CLIMATE CHANGE IMPACTS ON PRECIPITATION EXTREMES: POTENTIAL AND PERCEIVED IMPLICATIONS FOR WATER RESOURCES MANAGEMENT ACROSS UGANDA

BY

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DECLARATION

I, Ebalu Moses, declare that this work is entirely my own and contains no previously published or written material except where properly cited and referenced. To my knowledge, none of this content has been submitted for any degree or qualification at any academic institution. I acknowledge the valuable guidance and support provided by my supervisor throughout this process.

Signed: …………………………………… Date: ………………………………

APPROVAL

The undersigned approve the submission of this dissertation titled 'Climate Change Impact on Precipitation Extremes: Potential and Perceived Implications for Water Resources Management Across Uganda' to the Directorate of Research and Graduate Training, Kyambogo University, in fulfilment of the requirements for the award of the Master of Science degree in Water and Sanitation Engineering.

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DEDICATION

This work is dedicated to the Almighty God, the source of all strength and wisdom, and to the communities across Uganda who shared their experiences and knowledge, making this work both meaningful and grounded in the realities of those most affected by climate change.

ABSTRACT

Water resources are increasingly being affected quantitively by climate change impacts. This requires carefully planned adaptation measures. This study investigated climate change impacts on precipitation extremes indices, including the annual maximum series (AMS), Severe dry spell (MDS1). Climate Forecast System Reanalysis (CFSR) was used to characterise historical precipitation conditions. Output from the eight General Circulation Models (GCMs) was used to project climate change signals for the 2050s, 2070s, and 2090s. Bias of a GCM output over the historical period (1985-2014) was assessed in terms of the ratio of observed to the model's output. The best result, indicating no bias, would be indicated by a ratio of 1. The perception of water users in the various Water Management Zones (WMZs) across Uganda was assessed. The AMS over the study period 1985-2014 ranged from about 45 mm/day to nearly 55 mm/day in Victoria and Upper Nile WMZs, respectively. The biases in reproducing observed AMS ranged from 0.06 (for MPI-ESM1-Ham in Kyoga WMZ) to 0.82 (for INM-CM5 in Victoria WMZ). The best performance was exhibited by ACCESS-CM2 being the sole exception, demonstrating nearly accurate AMS estimation in the Victoria WMZ with a bias of about 1.01. Future projections of AMS under SSP245, SSP370, and SSP585 scenarios predict decreasing AMS in the Upper Nile WMZ (up to about 16% decline by 2090s) but increasing in Victoria WMZ up to about 60%. A survey (using questionnaire administered to water users of sample size n = 737) revealed that about 60% of respondents observed reduced precipitation, with approximately 48.1% expecting further declines. Nearly half (49.7%) cited extreme disruptions in rainfall timing, leading to agricultural losses and income reduction. Findings from both GCMs and the assessment of perceptions of water users show the need for carefully planned climate change adaptation in the various WMZs.

Keywords: Climate Change, Precipitation Extremes, Water Management Zones, CMIP6 GCMs.

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LIST OF ACRONYMS

AMIP	Atmospheric Model Inter-comparison Project
AMS	Annual maximum series
ASAL	Arid and Semi-Arid Land
CDD	Consecutive dry days
CDF	Cumulative Distribution Function
CFSR	Climate Forecast System Reanalysis
CMIP6	Couple Model inter-comparison Project phase 6
CWD	Consecutive wet days
DWRM	Directorate of Water Resources and Management
EASM	East Asian Summer Monsoon
ECA	Event Coincidence Analysis
ESGF	Earth System Grid Federation
ETCCDI	Expert Team on Climate Change Detection and Indices
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GCMs	General Circulation Models
GDP	Gross Domestic Product
GHA	Greater Horn of Africa
GoU	Government of Uganda

IDW	Inverse Distance Weighting
IPCC- AR6	Intergovernmental Panel on Climate Change Sixth Report
ITCZ	Inter-Tropical Convergence Zone (ITCZ)
IVS	Inter-annual Variability Skill Score
MDS1	Severe dry spell
MDS5	Dry spell
MoFPED	Ministry of Finance, Planning and Economic Development
MWE	Ministry of Water and Environment
NCEP	National Centres for Environmental Prediction
NWD5	Wet day
NWD10	Very wet day
PET	Potential Evapotranspiration
POT	Peak Over Threshold
PRCPTOT	Total Precipitation
RCA4	Rossby Centre Regional Climate Model
RCMs	Regional Climate Models
RCP	Representative Concentration Pathways
RMSE	Root Mean Square Error
SDII	Simple Daily Intensity Index SDII

SPI Standardised Precipitation Index

SPI Standardised Precipitation Index

SSP Shared Socio-economic Pathways

STD Standard Deviation

Tpnre5 Precipitation total >5mm/day

TSS Taylor Skill Score

UN United Nations

UNDP United Nations Development Programme

WCRP World Climate Research Programme

WGCM Working Group on Couple Modelling

WMZs Water Management Zones

CHAPTER ONE: INTRODUCTION

1.1 Background

With escalating societal demands placing greater pressure on water resources, comprehending climate change's effects on several components of the water cycle is strategically significant for sustainable water resource management (Abbaspour et al., 2009). Climatic changes will predominantly lead to adverse consequences for supplies of water in addition to freshwater ecosystems across nearly all regions of the world (Seneviratne et al., 2021). However, the magnitude of these effects varies significantly based on the different locations. Certain areas are more prone to experiencing water shortages than others, coupled with the escalating demand. This is expected to substantially elevate the population facing the threat of water scarcity (Abbaspour et al., 2009).

Uganda, primarily tropical, will experience consistent precipitation seasons with bimodal and unimodal patterns, respectively. However, climate change will lead to more intense droughts and altered precipitation durations across Uganda, particularly affecting the eastern and north-eastern regions (ReliefWeb, 2022). The economy of Uganda is significantly impacted by climate change, with differential effects on vital sectors including food and agriculture, the fishing industry, forestry as a whole, water management, human settlement, and energy. The detrimental effect of changes in the climate on essential areas makes it harder to reduce poverty, enhance personal welfare, and increase family income (MWE, 2018). Understanding extreme rainfall events is crucial for water management as they present a lot of challenges to ecosystems, such as increased water supply and flooding, in addition to climatic changes. The management of water seeks to improve methods to precisely assess precipitation extremes and detect alterations in severe precipitation patterns over time (Towler et al., 2020).

Several past studies have found changes in precipitation across Uganda. For instance, Nandozi et al. (2012), annual precipitation has declined by 3.5 per cent since the 1960s, with further decreases anticipated in the future. Moreover, the March-May rainfall is diminishing at 4.7% per decade (Nandozi et al., 2012).

The information shared by the Government of Uganda indicates that the Lake Victoria region, the east and northwest parts of the country, are experiencing increased precipitation, leading to wetter conditions (Feldman, 2013). Numerous areas within Uganda are projected to experience notable increases in precipitation during traditionally dry seasons (Goulden, 2008). Changes in precipitation have implications for agricultural productivity. For instance, there has been a rise in the frequency of droughts nationwide, accompanied by a more unpredictable start and end to rainy seasons (Feldman, 2013).

Consequently, the repercussions of extreme precipitation have become more pronounced. Farmers in Uganda have observed a transition towards a less consistent rainfall pattern during the initial wet season (March–May), resulting in crop losses due to drought as well as heightened precipitation intensity, especially during the subsequent periods of (December–March), leading to flooding (Mubiru et al., 2018). Distribution of precipitation within the wet season is important for planning the cropping system (Ozor, 2015). However, due to the growing uncertainty of rainfall patterns caused by climate change, it is essential to conduct thorough research to guide the development of effective agricultural planning policies.

Planning adaptation strategies for the impacts of climate change on water resources requires analysing public opinions alongside scientific data. This research provides important insights into how climate change is perceived and its effects on agriculture. Results from this study can guide policymakers and aid organisations in devising targeted strategies to assist vulnerable communities in adjusting their cropping system to cope with changing climate conditions.

1.2 Problem statement

Uganda's total population stands at 45.9 million, making it one of the countries with the fastest population growth rates globally, estimated at 2.9% annually (UBOS et al., 2024). Most Ugandans live in rural regions, placing considerable demand on the agricultural sector to sustainably produce enough food to fulfil the people's demands without depleting the nation's natural resources (FAO et al., 2025). Swift action in water planning is essential to achieving United Nations Sustainable Development Goal 13, which focuses on climate action (UNDP et al, 2021).

Climate change exerts a notable influence on water resources in African countries, affecting them both in the near and distant future (Srivastav et al., 2021). Environmental challenges include a range of issues such as floods, droughts, depletion of rivers, decline in the quality of both surface and groundwater, changes in precipitation and water vapour patterns, and the uneven distribution of land ice and snow (Naderi et al., 2024). These effects of climate change significantly impact water resources in Uganda and other regions worldwide (Liebig et al., 2023). In addition, changes in climate have led to crop failures resulting in shortages of food (Caparas et al., 2021). There remains a significant portion of the population who need increased awareness regarding the presence of climate change or a more profound comprehension of its consequences (Venghaus et al., 2022).

Uganda's Vision 2040 emphasises the need for sustainable utilisation of natural resources, including water, to drive socio-economic transformation through climate-resilient and green growth pathways (NPA, 2025)Similarly, the Fourth National Development Plan (NDP IV) (2025/26–2029/30) prioritizes climate change adaptation and mitigation as key strategies for ensuring sustainable water resources management, agricultural productivity, and resilience of communities dependent on climate-sensitive sectors (NDPIV, 2024)Aligning with these frameworks calls for scientific understanding of how climate change affects rainfall variability and intensity, factors that directly influence water supply, agriculture, and food security.

Examining the impacts of climate change on extreme precipitation events is essential for understanding the potential and perceived implications for water resource management across Uganda. It is also critical to investigate community perceptions of how climate change influences precipitation extremes and shapes farmers' understanding of the need to adapt farming systems to the changing climate. Despite extensive research efforts in this area, a notable gap remains in comprehensive studies that explore community perceptions of climate impacts on precipitation extremes and how these perceptions influence adaptation decisions. This specific gap prompted the initiation of this research.

1.3 Objectives of the research

1.3.1 Main Objective

To investigate climate change impact on precipitation extremes: potential and perceived implications for water resources management across Uganda.

1.3.2 Specific objective

The specific objectives were:

i) To characterise the observed precipitation extremes in WMZs;

ii) To validate precipitation extremes in the historical output of GCMs;

iii) To quantify the climate change impact on the precipitation extremes; and

iv) To examine the perceived impact of climate change and precipitation extremes in the WMZs.

1.4 Research questions

i) What are the characteristics of the observed precipitation extremes in WMZs?

ii) What is the validity of the observed CFSR and historical output of the GCMs?

iii) What are the impacts of climate change on the precipitation extremes?

iv) What are the perceived impacts of climate change and precipitation extremes in the WMZs?

1.5 Justification of the Study

This study was necessary to address the growing challenges posed by climate change to Uganda's water resources. The country continues to experience an increasing frequency and intensity of precipitation extremes, ranging from severe floods to prolonged dry spells, which have disrupted agricultural production, water supply systems, and ecosystem stability (MWE et al., 2018). These challenges have serious implications for national development and the well-being of communities that depend heavily on climate-sensitive sectors.

Although several previous studies examined rainfall variability and extreme precipitation trends across Uganda (Onyutha et al., 2016), most relied solely on meteorological data or climate model outputs, offering limited insights into how communities perceive and respond to these changes. However, local perceptions and lived experiences provide critical information for understanding community-level vulnerability and adaptation (Parajuli et al., 2013). This study therefore bridges the knowledge gap between scientific evidence and community perceptions of climate change impacts on precipitation extremes and water resource management.

The research also responds directly to national and international priorities. It supports Uganda's Vision 2040 (NPA et al., 2025) and the Fourth National Development Plan (NDP IV et al., 2024), which identify climate-resilient water resources management as a cornerstone for sustainable development. Furthermore, the study aligns with the United Nations Sustainable Development Goal 13, which calls for enhanced adaptive capacity to climate-related hazards and natural disasters.

By integrating analyses of observed and projected precipitation extremes from General Circulation Models (GCMs) with perceptions gathered from communities across Uganda's four Water Management Zones, the research generated empirical evidence that strengthens both scientific understanding and policy formulation. The findings provide spatially differentiated insights into the changing nature of precipitation extremes and offer guidance for adaptive water management, agricultural planning, and disaster risk reduction.

The study was undertaken to fill a critical knowledge and policy gap. It contributes to the scientific understanding of precipitation extremes under changing climatic conditions, enhances awareness of community perceptions of climate impacts, and informs the design of targeted, climate-resilient water management strategies across Uganda.

1.6 Significance of the study

To develop effective strategies for mitigating water-related hazards and ensuring fair distribution of water resources across different regions of Uganda. It is crucial for addressing growing concerns about water scarcity and its adverse effects on sectors such as agriculture, industry, and household consumption.

i) This research provides valuable insights into how climate change could affect water availability in Uganda, helping to develop strategies for adaptation.

ii) It provides evidence-based recommendations for implementing sustainable practices and regulations in water management.

iii) This research also deepened our understanding of the socio-economic implications of water scarcity in Uganda, including its effects on livelihoods and poverty rates.

iv) The study also explored the advancement of more efficient water resource management plans for the nation by evaluating existing water management techniques and identifying their strengths and weaknesses.

1.7 Scope of the study

1.7.1 Time

The study took place across the four water management zones in Uganda, spanning from January 2022 to April 2024. It involved gathering rainfall data from sources such as the Uganda Meteorological Centre, CMIP6 models, and conducting surveys in selected districts of Uganda.

1.7.2 Content

This study focused on assessing how a changing climate may manifest in precipitation extreme events and their consequences on water resource management across Uganda. The results are essential for predicting future climate change trends, understanding public perceptions, and devising adaptation strategies.

1.7.3 Geographical coverage

The study covered the water management zone of Uganda, which is crucial for ensuring water supplies for the country. It encompasses various activities such as monitoring water quality, regulating water usage, and implementing conservation measures. Additionally, the zone collaborates with local communities and stakeholders to promote awareness and education about responsible water practices.

1.8 Conceptual framework

Figure 1-1 shows the conceptual framework for the research study. The dependent variables were climate change impact and climate change adaptation. The capacity to reproduce observed climatology was investigated using two independent variables: precipitation products and GCM outputs. The intervening variables included human perception and changes in land use/cover

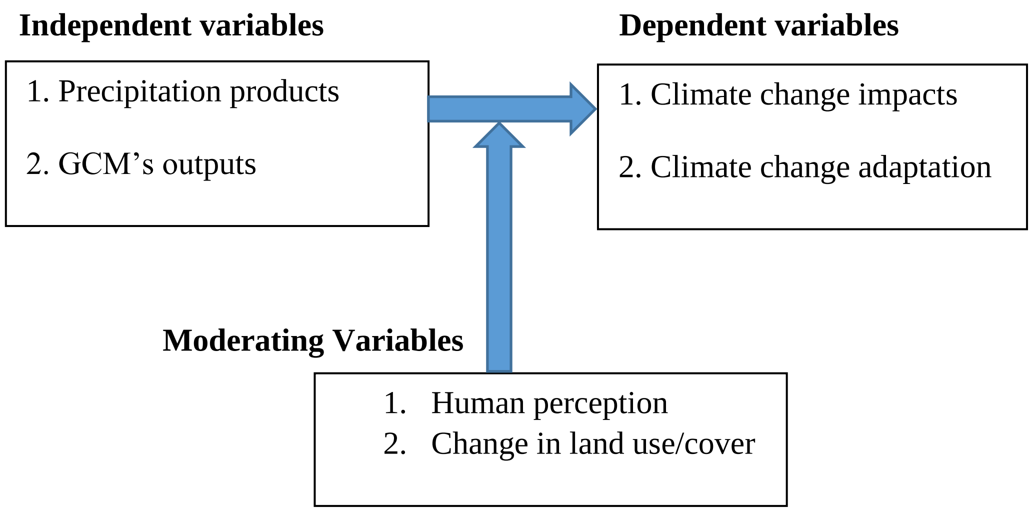

Figure 1-1: Conceptual framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Chapter Two explored the works of numerous researchers and authors aligned with the study objectives. It looked into different theories put forward by researchers and examined whether the influence of climate change on water is substantial and has a big effect on water supplies. According to the literature study, climate change greatly impacts water sources and can change how it rains.

Many theories have been proposed to explain these effects, with some suggesting that alterations in water availability influence land use and vegetation density, thereby impacting the hydrological cycle. The literature review also underscored the importance of understanding local contexts when assessing the possible effects of climate on water sources, by providing a comprehensive overview of existing literature.

2.2 Climate

Climate is the general weather condition of a place over a long period. This can include rainfall, temperature, snow, or other weather conditions (Ogega et al., 2023). The climate of a region is established by studying the enduring weather patterns observed over at least 30 years (Mukasa et al., 2020). Climate change is most likely to have a disproportionate demerit impact on Africa due to the continent's poor adaptation capabilities and sensitivity (Kusangaya et al., 2014). In addition, the socioeconomic and biophysical ecosystems will be directly and indirectly influenced by the effects of climatic changes on water resources (Kusangaya et al., 2014).

2.2.1 Climate and Weather Patterns in Uganda

2.2.1.1 Overview of Uganda's Climate Zones

Uganda experiences alternating wet and dry seasons defined by a bimodal rainfall distribution. The primary rainy period extends from March through May, followed by a secondary precipitation season occurring between November and early December (Ayugi et al., 2020). The division during the rainy season is clarified by the zonal and meridian arms of the Inter-Tropical Convergence Zone (ITCZ), with the former travelling from west to east, crossing over the Congo basin, and delivering the primary rainfall to much of subtropical Africa; the latter, offering shorter and more unpredictable precipitation, moves from north-east to south-west (Urama et al., 2010).

From June to August, dry air masses drive northwest through EA, altering the precipitation pattern in north Uganda. However, by October, the ITCZ in the northern hemisphere will no longer be affected by these masses, and its oscillations will return to being unimodal. The wet season in northern Uganda runs from April to October. More locally impacted air masses, or mesoscale, contribute to the extremely humid environment by increasing precipitation and determining diurnal rhythms (Nicholson et al., 2018). The components of climate include several key factors, such as;

i) Temperature refers to the long-term averages of high and low temperatures that define a region's climate profile
ii) Precipitation encompasses all forms of water falling from the sky, such as rain, snow, and hail, with the amount and distribution being vital for climate characterisation. In areas where snow is prevalent, snowfall amounts and frequency are critical climate elements. Additionally, other conditions like humidity, wind patterns, and sunshine hours further influence the overall climate of a region.

