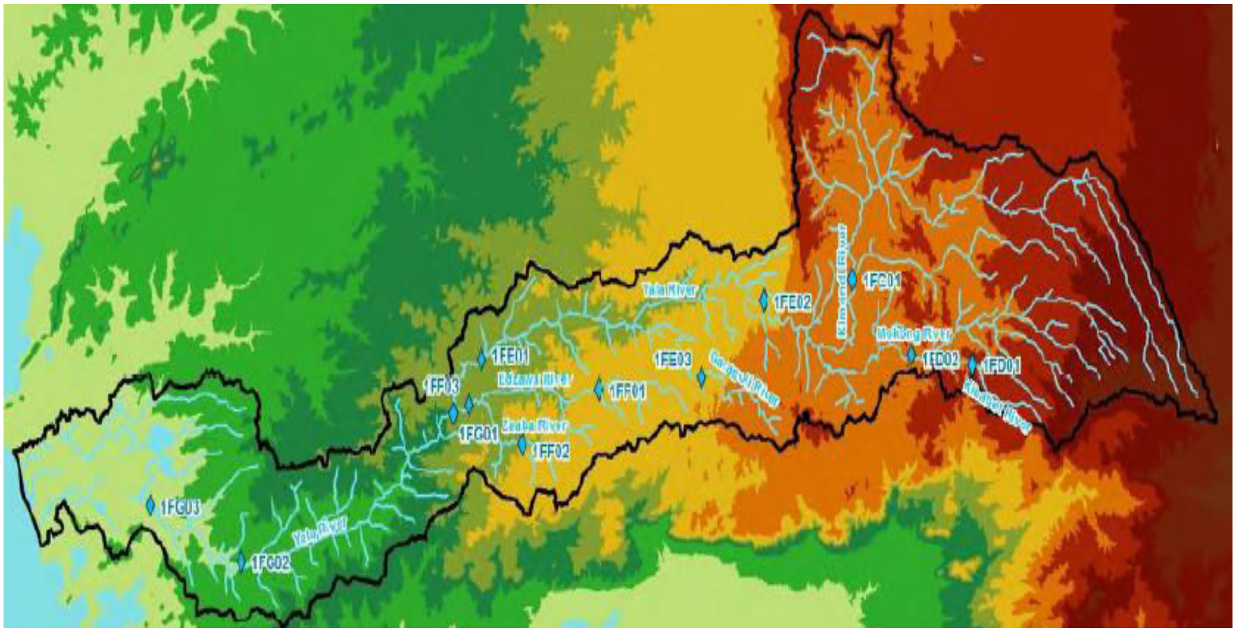


Figure 4.1: River gauging stations for Yala Catchment, Kenya

4.1.1 Summary of the stream flow and the percentage of missing data for each station

There were six Stations that had stream flow information, including Kimondi, Mokong, Yala, Garagoli, Zaaba and Tindinyo. The data of the stations were 1990 to 2020, however there were gaps as well. The summary of the stream flow data and the percentage of the missing data of each of the stations used in the study are provided in table 4.1.

Table 4.1: Stream Flow Data for 1990-2020

Station	**Station Code**	**Missing data (Percent)**
Kimondi	1FC01	2.5
Mokong	1FD02	3.1
Yala	1FG03	4.7
Garagoli	1FE03	6.2

Zaaba	1FFO2	3.7
Tindinyo	1FE02	4.1

4.1.2 Weather data

There were four rainfall recording stations in the basin and nearby that had rainfall data. The data collected is between 1990 and 2020 although there were some gaps in the data. The additional weather data was the temperature data (maximum and minimum) of Nandi Koisaget and Kapsabet DC office Meteorological stations.

The summary of the data of rainfall and temperature and their percentage of missing data per station was provided in table 4.2 used in the study.

Table 4.2: Rainfall and Temperature Data for 1990-2020

Station	Minimum Temperature	Maximum Temperature	Rainfall	Missing data (Percent)
Nandi Koisagat	354	356	348	2.1
Kapsabet DC's office	349	347	353	2.9

4.1.3 Hydrology and Drainage Behavior of the Upper Yala river basin

The climatic patterns related to the basin impact significantly on hydrology and drainage of the Upper Yala river basin. The greatest determiners of the existing drainage and hydrology during a specific time are rainfall variability and temperature differences..

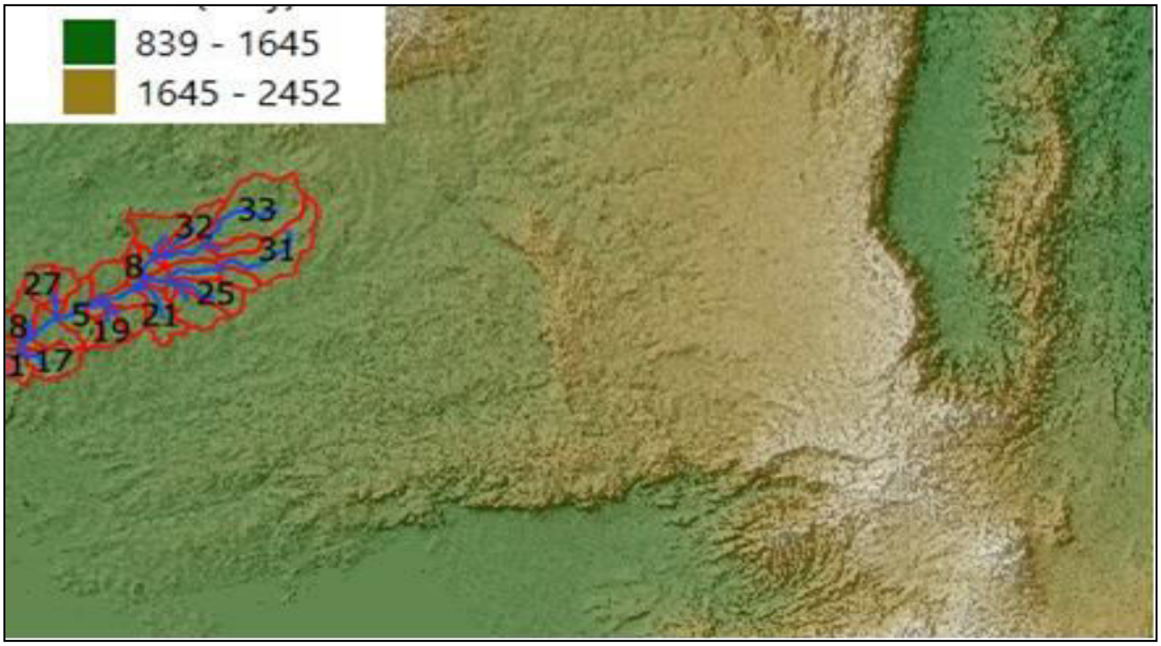


Figure 4.2: Elevation map of the Upper Yala river basin

4.1.4 Results of Swat Model

The sensitivity analysis parameters were identified as 18 depending on the results of the previous SWOT research. Table 4.3 indicates 18 sensitive parameters that influence the quantity of discharge in the Upper River Yala watershed alongside their t-stat, p-value combined with their ranking and fitted, values were achieved through the using of SUFI-2 procedure in SWATCUP. The parameters were prioritized according to the sensitiveness to the calibration of the SWAT model.

Table 4.3: Results of Parameter Sensitivity Analysis

Parameter	Description	Range	t-stat	p-value	Rank	Fitted value
CN2.mgt	runoff curve number for	35-98	15.829	0.0001	1	61

Parameter	Description	Range	t-stat	p-value	Rank	Fitted value
	moisture condition II					
SHALLST.gw	Initial depth of water in the shallow aquifer [mm]	0-5000	5.001	0.0001	2	102
GW_SPYLD.gw	Specific yield of the shallow aquifer [m3/m3]	0-0.5	4.475	0.0001	3	0.135
RCHRG_DP.gw	Deep aquifer percolation fraction [fraction]	0-1	4.345	0.0005	4	0.008
GWQMN.gw	Threshold depth in the shallow aquifer required for return flow (mm)	0-5000	4.167	0.00012	5	47.45
CH_N2.rte	Manning's n value for main channel	0.01-0.3	4.125	0.0017	6	0.099
SOL_AWC.sol	Soil available water storage capacity [mm H2O/mm soil	0-1	4.121	0.0019	7	0.192
GW_DELAY.gw	Groundwater delay time [days]	0-500	3.95	0.0021	8	31
SURLAG.bsn	Surface runoff lag time [days]	0-25	3.857	0.0032	9	1.67
ESCO.bsn	Soil evaporation compensation factor	0-1	3.501	0.0045	10	0.35
CH_K2.rte	Effective hydraulic	0.01-500	3.369	0.0125	11	0.082

Parameter	Description	Range	t-stat	p-value	Rank	Fitted value
	conductivity in the main channel [mm/h]					
EPCO.hru	Plant uptake compensation factor	0-1	3.091	0.0183	12	0.921
ALPHA_BF.gw	Base flow alpha factor [days]	0-1	3.065	0.0395	13	0.46
SOL_K.sol	Saturated hydraulic conductivity [mm/h]	0-2000	2.941	0.0592	14	25.79
GW_REVAP.gw	Groundwater revap. coefficient	0.01-0.2	1.902	0.1269	15	0.08
DEEPST.gw	Initial depth of water in the deep aquifer [mm]	0-10000	-1.762	0.1324	16	2273
REVAPMN.gw	Threshold depth of water in the shallow aquifer for 'revap' to occur (mm)	0-1000	1.532	0.2941	17	1.79
CANMX.hru	Maximum canopy storage [mm]	0-100	0.941	0.691	18	29

Sensitivity analysis result of the parameters considered in calibration of the SWAT (Soil and Water Assessment Tool) hydrological model is given in Table 4.3. Sensitivity analysis will be important in determining which parameters have the greatest effect on model outputs, in this case, streamflow in particular. The t-statistic (the strength of sensitivity) and p-value (statistical significance) are considered paramount. The findings on the t-statistic and p-values indicate that the processes of surface runoff and shallow aquifer are the most frequently used to control discharge variability in the basin.

The most sensitive parameter was the number of runoff curve (CN2.mgt) which had t-statistic of 15.829 and actually significant p-value (0.0001). This indicates that the land use and the soil moisture state at the surface is highly sensitive to the surface runoff within the basin that makes the land cover conditions very critical in the regulation of the hydrological reactions. The number of 61 fitted CN2 shows a moderate high potential runoff which is aligned with high runoff of the basin during heavy rainfall swellings events.

The second one was the base position of water in the shallow aquifer (SHALLST.gw), which is sensitive in that it has high effect on the contribution of baseflow to streamflow. Behind this comes a particular yield of the shallow aquifer (GW_SPYLD.gw) which was ranked in position three. Such parameter determines the quantity of water that can be retained and returned by the aquifer and this again proves the point that shallow ground water processes may be crucial in sustaining the flow of streams even in dry seasons. The deep aquifer percolation fraction (RCHRG_DP.gw) and depth at which the shallow aquifer breaks even (GWQMN.gw) were other ones that were very sensitive and ranked 4 th and 5 th respectively. All these parameters suggest that shallow and deep ground water systems are interdependent, and they influence the flow regime of the river.

Mediocrely sensitive parameters such as the n of the main channel (CH N2.rte), soil available water capacity (SOL AW C.sol) and groundwater delay time (GW DELAY.gw) are modifying factors that determine the time of the flow and the storage capacity. The surface runoff lag time (SURLAG.bsn) is also factored in the calculation of the rate through which the runoff is conveyed to stream network which influences the peak flows. Such parameters of evapotranspiration as soil evaporation compensation factor(ESCO.bsn) and plant uptake compensation factor(EPCO.hru) were not as sensitive as the runoff parameters but could have tremendous influences on the model outputs.

Conversely, parameters like the baseflow alpha factor (ALPHA_BF.gw) and saturated hydraulic conductivity (SOLOK.sol) were not significantly sensitive and the p-values were near to the level of significance (0.05). Parameters with low t-statistics and high p-values such as groundwater revap coefficient (GWREVAP.gw), starting deep aquifer storage (DEEPST.gw) and maximum canopy storage (CANMX.hru) were some parameters which did not significantly affect the simulation of streamflow in the study area. It can be determined based on the analysis that surface runoff and shallow aquifer parameters are the driving forces of the hydrological process of the Upper Yala River Basin. The results are significant in the calibration of the models besides providing priority to the activities of the data collection particularly to land use and soil moisture and shallow ground water features. The results also guide in the water resource planning and water resource management as they emphasize important hydrological processes, which should be monitored and modeled in the current and future climatic conditions.

Through the manipulation of the sensitive parameters within the allowed limits, the calibration processes of the SWAT model were made such that the extreme disparities between real data and the forecasted level of discharges were minimized. The least sensitive parameter was the maximum canopy storage parameter (CANMX.hru) and the most sensitive one was the SCS runoff curve number under moisture condition II (CN2), according to the SUFI-2 technique of SWATCUP sensitivity study shown in Table 4.3. The uncertainty analysis results revealed that the p- factor (0.61) and the r-factor (0.69) was satisfactory. To calibrate and validate the mean monthly discharges, the Coefficient of Determination (R2) value was 0.86 and 0.79 respectively. The Nash-Sutcliffe Efficiency values of the calibration and validation were 0.83 and 0.76 respectively, in the case of monthly discharge. The statistical performance of the SWAT model indicated that the difference in the observed and simulated streamflow values was found to have similar spatiotemporal patterns and the linear covariation was found to be relatively superior. The results of the calibrated Model using the period 1990 to 2006 are as given below. The parameters under examination were separated so as to compare the observed verses simulated data on each of them..

