

CLIMATE VARIABILITY AND ITS IMPLICATION FOR WATER RESOURCES AND LIVELIHOODS IN UGANDA

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CLIMATE VARIABILITY AND ITS IMPLICATIONS TO WATER RESOURCES AND LIVELIHOODS IN UGANDA.

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DECLARATION

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DISCLAIMER

This thesis consists of chapters that have been prepared for submission to, or published in a series of scientific journals. As a result styles may vary between chapters in the thesis and overlaps may occur to secure publication entities. Figures in some chapters appear with in the text, and in other chapters they have been added at the end of the chapters.

Some of the publications have more than three authors, but this does not mean that work done was proportionate. Work in these publications is solely my effort and originally initiated by me.

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ABSTRACT

This thesis examines the climatic trends of rainfall and temperature in Uganda using historical data. And because climate is an important aspect in water resources management and livelihoods formation, an attempt to explain how the interaction impacts on the two is made in the context of climate variability and change. The assumption is that climate change/variability has had an effect on water resources management and the way individual, households and society at large form livelihoods in Uganda. The rationale for the investigation is the number of climate and livelihood related studies that have been undertaken for Uganda over recent years, which have not focused specifically on the water resources management and livelihood formation.

The study is grounded by reviewing the theoretical perspectives of climate science which underpin the concepts of climate change, climate variability and impacts on livelihoods in the world, tropics, Africa, east Africa and Uganda in that order.

A cross sectional research design based on selected case studies from sub-counties located in the main sub-basins across the country is used. Both qualitative and quantitative data analysis techniques are applied independently or in combination on climatic data from Uganda's Department of Meteorology, data generated from field interviews and landsat images. The data sets are analysed using MS EXCEL, SPSS, MATLAB, ANCLIM, TREND TOOL, GIS and ENVI 4.8 to establish climatic trends and deduce evidence of change and variability. The impact on livelihood formation is investigated through the assets available to the households using the DFID framework.

The study therefore has investigated the characteristics of climate in Uganda especially by following up on the responses that arose from the field study. Through their own observations, respondents noticed changes in temperature and rainfall. Temperature variables like diurnal temperature range, maximum and minimum temperatures and rainfall (monthly, seasonal, annual) have been investigated, to establish whether these observations were impacting on livelihood formations and water resources which are central in the wellbeing of individual households.

Results show decadal variability of rainfall with marked seasonal cycles, temporal variability of drought patterns is detected; variations in annual rainfall are low with no significant trends observed in the main drainage sub-basins. Significant trends occur in October, November, December and January. A noticeable decrease in the annual total rainfall was observed mostly in north-western and south-western sub-basins. Rainfall trend in the second normal of June-July-August (JJA) is decreasing in all the main drainage sub-basins; highest rainfall was recorded in April, while January, June and July have the lowest rainfall. Spatial analysis results show that stations close to Lake Victoria recorded high amounts of rainfall. Average annual coefficient of variability was 19% signifying low variability. Rainfall distribution is bi-modal with maximums experienced in March- April- May and September- October-November seasons of the year. PCI values show a moderate to seasonal rainfall distribution.

Spectral analyses of the time components reveal the existence of a major period around 3, 6 and 10 years. Intra-annual temperature show reduced variability over recent decades, which is not statistically significant. Maximum temperatures are more variable compared to minimum temperatures in Uganda. An increasing trend in hot days, hot nights, warm nights and warm spells are also detected. At seven of the stations, annual temperature range and diurnal temperature range trends are negative. The finding that intra-annual and intra-monthly variance is declining suggests that fewer anomalously extreme temperature episodes occur. The gap between maximum and minimum extremes is reducing, which supports the observation that minimum temperatures are on the increase. At a micro-level analysis using Namulonge as a case study, total rainfall in March-May season decreased, while maximum temperatures increased between April and September, with statistically significant trends at 5% confidence level. The Mann-Kendall test revealed that the number of wet days reduced significantly. Temperatures are warmer and rainfall higher in the first climate normal compared to the recent 30 years.

Direct rainfall, which is the most important source of water for water resources, recently, is experiencing variability, which is threatening the distribution of water resources in Uganda. The characteristics, availability, demand and importance of present day water resources in Uganda as well as the various issues, and challenges pertaining to management of water resources of the country are established. The present analysis reveals that surface-water area fluctuation is linked to rainfall variability. In particular, Lake Kyoga basin lakes experienced an increase in surface-water area in 2010 compared to 1986. This work has important implications to water resources management and people whose livelihoods depend on natural resources especially in this era of climate change. Evidence from the field survey validates what data analysis reveals from historical data. Respondents from the field study are aware of climate change, had noticed some changes in climatic variables and were adapting by changing lifestyle and diversifying to activities that are less prone to weather. Livelihoods in Uganda have evolved based on the availability of opportunity afforded by the natural resources base including water resources.