2.3 Variability

The fluctuation of extreme precipitation events has gained significant attention in recent decades due to its critical impact on human society and natural systems. With global warming, the rising moisture levels in the atmosphere may contribute to more frequent and intense extreme precipitation events (Babovic et al., 2018). Variability of precipitation is a measure of how consistent precipitation totals are from year to year. Higher variability means that annual totals fluctuate more around the annual mean. This can pose challenges for water-dependent fields such as agriculture and water management. If precipitation is highly variable, it can be difficult to predict how much water will be available for crops or how much runoff can be expected from a given storm (Horton et al., 2023).

Precipitation variability is a major factor in determining crop yields. When precipitation is highly variable, it can lead to crop failure and diminish the ability of a grazing area to support livestock. These factors can have a significant impact on the agricultural sector and the economy as a whole (Pendergrass et al., 2017).

2.3.1 Past studies on rainfall variability in Uganda or East Africa

Hawinkel et al. (2016) highlighted that the increasing variability and extremes of climate present a serious threat to ecosystem productivity and stability, particularly affecting the vulnerability of semiarid grassland and mixed cropland ecosystems. Ongoma et al. (2017) examined the temporal and spatial variability of temperature and precipitation in East Africa from 1951 to 2010. The data indicates that the most significant shift in yearly precipitation occurred during the 1960s, with a decrease of −21.76 mm/year. Although temperatures have increased steadily since the 1960s to the present, a notable shift in their pattern occurred in 1994. The rise in temperature attained a notable degree in 1992. The 1990s had a peak temperature increase of 0.05 °C per year. The highest drying rate was observed in the 1960s, reaching -21.76 mm per year. In 1953, a shift in rainfall patterns was noted, with a notable increase of around four times in 1980. However, these variations remained largely insignificant during the study period, except in 1963, which experienced a significant positive change at the 5% significance level. The peak level of precipitation was noted during the 1960s. Generally, the northern part of the study area experiences favourable precipitation and temperature patterns, whereas contrasting conditions are observed in the southern part (Chen et al., 2017).

Ongoma et al. (2018) investigated the fluctuations of severe weather occurrences in equatorial East Africa, concentrating on precipitation trends in Kenya and

Uganda. The data indicates that total precipitation associated with very heavy and severe rainfall is only slightly decreasing at the 5% significance level. The PRCPTOT is notably declining in the Arid and Semi-Arid Land, as in other regions in East Africa. The number of days with significant rainfall has generally declined, but there has been a slight increase over the past decade, though the changes are minor. Both PRCPTOT and heavy precipitation have shown a recovery trend that started in the 1990s. The Simple Daily Intensity Index (SDII) has decreased in most areas, particularly in ASAL. These changes suggest potential ongoing climate variability and shifts that are affecting rainfall patterns in East Africa (Omony et al., 2018).

Park et al. (2011) examined trends and variations in localised precipitation around Kibale National Park in Uganda, Africa. Based on the study of precipitation indices and trends, it was found that annual time series patterns do not accurately show the direction and magnitude of seasonal trends or the spatial variability of interannual rainfall at a local level. Monitoring stations positioned to the north of the park exhibited notable increasing trends during the short rainy season, whereas those located west of Kibale demonstrated considerable decreasing patterns in both the long rains following the dry period and in the short rainy season. Areas closer to the park's western boundary experienced more frequent, notably dry years during the two dry seasons compared to those situated further away.

Study of spatiotemporal climate variability in north-eastern Uganda's semi-arid Karamoja sub-region. Egeru et al. (2014) discovered that the period from 1979 to 1994 contained a higher frequency of months with climate variability indices falling below the critical threshold (<1.0) when compared to the subsequent timeframe spanning 1995 to 2009, there was a growing prevalence of wet conditions, leading to a noticeable decrease in multi-year drought occurrences. Between 2004 and 2009, there were more frequent significant wet events (rainfall variability index > 2.6) compared to the period from 1984 to 2003.

2.4 GCMs

GCMs serve as the principal source for developing climate scenarios and underpin evaluations of climate change consequences across all scales, from local to global (Karyn et al., 2010). Impact studies, however, typically do not use GCM results directly because climate models frequently have systematic errors (biases) due to things like low spatial resolution, oversimplified thermodynamic processes and physics and numerical methods, or not fully understanding how the climate system works. GCM reflection has a significant glitch compared to past observations (Villegas et al., 2013). Consequently, adjusting the raw climate model outputs to eliminate bias is essential for generating climate projections that align more effectively with agricultural modelling needs. This will help improve our ability to predict future climate impacts on agriculture and food security. Since the Fourth Assessment Report, Climate models have been continuously developed and refined. Many of these models have evolved into Earth System models, containing illustrations of biogeochemical processes that are critical to changing the climate (Kattsov et al., 2013).

Estimates of climate change are now based on a new set of climate models that are becoming available (Gettelman et al., 2013). The latest 22 ensembles show improved alignment with observations compared to previous versions, and the least effective models have been removed. The National Centre for Atmospheric Research notes that the Coupled Model Intercomparison Project provides a standardised experimental framework for evaluating the results of coupled atmosphere-ocean GCMs. This enables the evaluation of the advantages and limitations of climate models, which can improve and direct the creation of upcoming models. This research concentrates exclusively on two models from the CMIP5 and CMIP6 frameworks.

2.4.1 CMIP5

Simulations from CMIP5 were essential in the creation of the IPCC Fifth Assessment Report (AR5) (Emori et al., 2016). The information derived from these models has been utilised across various areas in evaluating climate change via dynamical downscaling techniques to achieve regional or local specificity (Meehl et al., 2012). Even though the models have seen many enhancements in spatial resolution and various aspects, there remain significant discrepancies in accurately reflecting the observed weather and climate (Sedláček et al., 2013). CMIP5 aimed to deliver a multi-model framework for;

i) Evaluating the processes that contribute to variations in models regarding the complex interactions tied to the carbon cycle and cloud dynamics

ii) Investigating the reliability of climate forecasts and assessing the capacity of models to project climate trends over ten-year periods, and, more broadly,

iii) Analysing the reasons behind the varied responses of similarly influenced models.

2.4.2 CMIP6

According to Carlson et al. (2017) CMIP6 faces a series of significant challenges. More centres will operate multiple versions of increasingly complex models. The ongoing need to address additional processes demands higher model resolutions. The tasks of archiving, documenting, sub-setting, supporting, distributing, and analysing the vast amounts of CMIP6 model outputs will test the capabilities and ingenuity of even the largest data centres and the fastest data networks. Ultimately. The CMIP6 framework promotes ongoing and adaptable model development while coordinating with IPCC procedures. This approach ensures that CMIP outputs respond to climate research community priorities and foster transparent and widespread engagement (Eyring et al., 2016).

Following extensive and broad community engagement, a new and more decentralised framework was established. It comprises three key components (Eyring et al., 2016);

i) A selection of standard experiments, including the Diagnostic Evaluation and Characterisation of Klima (DECK) and CMIP historical simulations (1850–near present), designed to ensure continuity and assist in documenting fundamental traits of models throughout various phases of CMIP;

ii) Shared standards, coordination, infrastructure, and documentation will improve the dissemination of model outputs and the description of the model ensemble

iii) An assembly of approved model Intercomparison projects will focus on specific phases of the initiative (currently CMIP6) and build on foundational and previous simulations aimed at tackling various specific enquiries and closing scientific gaps recognised in the earlier phase. The CMIP6 multi-model ensemble shows improved performance over the CMIP5 in terms of spatial correlation and standard deviation (SD) of climatological precipitation. All CMIP6 models exhibit better skill scores in the climatological patterns compared to CMIP5 models, due to their reduced biases in sea surface temperature (SST).

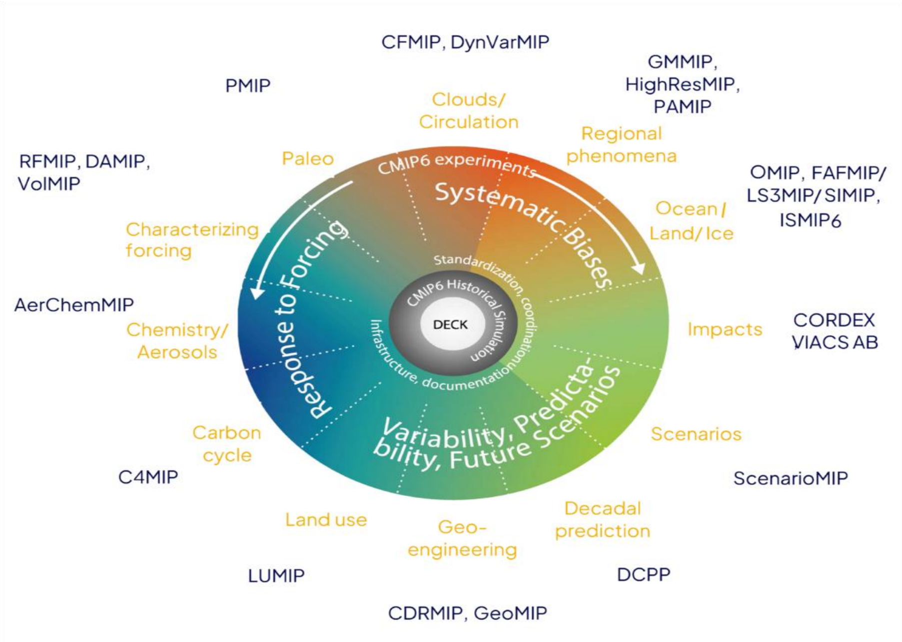

Figure 2-1: Schematic of the CMIP6 experiment design. Source Adapted from Eyring et al. (2016)

From Figure 2.1, the inner ring and surrounding white text involve standardised functions of all CMIP DECK experiments and the CMIP6 historical simulation.

2.4.3 Climate scenarios

The climate change research community created the Shared Socioeconomic Pathways (SSPs). The SSPs are a component of a new scenario framework that supports the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation. The SSPs describe alternative futures that are plausible given the current state of knowledge about the Earth system and human activities. They are designed to be consistent with the latest climate science and to provide a common basis for comparing and contrasting climate change scenarios (Riahi et al., 2017).

The SSPs consist of five narratives that outline different paths for economic and social progress, encompassing sustainable growth, regional competition, inequality, reliance on fossil fuels, and a balanced approach to development (Riahi et al, 2017). The SSP narratives consist of textual descriptions outlining potential future scenarios based on broad societal trends. Their primary aim is to offer a coherent explanation of the main causal relationships and to describe trends that are often challenging for models to capture. In this way, the SSP narratives serve as a valuable complement to quantitative model projections (Riahi et al., 2016).

The SSP narratives, as summarised by Riahi et al. (2016), are as outlined as follows;

i) SSP1: The sustainable and "green" pathway depicts a world increased focused on sustainability. Global commons are being preserved while adhering to the natural boundaries. The primary focus is on individual welfare rather than economic expansion. Disparities in come between and within states are diminishing. Consumption patterns prioritise reducing material resources.

ii) SSP2: The "middle of the road" or moderate route extends previous and current developmental tendencies into the future. Income distribution across many nations is showing significant divergence. Collaboration among governments is limited, with minimal scope. Global population growth is moderate, expected to stabilise later in the century. Environmental systems are undergoing deterioration.

iii) SSP3: The regional rivalry theme is central in this scenario. The prioritisation of nationalistic and regional issues often overshadows global concerns. There is a strong focus on addressing national and regional security issues in policies. Investments in education and technological advancement decrease, as inequality levels continue to soar. Some areas experience significant environmental deterioration.

iv) SSP4: Inequality. The gap between highly developed countries and those lagging in development widens, characterised by poverty and limited education. Environmental policies demonstrate effectiveness in addressing localised issues in certain areas, but have less success in other areas.

v) SSP5: Fossil-fuel-driven development. Increasing interconnectedness through global markets drives technological advancements. Social and economic progress relies on expanded utilisation of fossil fuel reserves, particularly coal, and a globally prevalent energy-intensive lifestyle. The global economy expands, and efforts to tackle local environmental issues like air pollution show effectiveness.

2.4.4 Standard scenarios in ScenarioMIP

SSP585 projects the highest level of radiative forcing among the scenarios outlined in the literature, with an additional 8.5 W/m^2 expected by 2100. This revised scenario incorporates the CMIP5 scenario RCP8.5 along with socioeconomic factors. By the year 2100, SSP370 is projected to have a radiative forcing value of 7 W/m^2, placing it in the upper-middle range of possibilities. It was introduced to address the differences between the RCP6.0 and RCP8.5 scenarios. SSP245, an updated scenario based on RCP4.5, projects a potential increase in radiative forcing of 4.5 W/m^2 by the year 2100.

Illustrating a potential route for future greenhouse gas emissions, this scenario considers the adoption of measures to address climate change. According to SSP126, there is a projected global radiative forcing of 2.6 W/m^2 by 2100. Essentially an updated version of a positive outlook, SSP126 is designed to simulate development in line with reducing global warming to 2°C. Like SSP245, this scenario assumes the implementation of measures to protect the environment (Nicholson et al., 2018).

2.4.5 Downscaling of GCMs

Downscaling offers localised perspectives on the range and potential outcomes forecasted by GCMs, delivering detailed and timely climate data, including precipitation, temperature, winds, radiation, and moisture. It also includes bias correction, though this may occasionally result in misleading results if the GCM exhibits biases in both its average climate and anomalies (Berg et al., 2022). The two ways of downscaling GCMs are;

i) Dynamic Downscaling. This method involves extracting localised information by developing and applying limited-area or regional climate models, utilising coarse global climate model data as boundary conditions. The fundamental procedures involve utilising the GCMs to model the global circulation's reaction to extensive forcing, while employing the nested RCM to address sub-GCM grid scale influences, including intricate topographical characteristics and variations in land cover. This approach aims to improve the simulation of atmospheric circulations and climate variables at detailed spatial resolutions (Berg et al., 2022). The method boasts multiple advantages; however, its implementation and interpretation necessitate substantial computational resources, extensive data, and advanced expertise, posing challenges for institutions in developing nations.

ii) Statistical downscaling involves establishing empirical links between historical large-scale atmospheric conditions and local climate characteristics. (Berg et al., 2022) report. Statistical downscaling encompasses a heterogeneous group of methods that vary in sophistication and applicability. These include: linear methods, weather classifications and weather generators.

2.4.6 Past studies on GCM in Africa

Onyutha et al. (2019) examined how effectively climate models replicate observed rainfall variability using outputs from CMIP3, CMIP5, and CORDEX models. Due to their higher spatial resolution, the CORDEX RCMs demonstrated better replication of daily rainfall variability in the study area compared to CMIP3 and CMIP5 GCMs. Meanwhile, Akurut et al. (2014) investigated the potential impacts of climate change on precipitation over Lake Victoria, East Africa, in the 21st century.

Akurut et al. (2014) forecast only modest increases in annual precipitation totals during the 21st century (under 10% for RCP4.5 and 20% for RCP8.5); however, they predict that extreme daily precipitation events will intensify much more dramatically, with potential increases reaching 40%.

Ongoma et al. (2016) assessed the performance of 22 CMIP5 models in simulating historical rainfall patterns across East Africa using reanalysis datasets spanning 1951 to 2005. Their evaluation revealed considerable variation in individual model performance, with most models demonstrating generally poor overall performance in the East African region. While the models successfully captured the characteristic bimodal precipitation, pattern observed across the region, they consistently misrepresented both the October-November-December (OND) and March-April-May (MAM) seasonal rainfall amounts. Consequently, the monthly correlations between model outputs and reanalysis data were predominantly non-significant.

The research conducted by Onyutha et al. (2016e) involved a comparison between CMIP5 and CMIP3. The usual deviation of the GCMs in depicting rainfall extremes for return periods ranging from 1 to 40 years varied from -19.05% to 3.11% for CMIP5, and from -65.85% to -4.86% for CMIP3. Onyutha et al. (2018) examined the effectiveness of climate models in replicating the variability of observed rainfall, utilising GCMs from CMIP3 and CMIP5, along with the RCMs from CORDEX across Africa. The ability to replicate the variability in observed wet and dry conditions is influenced by the particular GCM from CMIP3, CMIP5, or the CORDEX RCM.

Onyutha et al. (2020) utilised daily rainfall data collected from 1961 to 1990 in East Africa. The ability of six CORDEX Africa Regional Climate Models, influenced by twenty-six General Circulation Models from the Climate Model Intercomparison Project phase 5, to replicate the observed Extreme Rainfall Indices about the long-term mean and trends was assessed. The RCMs surpassed their driving GCMs in accurately representing MDS. The differences between the RCMs and GCMs were less significant when reflecting the MWS compared to the MDS.

Almazroui et al. (2020) examined data from 1981 to 2010 using 27 global climate models from the sixth phase of CMIP6. They explored projected changes in temperature and precipitation patterns across Africa in the 21st century. The

CMIP6 multi-model ensemble predicted a steady and significant increase in average annual temperatures throughout Africa and its eight subregions during this period. Their study revealed that future warming in Africa will not be uniform and will differ by region. By the end of the century, the Sahara is anticipated to experience the most significant rise in average annual temperature (5.6°C), whereas Central East Africa is expected to see the smallest increase (3.5°C) under the strong forcing SSP585 scenario. Moreover, the CMIP6 model ensemble predicts a consistently higher average temperature increase compared to the ensembled CMIP5 across most parts of Africa, with rises to 2.5°C in some areas, while rainfall patterns exhibit a more varied spatial distribution.

2.5 Precipitation reanalysis products

Precipitation reanalysis products are datasets that provide historical estimates of precipitation, including rainfall, snowfall, and other forms of precipitation, over a specific period (Jiang et al., 2024). These products aim to reconstruct past precipitation patterns using a combination of observational data and numerical weather models (Nakyembe et al, 2019a).

Precipitation reanalysis products play a crucial role in advancing the understanding of historical weather patterns and trends, which is essential for various applications (Jiang et al., 2024). They provide a comprehensive and consistent record of precipitation data, enabling the study of climate variability and change (Alamirew et al., 2021), and supporting improved weather forecasting and prediction (Lorenz et al., 2016), these products also inform water resource management, flood and drought risk assessment (Sivakumar, 2011), agricultural planning, and hydrological modelling (Jiang et al., 2019), ultimately contributing to better decision-making and policy development. Furthermore, they facilitate the analysis of extreme weather events (Abebe et al., 2023), support research in ecology and environmental science (Nakyembe, 2019b), and enable the development of climate services and applications (Khoi et al., 2021). By offering a reliable and accurate representation of past precipitation patterns, reanalysis products help to mitigate the impacts of climate-related hazards, promote sustainable development, and enhance our ability to adapt to a changing climate.