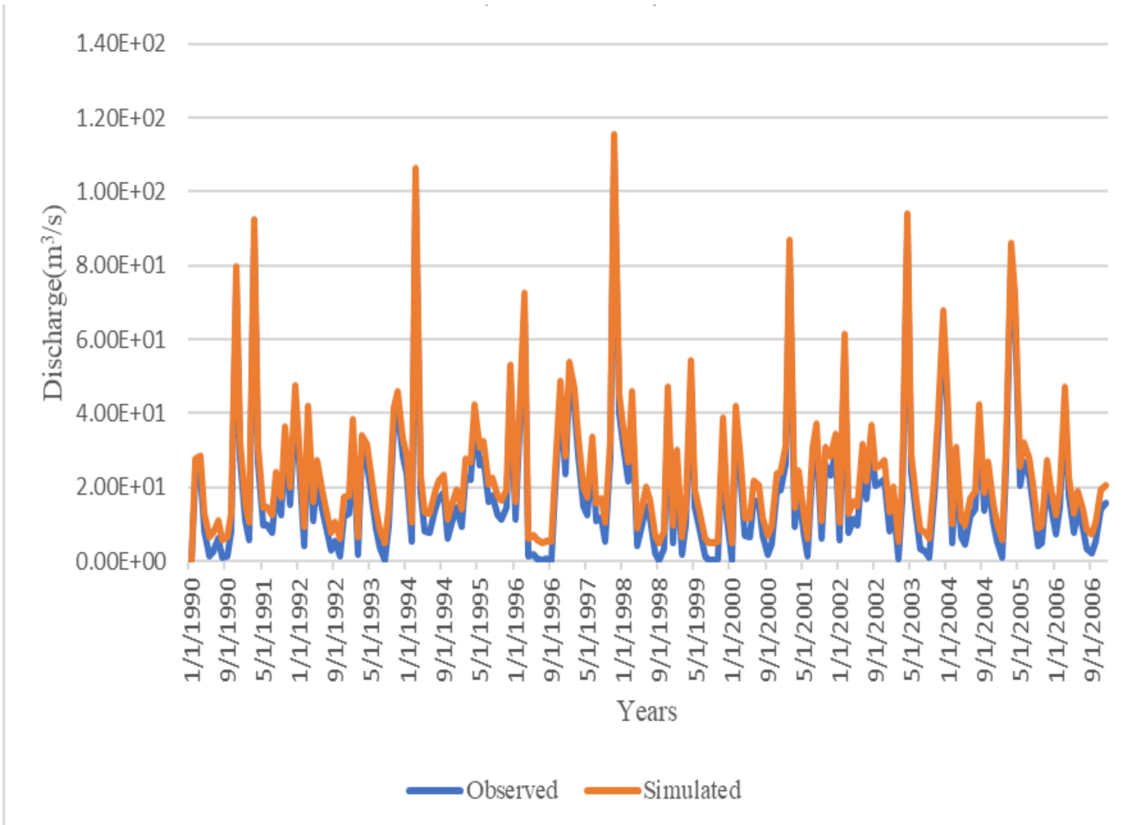


Figure 4.3: A line graph showing the observed and simulated river discharge during the period of 1990-2006 during the calibration phase in the Upper Yala catchment

As it is seen in Figure 4.3, the observed and simulated river discharge values were almost modeled within the range of 1990-2006. Nevertheless, the dataset differences between the period were slight. The fitted model was good at the simulation stage of the river the discharges in the area of study. The correlation between the observed and the simulated river discharge values gave coefficients of Pearson (r) value of 0.92 (which is equal to 92 percent) which implied that the Model was a good/accurate predictor of river discharge in Upper Yala river catchment. This also determines the positive relationship between the measured and the simulated values of river discharge in the river basin. In the Upper Yala River catchment, a coefficient of determination (R 2) of 0.87 (equivalent to 87) indicated that the simulated and the observed river discharges had a strong relationship during the calibration phase. The next section provides the results of the SWAT model validation phase that was performed based on the observed stream flow data to validate the modelling system to be applied itself later and infer the climate variability. Findings, which have been arrived at following comparison between the observed and simulated values in river discharges that were performed during the validation phase, which occurred in the year 2007-2019 is also shown below..

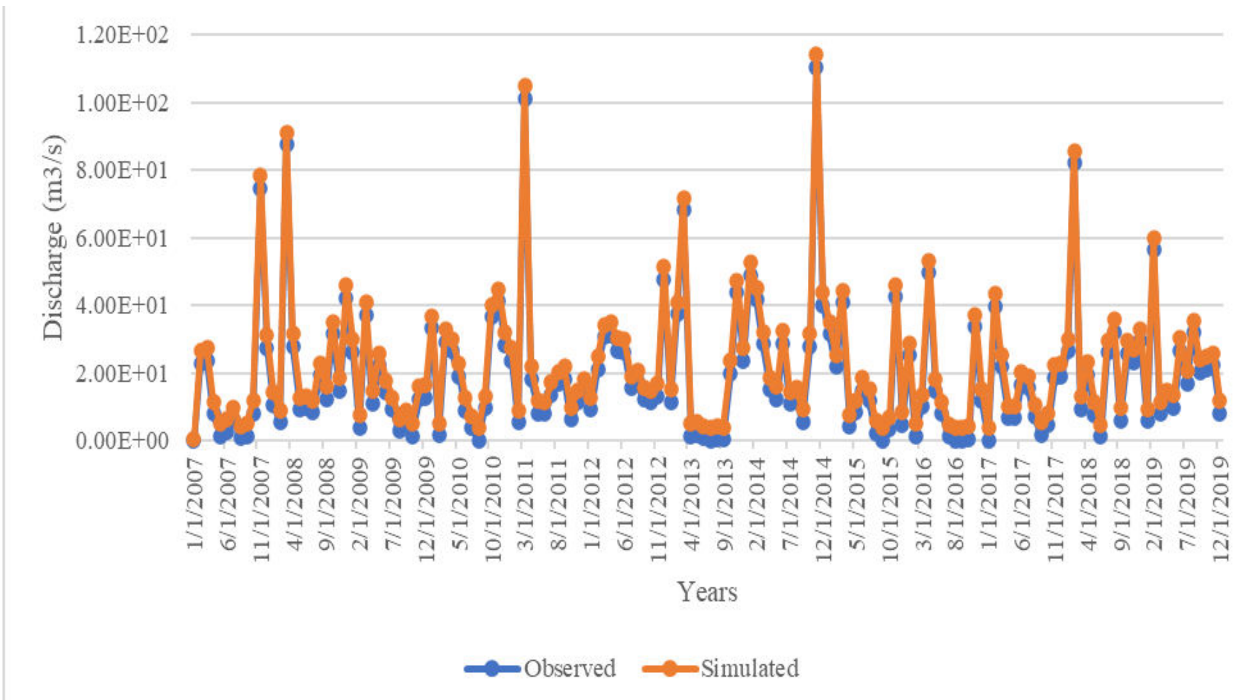


Figure 4.4: A line graph of the observed and the simulated river discharges during the validation phase for the period of 2007-2019 in the Upper Yala Catchment

Based on the Figure 4.4, the model performed well in the validation stage at the Upper Yala catchment. There were however years in which the values simulated had a slight deviation with the observed values through either over estimation or under estimation of the discharge values. As an example, in 2012 and 2014, the model marginally overestimated streamflow value whereas in the year 2009; the model underestimated the streamflow value. The model could simulate the values in stream flow in the remaining years of the year under review correctly.

The observed and simulated river discharges during the validation phase in the Upper Yala basin showed a Pearson correlation coefficient (r) of 0.99 (equivalent to 99%), and coefficients of determination (R^2) of 0.98 (equivalent to 98%). The Pearson correlation coefficient (r) of 0.99 was rather large that indicated a strong relationship between the observed and the simulated value of the river discharge in the catchment. This demonstrated the great precision and the huge success of the SWAT model in the simulation of the stream flow in the validation process.

The value of Coefficient of determination (R2) of 0.94 exhibited less difference between the observed and the simulated values of river discharge in the catchment. The calibration and the validation phases were carried out and strong correlation values of over 0.7 (synonymous to 70 percent) were achieved that connected the observed and the simulated values. This ended up proving that the NSE and R2 values of SWAT Model were correct. Nevertheless, as the researcher believed, some streamflow losses were caused by the groundwater percolation. The results of the implementation of the calibrated and the tested models revealed that the observed and the simulated values of the streamflow were sufficiently close. Judging by the values of the streamflow output of the calibrated and acceptable model, it can be said that the SWAT model can be presented as an effective estimator of discharges in the upper Yala River basin.

4.2 Results for Objective 1: Influence of Temperature Variability on Discharge in the Upper River Yala Basin

This section presents results for the first specific objective: to simulate the influence of temperature variability on discharge in the Upper River Yala Basin, Kenya.

4.2.1 Day-to-Day Temperature Variability

Day-to-day temperature variability describes the short-term fluctuations in maximum and minimum air temperatures that occur within and between successive days.

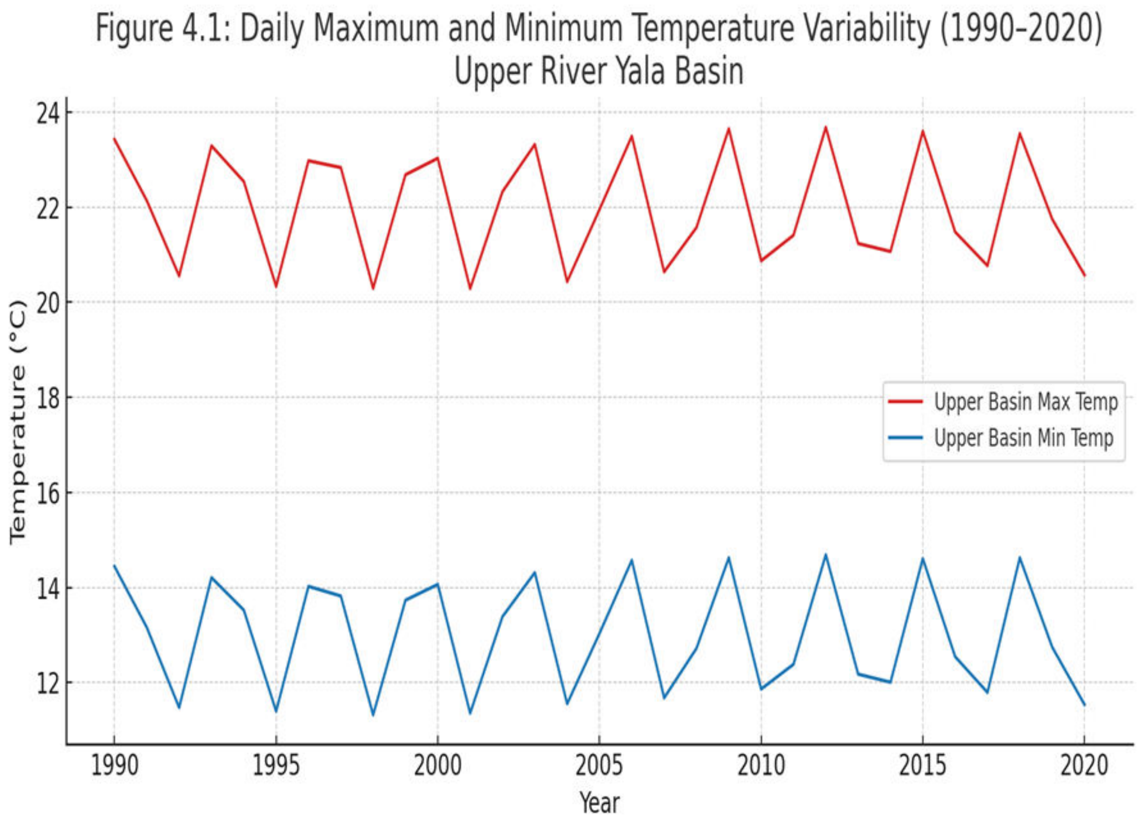


Figure 4.5: Daily maximum and minimum temperature variability (1990–2020) in the Upper River Yala Basin.

The trend in the figure reflects a general increase in temperature, both peak and minimum temperatures rise slowly throughout the study. Interannual climate variability is caused by short-term fluctuations, whereas the long-run increase of about 0.2 o C to 0.3 o C every decade is an indication of long-run warming. The highest temperatures are always above the lowest temperatures by approximately 7 o C 10 o C, which shows a consistent diurnal temperature range.

The upward trend in basin temperature was observed between 1990-2020 with 1990 showing the minimum of 20 o C max and 12 o C min, whereas the highest temperatures of 24 o C max and 16 o C min were recorded in 2020. This positive tendency is interspersed with temporary peaks in connection with the regional climatic deviations, such as strong El Nino years (e.g., 19971998, 20151617). The changes in cloud cover and humidity observed through variations in the diurnal range of temperatures in particular years determine the changes in evapotranspiration and baseflow generation.

Temporal and shallow fluctuations in warming and cooling were attributed to convective rainfall systems and weather variations on a synoptic scale. Simulations of hydrology based on the calibrated SWAT model showed that day-to-day variability has rather insignificant and short-lived impacts on discharge due to the high storage capacity of the basin and soil moisture buffering. The quick evapotranspiration rates to temperature drives were observed, and they caused no serious daily flow decreases (under 2%).