GLOSSARY OF IMPORTANT ABBREVIATIONS

AIAE	African Institute for Applied Economics
AMSL	Above mean Sea level
CBOs	Community Based Organisations
CCCM	Canadian Centre for Climate Modelling
CCCP	Climate Change Country Profiles
DFID	Department for International Development
DJF	December, January, February
DOM	Department of Meteorology
DSS	Decision Support Systems
DWRM	Department of Water Resources Management
ENSO	El-Nino Southern Oscillation
FAO	Food and Agricultural Organisation
GCM	General Circulation Model
GDP	Gross Domestic Product
GIS	Geographical Information System
GOU	Government of Uganda
IDS	Institute of Development Studies
IISD	International Institute for sustainable development
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
IUCN	International Union Conservation of Nature
IWRM	Intergrated Water Resources Management
JJA	June, July, August
MAM	March, April, May
MDGs	Millenium Development Goals

MOFPED	Ministry of Finance Planning and Economic Development
MOLG	Ministry of Local Government
MWE	Ministry of Water and Environment
NaCRI	National Crop Resources Research Institute
NAPA	National Adaptation Programmes of Action
NARO	National Agricultural Research Organisation
NEMA	National Environmental Management Authority
NGOs	Non- Government Organisation
ODI	Overseas Development Institute
QBO	Quasi Biennial Oscillation
SEI	Stockholm Environment Institute
SL	Sustainable Livelihood
SON	September, October, November
UBOS	Uganda Bureau of Statistics
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Organisation
UNFCCC	United Nations Framework Conventions on Climate Change
UNICEF	United Nations International Children Fund
UNWDR	Uganda National Water Development Report
WHO	World Health Organisation
WMO	World Meteorological Organisation
WPC	Water Policy Committee
WSSD	World Summit on Sustainable Development
WWAP	World Water Assessment Programme
WWF	World Wide Fund for nature.

CHAPTER 1

INTRODUCTION AND BACKGROUND

1.1 Introduction

Livelihoods can be affected by climate change and variability and inter-specific interactions with water resources. Indeed, this has been demonstrated, for example, by Badjeck *et al.* (2010) that climate dynamics often influence livelihoods dependent on natural resources. Given that majority of the people especially the poor heavily depend on natural resources within the ecosystem they are severely affected by deteriorating environmental conditions and factors like climate change that limit access. While climate change is not the only threat to natural resources and livelihoods, climate-induced changes to resources flows will affect the variability of livelihoods unless there is an intervention process.

Therefore in this thesis I examine the climatic trends of rainfall and temperature in Uganda using historical data. And because climate is an important resource in water resources management and livelihoods formation, an attempt to explain how the interaction impacts on the two is made in the context of climate variability and change. The assumption is that climate change/variability has had an effect on water resources management and the way individuals, households and society at large form a livelihood.

A number of climate and livelihood related studies (Basalirwa 1995; Smith *et al.* 2001; GOU 2007; Asadullah *et al.* 2008; Hepworth and Goulden 2008; Oxfam 2008; Anyah and Semazzi 2009; Kizza *et al.* 2009) have been undertaken for Uganda over recent years, though not all focused specifically on the water resources management and livelihood formation. It is important that the work i undertake builds on these studies at a country, regional, sub-county and household level to inform intervention policy.

While each research chapter (Chapters 4 – 6) has its own aims, results and discussion (and some are formatted as manuscripts), their combined results allow an assessment of this broader question (section 6). The study is presented in six sections as summarised below.

Section 1 constitutes two Chapters on theoretical background and methodology.

In Chapter 2, theoretical perspectives of climate science, which underpin the concepts of climate change, climate variability, water resources and livelihoods are explored. The chapter attempts to capture debates and evaluate positions of scholars with regard to climate change, climate variability and its orientation in the world, tropics, Africa, East Africa and Uganda.

Chapter 3 is a summary of the research design and analysis methods, including study site selection, procedure followed when sampling and data collection and its management are given.

Section 2 comprises of four Chapters about the long term variations and trends of rainfall and temperature in Uganda.

Each chapter originates from articles that present and discuss long term variations and trends of rainfall and temperature in Uganda. The four chapters use historical data from the Ugandan Department of Meteorology (DOM) in Kampala. Rainfall and temperature data was collected over a period of seventy years from observatories around the country distributed in the four management zones.

Chapter 4 presents a study of rainfall trends, temporal variations of rainfall derived from 36 rain gauge stations found in the main drainage sub-basins of Uganda. Characteristics and nature of rainfall in Uganda from 1940 to 2009 is described in accordance with the main drainage sub-basins that form part of water resources management.

Chapter 5 presents an analysis of variability and trends in daily and monthly near-surface temperatures in Uganda over a period of 49 years. For this purpose, daily observed maximum and minimum temperature records from eight selected stations in Uganda were exposed to a rigorous statistical process in order to ascertain the past trend of temperatures.