2.5.1 Types of Global Precipitation Reanalysis Products

Global precipitation reanalysis products have been developed to provide comprehensive and consistent records of precipitation data.

i) The Global Precipitation Climatology Centre (GPCC) Reanalysis is one such product, based on gauge observations (Wetterdienst et al., 2021),

ii) ERA-Interim Reanalysis, produced by the European Centre for Medium-Range Weather Forecasts (ECMWF), which has been widely used for climate research and weather forecasting (Dee et al., 2012),

iii) The MERRA-2 Reanalysis, produced by NASA's Global Modelling and Assimilation Office (GMAO), is a state-of-the-art product that incorporates advanced data assimilation techniques (Gelaro et al., 2017),

iv) The NCEP-CFSR Reanalysis, produced by the National Centres for Environmental Prediction (NCEP), is another widely used product that provides high-resolution precipitation data (Saha et al., 2014),

v) The 20th Century Reanalysis (20CR) Project, global atmospheric reanalysis focusing on the 20th century (Compo et al., 2011),

vi) ERA-20C Reanalysis, global atmospheric reanalysis focusing on the 20th century, produced by ECMWF (Poli et al., 2016),

vii) JRA-55 Reanalysis, A global atmospheric reanalysis produced by the Japan Meteorological Agency (JMA) (Harada et al., 2016), and

viii) CFSR Reanalysis, global atmospheric reanalysis produced by NCEP (Saha et al., 2010)

2.5.1.1 NCEP-CFSR Reanalysis

The NCEP-CFSR Reanalysis is a global atmospheric reanalysis that covers the period from 1979 to 2014 (Saha et al., 2010). It was produced using the Climate Forecast System Reanalysis (CFSR) model, which assimilates a wide range of observational data, including satellite, radar, and in situ measurements. The reanalysis has a horizontal resolution of approximately 38 km and 64 vertical levels, making it one of the highest-resolution reanalyses available (Saha et al., 2010). It is similar to the NCEP-CFSR Reanalysis but uses a slightly different model configuration and data assimilation scheme. Both reanalyses have been widely used in various climate research applications, including climate modelling and weather forecasting.

2.6 Precipitation indices

Statistical measures are used to describe and analyse precipitation patterns, variability, and trends (Mishra et al., 2015). They are calculated from precipitation data and provide a quantitative way to understand and compare precipitation characteristics across different regions, seasons, or periods (Hawinkel et al., 2016).

2.6.1 Application of precipitation indices

Precipitation indices are widely used in various fields to analyse and understand precipitation patterns, variability, and trends. They are utilised in climate change research to study the impacts of climate change on precipitation patterns (Harrington et al., 2019), and in drought and flood monitoring through indices like the Standardised Precipitation Index (SPI) and Precipitation Concentration Index (PCI) (Mishra et al., 2015).

Additionally, precipitation indices are employed in water resources management to predict water availability and optimise water allocation (Plessis et al., 2024), agricultural planning to predict crop yields and optimize planting dates (Ozor et al., 2010), hydrological modelling to simulate streamflow and predict floods (Chelangat et al., 2021), weather forecasting to predict precipitation events and issue weather warnings (Donat et al., 2016), ecosystem management to understand the impacts of precipitation on ecosystems (IPCC et al., 2007) and urban planning to design drainage systems and predict urban flooding (Ser et al., 2013).

2.7 Extreme Precipitation

Extreme rainfall events in Uganda are happening more often and with more force. As of NMA et al., (2023), the Uganda National Meteorological Authority (UNMA) says that both the intensity and number of heavy rain events have been significantly increasing over the previous ten years (UNMA et al., 2023). The trend is consistent with broader regional patterns observed across East Africa (Ayugi, et al., 2021).

According to the IPCC (2007) report, East Africa is experiencing shifts in precipitation patterns due to climatic change, accompanied by a rise in the incidence of severe weather occurrences (IPCC, 2007). In Uganda, this is reflected in the occurrence of torrential rains and flooding, particularly during the rainy seasons (Kerudong et al., 2022). The occurrences of heavy rainfall represent extreme weather phenomena or climatic situations that may lead to significant consequences for people, structures, or the natural world (McPhillips et al., 2018). They are usually characterised by rainfall measurements that exceed or fall short of a certain statistical threshold and can manifest as brief events, such as floods, or endure for extended durations, like droughts. Extreme rainfall events are typically analysed by the ETCCDI (Zhang et al., 2011). The ETCCDI uses globally recognised indices that show how severe weather occurrences are becoming more often, how long they last, and how intense they are.

The Expert Team on Climate Change Detection and Indices developed a set of climate change indices aimed at measuring and analysing shifts in extreme weather events. These indices are widely utilised in climate change research to assess and attribute changes in extreme precipitation, temperature, and other climate variables. The ETCCDI indices include temperature indices such as TXx (maximum temperature), TNx (minimum temperature), and WSDI (Warm Spell Duration Index), along with DTR (Diurnal Temperature Range) and R10mm (number of days with precipitation exceeding 10mm). Precipitation indices comprise NWD5 (annual number of days with ≥ 5mm), NWD10 (annual number of days with ≥ 10mm), Tpnre5 (annual total of consecutive days with precipitation ≥ 5mm), MDS5 (annual maximum number of consecutive days with precipitation ≤ 5mm), AMS (annual maximum series), MDS1 (severe dry spell ≤ 1mm), RX1day (maximum 1-day precipitation), RX5day (maximum 5-day precipitation), SDII and R20mm.

The indices also incorporate R20mm (number of days with precipitation exceeding 20mm), R50mm (number of days with precipitation exceeding 50mm), CDD (Consecutive Dry Days), CWD (Consecutive Wet Days), PRCPTOT (total precipitation), PRCPTOTSQ (squared total precipitation), PRCPTOTCU (cubed total precipitation), R95p (precipitation amount from events above the 95th percentile), R99p (precipitation amount from events above the 99th percentile), PRCPTOTRX (total precipitation from extreme events), and SDIIRX (Simple Daily Intensity Index from extreme events) to thoroughly analyse and understand the impacts of climate change (etccdi et al., 2023).

2.7.1 Impacts of Extreme Precipitation

The effects of extreme precipitation in Uganda are extensive and severe. Extreme rainfall events have caused major disruptions in agriculture, damaging crops and decreasing productivity. The National Agriculture Research Organisation (NARO) has observed that erratic rainfall patterns are negatively impacting crop yields and farming practices (NARO et al., 2023).

Moreover, flooding has resulted in significant damage to infrastructure, including roads, bridges, and buildings, disrupting transportation and economic activities, which imposes a considerable economic burden on the country, as noted by the World Bank (Bank et al., 2023).Human health and safety are also jeopardised, with a rise in cases of waterborne diseases and injuries reported during heavy rainfall, according to the Ministry of Health Uganda (Health et al.,2023).

Extreme weather has resulted in the displacement of communities, with the Office of the Prime Minister (OPM) reporting the evacuation of thousands of individuals due to flooding (Eyeling et al., 2020). In the Great Lakes region, climate impacts are anticipated to exacerbate existing challenges across various sectors. The increasing frequency and intensity of cyclones are likely to disrupt and damage numerous agricultural, economic, and environmental sectors. Changes in extreme precipitation events will directly affect runoff management, water quality, public health, and transportation (Easterling et al., 2017).

2.7.2 Past studies on the precipitation extremes

Severe weather events can result in critical challenges, including fatalities, infrastructure destruction, and population displacement. Consequently, analysing precipitation pattern changes over extended periods is essential for effective water resource management planning, especially when developing durable, risk-informed adaptation approaches (Onyutha et al., 2023).

Research conducted by Mubialiwo et al. (2023) examined extreme precipitation variations in Uganda's Mpologoma catchment. Their analysis determined that while rainfall frequency decreased with some events showing high intensity, the reduction in wet days was not statistically significant ($p > 0.05$). However, annual precipitation totals for days experiencing rainfall intensities above 5 mm/day (Tpnre5) demonstrated a significant reduction ($p < 0.05$).

The annual maximum series (AMS) showed a non-significant increase (Onyutha et al., 2023). Additional research investigating regional climate change effects on extreme precipitation and temperature throughout the Nile River basin suggested potential increases in most extreme precipitation metrics, indicating the basin might experience more intense and frequent extreme precipitation events in the coming years (Gan et al., 2018).

Research by Onyutha et al. (2016) explored geographical distribution and decadal variations of intense rainfall across Uganda. Findings revealed above-average precipitation periods during the mid-1950s through late 1960s and again throughout the 1990s, contrasted by precipitation decline from approximately 1970 until the late 1980s (Onyutha et al., 2016). Nimusiima et al. (2019) analysed historical and projected extreme rainfall characteristics in eastern Uganda, identifying a general decline across all rainfall indicators between 1981 and 2010. Projected trends indicated positive improvements across most metrics, except the Simple Daily Intensity Index, which was forecast to show negative patterns under RCP4.5. Furthermore, anticipated changes in average values suggested significant increases across all metrics.

2.8 Perception

Perception analysis involves the opinions individuals articulate when prompted through various methods to describe and assess concerns that may contribute to problem-solving and mitigate potential risks. (Parajuli et al., 2013) stated that an individual's view of their capabilities establishes a boundary on their actions and, thus, their potential achievements. The Anomie theory elucidates the impact of perception, which delineates an individual's self-view and their interpretation of the surrounding reality, and how it typically dictates action. It explains that deviance can arise when culturally accepted goals are pursued without the support of culturally approved methods (Ukpebor et al., 2009). The way environmental issues are perceived and their impacts will shape cultural values, responses, and the effectiveness of any system. According to (Ukpebor et al., 2009), if people view water services as being funded by taxes or as a social service provided by the government, it influences their perception.

Pfeffer et al. (2000) emphasise that public perceptions of rainfall are a vital aspect of water resource management that requires careful examination. Within the social-ecological model, the social environment surrounds the individual and includes their relationships, culture, and society. This social context significantly influences water resource management practices. Factors such as cultural background, community socioeconomic status, and institutions like schools are all part of the social environment. For effective water resource management, substantial community engagement is essential for achieving successful outcomes.

Communities consist of diverse combinations of students, age demographics, income brackets, and cultural backgrounds. Consequently, understanding the communities is essential for designing programs that address their particular needs. Awareness-building efforts and education regarding the detrimental effects of insufficient water collection on public health and environmental circumstances might significantly affect attitudes.

2.8.1 Past studies on: Characterise precipitation extremes, validate precipitation extremes, quantify climate change impact on the precipitation extremes, perceived impact of climate change and precipitation extremes in Uganda or East Africa

Afuecheta et al. (2021) analysed the variability and trends in daily precipitation and temperature extremes in the Horn of Africa. Their findings indicated that, irrespective of the country, climatic factors, and agricultural products, the strongest correlation was found with cereal crops, while the weakest correlation was observed with regular potatoes (Omar et al., 2021).

Alupot et al., (2024) study focused on using ETCCDI extreme weather indicators to describe the heavy downpours that occurred in Uganda between September and November. The analysis centred on four indices (R99p, R95p, Rx5day, and Rx1day) within the September to November (SON) period. October had the most intense rainfall days across all four indices. According to the longitudinal study, there were variations in the frequency and severity of heavy rainfall events throughout the years. The study examined the distribution of excessive rainfall over the past decade. It focused on Eastern Uganda and the regions surrounding Lake Victoria. Extreme rainfall has been on the rise across all indices during the last decade (2011–2022). The most extreme years for the SON season were 2019/2020 and 2020. Even though trendlines suggested a slight increase in such events, the SQMK tests confirmed a statistically significant trend in the prolonged durations of severe daily rainfall events (Alupot et al., 2024).

Ayugi et al., (2021) examined projected changes in precipitation extremes in East Africa using CMIP6 models. By the end of the 21st century (2081-2100), the results indicate that, for both seasons, there will be more continuous dry days (CDD) and fewer consecutive wet days (CWD) compared to the baseline period (1995-2014). Additionally, significant changes are observed in metrics such as (SDII), very wet days (R95p), heavy precipitation exceeding 20 mm (R20mm), and total wet-day precipitation (PRCPTOT) during the October-November-December (OND) period compared to the March-April-May (MAM) season. Extreme events may be on the rise in Uganda and a large portion of Kenya, according to the spatial study, while they are on the decline in the Tanzania region (Ayugi et al., 2021).

Kuya et al., (2016) examined the extremes of precipitation and temperatures in East Africa, focusing on both historical data and future projections. The findings indicate that the RCM effectively represents the key characteristics of weather patterns in the region and can reliably reflect the observed climatic trends, though with a minor degree of error. Severe fluctuations in temperature and precipitation are also quite consistently mirrored. RCA4, in contrast, performed poorly in simulating temperatures, particularly the minimum temperature. Additional insights on extreme weather revealed that intense rainfall events were occurring more frequently and with greater intensity, as indicated by metrics such as annual total precipitation from days exceeding the 95th percentile and the number of days with rainfall of 20 mm or more. While warm extremes were becoming increasingly severe, cold extremes were showing signs of improvement (Kuya et al., 2016).

Adhikari et al., (2015) examined climate change's impact on major crops in eastern Africa; the results indicated that climate change generally harms agricultural products; wheat was identified as the most vulnerable grain crop, with forecasts suggesting a potential yield decline of up to 72%. Observations showed that there will be a 45 per cent drop in yield for other grains by century's end, including soybean, rice, and maize. Grains like millet and sorghum can withstand more extreme weather with anticipated yield impacts of less than 20%. Root crops like sweet potatoes, potatoes, and cassava are projected to experience milder effects compared to grain crops, with yield changes estimated between approximately -15% and 10%. Yields for tea and coffee, two major export commodities, are expected to take a hit, losses of up to 40% due to a decrease in suitable growing areas caused by rising temperatures. Similar reductions in suitable regions are expected for bananas and sugarcane, primarily attributed to precipitation changes across lowland regions. Cotton, sugarcane, and other crops are likely to face increased vulnerability due to significant fluctuations in rainfall patterns in the region (Woznicki et al., 2015).

A study by Kisauzi et al., (2012) investigated how farmers in the Teso sub-region of eastern Uganda perceive and comprehend climate change from a gender perspective. The results indicated that all farmers, regardless of gender, acknowledged the presence of climate change. There were no significant differences in perceptions between male and female farmers on most aspects, except for drought frequency recognition, where females were more prone to noticing an upsurge Additionally, the gender of the household head was the only significant factor affecting awareness of the causes of climate change, The study found that households led by women were more likely to be either ignorant of the causes or misinformed about them. Unequal access to information sources like radio, extension programs, and community groups, as well as disparities in educational attainment, were identified as possible reasons for gender-based knowledge gaps (Kisauzi et al., 2012).

Taylor et al., (2017) explored farmers' views on climate variability and disaster preparedness techniques in Central Uganda. They identified prolonged droughts and rising pest and disease outbreaks in crops and livestock as the most severe climate-related disasters. The study found that the implementation of climate change disaster preparedness at the community and village levels was lacking. Similarly (Taylor et al., 2019) investigated perceived and actual rainfall trends and variability in Eastern Uganda, evaluating their effects on community readiness and reaction. The data indicated notable upward trends ($P < 0.05$) in both annual and seasonal rainfall for elevated regions, while low-lying areas showed negative but non-significant trends. Analysis of Variance indicated considerable fluctuations within and between seasons for Lake Victoria, but less variability for the Mt. Elgon and south eastern Lake Kyoga agro-ecologies. Notably, Mt. Elgon exhibited a very high coefficient of variation for the ASON period ($CV > 30\%$), reflecting significant rainfall variability. Over 90% of the farmers surveyed reported changes in rainfall patterns over the past 10 to 15 years.

2.9 Summary of literature review

Previous research has provided valuable insights from scholars that have greatly enhanced our understanding of climate change findings. However, these studies have often lacked specific data. This current study aims to address this knowledge gap by focusing on the collection of both scientific and respondent-based data. The goal is to deepen the understanding of the diverse impacts of climate change. By incorporating quantitative data, this research seeks to provide a more comprehensive and evidence-based perspective on climate change.

Furthermore, by integrating insights from respondents, the study intends to capture the personal experiences and viewpoints of those affected by climate change, fostering a deeper understanding of its effects on various communities and stakeholders.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

Chapter three present the information on the study area, research designed, methodological framework and steps undertaken to conduct each specific objective. The details are provided under sections 3.2 through 3.4.

3.2 Study Area

Uganda is an East African nation without coastal access, sharing boundaries with Kenya to the east, South Sudan to the north, the Democratic Republic of the Congo to the west, Rwanda to the southwest, and Tanzania to the south. The country features numerous water bodies across its landscape.

Some of the lakes within Uganda include Victoria, Albert, Kyoga, Edward, and George. The nation's waterways encompass several rivers such as the Nile, Katonga, Mpanga, Narus, Manafwa, Lamia, Nyamwamba, Rwizi, and Nyamugasani.

The proximity of Uganda to the equator significantly influences its precipitation patterns, leading to a distinct geographical variation. The central and southern regions of Uganda experience two separate rainy seasons, known as a bimodal rainfall pattern. The first rainy season is from March to April, and the second is from October to December. These regions also experience two distinct dry seasons: the first running from January to February and the second spanning from June through July, August, or sometimes extending into September.

Moving away from the equator, especially in northern Uganda, the precipitation pattern shifts to a unimodal system (Atube et al., 2022). This results in a simpler annual cycle compared to the more complex double-season pattern near the equator (Muthoni et al., 2019). This change in rainfall patterns highlights the gradual diminishing of equatorial influence with increasing distance from the equator, leading to varied precipitation cycles across Uganda's regions (Kisembe et al., 2019). Average temperatures in Uganda typically range between 20°C and 25°C (68°F and 77°F) throughout the year (Nkuringo et al., 2024). December to March represents a warmer period, particularly noticeable in the northern regions, whereas June to September is cooler (Egeru et al., 2019). There can be significant daily temperature variations, with days occasionally becoming very hot, especially from December to April, and nights can be surprisingly cool or even cold, particularly from June to August (Nkuringo et al., 2024).

Uganda encompasses four WMZs; Albert, Kyoga, Upper Nile, and Victoria, as outlined in Table 3-1. The spatial extents of these WMZs determined through Digital Elevation Model (DEM) delineation differed from the measurements presented in the Uganda Catchment Management Planning Guidelines (MWE, 2014). These discrepancies may be attributed to variations in the spatial resolution of the DEM employed during the delineation process. Areas obtained from the study were used for analysis since they were obtained from a high-resolution DEM, thus, the areas were deemed more accurate than those of MWE. The map of Uganda showing zonal areas of WMZs along with the physical features can be seen in Figure 3-1.