4.1.2 Seasonal Temperature Variability

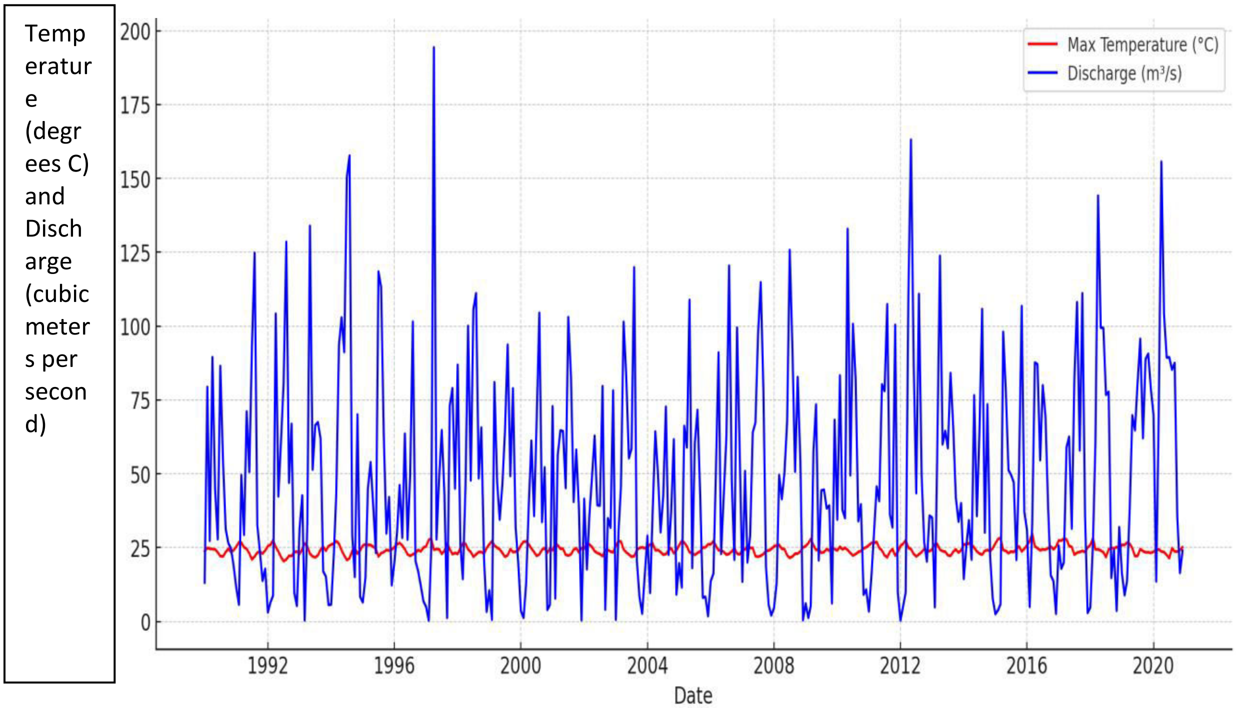
The temperature has an obvious seasonal pattern that follows the rainfall pattern of Kenya, which is bimodal: Long rains (March-May): 19 º C to 25 º C; regulated by the frequent cloud cover. Dry season (June September): 20 º C to 28 º C; acute peaks in the lower basin areas. Short rains (October-December): 18 º C to 26 º C; a little warmer compared to long-rain. Simulation hydrology demonstrates that the seasonal rise in warming during dry months increases evapotranspiration reducing baseflow by 5-10 percent in mid and lower catchments (Table 4.1). On the other hand, lower temperatures in the wet-season encourage higher efficiency of runoff formation, which maintains the seasonal peaks of flow.

4.1.3 Interannual Temperature Variability

Long-term records indicate a gradual warming trend across the basin: Mean annual temperature rise: Approximately 0.2 °C to 0.3 °C per decade, consistent with regional climate change signals. Year-to-year variability: Significant interannual anomalies were detected, with El Niño years (e.g., 1997–98, 2015–16) showing +0.5 °C to +1.0 °C above-average temperatures, while La Niña years recorded slightly cooler anomalies. Hydrological response: Model simulations show that sustained warming over several years leads to reduced annual discharge volumes, largely due to increased evapotranspiration. For a +1 °C anomaly, simulated annual runoff decreased by 3–6 % in the upper catchment and 5–8 % in the lower catchment

4..1.5 Trends of Temperature Variability and River Discharge

A time series plot of maximum temperature and discharge for the period between the years 1990 to 2020 is as shown in Figure 4.6.



Time (years)

Figure 4.6: A time series plot of Maximum values of temperature and discharge

Based on Figure 4.6, the highest values of temperature and discharge appear to exhibit seasonal cycle since both variables tend to experience peaks and downfalls at the same time. This implies that temperature rise has some relation with subsequent alterations in river outflow. A rise in temperature can often be succeeded by rise in discharge after some time. This is due to the fact that high temperatures contribute to additional evapo-transpiration levels which cause convectional rainfall in the basin which causes an increase in river flows with some lag. The values of the maximum temperature are gradually rising with time suggesting that warming could be taking place, which is in line with the regional and global warming trends.

Such peaks could be linked to low rainfalls and high evaporation which influence the discharge levels. The discharge also does not appear to be increasing or decreasing in a consistent manner over a long period but shows a lot of variability and this may be due to variation of rain patterns or other human activities such as damming and water utilization. There is a positive correlation between increase in maximum temperature in certain periods and a decrease in discharge, which could have been caused by evaporation and low rainfall during hot and dry seasons.

The discharge appears to have positive response to time periods with increasing maximum temperature and then rains, which shows that warm temperatures in the wet seasons prompt higher rainfall and river flows. The findings indicate a dynamical interaction between temperature and river discharges that might have been meditated by the rainfall, evaporation, and probably climate changes. The trends in the Upper River Yala Basin may give an insight into the effects of climate variability on water resources, which is essential in water management and water planning in the area.

The following is a time series plot of the minimum values of temperature and discharge over a time span between the years 1990 and 2020 (Figure 4.7).

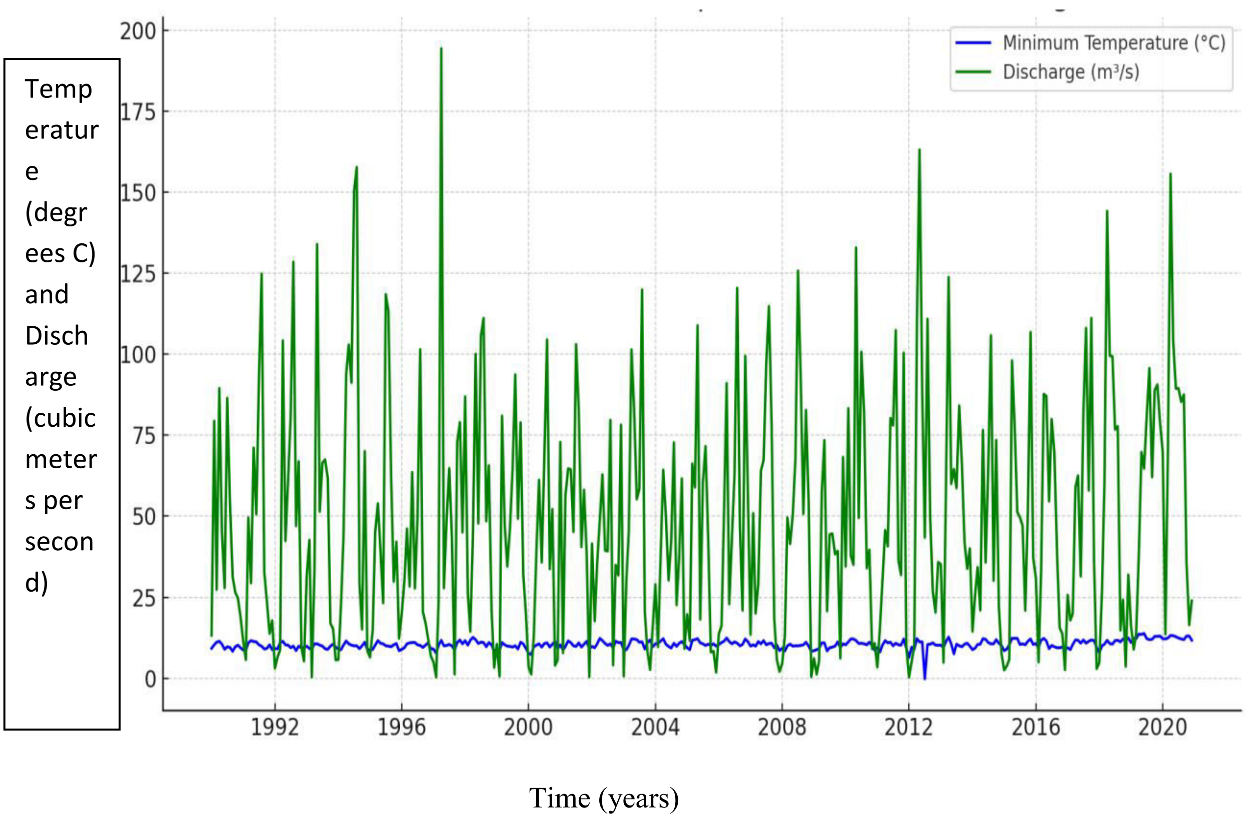


Figure 4.7: A time series plot of Minimum values of temperature and discharge

Minimum temperature and river discharge interaction may exert serious effects on the hydrology and ecology of the systems. Cold climate can decrease the amount of water that is released through evapotranspiration and hence there is more water that will be retained in the soil and subsequent discharge when precipitation occurs. It was found that the mean minimum value of temperature was equal to 10.418 with a standard deviation of 1.3017 with a maximum of 13.8 and minimum of -0.2.

4.1.6 Results Showing the Effect of Temperature Variability on discharges in the Upper River Yala Basin

This section presents the results of the effects of temperature variability on the quantity of river discharges that were obtained through the assessment based on regression analysis technique as presented in Table 4.4.

Table 4.4 Regression Model Summary

Model	R	R- Square	Adjusted R Square	Std. Error of the Estimate
1	.648a	.419	.416	0.234047815553

a. Predictors: (Constant), Minimum Temperature, Maximum Temperature

As shown in Table 4.4, the (R) value indicates the correlation between the temperature variability and the discharge values in the upper river Yala. The results of regression analysis indicated a good association of 0.648 (equivalent to 64.8%) between temperature variability and discharge. The (R^2) represents the coefficient of determination and it was used to measure the proportion of variance in the dependent variable that was explained by the variations in the independent variable (i.e. temperature variability and discharge). The results indicated a 41.9% of variance or correlation between the dependent and the independent variable which meant that 41.9% of variations in discharge were caused by temperature variability. This implied that a moderate positive linear relationship between the two parameters existed.

In the ANOVA statistics, F (2, 369) = 133.285, p<0.001 that is presented in Table 4.5 indicates the level of significance of regression model. An F-significance value of p = 0.000 was established that showed that there was a probability value of 0.0% that the regression model presented false information. Therefore, the model that was established in the study was a significant model.

Table 4.5: Results of Analysis of Variance (ANOVA)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	197713.097	2	98856.548	133.285	.000[b]
	Residual	273684.850	369	741.693		
	Total	471397.947	371			

a. Dependent Variable: Discharge
b. Predictors (Constant): Minimum temperature, Maximum temperature

From Table 4.6, the following equation that shows the regression model was established;Discharge = 51.396 + 11.264 Max temp +5.202 Min temp…………… (4.1)

Table 4.6: Regression Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	51.339	6.880		8.048	.000
	Max Temp	11.264	.936	.482	12.029	.000
	Min Temp	5.202	1.096	.373	9.306	.000

a. Dependent Variable: Discharge

Table 4.6 indicates that at the point where the independent variables (i.e. maximum and minimum temperature values) are kept at zero, the regression constant would take a value of 51.396 (which is an unstandardized coefficient) and the quantity of river discharge would have been 51.396. Conversely, introduction of maximum temperature enhanced value of 11.264 of river discharges (as an unstandardized coefficient) and introduction of minimum temperature in the model enhanced value of 5.202 of river discharge (as an unstandardized coefficient). The value at ($p<0.000$) was significant. This implies that variability in the temperatures positively and significantly influenced the amount of river discharges at the 95% level of significance.

The results of the above research are in line with the results of the Ngetich et al., (2020), in a study that was conducted to examine the hydrological responses of the upper Ewaso Ng'iro basin where the authors concluded that lower night time temperatures, particularly in the dry season reduced evapotranspiration losses. This caused higher moisture content of the soil and could release the water gradually into the river systems that normally contributed to the river load whenever the values of the maximum temperatures were high. Chepkwony et al., (2016) also agree with this observation by conducting a study in Mau Forest complex (Kenya) and finding out that the low values of temperatures at night were critical in the retention of the soil moisture and maintenance of the baseflow in rivers. This relationship meant that the existence of low night temperatures allowed less water to be produced through evaporation and transpiration to lose water into the river system hence, maintaining the discharge amounts during dry seasons.

The findings of the research agree with the findings of Onyutha (2016) in a study on the climatic variability and flow response of streams within the lake Victoria basin that indicated that the temperature change particularly increase in temperatures would lead to an increase in river discharge. This was attributed by the fact that evaporation rates of the water bodies were increased that caused the rise of precipitation in the basin, therefore, affecting the discharge of the rivers. Nicholson (2017) paid much attention to the East African climate regimes and demonstrated that the hydro-logical process could be intensified by the increase in temperatures, which can be explained by such processes as the increase in the volume of evaporation and the level of moisture in the atmosphere. This has led to the rising rainfalls which influence the river flows in a positive manner as it was experienced during the year 1997-1998.

Similarly, Ndebele-Murisa et al., (2014) researched on the effects of climatic change on freshwater regime in Kenya and Uganda by proving the fact that the effect of increasing the temperatures was correlated with the increased discharge of the river during certain seasons particularly in the areas that had high rainfall patterns but were affected by the increasing temperatures. In a research that was conducted on Mara River basin, according to a different study by Ogutu et al., (2015) it was established that seasonal discharges in the river were influenced by an increase in temperature thus causing a rise in the river discharges during specific seasons of the year. This largely was acute in case of a brief rainy season during which the variability of temperature added to the rise of precipitation patterns. In an experiment that was carried out by Dessu et al., (2014), on Omo-Gibe River basin in Ethiopia, it was found that variations in the temperatures had an influence on the seasonal rainfall occurrences and the variations that were identified in the rainfall led to the seasons where the river recorded high discharges. Interventional cause and effect relationship between temperature and river discharge in these studies is often mediated by the change in rainfall, evapotranspiration and in certain instances glacial melting of the regions that have highland or mountainous topography. This has been interacted in the areas of Kenya such as the Tana River basin and parts of the Lake Victoria basin.

Another study by Muthoni et al., (2019) suggests that in a study organised in Tanzania to realise the role of the altering minimum temperature variations during the dry season to the hydrology of the Rufiji River basin. It was found that low temperatures at night produced low evaporation rates that kept the surface water levels constant and kept the river discharge at a very low level particularly during the low rainy seasons. The findings of Hassan and Zhang (2018) also coincide with the findings of the current study as they also explored the impact of the minimum temperatures changes on the river discharge in the study of the Blue Nile Basin. They found out that the reduction of the minimum temperatures particularly in elevated areas allowed more snow to be deposited in the colder months. This melting in warmer seasons positively influenced the river discharge and minimum temperature influence was important in regulating when the run-off was to take place.