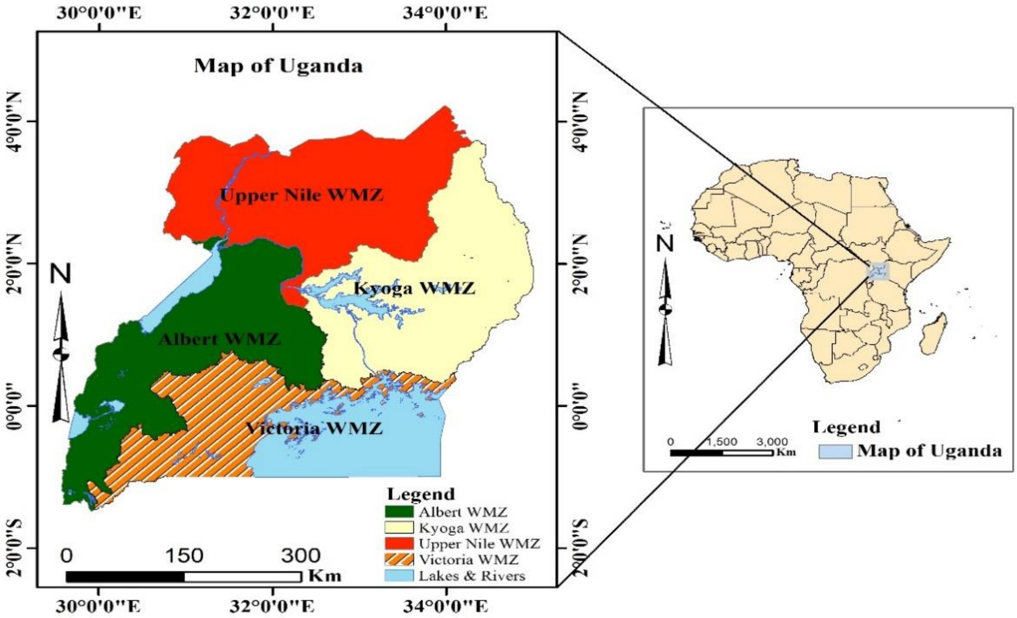

Figure 3-1: Study area

3.3 Research design and approach

The research employed both longitudinal and prospective approaches to conduct experimental studies aimed at characterising precipitation extremes in Uganda's water management zones. The longitudinal design, covering the period from 1985 to 2014, facilitated an evaluation of data over 30 years, uncovering trends and patterns that developed over time. In contrast, the prospective design, spanning from 2041 to 2100, enabled forecasts and predictions of future events based on current data and observed patterns. This combination of designs provided a comprehensive understanding of precipitation extremes in Uganda's water management zones. Employing both descriptive and experimental research methods, I utilised both qualitative and quantitative approaches. This research design and approach are the cornerstones of the study, guiding data collection, analysis, and interpretation, ensuring the trustworthiness and credibility of the findings.

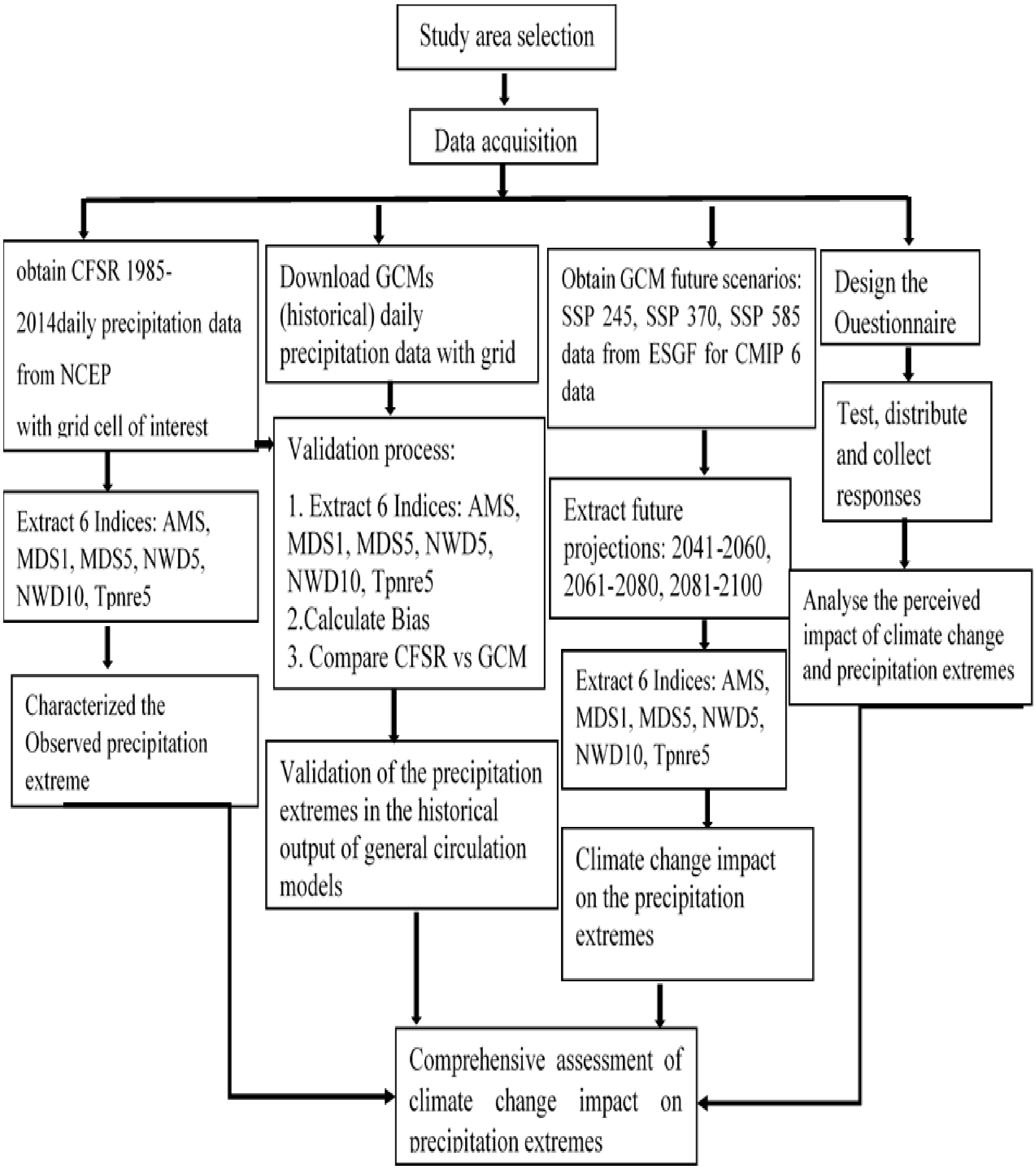

Figure 3-2: Methodological framework

3.4 Data

3.4.1 Precipitation data

3.4.1.1 CFSR precipitation

The CFSR precipitation data (Saha et al., 2014), produced by the NCEP and National Centre for Atmospheric Research (NCAR), covers the period from 1979 to 2013. This dataset is known for its high spatial resolution of 0.25° × 0.25° (Saha et al., 2014). For this study, data from 1979 to 2013 were used. The dataset was selected for its high resolution and free accessibility via https://globalweather .tamu.edu/data/cfsr/ (May 2021).

While climate forecast system reanalysis might show somewhat reduced accuracy, occasionally overestimating or underestimating station-based hydro-climatic measurements in certain areas (Wanzala et al., 2022), its implementation has produced reliable outcomes when evaluated against station-based information from diverse global locations (Asiimwe and Muhwezi, et al., 2021). Furthermore, research conducted by Onyutha and Kerudong (2022) endorsed utilizing CFSR series specifically for hydrological forecasting in regions with limited data availability. Consequently, this study incorporated the CFSR series.

3.4.1.2 Outputs of GCMs

The historical and scenario datasets of the GCMs were obtained via https://esgf-data.dkrz.de/projects/cmip6-dkrz (accessed on 14 May 2021). The GCMs were from the Coupled Model Intercomparison Project (CMIP) phase 6 (CMIP6). A total of 8 GCMs (Table 3-1) were considered. The historical period considered for analysis was from 1979 to 2013. Daily precipitation data from three scenarios, SSP245, SSP370 and SSP585, were considered in this study. Future projections encompassed three future sub-periods: 2041-2060 and 2061-2180, and 2081-2100, referred to as the 2050s, 2070s and 2090s, respectively.

Table 3 -1: The GCMs

NO.	Model Name	Institution	Original spatial resolution
1	ACCESS-CM2	The Commonwealth Scientific and Industrial Research Organisation and the Australian Research Council Centre of Excellence for Climate System Science, Australia.	1.9 ° × 1.3°
2	CCESS-ESM15	The Commonwealth Scientific and Industrial Research Organisation, Australia.	1.9 ° × 1.2°
3	CanESM5	The Canadian Centre for Climate Modelling and Analysis, Canada.	2.8 ° × 2.8°
4	CESM2	National Centre for Climate Research, USA	1.3 ° × 0.9°
5	INM-CM5	Institute for Numerical Mathematics, Russia	2 ° × 1.5°
6	MIROC6	Atmosphere and Ocean Research Institute, The University of Tokyo, Japan	1.4 ° × 1.4°
7	MPI-ESM-HAM	Max Planck Institute for Meteorology (MPI-M) (Germany)	0.9 ° × 0.9°
8	NorESM2	NorESM Climate modelling Consortium, Norway	2.5 ° × 1.9°

3.4.2 Survey data

The study population included communities living in the following districts:

i) Victoria WMZ: Mukono, Mpigi, and Wakiso

ii) Albert WMZ: Ibanda, Bushenyi, and Buhweju

iii) Kyoga WMZ: Kalaki (Kaberamaido), Amuria, and Serere

iv) Upper Nile WMZ: Koboko, Arua, and Maracha

3.4.3 Justification for District Selection

The Victoria WMZ districts of Mukono, Mpigi, and Wakiso represent the densely populated central region characterised by rapid urbanisation and high competition for water resources across domestic, industrial, and agricultural sectors. These districts experienced record-breaking Lake Victoria floods in 2019-2020, which displaced over 40,000 people and damaged critical infrastructure, including water systems, roads, and power stations (Pietroiusti et al., 2024). Additionally, wetland encroachment in areas like Wakiso has altered local climate patterns, causing increased drought conditions and rising temperatures (Kabiri et al., 2022). These districts provide insights into how communities perceive climate extremes in Uganda's economic heartland, where both flooding and water scarcity present significant challenges.

The Albert WMZ districts of Ibanda, Bushenyi, and Buhweju in southwestern Uganda represent mountainous terrain within the Albertine Rift region. This area is highly vulnerable to landslides triggered by intense rainfall, particularly affecting hilly agricultural areas where farmers have had to adapt their crop choices and cultivation practices (Kitutu et al., 2021)As major coffee, tea, and banana production zones, these districts are ideal for capturing community perceptions in contexts where excessive rainfall and extreme precipitation events, rather than water scarcity, pose the primary climate-related challenges.

The Kyoga WMZ districts of Kalaki, Amuria, and Serere form part of the semi-arid "cattle corridor" in eastern Uganda. This corridor covers 43% of Uganda's land area and supports 90% of the national cattle population, with communities experiencing irregular rainfall and periodic droughts (Olupot et al., 2020). The region is characterised by unpredictable rainfall patterns, recurring severe droughts, water scarcity, and crop failures, making agro-pastoral livelihoods highly sensitive to rainfall variability (Nalwanga et al., 2024). These districts represent high climate vulnerability contexts where water scarcity dominates and every rainfall event is critical for community survival.

The Upper Nile WMZ districts of Koboko, Arua, and Maracha in north western Uganda exhibit a distinct unimodal rainfall pattern that differs from the bimodal patterns observed elsewhere in the country (Onyutha, Asiimwe, Muhwezi, *et al.*, 2021). Significantly, this West Nile region hosts large refugee populations from South Sudan and the Democratic Republic of Congo, creating immense pressure on existing water infrastructure and leading to tensions between host communities and refugees as both groups compete for limited water resources (Alliance et al., 2024). As part of the transboundary Nile basin, these districts provide insights into climate change perceptions in regions facing both environmental stress and humanitarian challenges, where water management must address multiple competing demands.

The sample size for each district was determined to ensure a representative cross-section of the population, as shown in Table 3-2**.**

Table 3-2: Distribution of Sample Size per District

S/N	WMZ	District	District Population	Sampled population	% of sampled population
1	Victoria WMZ	Mukono	599,817	74	0.012
		Mpigi	251,512	59	0.023
		Wakiso	2,007,700	73	0.004
2	Albert WMZ	Ibanda	248,083	83	0.033
		Bushenyi	235,621	70	0.030
		Buhweju	124,044	62	0.050
3	Kyoga WMZ	Kalaki	208,163	52	0.025
		Amuria	785,189	52	0.007
		Serere	186,178	55	0.030
4	Upper Nile WMZ	Koboko	213,374	44	0.021
		Arua	270,601	57	0.021
		Maracha	283,630	56	0.020

Source: (UBOS, 2024)

3.4.4 Characterisation of the observed precipitation extremes

To characterise the extreme precipitation, a total of six indices were considered. The extreme precipitation indices (EPI) considered were those used in the previous study (Onyutha, 2020). Their details are provided in the Table 3-3

Table 3-3: Extreme precipitation indices

ID	Indicator name	Indicator definition	Unit
NWD5	Wet day	The annual number of days each has rainfall >5 mm	days
NWD10	Very wet day	The annual number of days each has rainfall >10 mm	days
Tpnre5	Precipitation total >5mm/day	Annual total precipitation from days with rainfall >5 mm	mm
MDS5	Dry spell	Annual maximum number of consecutive days with precipitation ≤ 5mm	days
AMS	Annual maximum series	Series comprising the maximum rainfall intensity in each year	mm/day
MDS1	Severe dry spell	Annual maximum number of consecutive days with rainfall<1 mm	days

From the data of each grid, the six indices were extracted, and spatial interpolation was conducted to visualise the variation in the characteristics of precipitation extremes across the water management zones. The data of the entire period was averaged at each grid before the spatial interpolation. The values for each EPI across the water management zone were averaged; comparisons of these values were made using the bar graphs.

3.4.5 Validation of the precipitation extremes in the historical output of the GCMs

The indices for both CFSR and historical GCM were extracted at each grid point. The grid points for the GCM were validated to match those of the CFSR before comparison, The CFSR and GCM (historical) datasets were remapped onto a uniform $0.25^0 \times 0.25^0$ grid by using the bilinear interpolation method, which is popular in meteorology and climate studies (Hu et al. 2013; Zhu et al. 2015).

Equation 3.1 was applied to the averaged indices of the dataset for each EPI in all four water management zones.

Equation 3.1: Bias

$$\text{Bias}=\frac{\text{GCM (historical)}}{\text{CFSR (observed)}} \tag{3.1}$$

Interpretation of Bias:

i) **Bias > 1**: The GCM **overestimates** precipitation extremes (the model predicts higher values than observed).

ii) **Bias < 1**: The GCM **underestimates** precipitation extremes (the model predicts lower values than observed).

iii) **Bias = 1**: The GCM **accurately simulates** precipitation extremes, matching the observed values without over or underestimation.

3.4.6 Climate change impact on the precipitation extremes

Bias correction was applied to adjust systematic errors in the GCM outputs before analysing climate change impacts. The Linear Scale (LS) bias correction method was selected as the primary approach due to its effectiveness in handling precipitation data. This method was applied to correct precipitation data from the ensembled GCM across three scenarios (SSP245, SSP370, and SSP585).

The LS bias correction was implemented by applying a multiplicative correction factor as in equation 3.2 during the reference period of (1985-2014)

Equation 3.2: Scaling factor

$$\text{Scaling factor}=\frac{\text{mean\_CFSR}}{\text{mean\_scenario}} \tag{3.2}$$

The correction was performed for future projections. The correction factors derived from the historical period were applied to three-time horizons: 2041-2060 (2050s), 2061-2080 (2070s), and 2081-2100 (2090s) using the equation

Equation 3.3: Corrected precipitation future value (Pfc)

$$fc = Pfr \times \text{scaling factor} \tag{3.3}$$

Where;

Where; Pfc represents the corrected precipitation future value,

Pfr is the raw GCM precipitation future value.

Therefore, to analyse the climate change impact the equation 3.4 was applied.

Equation 3.4: Impact of climate change

$$\Delta \text{ in climate} = \frac{\text{CFSR-Pfc}}{\text{CFSR}} \times 100\% \tag{3.4}$$

The percentage changes in precipitation extremes for each index, scenario, and time horizon across the WMZs were plotted in bar graphs showing their variation. This visualization approach enabled effective comparison of projected change impact in extreme precipitation events, outlining zones more susceptible to extreme precipitation events and their potential intensification under different climate change scenarios.

3.4.7 Perceived impact of climate change and precipitation extremes in the water management zones

3.4.7.1 Population and Sample

The study population comprised district listed in Table 3.2 within WMZs of Uganda. A representative sample was selected using random sampling techniques to ensure statistical significance and minimise bias in the research outcomes.

3.4.7.2 Data Collection

The study employed a comprehensive data collection approach using structured questionnaires divided into four main sections: biodata for demographic information, general climate change information, adaptation strategies, perceptions and awareness, and knowledge of extreme precipitation events. Data collection methods include structured interviews with predefined questionnaires, in-depth interviews with key stakeholders, and field observations of climate change impacts on the precipitation extremes. The study engaged diverse participants, including district technical staff, Local Council (LC1) members, farmers, traders, water officers, environmental officers, and agricultural officers.

The research protocol began with obtaining an authorisation letter from Kyambogo University to facilitate access to various water resource management stakeholders. All interviews were conducted following ethical guidelines, including obtaining informed consent from participants, and were carried out at convenient locations such as workplaces, offices, homes, or community meeting places. Data was systematically recorded using paper-based forms to ensure accuracy and reliability in data collection and subsequent input to the Statistical Package for the Social Sciences to obtain the agreement, disagreement and the views expressed by each participant for each question in the questionnaire.

3.5 Ethics

Strict University's data collection regulations were adhered to the established guidelines set by the data providers, and proper attribution to the cited authors in this report ensured that any potential plagiarism issues were effectively addressed.

3.6 Chapter summary

This chapter outlines the research's geographic boundaries, identifies the data origin points, and explains the methodological approaches and analytical frameworks implemented throughout the investigation. A range of approaches and strategies was implemented for data collection and analysis. The next section presents the findings obtained from the analyses conducted using the techniques outlined in this chapter.

CHAPTER FOUR: RESULTS AND DISCUSSION

4. 1 Characterisation of the observed precipitation extremes

Characterising precipitation extremes is essential in Uganda's water management zones, as it aids in understanding the frequency and duration of intense precipitation events by analysing data from various indices. Figure 4-1 presents the result for characterising the observed precipitation extremes in Uganda's water management zones.

4.1.1 AMS

The AMS ranged from highest to lowest in the Upper Nile, Kyoga, Albert, and Victoria WMZs, respectively, as illustrated in Figure 4-1a). The AMS of the Albert WMZ was, to some extent, comparable to that of the Victoria WMZ.

Nsubuga et al., (2018) observed a similar pattern of precipitation distribution in the Upper Nile WMZ, identifying the region as having longer and more intense rainfall periods compared to other areas in Uganda. Additionally, the Victoria WMZ shorter rainfall durations align with findings by Kizza et al. (2012), who noted that the region experiences more intermittent rainfall compared to its neighbouring WMZ.