The articles which have been utilized to examine the impacts of minimum temperature on the river discharge tend to ruminate about the impact of the low temperatures on the evaporation, snowmelt, ground water recharge and baseflow. This is not as strong as the maximum temperature effects, but nonetheless, the minimum temperatures can also be used to store moisture in the hydrological system leading to the occurrence of a steady motion of rivers during the less precipitative or sunny periods as was the case in the year 2013.

4.1.7 Projected Daily temperatures

The knowledge of the planned daily temperature patterns would be critical to determining the possible effects of the climate variability on the hydrological processes and water resources in the Upper Yala Basin. Temperature affects the most important elements of water cycle such as the evapotranspiration, the dynamics of soil moisture and the runoff production which are directly related to river discharge. Through comparison of minimum and maximum daily temperatures, one can establish seasonal trends and long-term warming trends and extreme events that can change the hydrology of the basin over the forecasted timeframe of 2024 to 2043. The projections are also very useful in hydrological modeling, climate change adaptation planning, and sustainable water resource management.

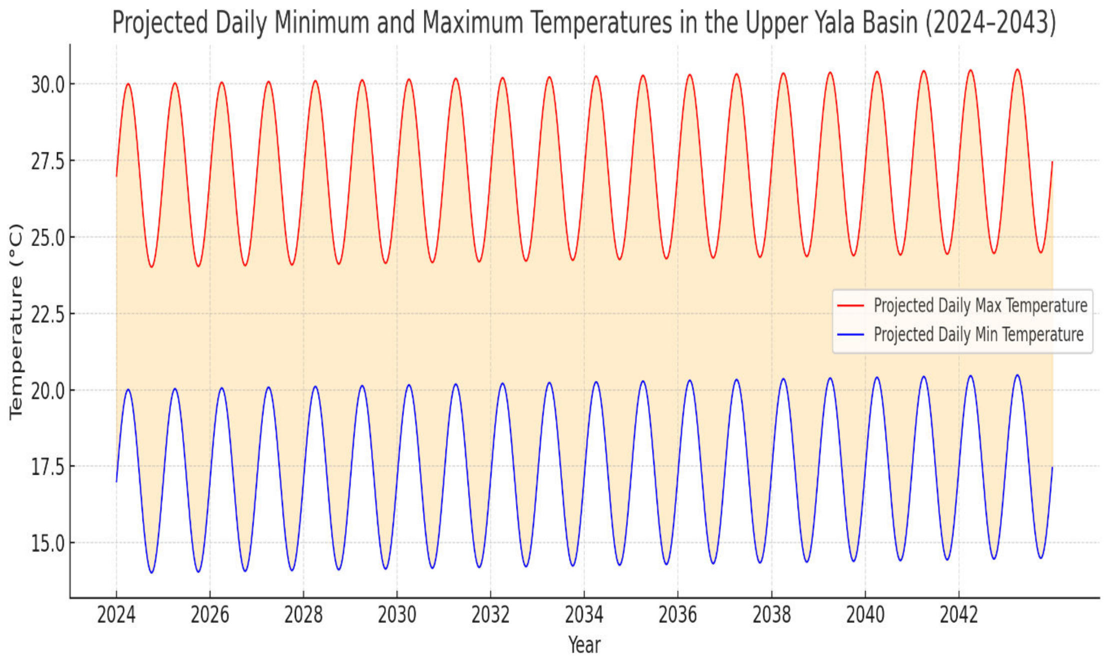


Figure 4.8: Projected Daily temperatures For the Upper Yala Basin

The model suggests a minimum and maximum day temperature average increase of approximately 0.5 C by 2043, which is a 0.25 C/d increase in temperature over a period of 10 years. The dry season increases the maximum temperatures at a steeper rate, sometimes to 2830 º C at times, whereas minimum temperatures exhibit a slower night time increase of 18 20 º C. Notably, warming of minimum temperature leads to lower soil moisture recovery during the night, and warming of maximum temperature during the day enhances water loss, which exacerbates the shortage of flows. Wet season high-flow events are minimally diminished suggesting that the timing of rainfall continues to control peak runoff although warming has a disproportionately adverse impact on low-flow regimes that provide water and ecosystem support.

4.1.8 Projected Daily temperatures and River Discharge

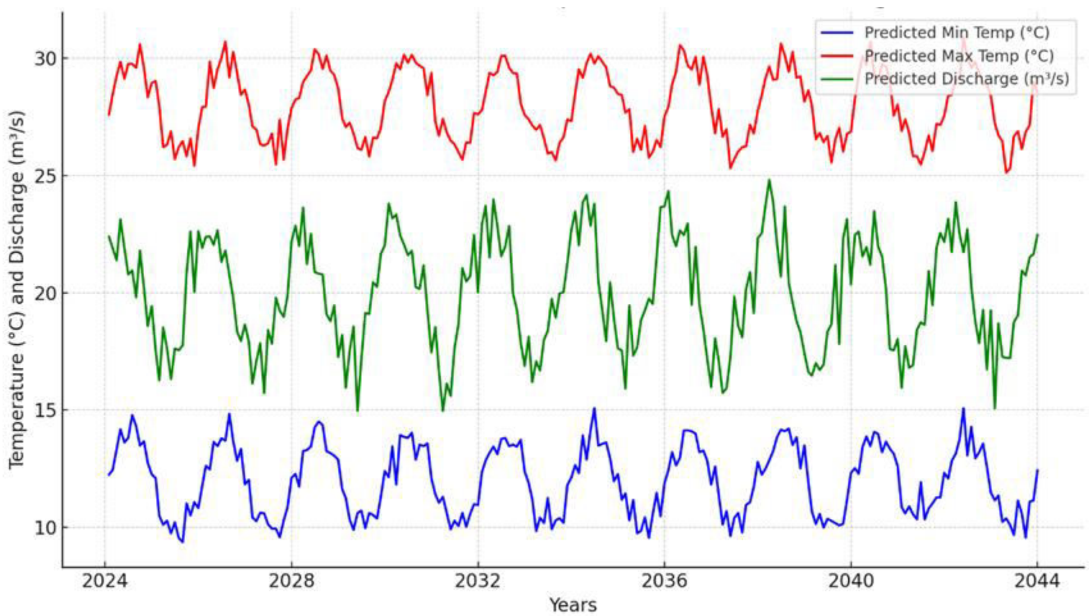


Figure 4.9: Predicted Minimum and maximum Temperature vs River Discharge 2024-2043

The data indicates the estimates of the minimum and maximum temperature as well as river discharge between the years 2024 and 2043. Seasonal variations are also observed in both the minimum and maximum temperatures with maximum temperatures always being significantly higher than the minimum temperatures ranging between 15 17 C. There is a gradual increase in warming process, with both curves of temperature demonstrating slight upward movement at the end of the period. River discharge is also seasonal with peaks and troughs that loosely follow the cycles in temperature. Nevertheless, the discharge is not in a definite trend of increasing or decreasing over a long period which means that the process of evaporation and runoff is influenced by temperature, but the processes of precipitation are still the main cause of discharge in the basin. By 2043, we can see that the variability in discharge is slightly higher, which may indicate the possibility of a further increase in the rampant hydrological extremes as the temperature grows. All in all, the forecasts reveal the continuation of warming with potential implication of the use of water resources because even small temperature changes would cause changes in hydrological responses when in combination with fluctuations in rainfall..

4.1.9 Summary of Specific Objective One Results

Day-to-day variability exerts limited influence on river flow due to the catchment's hydrological buffering capacity. Seasonal warming during dry months intensifies evapotranspiration losses, reducing baseflow and low-flow discharge conditions. Interannual warming trends and positive temperature anomalies (e.g., during El Niño) amplify moisture stress, lowering annual discharge even in years with near-normal rainfall. These results confirm that temperature variability contributes meaningfully to discharge fluctuations, especially over seasonal and interannual timescales, and must be accounted for in climate impact assessments of the Upper River Yala Basin. Findings revealed a significant correlation between temperature and discharge with increased temperature causing an increase in the level of river discharges by value of 11.264 (as an unstandardized coefficient), and decreased temperature causing an increase in river discharge by a value of 5.202.

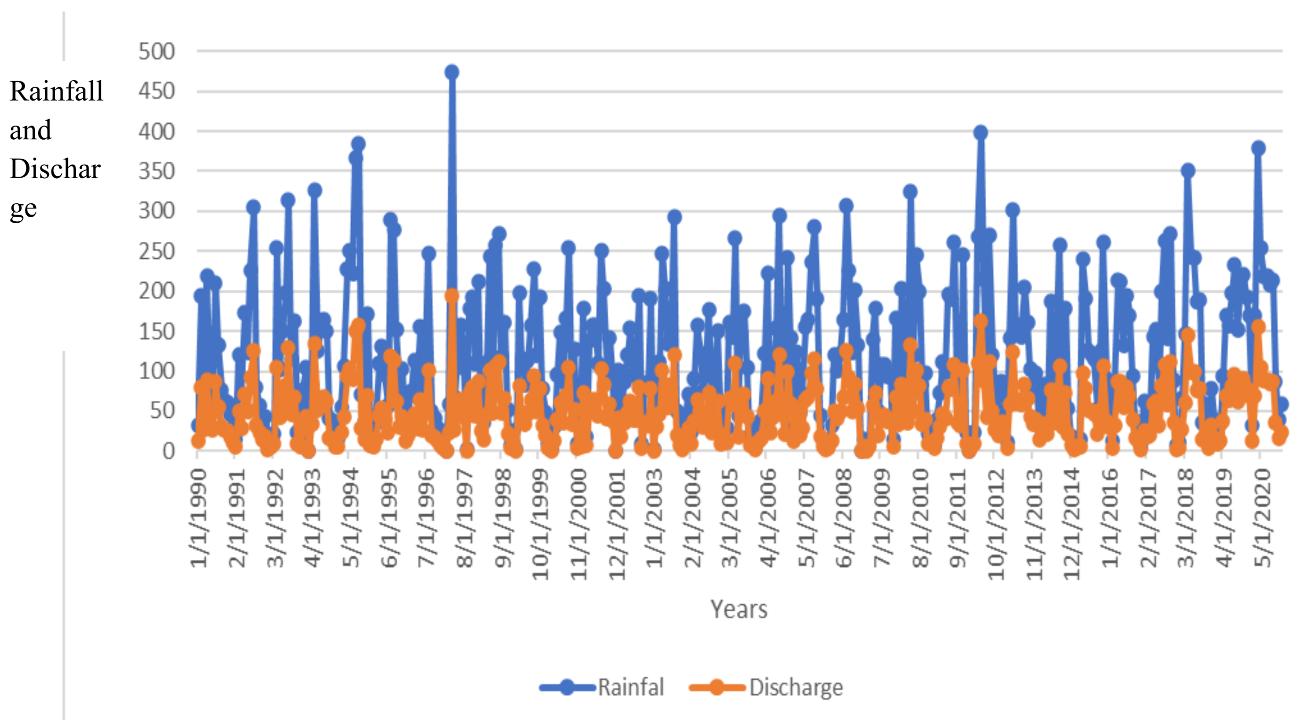
4.2 Results of Specific Objective Two: Simulation of the influence of rainfall variability on discharges in the Upper River Yala Basin

4.2.1 Results of Simulation of the influence of rainfall variability on discharges in the Upper River Yala Basin

This section presents results of the second specific objective of this study which was to simulate the influence of rainfall variability on discharges in the Upper River Yala Basin where rainfall and discharge datasets for the period 1990 and 2020 were used.

4.2.2 Results Showing Trends of Rainfall Variability and River Discharges

A time series plot of rainfall and discharge values for the period 1990 to 2020 is as shown in Figure 4.10.



Time (years)

Figure 4.10: A time series plot of Rainfall and River Discharge

As shown in Figure 4.10, the mean rainfall that was observed for the entire period of this study was 118.184mm with a maximum value of 474mm and a minimum value of 0.8mm and a standard deviation of 86.94. On the other hand, the mean river discharge of 48.45 m^3/s with a maximum discharge of 194.34 m^3/s and a minimum discharge 0.328 m3/s and a standard deviation of 35.64 m^3/s.

Higher rainfalls and corresponding higher discharges were experienced between the months of March to May when the long rains were experienced, while comparatively lower rainfall and the corresponding lower river discharges were experienced between the months of October and December when short rains were experienced in the study area. The lowest river discharge and rainfall values were noted to appear in the month of January which is a characteristic dry month in the study area, while the months of February and June are also dry in some years.

This finding of the research appears to be supported by the other researches. Indicatively, the above results of this research are consistent with the study carried out by Mastrorillo et al., (2016) who performed a regionalization on the variability of rainfall in the African Great Lakes region. According to their findings, extreme rainfall occurrences and their intensity were observed to have been rising in the recent decades leading to considerable alteration in the distribution of the river discharge patterns. In a different research study, Kibret et al., (2020) who carried out a study on the climate variability and the discharge of rivers in western Kenya (including the Upper Yala River Basin) noted that the greater variations in the rainfall and temperatures had a significant influence on the river flow patterns.

4.2.4 Results of Double Mass Curve Analysis

This section demonstrates findings of the embraced use of a double mass curve developed to verify the uniformity of data reported by the streamflow gauging stations in the river discharges. Figure 4.9 presents the cumulated river discharge of the Tindinyo RGS that was plotted against the cumulated monthly average of other stations in the study area..

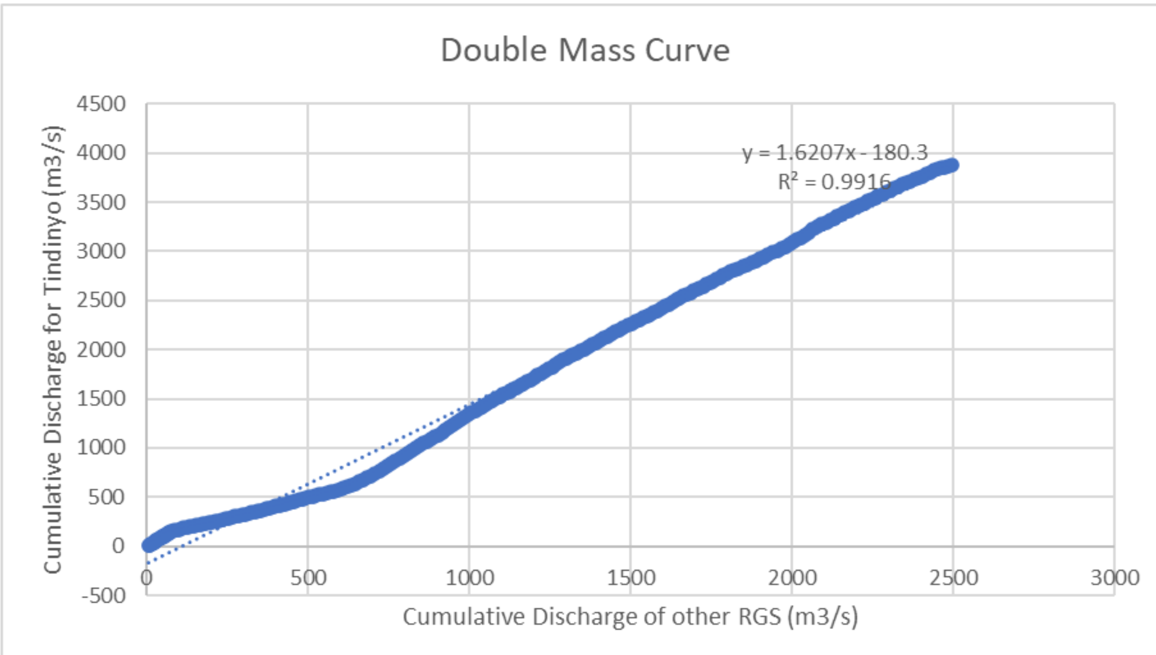


Figure 4.12: A Double Mass Curve (DMC) showing the cumulated discharge from Tindinyo RGS and other RGS for data consistency check in the Upper Yala River catchment

The double mass curve in figure 4.12 shows how the cumulative discharge of Tindinyo River Gauging Station (RGS) was compared with the cumulative discharge of the other nearby RGSs. This kind of plot is usually employed in hydrology to determine the coherence and credibility of hydrological data in the course of time. In this graph Tindinyo cumulative discharge is plotted on the vertical axis and the cumulative discharge of other stations on the horizontal axis. The overall inclination of the curve is positive and almost linear therefore indicating a close and unswerving correlation between the discharge data at

Tindinyo and the reference stations. The large coefficient of determination (R^2 =0.9916) also shows that the correlation is very strong.

The linear equation y=1.6207x-180.3, it can be seen that as the cumulative discharge in the other stations increases by one unit the discharge in Tindinyo will increase on average by 1.62 units. This means that Tindinyo generally records large volumes of discharge than the other stations, and this may be measured by its size of catchment, topography, and land use features. The negative intercept (-180.3) can indicate some underreporting or delayed reporting of discharges at Tindinyo at the beginning of the period of study. On further scrutiny, a slight bend or curve in the gradient of the curve is seen at approximately the point where the cumulative discharge of approximately 1000 m^3/s. Such a change in slope can suggest a change in the relationship amongst the stations, which could be related to the change in instrumentation, calibration processes, changes in land use of the area covered by the catchment, or even possible problems in the quality of the data. These deviations are important in the hydrological analysis because they can indicate actual environmental variations or inconsistencies in data gathering. The curve of the doubled mass shows that the discharge figures of Tindinyo are mostly in agreement with the figures of the reference points with a few slight deviations. Such consistency makes the data useful in further hydrological modelling and analysis..

4.2.3 Variability of Discharge in different River Gauging Stations

The Upper Yala river Basin has a great inter-seasonal and inter-annual fluctuation in streamflow. These differences are connected primarily to the differences in climatic conditions especially the rain falls amounts in the basin. The change in the values of streamflow in the years January 2000 to December 2019 is depicted in figure 4.8. The difference between the measured streamflow in 2007, 2008 and 2016 is very huge. It was observed that, the year 2016 recorded a relatively greater level of streamflow values of all the tributaries within the Upper Yala River basin where the river discharge stood at 337m3/s of the main river of Yala. It was observed that streamflow was usually greater within the month of April to June 2016. Conversely, the values of the streamflow were low in the months between January and March 2016.

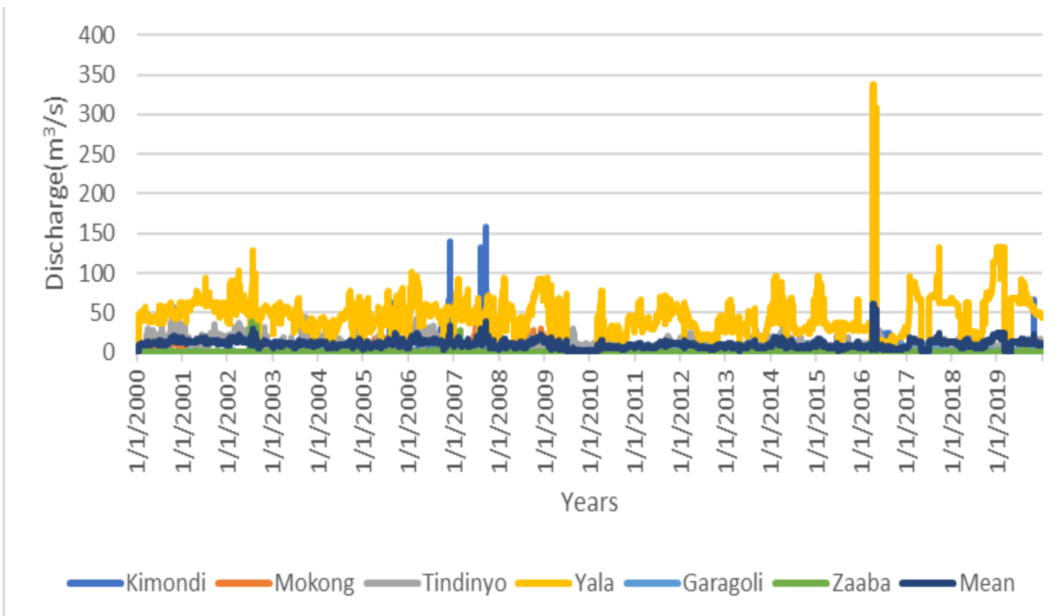


Figure 4.11: A line graph showing Variation of River Discharges in different Streamflow Gauging Stations

The seasonal variability observed in the streamflow is consistent with the seasonal rainfall patterns. The area of study receives the long rains during the months of March, April, and May (MAM) through to the month of June; hence the maximum streamflow was expected during this period. On the other hand, the Sub catchment receives least rainfall during the months of December to February, frequently extending into the month of March. This explains the low streamflow rates observed for the same period.

As can be observed from Figure 4.11, the streamflow values were generally higher during the short rainy seasons in the period under review. There is evidence of extension of the short rainy season with the streamflow values beginning to rise much earlier than the usual period of commencement of the short rains in the month of August. A visual inspection of Figure 4.11 shows the streamflow values increasing rapidly from the month of August to attain the peak value in the month of October. From the month of October, there is a rapid decline in streamflow up to the months of February to March. It is important to note that during the long rainy season, the streamflow values were unusually low. Notably, the results presented in Figure 4.11 show a significant shift in the patterns of streamflow in the Upper Yala River Basin.

These shifts in the patterns of streamflow in the Upper Yala River Basin can be attributed to climate change, even then, the short rainy season seems to be beginning much earlier (in months of July to August) than in the past. The short rainy season seems to extend up to the months of February and March in the basin. It is also clear from Figure 4.11 that the traditional long rainy season (March – April - May) seems to be losing its dominance while the short rainy season (October – November - December) seems to be becoming a more dominant season in the basin. Streamflow of rivers found in the Upper Yala River Basin shows significant differences and no two rivers have the same level of discharges.

4.2.5 Results of Modeling Rainfall Variability and Discharge of the Upper River Yala Basin

This section presents finding of modeling the rainfall variability and discharges of the Upper River Yala Basin which was done through simulation exercises using SWAT modeling system as seen in Figure 4.13.

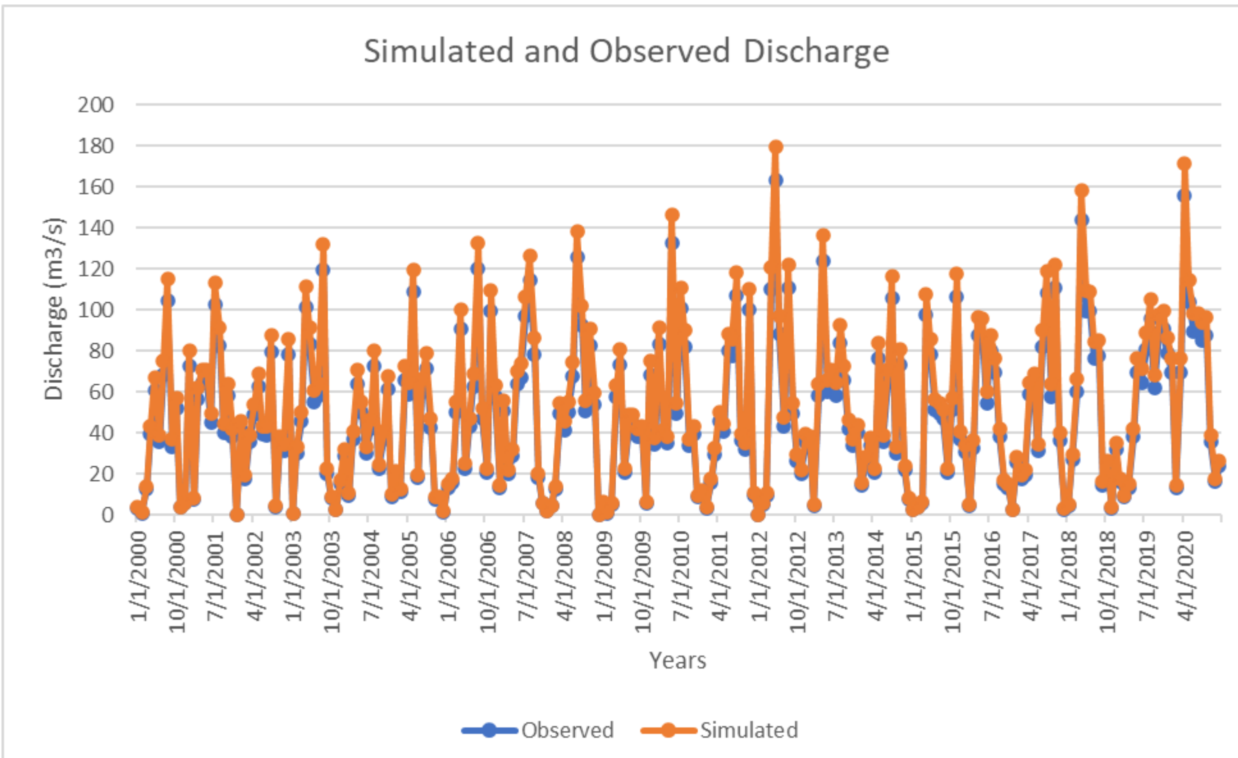


Figure 4.13: Simulated and Observed Discharge

As illustrated in Figure 4.13, the simulated streamflow is good and that the simulated values were not significantly different to the observed values. The average values of the measured discharge were 48.69 m3/s while the maximum discharge was 163.09 m3/s. The smallest discharge figure was 0.328 m3/s and the standard deviation figure was 34.28 m3/s. The average value of the simulated discharge was 53.56 m3/s and the maximum value of the simulated discharge was 174.41 m3/s, the minimum value of the simulated discharge was 0.360 m3/s and the standard deviation value was 37.87 m3/s. Based on the calculated statistics it can be well discerned that there was very little difference between the observed value of discharge and the value of discharge which had been simulated during rainfall variability..

4.2.6 Influence of rainfall variability on discharges in the Upper River Yala Basin

Regression analysis was used to evaluate the influence of rainfall variability on the amount of river discharge, as shown in Table 4.7.

Table 4.7 Regression Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.963[a]	.942	.939	27.234047815553860

a. Predictors: (Constant), Rainfall

Table 4.7 has presented the (R) value between precipitation variability and discharges in upper river Yala. It showed very good association of 0.963 (which equals to 96.3 percent) between discharges and temperature variability. The (R2) value is a coefficient of determination, which was used to estimate the percentage of the variance in the dependent variable that is attributable to the changes in the independent variable (rainfall variability and discharge). The findings led to the conclusion that it had a 94.2 per cent (synonymous to 94.3) of variance or correlation between the dependent and the independent variables and implies that 94.2 per cent of the variations or changes in discharge levels were contributed by the variability of rainfall. This meant that there was a very strong positive linear association existing between the two parameters.

The regression model significance in Table 4.2 in the ANOVA statistics is F (1, 370) = 133.285, p=0.001. It is important to note that a F-significance value of p = 0.000 was set indicating that the probability of 0.0% of the regression model containing false information was created. Consequently, the model was quite important.

Table 4.8: Results obtained from the Analysis of Variance (ANOVA)

Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	405475.907	1	405475.907	511.865	.000[b]
	Residual	293096.980	370	792.154		
	Total	698572.887	371			

a. Dependent Variable: Discharge
b. Predictors: (Constant), Rainfall

From Table 4.9, the following regression model was established;

Discharge = 49.348 + 0.614 Rainfall……………………….(4.2)

Table 4.9: Regression Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	49.348	6.880		8.048	0.000
	Rainfall	0.614	0.936	0.582	14.029	0.000

a. Dependent Variable: Discharge

According to Table 4.9, the regression constant indicated that at the point of constant values of the independent variable (i.e. rainfall, that is, at the point where the independent variable is at zero), the amount of river discharge would be 49.348 (as an unstandardized coefficients). Therefore, the introduction of rainfall raised the level of river discharge by the value of 0.614. This value was noteworthy at ($p<0.000$) level. It implies that there is a significant positive relationship between the rainfall variability and the amount of river discharge at 95% level of significance. Rainfall variability explained 94.2% of the changes in the amount of river discharge in the River Yala watershed; a correlation of 0.963 was determined to show that rainfall variability and the amount of river discharge have a strong positive linear correlation; the results further showed a strong significant correlation (where $p = 0.000$). This was due to the heavy rainfall events that created runoffs during the wet season as it was experienced in the year 2016.