4.1.2 MDS1 and MDS5

Figure 4-1 b shows the MDS for a threshold of 1 mm/day, indicating a range of about 63 days to 77 days in the Kyoga and Upper Nile WMZs, respectively. In contrast, the Albert and Victoria WMZs were observed to have comparable MDS of approximately 70 days each. When the threshold was raised to 5 mm, all WMZs recorded more than 100 days. The Victoria WMZ achieved the highest MDS, around 130 days, followed by the Albert WMZ at about 123 days. Both Kyoga and Upper Nile WMZs each experienced MDS of around 107 days.

The study by Sebukeera et al., (2023) on rainfall variability across Uganda found that the Victoria WMZ is prone to longer dry spells (MDS5), which corroborates the results observed in this study. Furthermore, the Upper Nile's prolonged periods of severe dry spells align with findings by Nigatu et al., (2024) who indicated that the region experiences extended periods of extremely low rainfall, making it vulnerable to droughts.

4.1.3 Tpnre 5

The Tpnre5 ranged from highest to lowest in the Albert, Upper Nile, Victoria, and Kyoga WMZs, respectively, as illustrated in Figure 4-1d. The Albert WMZ recorded the highest Tpnre5 at about 910 mm. The Upper Nile and Victoria WMZs followed with intermediate values of about 800 mm and 740 mm, respectively, while the Kyoga WMZ had the lowest, at about 705 mm.

4.1.4 NWD5 and NWD10

The analysis of the NWD reveals spatial and threshold-dependent variability across the WMZs. At a precipitation threshold of 5 mm, the Albert WMZ recorded the highest NDW5, followed by Victoria and Upper Nile. The Kyoga WMZ recorded the lowest NDW5. When the threshold was increased to 10 mm, a sharp decline in NWD occurrences was observed across all WMZs. Albert WMZ continued to experience the highest NWD, while Kyoga WMZ remained the lowest, as shown in Figure 4-1c.

Research by Onyutha et al., (2021) on rainfall intensities in Uganda confirmed that the Albert WMZ receives more frequent and intense rainfall compared to other WMZs. This is in line with the findings for both NWD5 and NWD10. Similarly, a study by Obubu et al., (2021) highlighted the lower intensity of rainfall events in the Kyoga region, supporting the observation of fewer days with intense rainfall in this zone.

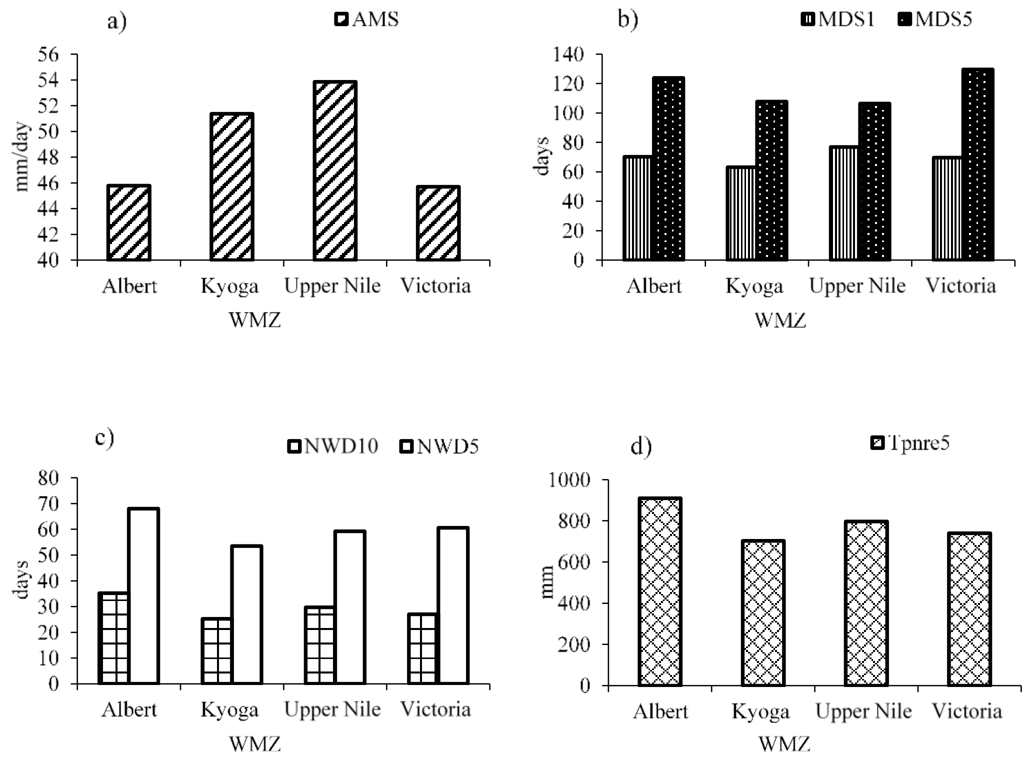

Figure 4-1: Characterisation of the precipitation in terms of (a) AMS, (b) MDS1 and MDS5, (c) NWD10 and NWD5, and (d) Tpnre5

4.2 Validation of Precipitation Extremes in the Historical Output of General Circulation Models (GCMs)

This section presents the ability of the models to simulate the observed climatological mean of annual totals for the indices, displayed as spatial distributions across Uganda’s water management zones for the period 1985–2014. It begins with the observed spatial distribution, followed by spatial bias maps for each climate index across all models

4.2.1 Annual Maximum Series (AMS)

Figure 4-2a) depicts the analysis of Annual Maximum Series revealing a consistent underestimation by nearly all evaluated climate models: ACCESS-ESM1-5, ACCESS-CM2, CanESM5, CESM2, INM-CM5, MIROC6, NorESM2, and MPI-ESM1-Ham across Uganda's WMZs for the period 1985–2014.

The bias values ranged from approximately 0.82 for INM-CM5 in Victoria WMZ to around 0.06 for MPI-ESM1-Ham in Kyoga WMZ, with ACCESS-CM2 being the sole exception, demonstrating nearly accurate AMS estimation in the Victoria WMZ with a bias of about 1.01. This systematic underestimation aligns with broader findings in climate model literature, particularly in tropical regions where models struggle to capture extreme precipitation due to coarse resolution and inadequate representation of convective processes, as documented by Kharin et al., (2013).

4.2.2 Dry Days Analysis

Consecutive dry days (MDS1 and MDS5) represent a key indicator of low precipitation patterns. An increase in the MDS over time in a specific area suggests a higher probability of drought conditions developing in that region.

Figure 4-2b demonstrates that six climate models; ACCESS-ESM1-5, ACCESS-CM2, CanESM5, CESM2, NorESM2, and MPI-ESM-2-Ham systematically overestimated the MDS1 across all WMZs. Conversely, INM-CM5 and MIROC6 models exhibit underestimated the MDS1, with bias magnitudes ranging from 0.21 to 0.85.

When the threshold was increased from 1mm to 5mm, all eight evaluated models; ACCESS-ESM1-5, ACCESS-CM2, CanESM5, CESM2, NorESM2, MPI-ESM-2-Ham, INM-CM5, and MIROC6 overestimate the MDS5 across the WMZs.

The studies of Endris et al. (2019) indicate that some CMIP6 models, including MIROC6, underestimated dry spell frequency in East Africa, contradicting the overestimation trend observed in most models in this study. Nikulin et al. (2018) found that NorESM1 and MPI-ESM-Ham overestimated dry spell duration in certain African regions while underestimating it in others, highlighting the spatial variability of model biases. Furthermore, (Haarsma et al. 2020; Eyring et al. 2021) emphasised that while CMIP6 models have improved in several aspects, uncertainties in soil moisture-atmosphere interactions continue to hinder accurate dry spell simulation, particularly in convective rainfall-dominated regions like Uganda.

4.2.3 Wet Days Analysis

The precipitation indices for wet days (Tpnre5, NWD5, and NWD10) are important for measuring high-precipitation a cross the WMZs. Systematic overestimation of these metrics means that the area is more likely to be flooded by high precipitation, while systematic underestimation means that the area is receiving less precipitation.

Eight GCMs are shown in Figure 4-3 e-f: ACCESS-ESM15, ACCESS-CM2, CanESM5, CESM2, NorESM2, MPI-ESM-2–Ham, INM-CM5, and MIROC6. Each of these indices, NWD5, NWD10, and Tpnre5, across the WMZs, consistently showed underestimation by the GCM models.

However, several statistically significant exceptions emerge from this pattern; MIROC6 exhibits overestimation bias for NWD5 across three WMZs: Upper Nile WMZ, Kyoga WMZ, and Victoria WMZ. Additionally, this model demonstrates overestimation of Tpnre5 specifically within the Victoria WMZ, as evidenced in Figure 4-3f. Similarly, ACCESS-ESM1-5 and ACCESS-CM2 display overestimation bias for both the NWD5 and Tpnre5 indices, though this overestimation is constrained to the Victoria WMZ.

The results are similar to Ayugi et al. (2021) who found CMIP6 models over East Africa consistently underestimated bias, with MIROC6 showing a particularly strange positive bias in the Lake Victoria region. Similarly, Mumo et al. (2020) assessed ACCESS-ESM15, ACCESS-CM2, and MIROC6 performances over the Greater Horn of Africa, documenting consistent underestimation bias in precipitation indices with notable exceptions in the Victoria basin, where topography and lake-atmosphere dynamics present unique modelling challenges. Kisembe et al. (2023) specifically examined NWD5 and NWD10 metrics using CMIP6 models, including CanESM5 and NorESM2, over Uganda's water management zones, revealing analogous patterns of underestimation across most zones with localised overestimation bias in the Victoria WMZ.

Most models underestimate the extreme precipitation. However, some models, especially MIROC6 and ACCESS-ESM1-5, perform differently in different WMZ. The Victoria WMZ consistently deviates from this general pattern, showing an overestimation bias in multiple precipitation indices that is unique. When considered alongside the wet day indices analysis, the findings reveal a consistent pattern of model bias toward drier conditions than observed across the most Water Management Zones. The combination of overestimated dry spells and underestimated wet days suggests potential systematic biases in the representation of precipitation processes that may impact future climate projections for the region.

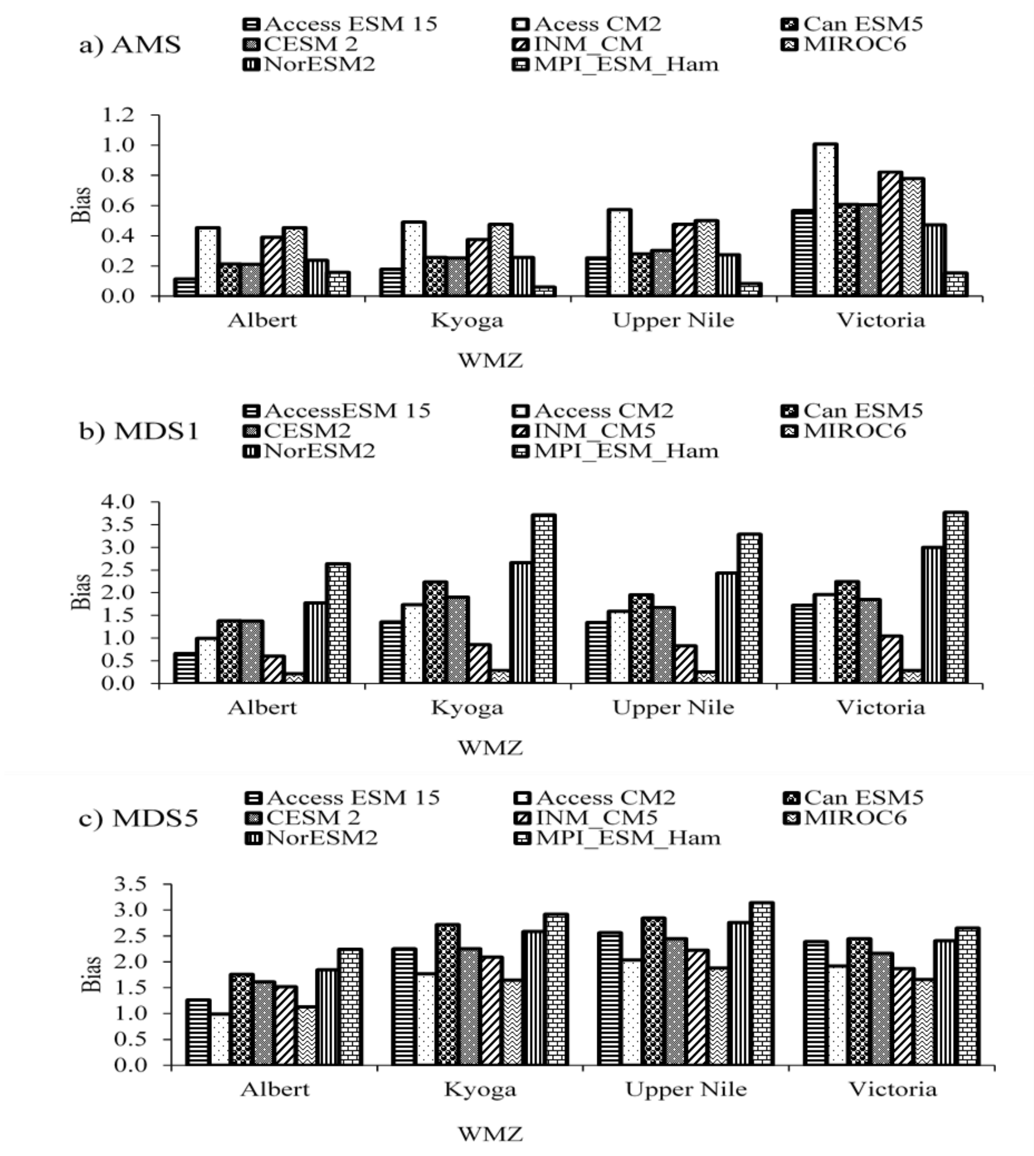

Figure 4-2: Validation of; (a) AMS, (b) MDS1, and (c) MDS5 in the Historical Output of GCM

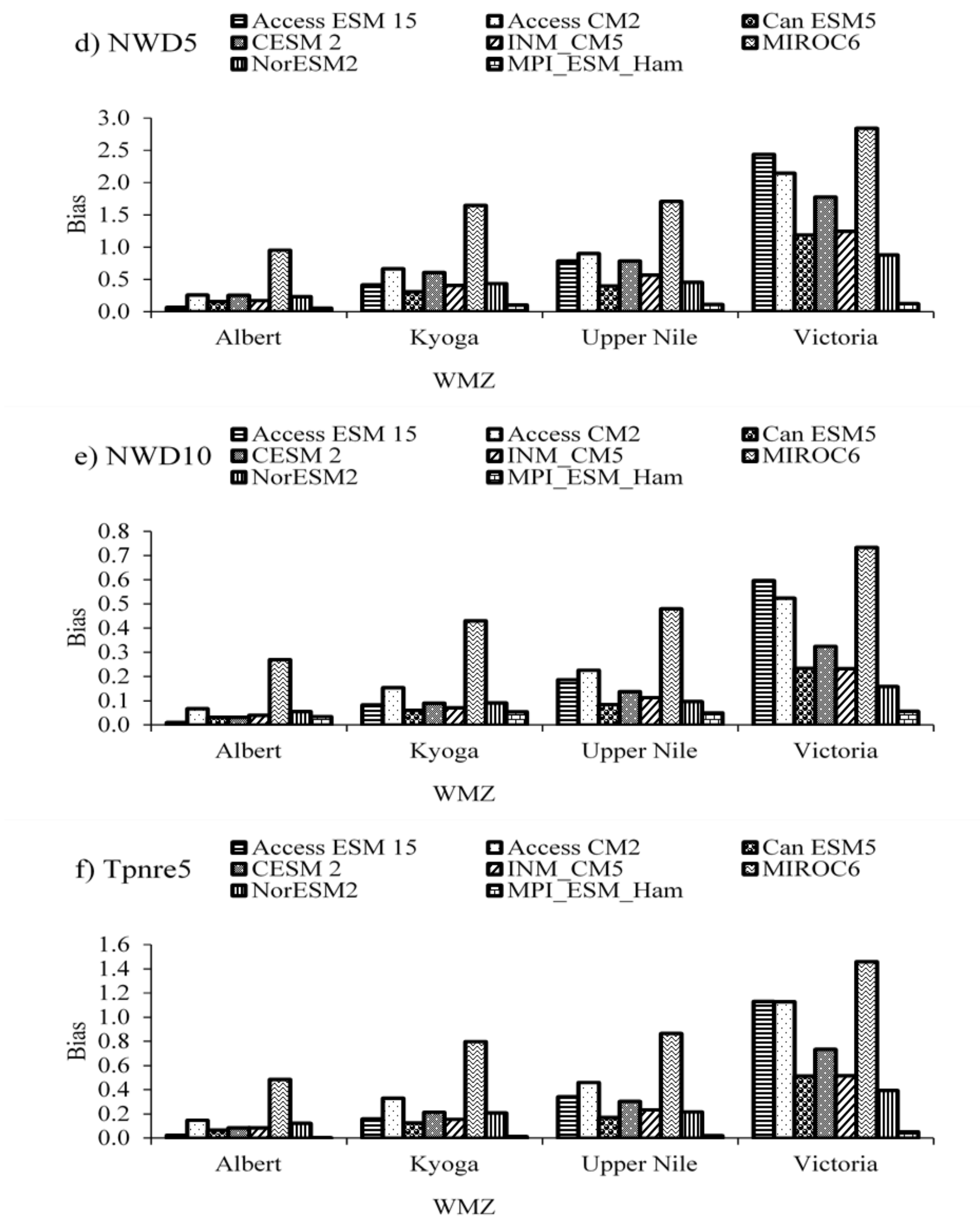

Figure 4-3: Validation of; (d) NWD5, (e) NWD10, & (f) Tpnre5 in the Historical Output of GCM

4.3 Quantification of climate change impact on the precipitation extremes

This section assesses the impact of climate change on precipitation extremes using six key precipitation indices, namely AMS, MDS1, MDS5, NWD5, NWD10, and Tnre5, across Uganda's water management zones.

To comprehensively evaluate future changes, the study used different scenarios (SSP245, SSP370, and SSP585) to project changes in precipitation patterns up to the 2050s, 2070s, and 2090s.

4.3.1 Annual Maximum Series (AMS)

Figure 4-4 shows the consistent decrease in AMS values across all zones and periods.

The variability in the AMS results illustrates how different WMZswill react to the index, with the Upper Nile zone at about 16.0% under SSP585 by the 2090s and the Victoria zone at approximately 60.4% under the same scenario. This is consistent with the findings of Ito et al. (2023), who observed decreasing trends in annual maximum series across various African regions under different scenarios, including SSP245, SSP370, and SSP585. Their analysis indicated reductions of 3-7% by the 2050s and 7-12% by the 2090s under SSP245. In contrast, under SSP585, the reductions were more pronounced, ranging from 8-15% by the 2050s to 25-40% by the 2090s.

Chen et al. (2022) investigated extreme precipitation patterns across Uganda under various scenarios, including SSP 245, SSP 370, and SSP 585. Their findings showed that by the 2080s under SSP 585, the Upper Nile region could experience up to a 45% reduction in annual maximum series, while the Lake Victoria basin showed greater resilience with only 20-30% reductions. This corresponds closely to the findings of this study, where the Upper Nile exhibits the highest vulnerability, decreasing to 16.0% under SSP585 by the 2090s, while Victoria demonstrates the greatest resilience, maintaining 60.4%.

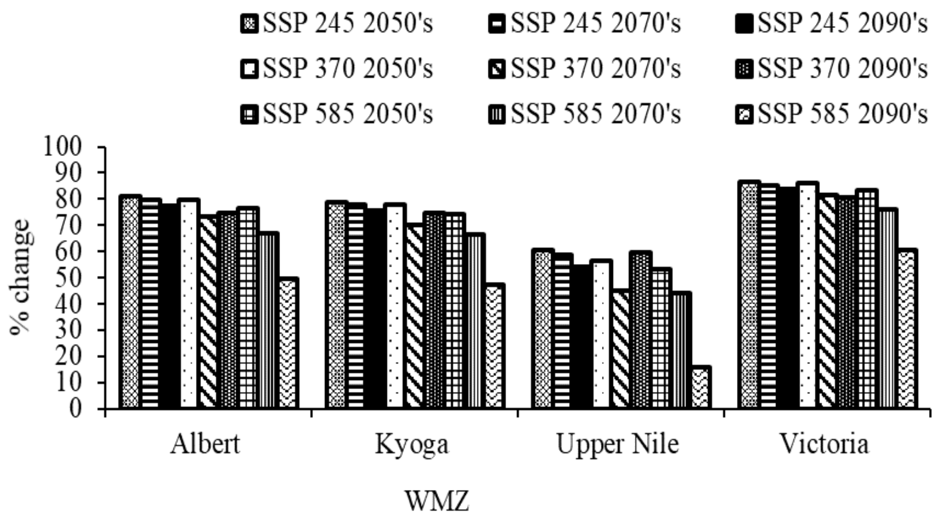

Figure 4-4: Climate change impacts on AMS

4.3.2 Severe dry spell (MDS1)

Albert, Kyoga, and Victoria show an increase in dry spell severity, ranging from -19.6% to -249.3%, whereas the Upper Nile displays resilience with values between +7.5% and +53.1%, as shown in Figure 4-5. These results are consistent with Fitzpatrick et al. (2020), who also found variations in precipitation extremes across East Africa by -30% changes in dry spell duration in the Lake Victoria basin and +15% increases in precipitation in some parts of the Upper Nile catchment.

The SSP 585 leads to dry conditions by the 2090s in most areas, while SSP 370 shows a reduction in dry spell severity. This response to emissions aligns with Gebrechorkos et al. (2019), who analysed precipitation extremes in East Africa. They found that under SSP585, dry spell durations increased by 25%-38% in the Victoria and Albert basins, while under SSP370, the increases are within 12-18%. Their research similarly identified threshold effects in precipitation extremes between SSP 245, SSP 370, and SSP 585 responses, with the Victoria basin showing a 42% increase in consecutive dry days under SSP 585.

The changes in precipitation extremes show irregular patterns, with the most severe precipitation decrease occurring in the 2090s under SSP 585, especially in the Victoria zone - 249.3%. These findings are in line with Endris et al.'s (2019). Their regional climate model for East Africa predicted that by the 2080s, high emissions scenarios would increase dry spell durations by up to 68% in some parts of the Victoria basin while also showing 7-15% decreases in dry spells in parts of the Upper Nile watershed. Their study also noted irregular changes, with the period from 2060 to 2080 showing a rise in extreme precipitation trends, similar to the patterns of this study in the 2070s to the 2090s.

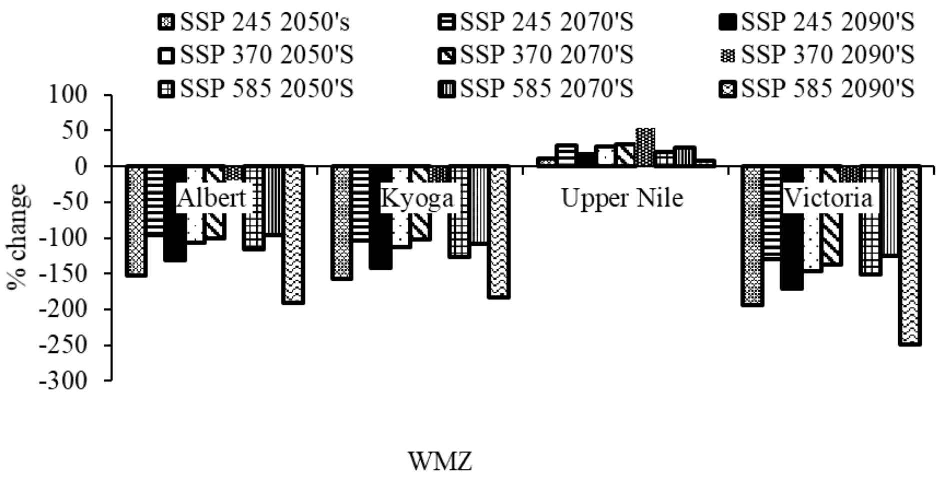

Figure 4-5: Climate change impact on MDS1

4.3.3 Dry spell (MDS5)

Figure 4-6 depicts the consecutive dry days revealing a consistent pattern of substantial decreases across all water management zones, scenarios, and periods, ranging from -84.4% to -332.2%. The WMZ of Kyoga indicates a decrease in MDS5 (-221.4% to -332.2%), while Upper Nile shows comparatively moderate changes (-84.4% to -156.4%).

The trend in extreme precipitation indicates that the decreases usually happen in the 2050s (-133.2% to -332.2%). The study by Rowell et al. (2019) show similar unpredictable changes in East African precipitation extremes, with variations of -145% to -270% in the dry spell. Williams et al. (2020) similarly quantified a -180% to -230% change in dry spell duration across comparable tropical African watersheds under SSP370.

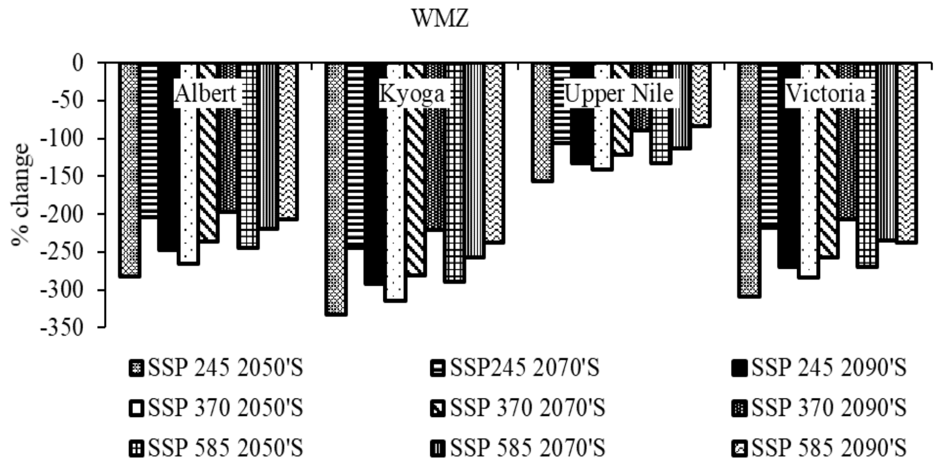

Figure 4-6: Climate change impact on MDS5

4.3.4 Wet days

The precipitation indices for wet days (Tpnre5, NWD5, and NWD10) shown in Figure 4-7 (a-c)

4.3.5.1 NWD10

The NWD10 index is expected to increase, with ranges from 14.1% in the Upper Nile WMZ in the 2050s under SSP370 to 92% in the Victoria WMZ in the 2090s under SSP245. The Albert WMZ maintains high values across most scenarios: 93.0% under SSP245 for the 2050s to 89.4% under SSP585 in the 2090s. The Victoria WMZ shows similar patterns with NWD10 values of 94.4% under SSP245 in the 2050s to 92.9% under SSP585 in the 2090s.

The Kyoga WMZ demonstrates moderate values, with 72.8% under SSP245 in the 2050s to 55.0% under SSP585 in the 2090s. However, the Upper Nile WMZ shows different patterns, with much lower values of 18.0% under SSP245 in the 2050s to

-30.6% under SSP585 in the 2090s. These findings are similar to Dosio et al. (2021), who projected increases of 85-95% in wet days for the Lake Victoria basin compared to decreases of 25-35% for northern Uganda under SSP5-8.5 for the 2070-2099 period.

4.3.5.2 NWD5

The NWD5 index is expected increase from 7.9% in the Upper Nile WMZ in the 2050s under SSP585 to 95.6% in the Victoria WMZ in the 2070s under SSP245. The Albert WMZ maintains high values: 91.8%, under SSP245 in the 2050s to 93.3% under SSP585 for the 2090s. The Kyoga WMZ demonstrates moderate values with 74.8%, under SSP245 in 2050s to 65.8% under SSP585 in 2090s.

However, the Upper Nile WMZ shows substantially different patterns, with much lower values of 33.8% under SSP245 in 2050s to 11.6% under SSP585 in 2090s. The Upper Nile is the only zone showing a negative value, -14.1% projected under SSP370 by the 2090s. Similarly, Kisembe et al. (2019) found increasing trends in moderate to extreme precipitation, projecting increase of 80-90% in NWD5 for the Lake Victoria Basin under SSP585 by 2071-2100.

4.3.5.3 Tpnre5

The Tpnre5 index is expected to increase from 6.5% in the Upper Nile WMZ in the 2050s under SSP585 to 95.6% in the Victoria WMZ in the 2070s under SSP245. The Albert WMZ maintains consistently high values across with 92.4% under SSP245 in 2050s to 87.8% under SSP585 in 2090s. The Victoria WMZ shows similarly high patterns with Tpnre5 values of 94.5% under SSP245 in 2050s to 92.5% under SSP585 in 2090s.

The Kyoga WMZ demonstrates moderate values with 75.6%, under SSP245 in 2050s to 57.1% under SSP585 in 2090s. However, the Upper Nile WMZ displays different patterns, with lower values of 24.7%, under SSP245 to 4.0% in 2070s and a substantial increase to 71.1% under SSP370 by the 2090s. The Upper Nile is the only zone showing negative trends under SSP585, with 6.5% in the 2050s declining to -4.3% in the 2070s and further decreasing to -35.6% by the 2090s. Nicholson et al. (2018) identified a general trend toward intensification of the hydrological cycle, with wet areas becoming wetter by 75-85% under SSP585 by the 2080s and exceptions in northern regions with decreases of 20-30%. Thiery et al. (2021) found significant increases in total precipitation on wet days of 85-95% under SSP585 by 2081-2100 using high-resolution climate models, closely matching the projections of 92.5% for the Victoria WMZ under SSP585 by the 2090s.

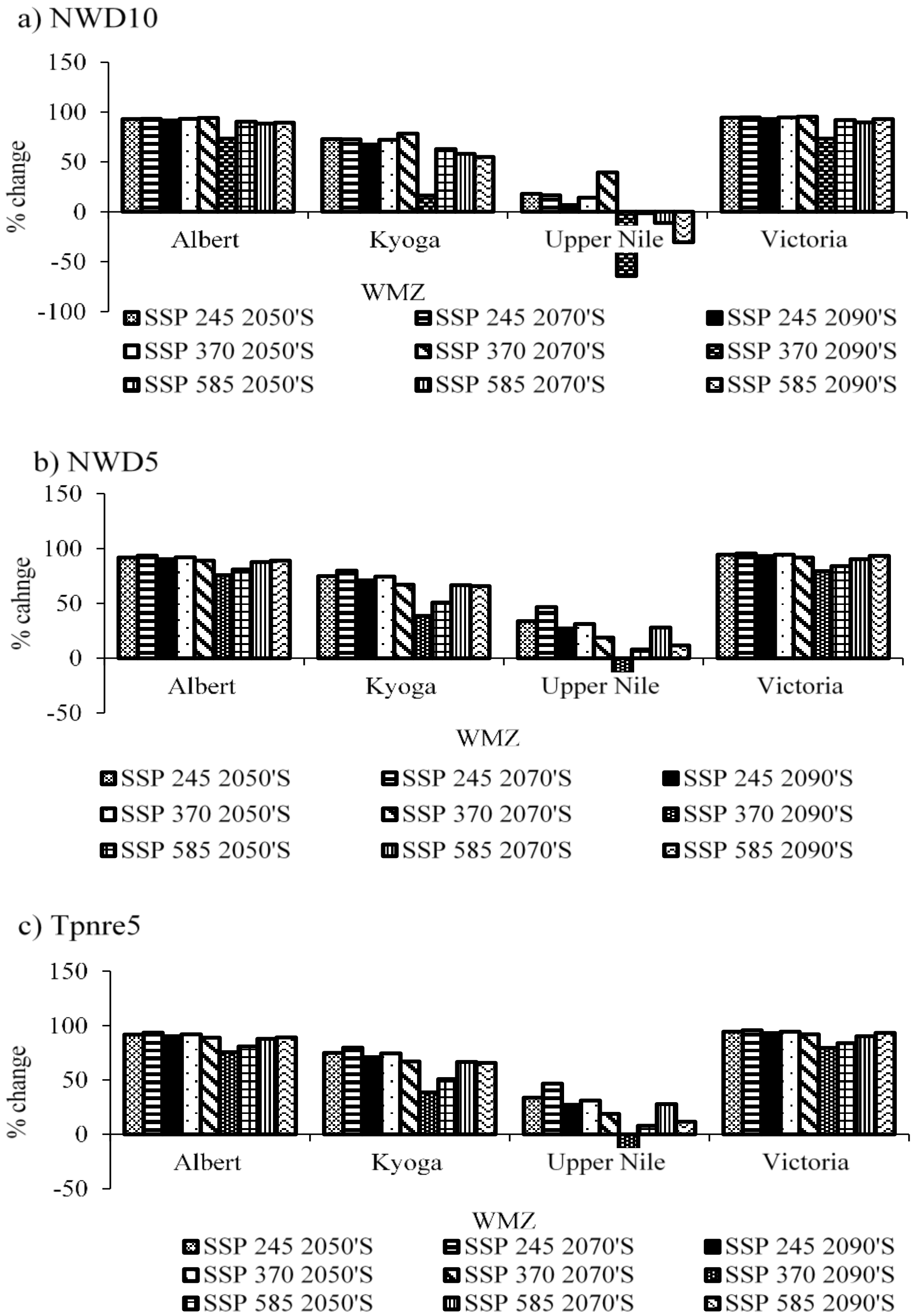

Figure 4-7: Climate change impact on (a) NWD5, (b) NWD10, and (c) Tpnre5

4.4 Analysing the Perceived Impact of Climate Change on Precipitation Extremes in Water Management Zones of Uganda

4.4.1 Respondents' views on the losses caused by climate change

Figure 4-8 illustrates respondents' perceptions of climate change-related losses, based on 2,407 cases. There is a strong prioritisation of agricultural and livestock production losses 621 cases (25.8%) and income losses 597 cases (24.8%) as the most significant effects. This trend reflects the reliance of respondents on climate-sensitive livelihoods, particularly rain-fed agriculture and livestock rearing. According to the Uganda Bureau of Statistics (UBOS, 2023), over 68% of Uganda's population is employed in agriculture, making it the backbone of its economy.

Limited access to potable water attracted 313 cases (13.0%) was viewed as the least significant impact. While water scarcity is increasingly evident due to reduced rainfall and groundwater recharge, the relatively low concern may be due to limited awareness of its connection to climate change or the presence of water access infrastructure in some areas. A recent report by the Ministry of Water and Environment shows that Uganda's rural safe water supply coverage is at 67%, while only 5% of the country's irrigable land is under formal irrigation systems (Bbosa et al., 2020). This explains respondents' perception patterns.

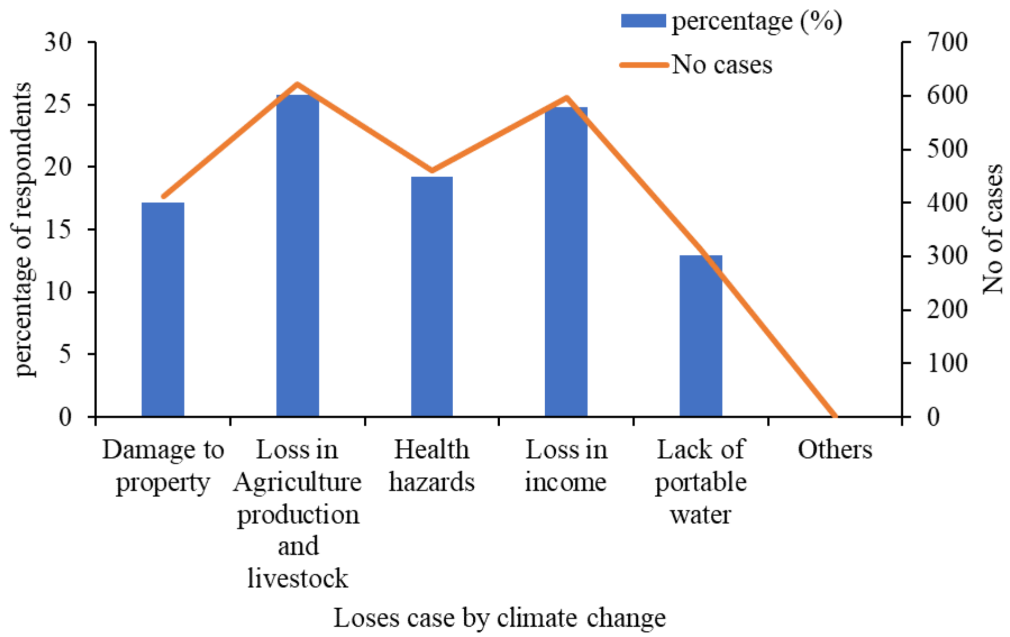

Figure 4-8: Respondents' views on the losses caused by climate change

4.4.2 Respondents' Views on the expected future impacts of climate change

The pattern of responses presented in Figure 4-9 is attributed mainly to respondents' direct experiences with climate change impacts in their surroundings. Among the 1,985 total cases, most respondents anticipated the effects of climate change would be "less rain," cited in 542 cases (27.3%). This predominance reflects the recurrent droughts and water scarcity that affect many regions of Uganda, especially the semi-arid northern and eastern Uganda, where agricultural productivity and water access are highly dependent on rainfall patterns (Mubiru, 2010). These dry spells have made drought a dominant and memorable climate hazard, shaping public perceptions of future risks. Similarly, 435 cases (21.9%) reported "loss in animals and plants" as a key impact, while 348 cases (17.5%) anticipated that "trees may die," highlighting the close relationship between rural communities and natural ecosystems. These findings are consistent with observed trends in deforestation, biodiversity loss, and reduced crop yields, which directly affect food and income security (NEMA, 2019).