In comparison with a corroboration and to further evidence the results of the previous discoveries, Zhang et al., (2014) found the same results in their analysis of the streamflow variations in the Heihe River Basin in northwest China that drew a conclusion that the rise in the streamflow was primarily caused by warmer weather and more precipitation. Similarly, Xiaoying et al., (2016) observed that greater precipitation and the reduction of potential evaporation were the primary sources of the runoffs in the research on the influence of climate variability and the anthropogenic activity on the Minjiang River Basin. In addition, Njogu and Kitheka (2017) evaluated the impact of river discharge and rainfall at the upper Tana Catchment and found that there was a good relationship between streamflow and rainfall (r-value = 0.9) that was significant at $p = 0.05$. According to Kitheka et al., (2019), it has been found that the percentage of excessive rainfall and discharges has been observed to rise in spite of the fact that the correlation between rainfall and river discharge in the watershed was rather complicated.

To further support this study finding, Gikonyo et al., (2021) found out the impact of rainfall variability on hydrological response of the Upper Yala River Basin and concluded that the influence of increased rainfall variability had a profound impact on the discharge pattern of the river. The authors noted that the extreme discharges were predetermined by the occurrences of heavy rainfall and it aggravated risks of floods in the basin. Low rivers flow in the dry seasons was on the other caused by dry seasons that influenced water supply in agriculture and domestic water. Wambua et al., (2019) also confirm these results and examined the existence of correlations between rainfall variability and river discharge in the Ewaso Ng'iro River Basin and compared them to the Upper Yala River Basin where the relationship between rainfall and river discharge is positive as supported by the findings. The scholars found that this relationship played a critical role in the understanding of the hydrological processes in the region particularly in terms of the impacts of climate change.

Another related study was Obiko et al., (2018) that established the risk of floods in the Upper Yala River Basin focusing on the rainfall variability. The study established that there was a direct relationship between the increase of variation of rainfalls and the presence of flooding. The authors have pointed out the need to possess better methods of managing floods to mitigate the dangers associated with the heavy precipitation. The same was also discovered by Nyamai et al, (2015) who analyzed statistical data on rainfall/river discharges obtained on the Upper Yala River Basin and established significant correlations between the rainfall and river discharge as well as revealed significant relationship between the variability in rainfall and the rate of discharge. The authors suggested that additional rainfall and discharge was to be observed to ensure that the policy remained in line with the hydrologic conditions.

4.2.7 Predicted Rainfall and Streamflow Future Trends

The following section gives the results obtained when carrying out the calibrated simulation exercise of the SWAT model on forecasting the rainfall and river discharges future tendencies between the years 2024 and 2043 as represented in Figure 4.14.

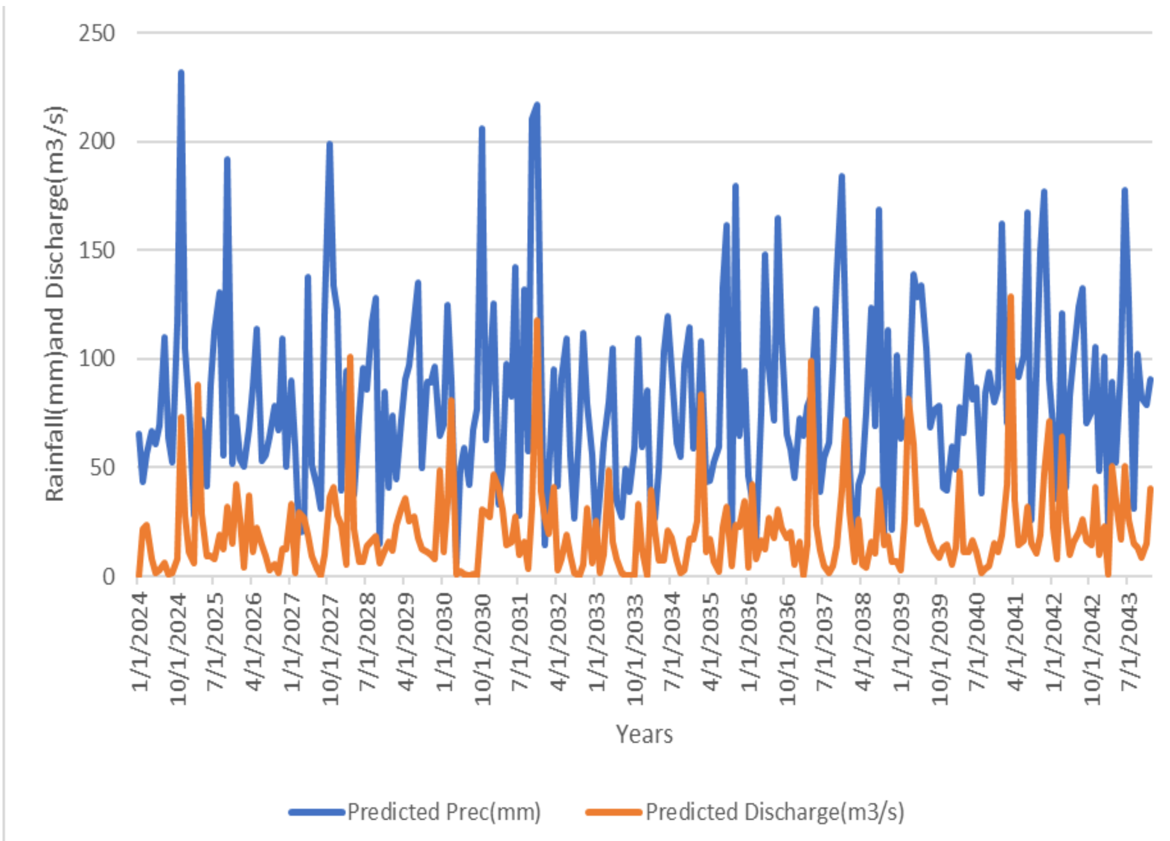


Figure 4.14: Annual rainfall and river discharge future trends in the Upper River Yala basin

In climate models, the climate change leads to more variability of rainfall as shown in Figure 4.14 and both excessive exposure to rainfall and long dry periods are likely to become more common. It is the case that climate change will increase the occurrence and intensity of excessive rainfall in a majority of the places which include East Africa. The occurrence of heavier rainfall could lead to harsh discharges of rivers, which result in flash floods. Soil erosion and transportation of sediments can be intensified because the period of runoff is more aggressive during rainy seasons and could affect the water quality and aquatic life. It may have higher variations in seasonal rainfall levels whereby a particular season may have very high rainfall when compared to the other season. This fluctuation can disrupt natural hydrological cycle resulting in variation in timing and magnitude of river flow. A good example would be that extended dry seasons can lead to low discharge during the most essential agricultural seasons and therefore farmers would not be able to know the most appropriate times to plant and irrigate and as such they would not produce or produce harvest at the right time.

The uncertainty in rain patterns can lead to the occurrence of more droughts and floods in the Upper Yala River Basin. The river may go through a protracted wait of droughts which may result in decrease of base flow and consequently, affect water availability that can be utilized in drinking, agriculture, and ecosystems. The inconsistency of rainfalls may also vary in case of change in land use, urbanization and deforestation that in turn may alter the river discharge processes and therefore hydrological models require adjustments to reflect the fluctuating conditions in respect to rainfall variability. Increase or decrease in long term discharges patterns may be general with the size and nature of variability in rainfall. In the cases when the drought conditions are more diffused the situation with the low flow can be more common as well and affect the water supply and the well-being of the ecosystem. Conversely, high frequency of rainfalls will lead to increase in the average discharge values which will have impacts on the floodplain processes and management.

These results are comparable to the results of Ochieng et al., (2020) who conducted their research on the basis of hydrological models to evaluate the effects of climate change on rainfall and river discharge in the Upper Yala River Basin. Using the study, it was determined that higher Rainfall Variability projections imply that the rainfall will turn out to be more variable with great implication on river discharge patterns. The models demonstrated that the peak discharge events will tend to rise depending on different climate scenarios especially during the rainy season and that the low flow conditions will be enhanced during the dry seasons. Hence the future patterns in the variability of rainfalls on river discharge in Upper Yala River Basin are anticipated to be complicated, with more intensity and uncertainties in the rainfall events that could result in more flood tendencies and change in hydrological reactions. The proactive efforts that will play a significant role in alleviating the impacts of these changes as well as guaranteeing the sustainable use of water resources against climate change will involve better infrastructure, adaptive water management and community participation..

4.2.8 Summary of Specific Objective Two

The variation in rainfall is also very important in setting the discharge in the upper river Yala Basin. The correlation of the rainfall variability and river discharge is multifaceted because it relies on a number of hydrological and environmental variables. Alteration in the pattern of rainfall has numerous impacts on river discharge. The Upper Yala River Basin is seasonal and very sensitive to the changes. The alteration in the intensity and timing of rainfall will affect the pattern of discharge with the probability of higher occurrence of flash floods during heavy rainfall seasons and lower baseflow during prolonged dry seasons.

4.3 Results of Specific Objective Three: Influence of the simulated climate variability on discharge under different land use and land cover scenarios in the upper river Yala Basin

This section presents the results obtained for specific objective three of this study that was to establish the influence of the simulated climate variability on discharge under different land use and land cover scenarios in the upper river Yala Basin, where rainfall and temperature were considered to be key factors influencing streamflow variability, and other factors such as land use/land cover change also seemed to be important.

4.3.1 Results of Land Use / Land Cover Classification

Table 4.10 shows the classification of land use / land cover classification in the study area

Table 4.10: Land use/land cover classification showing major units and sub-units within the major units in the upper Yala river basin

Major units	**Sub units within the major units**
Cropland/agriculture	Intensively cultivated land
	Moderately cultivated land
	Scattered cultivated land within shrubs
Vegetation/forest	Dense natural forest
	Plantation forest
	Natural and plantation forest
Grass land	Wooded grass land
	Open grass land
	Shrub grass land
	Open shrub land
	Dance bush land
	Degraded wooded shrub land
Built-up area/urban	Villages
	Roads
	Town
Water	Water pond
	River

Major units	Sub units within the major units
	Reservoir

Source USGS

4.3.2 Derived land use/land cover areas in the Upper River Yala watershed

4.3.2.1 Derived land use/land cover areas for the year 2000

Table 4.11 shows the land use/land cover types, the acreage in hectares and percentage in the upper Yala river basin. This shows the impact of land use/land cover change on the streamflow in the Upper River Yala watershed for the year 2000.

Table 4.11: Land use/land cover types, the acreage in hectares and percentage in the Upper River Yala basin for the year 2000

Type	Area in Hectares	Area in Percent
Water Body	847.13	0.622
Vegetation	11,464.87	8.418
Grassland	35,802.86	26.288
Cropland	80,267.69	58.936
Built-up area	7,812.13	5.736
Total	**136,194.68**	**100**

Source: USGS

The overall coverage of cropland, grassland, vegetation, built-up area and water bodies on the LULC map of the year 2000 was about 59.936%, 26.288%, 8.418%, 5.736%, and 0.622%, respectively, representing the whole part of Upper River Yala watershed.

4.3.2.2 Derived land use/land cover areas for the year 2010

Table 4.12 shows the land use/land cover types, the acreage in hectares and percentage in the upper Yala river basin. This shows the impact of land use/land cover change on the streamflow in the Upper River Yala watershed for the year 2010.

Table 4.12: Land use/land cover types, the acreage in hectares and percentage in the Upper River Yala basin for the year 2010(source, USGS)

Type	Area in Hectares	Area in Percent
Water Body	690.51	0.507
Vegetation	6,921.41	5.082
Grassland	19,936.18	14.638
Cropland	98,886.87	72.607
Built-up area	9,759.71	7.166
Total	**136,194.68**	**100**

According to the land use/land cover state for the year 2010, it showed that cropland covered 72.607%, followed by grassland, built-up area, vegetation and water bodies, which covered 14.638%, 7.166%, 5.082%, and 0.507%, respectively. Due to the expansion of farming regions from time to time, the cropland coverage had the largest coverage of 98,886.87 hectares while the water bodies covered the smallest acreage of 690.51 hectares during this year.

4.3.2.3 Derived land use/land cover areas for the year 2020

Table 4.13 shows the land use/land cover types, the acreage in hectares and percentage in the upper Yala river basin. This shows the impact of land use/land cover change on the streamflow in the Upper River Yala watershed for the year 2020.

Table 4.13: Land use/land cover types, the acreage in hectares and percentage in the Upper River Yala basin for the year 2020

Type	Area in Hectares	Area in Percent
Water Body	502.56	0.369
Vegetation	5,066.44	3.720
Grassland	19,737.33	14.492
Cropland	93,181.68	68.418
Built-up area	17,706.67	13.001
Total	**136,194.68**	**100**

Source, USGS

The LULC map of the year 2020 shows that the cropland occupied 68.418% of the total area of the watershed of the Upper Yala River. This could have contributed to the growth in settlement and farming units on the available land due to high increase of human population in the Upper Yala River watershed. The water bodies, vegetation, grassland, and build up area on the other hand occupied different percentages i.e.: 0.369, 3.720, 14.492, and 13.001, respectively. This character of coverage might have been attributed to the annuities of clearing forests to farmland and standard of novel urbanization and rural communities around the Upper Yala River watershed..

LULC

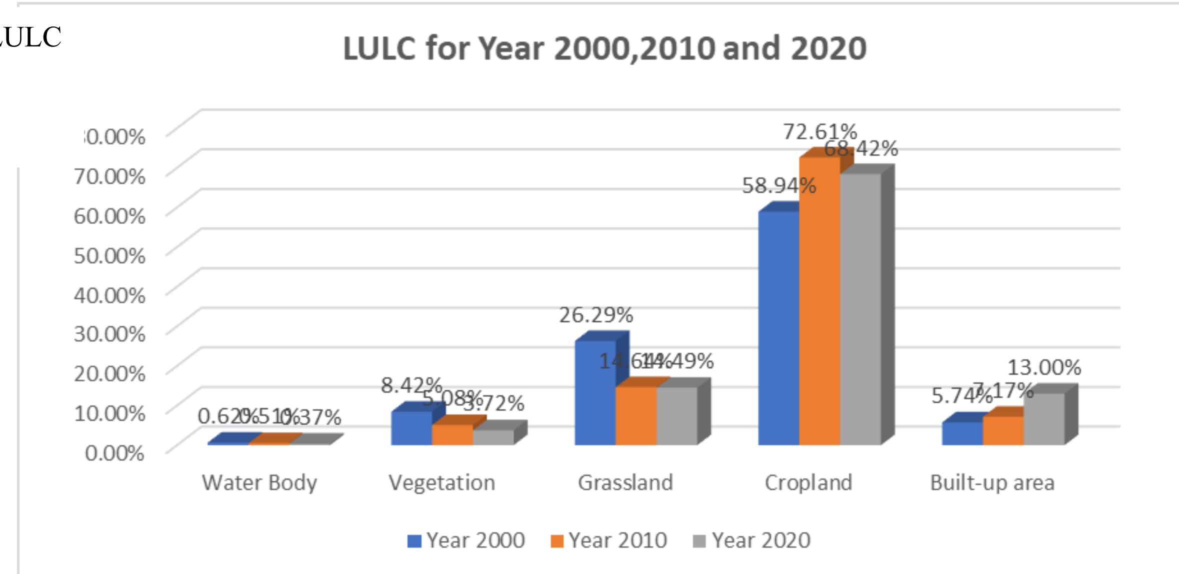


Figure 4.15: A bar graph showing the land use/land cover types and their area of coverage (%ge) in the Upper River Yala basin for the years 2000, 2010, and 2020

After interrogation of Figure 4.15, it has been indicated that Upper River Yala watershed experienced land use/land cover change from the years 2000 to 2020. The coverage of built-up areas increased by 1.43% from 5.74% in the year 2000 to 7.17% in the year 2010 while the land cover increase was by 13.00% in the year 2020.

Similarly, cropland coverage increased by 13.67% from 58.94% in the year 2000 to 72.61% in the year 2010, while it reduced by 4.19% to 68.42% in the year 2020. On the other hand, the grassland coverage reduced by 11.65% from 26.29% in the year 2000 to 14.64% in the year 2010 and further reduced by 0.15 to 14.49% in the year 2020. Areas of coverage under vegetation decreased by 3.34% from 8.42% in the year the year 2000 to 5.08% in the year the year 2010 and reduced further by 1.36% to 3.72 in the year 2020. Similarly, the coverage in areas under water bodies declined by 0.11% from

0.62% in the year 2000 to 0.51% in the year 2010, and further declined by 0.14% in the year 2020 to 0.37%.

4.3.3 Land use/land cover change detection for the period 2000–2020

Table 4.14 compares the detection of land use/land cover change for the period 2000 to 2010, 2010 to 2020, and 2000 to 2020.

Table 4.14: Land use land cover change detection

Land use/cover type	**Area change (Ha) 2000-2010**	**% Change**	**Area change (Ha) 2010-2020**	**% Change**	**Area change (Ha) 2000-2020**	**% Change**
Water Body	-156.62	-0.11	-187.95	-0.13	-344.57	-0.25
Vegetation	-4543.46	-3.33	-1854.97	-1.36	-6398.43	-4.69
Grassland	-15866.68	-11.65	-198.85	-0.14	-16065.53	-11.79
Cropland	18,619.18	13.67	-5705.19	-4.18	12,913.99	9.48
Built-up area	1947.58	1.43	7946.96	5.83	9894.54	7.26

According to Table 4.14, the gradual change of LULC, particularly the incremental of cropland by a percentage of 13.67% between the years 2000–2010 and decreased by 4.18% between the years 2010–2020. The coverage of built-up area increased by 1.43% and 5.83% between the years 2000–2010 and the years 2010–2020, respectively, while the vegetation, grassland, and water body coverage values were decreased by 3.33%, 11.65.%, and 0.11% between the years 2000–2010 and by 1.36%, 0.14% and 0.13% between the years 2010–2020, respectively.

The decrease in Yala river streamflow can be attributed to the high percentage reductions of water body, vegetation, and grassland as well as the increases in cropland and built-up area in the watershed. For over 20 years, water bodies, vegetation and grassland were decreased for both periods of the years 2000–2010 and the years 2010–2020 and also the years 2000–2020. However, cropland coverage increased and decreased during the period of 2000–2010 and 2010–2020, respectively, but in overall it realized an increase in coverage in the period 2000–2020. The buildup area coverage increased throughout the period of the years 2000–2010, 2010–2020 and 2000–2020.

These findings are in line with research results on the classification and change of land use/land cover in the Chaohu Lake basin research done by Oyedotun (2018), who found out that the percentage of built-up area rose from 3.5% in the year 1979 to 25.1% in the year 2015. Comparably, the area covered by agricultural land increased from 29.8% in 1979 to 45.2% in 2015 (Oyedotun, 2018), however the catchment's forested and vegetated land significantly dropped during this time, going from 59.8% in 1979 to 22.9% in 2015. In their investigation into the relationship between variations in rainfall and changes in land use/land cover in a small tropical river basin, Kitheka et al. (2019) found out that, from the year 2000 to 2016, the area covered by forests and shrubs grew by 5%, while built-up areas increased by 35%. Tea saw a marginal increase of 5%, while coffee saw a 38% decrease.

The results of this study are similarly consistent with those of Cheruto et al. (2016), who evaluated changes in land use and cover in Makueni County and discovered that evergreen forests had the greatest decline, from 39% coverage in 2000 to 17% coverage in 2016. Similarly, Panwar & Malik (2017) found out that during the previous 20 years

(1995-2015), the study area's forest area decreased from 43.58% to 31.47%, the agricultural area increased from 44.32% to 47.63%, and the settlement area increased from 9.70% to 18.38%. These findings were made while evaluating land use/land cover change in the Bhimtal Lake catchment. Consequently, Butt *et al.,* (2015) came to the conclusion that the shift in land use and land cover in the Sinily watershed was demonstrated by the decrease in the area covered by vegetation and the water class by 38.2% and 74.3%, respectively, and the increase in the area covered by settlement classes by 80.1%, agriculture by 163.7%, and barren land by 63.3%.

4.3.4 Impacts of Land use/covers Change

The findings of the LULC change analysis showed that satellite images of three consecutive years indicated that the streamflow of the River Yala was affected and used to develop three various simulations of the SWAT model. The outcome of the simulated streamflow during the year 2000, 2010, and 2020 did not match through the outcome of the entire streamflow calculated to match the observed streamflow. This implies that the LULC modifications affected the monthly and seasonal streamflow of the Upper Yala River. The LULC modifications occurring in the Upper Yala River Basin are profound influences on the river discharge, because they modify the natural processes of hydrological cycle. However, in a study on the flow simulation using land use change simulation, Kavian et al., (2017) concluded that in most cases, the model results indicated that in their study region, the alterations in the land use resulted in the enhancement of the average runoff.

Likewise, Setyorini et al., (2017) simulated the impacts of changing the land use and land cover in the upper Brantas Basin in Indonesia and discovered that the changes significantly affected the watershed hydrology through the quantity and distribution of surface runoff, groundwater table and soil moisture content. Katana et al., (2013a) in their study of the hydrological impacts of land cover and land use changes in the upper Athi catchment also observed that the change in land use and cover had an overall increase of runoff depths and peak flows associated with agricultural and urban growth.

As in the present study, Aduah et al., (2017) also assessed the impacts of the shifting land use on hydrology of lowland rainforest catchment in Ghana and found out that, under present land use, the peak and dry season streamflow rose by 21% and 37% respectively between the year 1990 and 2011 due to a reduction in the evergreen and secondary forest of 18 and 39 percent respectively. Ng'eno (2016) reported in the similar investigation that the extension of farmland by 8.7% and the shrubland by 1.2% and a decrease of 9.4% and 1.2% in tree plantations and forest corresponded to the increase in streamflow within the Nyangores sub-catchment of the Mara River.

The agricultural land area, especially the clearance of the forests and wetlands, alters the soil structure and leaves the soil vulnerable to erosion. In the regions where farming is used to replace the natural plants, soil compaction also decreases the capacity of the soil to absorb water. An increase in soil erosion causes an increase in sediment load into the river, which may block waterways and decrease channel capacity. This causes increased frequency of flooding and decreased water retention in soils and consequently decreased base flow. In a research on the impact of rainfall variability and land use and land cover changes on stream flow in the Black Volta Basin in West Africa, Akpoti et al., (2016) established that bare lands, urban areas, agricultural lands, and decisions increased by, 67.06 percent, 33.22 percent, 7.62 percent, 29.66 percent, 60.18 percent and 38.38 percent, respectively and grassland reduced by 44.54 percent over the same period. Although the recharge of the ground water decreased by 6 percent due to this change in land use and cover, surface runoff and lateral runoff grew by 27 percent and 19 percent respectively.

The development of roads, building and other impervious surfaces due to urbanization significantly enhances runoff. Cities decrease land resources to the water infiltration and recharge of ground water. The hard-paved surfaces cause greater direct discharge into rivers, which contribute to higher peak flows during storms and lower lag time between rainfall and peak discharge. This adds to the urban flooding and reduces the flow of rivers during dry seasons because of reduced ground water storage. In this case, Lang'at et al., (2019) argue that high and low flow may increase in the watershed where agriculture has continued to rise as time goes by, and the loss of woodland and grassland, which eventually results in the overall water yield increase in a river. Wetlands also serve as natural buffers, as they absorb the excess water during heavy rains and they release the water gradually over time thereby, keeping the rivers at base level. This buffering capacity is minimized by wetland degradation as a result of agriculture and urbanization.

The wetlands loss also causes increased and accelerated runoff during rainy seasons which increase peak discharge. This will decrease the ability of the river to have a consistent flow during dry seasons in the long run, which worsens droughts. The forms of vegetation such as forests to crops or grassland change influence the quantities of water lost by evapotranspiration. Trees and deep rooted vegetation can tap into the ground water in times of dry seasons and slow the release of this water through transpiration. Substituting deep rooted vegetation with shallow rooted crops may decrease the quantity of water that can be absorbed into the river system to be released slowly thereby causing the discharge to be low during the dry season and high during the wet seasons and resulting in higher seasonal variability. However, in contrast, Anaba et al., (2017) established that surface runoff rose by 26.7% when the percentage of built-up areas rose by 26.53 to 39.09 and forestland declined by 31.15 to 13.91 (data).

Deforestation and changing land to agricultural or urban areas, which constitute a form of land cover change, lead to a decrease in the underground storage and absorption of water by the land. Forests especially are also very useful in the recharge of groundwater. A decrease in the amount of groundwater recharge reduces the base flow of a river resulting in decreased discharge in dry seasons. This causes the river to be more reliant on direct rainfall and enhances changes in the river flow. Natural streamflow patterns can be altered by land use changes, including clearing of riparian vegetation or changing agricultural or urban development by altering river channel structure. The result of such changes is more sedimentation in the river, which changes its course, and influences the time and amount of discharge in the river. Changes in the streamflow patterns also predispose rivers to flooding during high precipitations and also decrease their capacity to sustain flow during dry seasons. The subsequent other studies have also reported that surface runoff increased following a reduction in the rangeland and forest cover (Baker and Miller, 2013; Briones et al., 2016; Pokhrel, 2018;

Chotpantarat and Boonkaewwan, 2018). As research results show, the land use change was a significant contributor of variation in the runoff of between 20 and 30 percent with the remaining half being due to climate change and human activity (He et al., 2013).

Urban development causes the risk of flash floods to be higher with less vegetation cover, a greater amount of surface runoff, and extreme weather outbreaks. During storms, peak discharge is elevated and base flow will be reduced and this will result in a greater variability of river discharges on an annual basis. Effects of the LULC alterations on river discharge within the Upper Yala River Basin are complex, and the main contributors of increasing runoff, decreasing infiltration, increasing peak flows, and decreasing the base flows are deforestation, agricultural development, and urbanization. The effects of this include increased flood risks during rainy seasons and low water supply during dry seasons. Sustainable land management practices including reforestation, conservation of wetlands, and urban planning that take into account green infrastructure will play an important role in ensuring that the negative impacts of LULC changes on river discharge in the basin are reduced.

4.3.5 Land Use land Cover accuracy assessments

A kappa coefficient of 81per cent and general accuracy of 83per cent were obtained on the 2020 land use/land cover classification, which means high agreement on the image that was classified with the reference image. The range of kappa coefficient in between 0 and 1 and above 0.7 is acceptable whereas equal to or less than 0.4 is a sign of very weak correlation between the classified image and the ground truth. As Pontius (2000) says, a kappa value of above 0.5 may be regarded as satisfactory in modelling land use change. The agreement as defined by landis and Koch (1977) was as follows; values exceeding 0.79 are excellent, value between 0.6 and 0.79 are substantial and 0.59 and below are moderate to poor. Carletta (1996) confirms that a K>0.8 normally indicates a good agreement and a good accuracy whereas the acceptable level of the overall accuracy as per USGS classification is 75%. Zhu and Li (2013) note that it can use such results to understand the spatial and temporal patterns of LULC change as well as assessing its hydrological effects in the long term.

4.3.6 Assessments of the effects of changes in land use/land cover on streamflow variable

The results of land use/cover change detection of the three year results of satellite images revealed a difference on the streamflow. During the calibration and validation of the model with three land use/land cover maps, the simulation was executed considering all the other parameters quantified in both simulations to measure the variability of the streamflow and to monitor the influence of land use /cover change on the variation.