The low number of cases indicating “no effect” (32 cases, 1.6%) and those selecting “I do not know” (62 cases, 3.1%) further illustrates broad public recognition of climate change’s effects across Uganda, likely influenced by increased public awareness through education, media, and outreach by governmental and non-governmental actors (Kigozi et al., 2016). Finally, the minimal selection of the “Other” category (11 cases, 0.6%) indicates that the survey design effectively captured the range of concerns relevant to climate change impact.

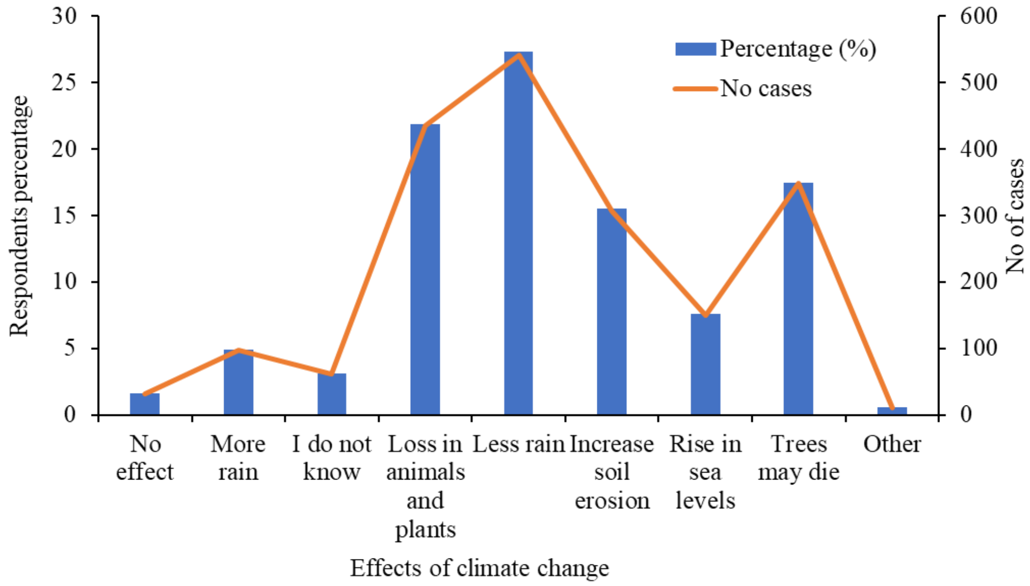

Figure 4-9: Respondents’ views on the expected future impacts of climate change

4.4.3 Respondents' views on the perceived negative impacts of climate change

The most felt impact was the change in the timing of rains, with 710 cases (49.7%) classified under "extreme effects," as shown in Figures 4-10 indicating the significant disruption unpredictable rainfall causes to Uganda's predominantly rain-fed agriculture. Shifts in rainfall timing lead to delays in planting, increased crop failure, and food insecurity, especially among small-scale farmers. Similarly, the increased frequency of droughts recorded 698 cases (48.3%) under "extreme effects," showing concern about prolonged dry spells that reduce water availability for crops, livestock, and domestic use, particularly in semi-arid areas like Karamoja. The disappearance of vegetation also attracted a high level of concern, with 696 cases (48.6%) marked as "extreme effects," reflecting direct observation of deforestation and degradation of natural ecosystems.

Potable water scarcity drew 674 cases (47.2%) under the "multiple effects" category, with fewer labelling it as "extreme," suggesting a higher perceived capacity to adapt to water shortages through measures such as boreholes, protected springs, or rainwater harvesting.

Meanwhile, the disappearance of lakes and rivers had 692 cases (48.5%) as having "multiple effects," indicating regional variation in the perception of these impacts. Some communities may have experienced reduced water levels, while others still have access to stable surface water bodies. Okonya et al. (2013) reported that Ugandan farming communities widely perceived climate-related disruptions in rainfall and water sources as key drivers of agricultural and livelihood stress.

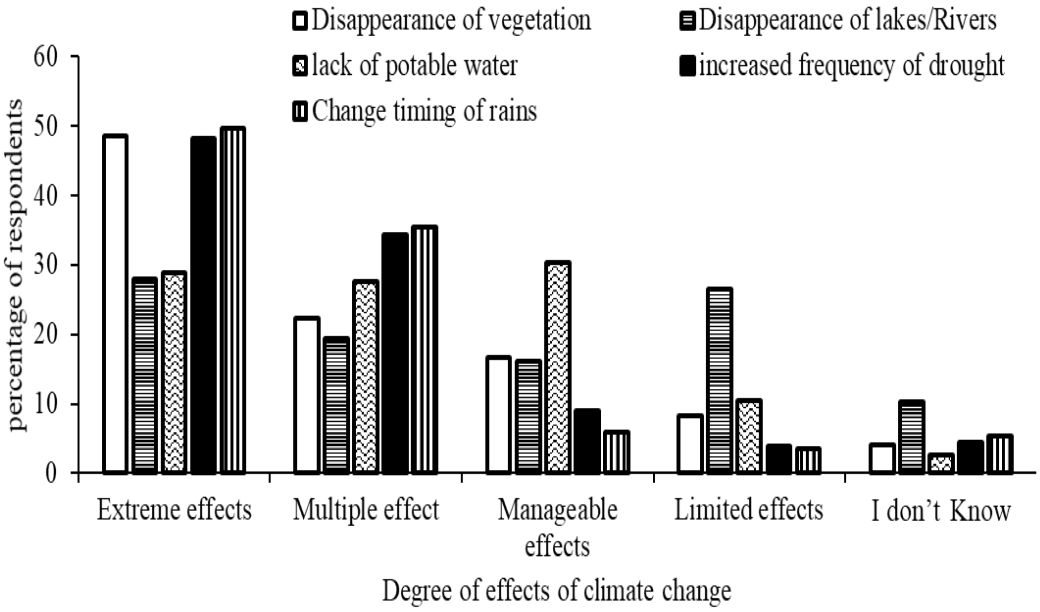

Figure 4-10: Respondents' views on the perceived negative impacts of climate change

4.4.4 Response to the amount of rainfall in 2023 compared to 2022 and previous years

Figure 4-11 shows the respondents' perceptions of rainfall patterns in 2023, particularly the 435 cases (60%) who observed a decreased amount of rainfall compared to 2022, and the 373 cases (53%) who noted a decrease relative to previous years, reflect the community's awareness to recent climatic fluctuations and their direct implications on their livelihoods. These responses indicate that people are more likely to recall and emphasise recent precipitation anomalies, especially those that disrupt food production and water availability.

The perceived decline in rainfall aligns with empirical studies from southwestern Uganda, where farmers have experienced shortening rainy seasons, irregular rainfall timing, and increasing challenges in determining optimal planting times (Twongyirwe et al., 2019).

Perceptions of increased rainfall remained relatively stable across both periods, with 170 cases (24%) reporting more rain for 2022 to 2023 and 161 cases (23%) for previous years to 2023. This stability suggests localised climatic variability, where certain regions may have received rainfall while others endured prolonged dry spells, patterns commonly attributed to climate change-induced shifts in precipitation extremes (Onyutha, 2016). Additionally, an increase in the number of respondents who perceived consistent rainfall, from 93 cases (13%) in the 2022 to 2023 comparison to 129 cases (18%) in the previous years to 2023 comparison, may reflect adaptive recalibration of expectations, as communities adjust to seasonal rainfall.

The noticeable rise in uncertainty, from 24 cases (3%) in the 2022 to 2023 comparison to 38 cases (5%) in the longer-term comparison, suggests growing confusion or diminishing confidence in traditional rainfall prediction methods, potentially due to the increasing unpredictability of climate signals (Adger et al., 2009). Although these patterns show how immediate weather experiences, particularly those affecting subsistence agriculture and water availability, strongly influence people's perceptions of long-term climate change, especially in regions like Uganda, where rainfall reliability remains a cornerstone of livelihoods.

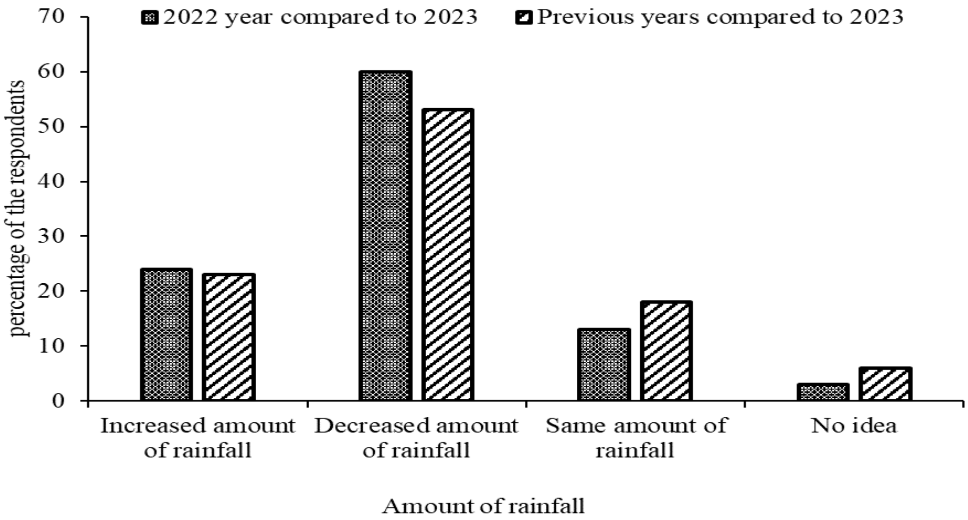

Figure 4-11: Response to the amount of rainfall in 2023 compared to 2022 and previous years

4.4.5 Respondents' views on future predictions of rainfall amounts

Figure 4-12 shows the respondents' views on long-term future rainfall trends indicate a dominant perception of declining precipitation in the coming decades. When asked to compare the current amount of rainfall to future expectations over 50, 70, and 90 years, most responses consistently projected a decrease. Specifically, 347 cases (48.1%) anticipated decreased rainfall over the next 50 years, 305 cases (42.6%) over the next 70 years, and 276 cases (38.5%) over the next 90 years. This consistent outlook of reduced future rainfall indicates deepening concern about long-term climate deterioration, particularly regarding agricultural sustainability and water availability, key livelihood factors in Uganda's largely farming society (Kigozi et al., 2016).

The portion of respondents predicted an increase in rainfall: 157 cases (21.8%) for the 50-year horizon, 140 cases (19.6%) for 70 years, and 140 cases (19.5%) for 90 years. These views may reflect an awareness of the unpredictability and regional variation associated with climate change, where certain areas may receive excess rainfall due to intensified weather systems, even as others dry out (IPCC, 2021).

The uncertainty regarding future rainfall increased with longer timeframes, respondents indicating "no idea" rose from 140 cases (19.4%) for the 50-year projection to 191 cases (26.7%) for 70 years, and further to 208 cases (29.0%) for the 90-year forecast. This upward uncertainty trend likely reflects lay knowledge's limitations in forecasting distant climate scenarios and the growing impact of climate change over time. Meanwhile, those expecting the "same amount of rainfall" remained a minority across all three timeframes, with only 76 cases (10.5%) for 50 years, 79 cases (11.0%) for 70 years, and 85 cases (11.9%) for 90 years, indicating that few respondents believe in climate stability over time.

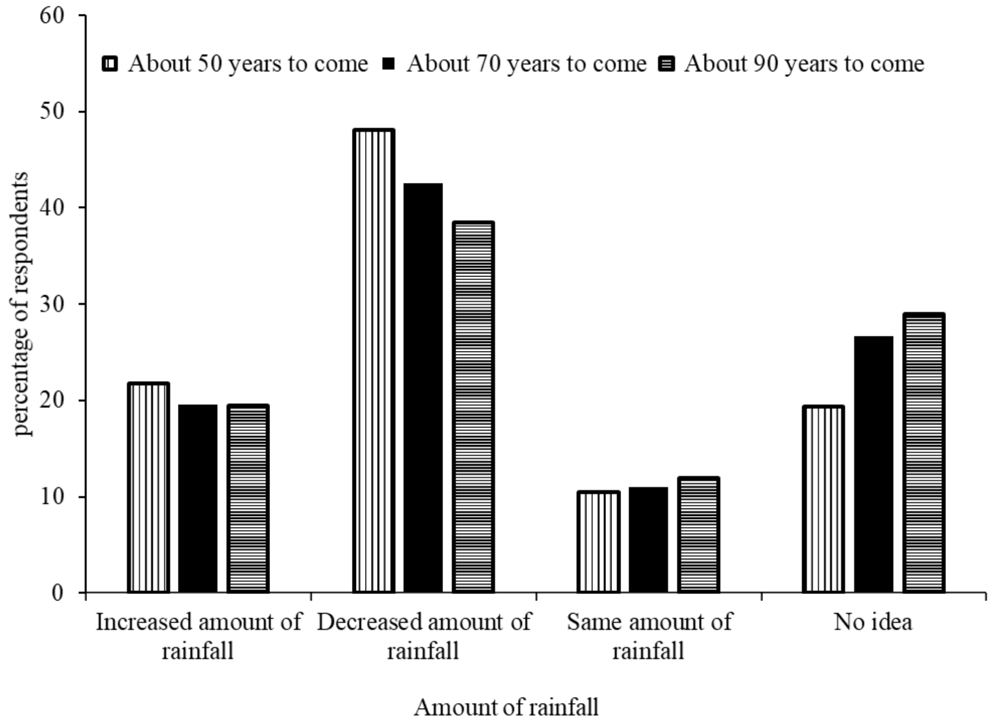

Figure 4-12: Respondents' views on future predictions of rainfall amounts

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

5.1.1 What are the characteristics of the observed precipitation extremes in WMZ?

The characterisation of precipitation extremes indicates distinct regional patterns across Uganda's water management zones. The Upper Nile zone consistently demonstrated higher precipitation levels, with an Annual Maximum Series of 54 mm/day, while experiencing prolonged severe dry spells (MDS1) of approximately 77 consecutive days.

The Victoria and Albert zones showed different precipitation patterns, with Victoria experiencing the longest moderate dry spells (MDS5) of around 130 days, and Albert recording the highest frequency of wet days, with 909 consecutive days exceeding 5mm rainfall and 68 annual days with rainfall above 5mm. These findings highlight the spatial variability of precipitation extremes across Uganda's water management zone

5.1.2 What is the validity of the observed CFSR and historical output of the GCMs?

The validation of General Circulation Models revealed systematic biases. Most models consistently underestimated the Annual Maximum Series across all water management zones, with bias values ranging from 0.82 to as low as 0.06. Similarly, six of the eight evaluated models overestimated the frequency of severe dry spells (MDS1), while all models overestimated moderate dry spells (MDS5). For wet day indices (NWD5, NWD10, and Tpnre5), most models demonstrated underestimation, with notable exceptions in the Victoria water management zone, where MIROC6, ACCESS-ESM1-5, and ACCESS-CM2 displayed overestimation bias. These consistent biases toward drier conditions than observed suggest potential systematic errors in the representation of precipitation processes that may influence future climate projections for the different regions

5.1.3 What are the impacts of climate change on the precipitation extremes?

The quantification of climate change impacts on precipitation extremes projected significant changes across all water management zones under different climate scenarios. The Annual Maximum Series is projected to decrease across all zones, with the Upper Nile showing the greatest vulnerability (reduction to 16.0% under SSP585 by the 2090s) and Victoria demonstrating the greatest resilience (maintaining 60.4% under SSP585). Severe dry spells (MDS1) are projected to increase in Albert, Kyoga, and Victoria zones (-19.6% to -249.3%), while the Upper Nile shows resilience with potential decreases in dry spell duration (+7.5% to +53.1%).

Moderate dry spells (MDS5) consistently show substantial decreases across all zones, scenarios, and periods (-84.4% to -332.2%). For wet day indices, the Victoria and Albert zones are projected to maintain high percentages of wet days, while the Upper Nile shows substantial decreases, particularly under SSP585. These findings indicate significant spatial variability in climate change impacts, with the Upper Nile zone showing distinct vulnerability patterns compared to other zones.

5.1.4 What are the perceived impacts of climate change and precipitation extremes in the WMZs?

The human perceptions show high awareness of climate change impacts among respondents, with agricultural and livestock losses (25.8%) and income losses (24.8%) identified as the most significant current impacts. Reduced precipitation was the most anticipated future effect (27.3%), while shifts in rainfall timing were perceived as having the most severe impacts (49.7% reporting "extreme effects"). Most respondents perceived decreased rainfall in recent years (60% comparing 2022-2023, 53% comparing previous years to 2023), and nearly half (48.1%) anticipated reduced rainfall in the next 50 years. However, uncertainty in these perceptions increased significantly for longer-term projections (from 19.4% at 50 years to 29.0% at 90 years). These findings highlight the alignment between scientific projections and local perceptions, particularly regarding decreased precipitation and increased variability.

This study has demonstrated the complex and spatially variable nature of precipitation extremes across Uganda's water management zones, the systematic biases in climate model simulations, the potential for significant changes in precipitation patterns under future climate scenarios, and the high level of awareness and concern among local populations. These findings emphasise the need for zone-specific adaptation strategies that address the unique vulnerability profiles of each water management zone and incorporate both scientific projections and local knowledge in decision-making processes.

5.2 Recommendations

5.2.1 To policy makers

i) Implement targeted early warning systems and zone-specific water management strategies across Uganda's water management zones based on their distinct precipitation vulnerability profiles. This will help to improve the accuracy and timeliness of flood warnings, allowing for more effective preparation and response measures.

ii) Promote climate-smart agricultural techniques and livelihood diversification programs that address the primary concerns identified by communities to integrate local ecological knowledge with scientific findings for more effective adaptation planning and implementation. This can enhance community resilience and reduce vulnerability to climate-related disasters, ultimately leading to more sustainable and adaptive practices in the face of changing environmental conditions

5.2.2 For future research

i) Future research should address the systematic biases identified in climate models, particularly the underestimation of Annual Maximum Series and wet day indices (NWD5, NWD10, Tpnre5) alongside overestimation of dry spell indices (MDS5, MDS1) across most GCMs, with special attention to the anomalous precipitation dynamics of the Victoria water management zone where several models showed unique overestimation patterns.

ii) Establish comprehensive precipitation monitoring networks across all zones to validate model projections and investigate the threshold effects observed between different SSP scenarios, especially the notably more pronounced changes under SSP585 compared to SSP245 and SSP370, to better quantify the potential benefits of climate mitigation actions and refine regional adaptation strategies as climate change advances.

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APPENDICES

Appendix A: Consent Form

Dear participant, I am a student at Kyambogo University pursuing a master's degree in water and sanitation engineering. I am researching on climate change impact on precipitation extremes: potential and perceived implication in water management zones of Uganda and am inviting you to participate in the research by completing the following survey, would like to know your experiences with rainfall occasions. Your responses are secret, you can skip any questions which you are not comfortable with.

a) Are you willing to participate in this research questionnaire?

Yes ☐

No ☐

(i) If **yes** proceed to the next Page

(ii) If No please **do not** proceed to the next Page

Appendix B: Questionnaire

Date of Interview	Date	Month	Year
Sex			
Age			
Occupation			
Name of Water Management Zone			
District			
Village			

(1) What is your expectation about future effects of climate change?

☐ no effect ☐ less rain

☐ more rain ☐ increase erosion

☐ I do not know ☐ rise in sea levels

☐ loss in animals and plants ☐ trees may die

Other (specify)……………………………………………

(2) What are the loses caused by climate change

☐ Damage to property

☐ loss in Agriculture production and livestock

☐ Health hazards

☐ loss in income

☐ lack of portable water

Others (specify)……………………………………………………………………

(3) Perception of the effects of climate change

Effect (Negative impact)	Extreme effects	Multiple effect	Manageable effects	Limited effects	I don't Know
26.1c Change timing of rains	☐	☐	☐	☐	☐
26.3c increased frequency of drought	☐	☐	☐	☐	☐
26.7c lack of potable water	☐	☐	☐	☐	☐
26.10c Disappearance of lakes/Rivers	☐	☐	☐	☐	☐
26.11c Disappearance of vegetation	☐	☐	☐	☐	☐

(4) How do you relate the amount of rainfall in the;

	Increased amount of rainfall	Decreased amount of rainfall	Same amount of rainfall	No Idea
(i) Year 2022 compared to 2023	☐	☐	☐	☐
(ii) Previous years compared to 2023	☐	☐	☐	☐

(5) How do you compare the amount of rainfall this year to?

	Increased amount of rainfall	Decreased amount of rainfall	Same amount of rainfall	No Idea
(i) About 50 years to come	☐	☐	☐	☐
(ii) About 70 years to come	☐	☐	☐	☐
(iii) About 90 years to come	☐	☐	☐	☐

Appendix C: Introduction Letters from the University

KYAMBOGO UNIVERSITY
FACULTY OF ENGINEERING
P. O. BOX 1, KYAMBOGO – P. O. BOX 7181 KAMPALA, UGANDA
Website: www.kyu.ac.ug Email: civil@kyu.ac.ug Tel: +256-41-4287340, FAX: +256-41-4289056/4222643
Office of the Head, Department of Civil and Environmental Engineering

Monday, 22nd May, 2023

To: Chief Administrative Officer,
Serere District Local Government

Dear Sir/Madam,

RE: INTRODUCTION LETTER FOR MR. EBALU MOSES

Warm Greetings! This communication is regarding the introduction of **Mr. Ebalu Moses** who is a graduate student of Kyambogo University undertaking Master of Science in Water and Sanitation Engineering from the Department of Civil and Environmental Engineering. Mr. Ebalu Moses is conducting a Master of Science research study on "Investigation of Climate Change Impact on Precipitation Extremes: Potential and Perceived Implication for Water Resources Management across Uganda". The survey will run from 24th May till 3rd June 2023.

To get perceived impacts of climate change on precipitation extremes, the researcher has designed questionnaire with which he intends to get important information from various Water Resources Management stakeholders such as Farmers, Traders of agricultural produce, Water Officers, Environmental Officers, and Agricultural Officers.

Therefore, this letter is to seek permission to allow the researcher, with the help of his Data Collection Assistant, to conduct the research survey within the district.

Any assistance rendered to **Mr. Ebalu Moses** will be highly appreciated.

Yours sincerely,
22.05.23

THE HEAD OF DEPARTMENT
CIVIL & ENVIRONMENTAL
ENGINEERING
KYAMBOGO UNIVERSITY

Charles Onyutha (Ph.D.)
Head, Department of Civil and Environmental Engineering, Email: conyutha@kyu.ac.ug

KYAMBOGO UNIVERSITY

FACULTY OF ENGINEERING

P. O. BOX 1, KYAMBOGO – P. O. BOX 7181 KAMPALA, UGANDA

Website: www.kyu.ac.ug Email: civil@kyu.ac.ug Tel: +256-41-4287340, FAX: +256-41-4289056/4222643

Office of the Head, Department of Civil and Environmental Engineering

Monday, 22nd May, 2023

To: Chief Administrative Officer,

Bushenyi District Local Government

Dear Sir/Madam,

RE: INTRODUCTION LETTER FOR MS. ATUKWATSE DAPHINE

Warm Greetings! This communication is regarding the introduction of **Ms. Atukwatse Daphine** who is a Data Collection Assistant for a research being conducted by Mr. Ebalu Moses who is a graduate student of Kyambogo University undertaking Master of Science in Water and Sanitation Engineering from the Department of Civil and Environmental Engineering. Mr. Ebalu Moses is conducting a Master of Science research study on "Investigation of Climate Change Impact on Precipitation Extremes: Potential and Perceived Implication for Water Resources Management across Uganda". The survey will run from 24th May till 3rd June 2023.

To get perceived impacts of climate change on precipitation extremes, the researcher has designed questionnaire with which he intends to get important information from various Water Resources Management stakeholders such as Farmers, Traders of agricultural produce, Water Officers, Environmental Officers, and Agricultural Officers.

Therefore, this letter is to seek permission to allow the researcher, with the help of his Data Collection Assistant, to conduct the research survey within the district.

Any assistance rendered to **Ms. Atukwatse Daphine** will be highly appreciated.

Yours sincerely,

22.05.23

THE HEAD OF DEPARTMENT
CIVIL & ENVIRONMENTAL
ENGINEERING
KYAMBOGO UNIVERSITY

Charles Onyutha (Ph.D.)

Head, Department of Civil and Environmental Engineering, *Email:* conyutha@kyu.ac.ug

KYAMBOGO UNIVERSITY

FACULTY OF ENGINEERING

P. O. BOX 1, KYAMBOGO – P. O. BOX 7181 KAMPALA, UGANDA

Website: www.kyu.ac.ug Email: civil@kyu.ac.ug Tel: +256-41-4287340, FAX: +256-41-4289056/4222643

Office of the Head, Department of Civil and Environmental Engineering

Monday, 22nd May, 2023

To: Chief Administrative Officer,
Mukono District Local Government

Dear Sir/Madam,

RE: INTRODUCTION LETTER FOR MS. NASIMIYU REGINA LOISE

Warm Greetings! This communication is regarding the introduction of **Ms. Nasimiyu Regina Loise** who is a Data Collection Assistant for a research being conducted by Mr. Ebalu Moses who is a graduate student of Kyambogo University undertaking Master of Science in Water and Sanitation Engineering from the Department of Civil and Environmental Engineering. Mr. Ebalu Moses is conducting a Master of Science research study on "Investigation of Climate Change Impact on Precipitation Extremes: Potential and Perceived Implication for Water Resources Management across Uganda". The survey will run from 24th May till 3rd June 2023.

To get perceived impacts of climate change on precipitation extremes, the researcher has designed questionnaire with which he intends to get important information from various Water Resources Management stakeholders such as Farmers, Traders of agricultural produce, Water Officers, Environmental Officers, and Agricultural Officers.

Therefore, this letter is to seek permission to allow the researcher, with the help of his Data Collection Assistant, to conduct the research survey within the district.

Any assistance rendered to **Ms. Nasimiyu Regina Loise** will be highly appreciated.

Yours sincerely,

22.05.23

THE HEAD OF DEPARTMENT
CIVIL & ENVIRONMENTAL
ENGINEERING
KYAMBOGO UNIVERSITY

Charles Onyutha (Ph.D.)

Head, Department of Civil and Environmental Engineering, Email: conyutha@kyu.ac.ug

KYAMBOGO UNIVERSITY
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Office of the Head, Department of Civil and Environmental Engineering

Monday, 22nd May, 2023

To: Chief Administrative Officer,
Wakiso District Local Government

Dear Sir/Madam,

RE: INTRODUCTION LETTER FOR MS. NASIMIYU REGINA LOISE

Warm Greetings! This communication is regarding the introduction of **Ms. Nasimiyu Regina Loise** who is a Data Collection Assistant for a research being conducted by Mr. Ebalu Moses who is a graduate student of Kyambogo University undertaking Master of Science in Water and Sanitation Engineering from the Department of Civil and Environmental Engineering. Mr. Ebalu Moses is conducting a Master of Science research study on "Investigation of Climate Change Impact on Precipitation Extremes: Potential and Perceived Implication for Water Resources Management across Uganda". The survey will run from 24th May till 3rd June 2023.

To get perceived impacts of climate change on precipitation extremes, the researcher has designed questionnaire with which he intends to get important information from various Water Resources Management stakeholders such as Farmers, Traders of agricultural produce, Water Officers, Environmental Officers, and Agricultural Officers.

Therefore, this letter is to seek permission to allow the researcher, with the help of his Data Collection Assistant, to conduct the research survey within the district.

Any assistance rendered to **Ms. Nasimiyu Regina Loise** will be highly appreciated.

Yours sincerely,
22.05.23
Charles Onyutha (Ph.D.)

THE HEAD OF DEPARTMENT
CIVIL & ENVIRONMENTAL
ENGINEERING
KYAMBOGO UNIVERSITY

Head, Department of Civil and Environmental Engineering, Email: conyutha@kyu.ac.ug

Appendix D: Permission Letters from the Districts

THE REPUBLIC OF UGANDA

AMURIA DISTRICT LOCAL GOVERNMENT
OFFICE OF THE CHIEF ADMINISTRATIVE OFFICER
P.O. Box 4, Amuria. Website: www.amuria. go.ug, E-mail: cao@amuria.go.ug

Alternative Communication Routes

District Chairperson
Officer
Office Line
Mobile: 0781073341
Chief Administrative Officer
Office Line Mobile: 0772586244

Deputy Chief Administrative

Mobile: 0772333941
Chief Finance Officer
Mobile: 0772855267

Our Ref : CR/ADLG/220/1
Your Ref :.......................

Date: 26th May, 2023

The District Engineer,
Amuria District Local Government.

PERMISSION TO CONDUCT RESEARCH BY MR. EBALU MOSES

This is to inform you that the above mentioned Student has been granted permission to conduct Research at Amuria District in partial fulfillment for the award of a Master's of Science in Water and Sanitation Engineering.

By copy of this letter, all the respondents in the sampled Department are requested to accord him the necessary assistance.

FOR CHIEF ADMINISTRATIVE OFFICER
26 MAY 2023
AMURIA DISTRICT LOCAL GOVERNMENT
P.O. BOX 4, AMURIA

Kaleeba Peter
FOR: CHIEF ADMINISTRATIVE OFFICER

Copy: The Head of Department Civil and Environmental Engineering,
File

KYAMBOGO UNIVERSITY
FACULTY OF ENGINEERING
P. O. BOX 1, KYAMBOGO – P. O. BOX 7181 KAMPALA, UGANDA
Website: www.kyu.ac.ug Email: civil@kyu.ac.ug Tel: +256-41-4287340, FAX: +256-41-4289056/4222643
Office of the Head, Department of Civil and Environmental Engineering

Monday, 22nd May, 2023

To: Chief Administrative Officer,
Mpigi District Local Government

(1) DPO
(2) District Environment Officer
(3) District Water Officer
M/s Nasimiyu Regina Loise has reported to my office. Allow her to do research in your department.

Dear Sir/Madam,

RE: INTRODUCTION LETTER FOR MS. NASIMIYU REGINA LOISE

Warm Greetings! This communication is regarding the introduction of **Ms. Nasimiyu Regina Loise** who is a Data Collection Assistant for a research being conducted by Mr. Ebalu Moses who is a graduate student of Kyambogo University undertaking Master of Science in Water and Sanitation Engineering from the Department of Civil and Environmental Engineering. Mr. Ebalu Moses is conducting a Master of Science research study on "Investigation of Climate Change Impact on Precipitation Extremes: Potential and Perceived Implication for Water Resources Management across Uganda". The survey will run from 24th May till 3rd June 2023.

CHIEF ADMINISTRATIVE OFFICER
30 MAY 2023
MPIGI DISTRICT LOCAL GOV'T
30/5/2023

To get perceived impacts of climate change on precipitation extremes, the researcher has designed questionnaire with which he intends to get important information from various Water Resources Management stakeholders such as Farmers, Traders of agricultural produce, Water Officers, Environmental Officers, and Agricultural Officers.

Therefore, this letter is to seek permission to allow the researcher, with the help of his Data Collection Assistant, to conduct the research survey within the district.

Any assistance rendered to **Ms. Nasimiyu Regina Loise** will be highly appreciated.

Yours sincerely,
22.05.23

THE HEAD OF DEPARTMENT
CIVIL & ENVIRONMENTAL ENGINEERING
KYAMBOGO UNIVERSITY

Charles Onyutha (Ph.D.)
Head, Department of Civil and Environmental Engineering, Email: conyutha@kyu.ac.ug

KYAMBOGO UNIVERSITY

FACULTY OF ENGINEERING

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Office of the Head, Department of Civil and Environmental Engineering

Monday, 22nd May, 2023

WAKISO DISTRICT LOCAL GOVERNMENT RECEIVED 25 MAY 2023 Sign:........ REGISTRY OFFICE

To: Chief Administrative Officer,
Wakiso District Local Government

Dear Sir/Madam,

RE: INTRODUCTION LETTER FOR MS. NALUWU RUTH

Warm Greetings! This communication is regarding the introduction of **Ms. Naluwu Ruth** who is a Data Collection Assistant for a research being conducted by Mr. Ebalu Moses who is a graduate student of Kyambogo University undertaking Master of Science in Water and Sanitation Engineering from the Department of Civil and Environmental Engineering. Mr. Ebalu Moses is conducting a Master of Science research study on "Investigation of Climate Change Impact on Precipitation Extremes: Potential and Perceived Implication for Water Resources Management across Uganda". The survey will run from 24th May till 3rd June 2023.

To get perceived impacts of climate change on precipitation extremes, the researcher has designed questionnaire with which he intends to get important information from various Water Resources Management stakeholders such as Farmers, Traders of agricultural produce, Water Officers, Environmental Officers, and Agricultural Officers.

Therefore, this letter is to seek permission to allow the researcher, with the help of his Data Collection Assistant, to conduct the research survey within the district.

Any assistance rendered to **Ms. Naluwu Ruth** will be highly appreciated.

Yours sincerely,

22-05-23

Charles Onyutha (Ph.D.)

THE HEAD OF DEPARTMENT CIVIL & ENVIRONMENTAL ENGINEERING KYAMBOGO UNIVERSITY

Head, Department of Civil and Environmental Engineering, Email: conyutha@kyu.ac.ug

Naluwu Ruth
0758065199
0772650165

To : Chief Administrative Officer,
Mukono District Local Government.

Dear Madam,

RE: Ms Naluwu Ruth – Data collection Assistant.

I am Ruth Naluwu a data Collection Assistant for research being conducted by Mr. Ebalu Moses who is a graduate of Kyambogo University undertaking a Master of Science in Water and Sanitation Engineering from the Department of Civil and Environmental Engineering. The survey will run from 24th May 2023 to 3rd June 2023.

Thank you for your consideration.

Your faithfully,
Naluwu Ruth

0772650165
0758065016s

KYAMBOGO UNIVERSITY

FACULTY OF ENGINEERING

P. O. BOX 1, KYAMBOGO – P. O. BOX 7181 KAMPALA, UGANDA

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Office of the Head, Department of Civil and Environmental Engineering

Monday, 22nd May, 2023

To: Chief Administrative Officer,
Ibanda District Local Government

IBANDA DISTRICT LOCAL GOVERNMENT RECEIVED 26 MAY 2023 P.O. BOX 388 IBANDA CENTRAL REGISTRY

Dear Sir/Madam,

Granted 29/5/2023

RE: INTRODUCTION LETTER FOR MR. MATOVU KELVIN PETER

Warm Greetings! This communication is regarding the introduction of **Mr. Matovu Kelvin Peter** who is a Data Collection Assistant for a research being conducted by Mr. Ebalu Moses who is a graduate student of Kyambogo University undertaking Master of Science in Water and Sanitation Engineering from the Department of Civil and Environmental Engineering. Mr. Ebalu Moses is conducting a Master of Science research study on "Investigation of Climate Change Impact on Precipitation Extremes: Potential and Perceived Implication for Water Resources Management across Uganda". The survey will run from 24th May till 3rd June 2023.

To get perceived impacts of climate change on precipitation extremes, the researcher has designed questionnaire with which he intends to get important information from various Water Resources Management stakeholders such as Farmers, Traders of agricultural produce, Water Officers, Environmental Officers, and Agricultural Officers.

Therefore, this letter is to seek permission to allow the researcher, with the help of his Data Collection Assistant, to conduct the research survey within the district.

Any assistance rendered to **Mr. Matovu Kelvin Peter** will be highly appreciated.

Yours sincerely,

22.05.23

Charles Onyutha (Ph.D.)

THE HEAD OF DEPARTMENT CIVIL & ENVIRONMENTAL ENGINEERING KYAMBOGO UNIVERSITY

Head, Department of Civil and Environmental Engineering, *Email:* conyutha@kyu.ac.ug

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Website: www.kyu.ac.ug Email: civil@kyu.ac.ug Tel: +256-41-4287340, FAX: +256-41-4289056/4222643
Office of the Head, Department of Civil and Environmental Engineering

Monday, 22nd May, 2023

To: Chief Administrative Officer,
Mukono District Local Government

CHIEF ADMINISTRATIVE OFFICER
MUKONO DISTRICT

District water resources office
please give support to the researcher
26/5/23

Dear Sir/Madam,

RE: INTRODUCTION LETTER FOR MS. NALUWU RUTH

Warm Greetings! This communication is regarding the introduction of **Ms. Naluwu Ruth** who is a Data Collection Assistant for a research being conducted by Mr. Ebalu Moses who is a graduate student of Kyambogo University undertaking Master of Science in Water and Sanitation Engineering from the Department of Civil and Environmental Engineering. Mr. Ebalu Moses is conducting a Master of Science research study on "Investigation of Climate Change Impact on Precipitation Extremes: Potential and Perceived Implication for Water Resources Management across Uganda". The survey will run from 24th May till 3rd June 2023.

In addition liaise with other officers mentioned to support the officer

To get perceived impacts of climate change on precipitation extremes, the researcher has designed questionnaire with which he intends to get important information from various Water Resources Management stakeholders such as Farmers, Traders of agricultural produce, Water Officers, Environmental Officers, and Agricultural Officers.

Therefore, this letter is to seek permission to allow the researcher, with the help of his Data Collection Assistant, to conduct the research survey within the district.

Any assistance rendered to **Ms. Naluwu Ruth** will be highly appreciated.

Yours sincerely,
22.05.23
Charles Onyutha (Ph.D.)

THE HEAD OF DEPARTMENT
CIVIL & ENVIRONMENTAL
ENGINEERING
KYAMBOGO UNIVERSITY

Head, Department of Civil and Environmental Engineering, Email: conyutha@kyu.ac.ug