Table 4.14: LULC change impact on average monthly and seasonal streamflow

Year			**2000**	**2010**	**2020**	**Change (2000–2010)**	**Change (2010–2020)**
Stream flow (m3/s)	Average monthly		34.22	36.56	42..21	2.34	5.65
	Seasonal	Dry	8.07	5.97	4.29	-2.1	-1.68

W et	62. 63	63. 81	69.5 0	1.18	5.69

The average monthly streamflow of the watershed of the Yala River improved in 2000-2010, 2010-2020, by 2.34 m3/s and 5.65 m3/s, respectively. With more agricultural and other land use/change, the seasonal streamflow in the Yala watershed reduces during the dry period than it does during the wet period hence higher streamflow during the wet periods. Findings of this research study showed that the seasonal streamflow declined by 2.1 m3/s, 1.68 m3/s in dry and rainy seasons at 2000-2010 and 2010-2020 respectively. In 2000, 2010, and 2020, 2000, 2010 and 2020 LULC variations of simulated mean monthly streamflow of Yala watershed during study periods were presented. In both the calibration phase and validation phase of land use/ cover, the results indicated an increased streamflow relatively in the year 2000 as compared to the year 2020. Table 4.12 below illustrates that changes in land use/cover influence the River Yala average monthly and seasonal streamflow in the course of the year.

4.3.7 Future prediction of Land use/land cover for the years 2030 and 2040

The following are results obtained using the 2020 land use map as a baseline map, the LULC 2030 and LULC 2040 future predictions.

Table 4.16: Future prediction of LULC for the years 2030 and 2040

Type	LULC (2030)	LULC (2040)
Water body	0.27	0.22
Vegetation	2.34	2.86
Grassland	13.65	11.91

Cropland	71.95	72.30
Built-up area	13.79	14.71
Total	**100**	**100**

Based on the predicted climate of the years 2030 to 2040 as indicated in (Table 4.16), the acreage of the cropland and built-up area improved whereas the acreage of vegetation, grass land and water bodies declined. The expected trends are that cropland, urban built-up and vegetation would keep on rising since the year 2030 to the year 2040. Based on the above findings of the research, it can be inferred that the Upper River Yala watershed has experienced land use/ land cover changes over the past three decades. These have impacted the amount of river discharge. The simulated land use land cover of the area of study projects decreased vegetation cover and upsurged settlements. The nature of plant cover and the nature of trees in a particular area directly influence the soil permeability to permit infiltration, and the vegetation cover has a positive impact of enhancing infiltration by dislodging the macrobiotic soil crust. Moreover, vegetation biomass stores longer water in it to be infiltrated by slowing down the runoff.

Climate Change and Variability is likely to elevate incidences of floods owing to the land use and land cover transitions that presuppose defecting the vegetation cover. Kiluva et al., (2011) noted that land use and climate changes have increased the occurrence and intensity of flooding in the Lower Yala Basin. The estimated reduced vegetation on the upper catchment indicates that the downstream flooding in the lower catchment is likely to aggravate the period projected. The impact of changes on human activities and change in rainfall patterns in a catchment are equally important with and observed 50 percent contribution each. (Eyadema et al., 2020). Therefore, the impact of human activities seems to be significant as compared to the impact of natural increase and decrease of rainfall on the river discharge changes within the Upper Yala Catchment and it is expected to rise in the next estimated period..

The simulated climate variability of the area of study projects generally shrinking rainfall patterns up to 2043, with increased seasonal maximums and reduced minimums. The effect of this it three-fold: there is likelihood of general reduced annual flows. In addition, the increased maximum seasonal flows depict likelihood of increased intensity of seasonal flooding downstream. The observed and simulated topography presents good drainage in the area of study hence the severity of floods would be moderate in the sub-catchment. However, the intensity of the floods in the lower catchment is likely to increase. In the face of climate change, this therefore calls for more structured forward-looking measures to mitigate the floods. On the other hand, reduced seasonal lows projects reduction in volumes of flow hence more stress on the water users. Empirical studies on LULC changes within watersheds have consistently demonstrated the significant impacts that such changes can have on hydrological processes. Deforestation, urbanization and agricultural expansions usually cause runoffs, sediment loads, and a change in stream flows and afforestation and conservation of wetlands can reduce some of these effects. These results help to make an emphasis on the significance of the watersheds functioning and watershed resources conservation through sustainable land use management.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter summarizes the findings of the study and concludes with the findings and the policy implications of the study on the impacts of climate variability on discharge of the Upper River Yala basin, Kenya. It also stipulates suggestions of more researches.

5.2 Summary of the Key findings

5.2.1 Objective 1 Key Findings: Influence of simulated Temperature variability on discharge in the Upper River Yala Basin, Kenya.

The average minimum temperature was 24.341 C and the highest temperatures were 20.4-29.8 C and its standard deviation was 1.52 C. Dry seasons or hottest months are most likely to be connected with sharp peaks in the maximum temperature. These peaks may be linked to a decrease in rainfall and increase in evaporation which influence the discharge levels. The discharge does not appear to follow any evident long-term uphill or downhill trend, yet it is quite variable, and might be caused by the changing patterns of rainfall or by human activities such as damming and water utilization. During certain times, it seems as though an increase in maximum temperature is associated with a decrease in discharge perhaps simply because of discharge during hot and dry seasons through evaporation and lesser rainfall. The discharge appears to react positively to the temperature with a lag and hence during high temperature followed by rain, there is discharge which is high and during wet seasons.

During certain times, the rise in the maximum temperature seems to be connected with a decrease in discharge, which might be caused by evaporation and the lack of rain in hot and dry seasons. When maximum temperature is rising with subsequent rainfalls, the discharge appears to have a positive lagging response meaning that the warm temperatures cause the flow of rivers and rainfall to increase during the wet months. The results of regression showed a 41.9 percent variance or correlation among dependent and independent variable that implies that the variations or change of discharge was due to changes in temperature by 41.9 percent. This meant positive linear relationship between the two parameters was medium.

5.2.2 Objective 2 Key Findings: Influence of simulated rainfall variability on discharge in the Upper River Yala Basin, Kenya.

Changes in rainfall trends influence river discharge in many ways. The Upper Yala River Basin, relies on seasonal rainfall, and is highly sensitive to variability. The shift in the intensity and timing of rainfall is likely to impact discharge patterns, with potential increases in flash floods during intense rainfall periods and reduced baseflow during extended dry spells. The mean observed discharge was 48.69 m^3/s with a maximum discharge of 163.09 m^3/s and minimum discharge of 0.328 m^3/s and standard deviation of 34.28 m^3/s. The simulated discharge had a mean of 53.56 m^3/s with a maximum of

174.41 m^3/s and a minimum of 0.360 m^3/s and standard deviation of 37.87 m^3/s. From the statistics, it can be clearly seen that there are minimal differences between the observed discharge and the simulated discharge under rainfall variability.

The outcomes of the regression showed that 94.2% of change or variance between dependent and independent variable which implies that 94.2% of the variations or changes in discharge were brought about by changes in rainfalls. This meant that there was a high positive linear correlation between the two parameters. The variability in rainfall contributes to 94.2 percent of the variance in the amount of river discharge in the River Yala watershed, the correlation of 0.963 was identified to be in the case of a strong positive linear correlation between the variable rainfall variability and the amount of river discharge. The use of climate change is likely to increase extreme precipitation and intensities in most regions like East Africa. There can be severe peaks of river discharge and flash floods because of heavy rains. Rainy seasons can cause high runoffs that increase soil erosion and sediment transportation that affect the quality and water bodies. The seasons will be erratic in their rainfall patterns and seasons will be heavier with rainfall compared to others. Such variability is able to disrupt natural hydrological cycle leading to dissimilar timings and quantities of river flows. One case is that a prolonged period of dry spells may result in low discharge during critical growth phases of the agricultural activity, and therefore, the farmer may not have the appropriate time to plant and water their crops hence exposure to crop failures or failure to produce.

5.2.3 Objective 3 Key findings: Influence of simulated climate variability on discharge under different land use and land cover scenarios in Upper River Yala Basin, Kenya

The outcome of the simulated streamflow in years 2000, 2010 and 2020 were not identical with the outcome of the entire streamflow that was calculated to its streamflow that was observed. This means that the streamflow of the monthly and seasonal of the Yala River was affected by the LULC changes. The land use and land cover (LULC) transformation in the Upper Yala River Basin have critical effects on the river discharge, as the transformation to the natural processes that control the hydrological cycle is brought about. Monthly average streamflow in the watershed of the Yala River grew between 2000 and 2010 and between 2010 and 2020 by 2.34 m 3/s and 5.65 m 3s, respectively.

Owing to augmented agricultural and other land utilization/cover change, seasonal flow in the Yala watershed is lesser during the dry season in contrast to the wet season leading to a higher streamflow during the wet periods. Findings of this paper are that the seasonal streamflow declined by 2.1 m3/s and 1.68 m3/s at 20002010 and 20102020 respectively, in the dry and rainy seasons respectively. The 2000, 2010, and 2020 presentations of LULC variations of simulated mean monthly streamflow of Yala watershed were given.

As indicated by the estimated trends of the 2030-2040 period as indicated in (Table 4.13) the cropland and built up areas will grow, whereas vegetation, grassland and water bodies will be reducing. The expected impacts would be that crop land, urban built-up and vegetation would keep on rising between 2030 and 2040 and these changes will impact on the amount of river discharge. The simulated land use land cover of the area of study projected lowered the vegetation cover and augmented settlements. Plant vegetation and tree properties in a particular site directly impact on soil permeability that enables infiltration; the plant cover plays the role of enhancing infiltration by eliminating the macrobiotic soil crust. Besides this, vegetation biomass will store water longer and will thus be infiltrated by slowing down runoff.

5.3 Conclusions

5.3.1 Objective 1 Conclusions- Influence of Temperature on discharge

Temperature variability has a significant influence on river discharge, especially in regions where changes in temperature directly affect precipitation patterns, evapotranspiration rates, snowmelt, and soil moisture. Based on empirical evidence, increased temperatures may lead to higher evapotranspiration, reducing available river flow, particularly during the dry season. Besides, variations in the precipitation pattern caused by the fluctuations in temperature might lead to extreme rainfall which will enhance peak flows and risk of floods. This relationship is critical to the management of water resources in the basin considering the current trends in climatic variability and the impact it is having on the availability of water and the risks of floods.

5.3.2 Objective 2 Conclusions- Influence of Rainfall on discharge

Rainfall variability is among the most significant aspects affecting discharge of river in the Upper Yala River Basin. The variation in the quantity, severity, and distribution of rainfall contribute a lot to the flow behavior of the river. The research and results showed that there is a direct relationship between the rainfall patterns and the river discharge in the Upper Yala Basin. The time of abundance of rainfall also meant that the river flow was more as compared to times of no rain or low rainfall. The process of seasonal rainfall variability like in the long rains (March-May) and the short rains (October-December) is a significant factor that determines the amount of water in the river. Extreme rainfall particularly during the rainy season leads to increased peak flows and possible flooding. The catchment area of the basin also has a high potential of runoff with increase in intensity of rainfall particularly when the soil is fully saturated or where there is a land use change that decreases infiltration capacity (deforestation or an increase in agricultural activities). This may cause flash flood and soil erosion, which impacts on the quality of water and the stability of riverbanks.

Another simulated finding shows that climate variability especially the variation in temperature and rain patterns, has an extensive influence on river discharge. In the conditions of high temperature and unpredictable precipitation probability, the Upper Yala River Basin will face even more severe events in its hydrology. When the intensity of rainfall increases, peak flows and risks of flooding also increase, whereas when the dry spells increase, the baseflows and water availability during drought conditions decrease.

5.3.2 Objective 3 Conclusions- Influence of Rainfall and Temperature under on discharge under varying Land Use Land Cover Scenarios

The impacts of climate variability are enhanced by LULC alterations, including deforestation and transformation of forested areas to agricultural lands. In cases of a lowered forest cover, simulation indicates that surface runoff is more and greater amounts of discharge are experienced during a rainfall condition. This also reduces the groundwater recharge and leads to reduced dry season flows. Deforested lands cannot absorb the rains, and the resulting river discharge is more rapid and extreme in reaction to the changes in climate.

Climate variability and changes in LULC interact in a complicated way that affects the river discharge. As an example, in the conditions of both higher temperature and deforestation, the Upper Yala River will become more susceptible to high peaks of the floods and less water in the dry period. On the other hand though, reforestation and climate change would have the perquisite of mitigating part of the worst effects of the rainfall variability by increasing the natural water holding capacity of the basin. Climate variability and land use and land cover scenarios simulation of the Upper Yala River Basin shows that both of the mentioned factors play a significant role in determining the river discharge patterns. Climate changes and especially rainfall and temperature cause drastic alterations to discharge which aggravates floodings and the severity of droughts. These effects are increased by LULC alterations, including deforestation and urbanization, which causes more adverse hydrological reactions. Nonetheless, reforestation and soil conservation, as a form of sustainable land use, can provide interesting solutions to reduce such effects and stabilize the river discharge in a changing climatic condition. This highlights the necessity to manage the two variables (land and climate) together in order to achieve water security and mitigate the risk of floods in the basin.

5.4 Recommendations

Based on the findings regarding simulated climate variability and its effects on river discharge in the Upper Yala River Basin, the following recommendations are made to enhance water management, mitigate the impacts of climate variability, and promote sustainable development in the Basin:

i. It is essential to maintain and upgrade hydrometeorological monitoring systems in the Upper River Yala Basin to ensure the continuous collection of accurate and high-resolution data on temperature and discharge.
ii. Continuous and detailed monitoring of rainfall and river discharge data is essential to detect and respond to hydrological changes in real time. Investment in automated hydrometeorological stations across the basin should be prioritized.
iii. Promote Climate-Resilient Land Use Practices by encouraging reforestation, terracing, and sustainable agriculture in the catchment to reduce runoff and enhance infiltration during rainfall events. These practices will help stabilize base flows and reduce flash floods.

The Upper Yala River Basin faces significant challenges related to climate variability and its impacts on river discharge. By implementing the above recommendations, stakeholders can enhance the region's resilience to climate change, ensuring sustainable water management and reducing the risks associated with floods and droughts. A proactive and integrated approach will foster a more sustainable and adaptive framework for managing water resources in the basin, ultimately benefiting both ecosystems and communities.

5.5 Recommendations for further research

The following are the recommendations for further research;

i. Future studies should incorporate multiple climatic and land-use variables to develop more robust models for predicting river discharge.
ii. Further researches need to be conducted to assess the effects of water quality pollution on human health in the Upper Yala river watershed
iii. Further researches need to be conducted to simulate groundwater flow and contaminant transport in the Upper Yala river watershed

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APPENDICES

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