Chapter 6, a methodology was applied in investigating the spatial variability and trends existent in the mid- twentieth century climatic time series for the period 1943 – 1977 at a regional level. Data was collected from 58 observatories found in the Albert – Victoria management zone in Uganda to detect rainfall behaviour in the past. The study serves as a baseline study for future climate studies in western Uganda.

Chapter 7 shows results from an investigation at a micro level of rainfall and temperatures in one of the parishes in the study area. Daily-observed temperature and rainfall records were aggregated into monthly means over a period of more than 55 years to establish both seasonal trends and shifts in climate. Study is based on a very small (micro) level using a single station with a long time series.

Section 3 constitutes of a single Chapter analysing climate change perceptions and livelihood formation using a case study.

The 8th chapter reports on the survey, which was carried out in Uganda to establish people's opinions on climate change and variability, evidences thereof, and the implications they experience during livelihood formation. A case study approach is used in acquiring data, and livelihood assets are examined to determine how people are responding to impacts of climate change/variability.

Section 4 has two Chapters on water resources and their relationship with climate change/variability in Uganda.

Chapter 9 reviews the characteristics, availability, demand and importance of present day water resources in Uganda as well as describing the various issues, challenges and management of water resources of the country.

Chapter 10 draws on climate characteristics and water resources to establish the potential impact that may arise when there are changes in surface- water area of Lake Kyoga basin using remotely sensed imagery in a changing climate.

Section 5 summary and conclusion

The aim of this section is to raise issues that are critical to climate change/variability, water resources management and livelihoods in Uganda. Limitations, recommendations for further study and implications of findings for research and policy are discussed.

The publication status of each article is noted on the chapter title page. Some repetition does occur between chapters particularly in the introductions in the various documents. Relevant acknowledgements and references are presented at the end of each chapter. The style of graphical presentation is similar throughout the thesis although published documents may show some variations due to external editorial requirements.

1.2 Background to the study

Variations in climate in many parts of the world, adversely affect social- economic sectors, which include water resources, agriculture, forestry, fisheries, human settlements, and health (Elasha *et al* 2005). These variations are expected to spread across regions (Parry *et al* 2007), causing changes that affect natural and human systems independently and or in combination with other determinants to alter the productivity, diversity and functions of many ecosystem and livelihoods in the world (IISD, SEI, IUCN 2003). This is expected to be serious for economies of most African countries, because they rely more on climate-sensitive activities; many operate close to environmental and climatic tolerance levels; and their ability to adapt may be limited because of technical, economic and institutional limitations (Tol *et al* 2004).

Africa is already vulnerable to climate variability and extremes, as evidenced by the impacts of current climate variability and weather extremes like floods and droughts, typhoons and storm surges, water supply problems, heat waves, disease vectors and the like. Which in turn affect economic performance, food security and natural resources on which, livelihoods of the many poor people depend (Parry *et al* 2007) to form capital assets. As a result achievements of millennium development goals are threatened, and high economic costs are eminent in Africa (Downing *et al* 2005). Conservative estimates put forward by van Aalst *et al* (2007) indicate that, African economies could be facing losses of at least 1-2% of GDP, or US\$10-20 billion annually though some sectors are much more exposed.

Uganda is one of the African countries whose economy is particularly vulnerable to climate variability because of its dependence on natural resources, e.g. agriculture that is a major employer. Over 80% of the population derives their livelihood either directly or indirectly from agricultural-related activities (GOU 2002). Consequently, GDP growth and inflation rates often correspond with fluctuations in weather (UBOS 2006). Increased climate variability can adversely impact on Uganda's food security arising from occurrences of drought and floods; outbreaks of diseases such as malaria, dengue fever, water borne diseases such as cholera, dysentery associated with floods and respiratory disease associated with droughts; heavy rainfalls which tend to accelerate land degradation; damage to communication infrastructure by floods and so on.

Climate scenario analyses conducted as part of the preparation of Uganda's First National Communication indicated that average temperatures are expected to rise significantly in the near future. Projections of rainfall under climate change conditions showed variations. Results from the CCCM model gave an overall decrease in rainfall while (GFDs) and (UK 89) models indicated that rainfall would increase slightly (GOU 2002). Generally few studies have come up with empirical evidence of climate variability and its impact on water resources and livelihoods formation.

Whereas it is evident from both historical and instrumental records that, the global general circulation and climate experience certain fluctuations, these fluctuations have ranged from

long-term changes of great magnitude to short-term regional anomalies (Ogallo 1981). Such fluctuations have been observed in all weather elements including rainfall and temperature.

Short-term variations of weather elements are referred to as weather changes while long-term fluctuations are known as climatic variations. The dynamics of which are determined by space-time characteristics of the general circulation. This general circulation is controlled by complex interactions between ecosystems, land, ocean and atmospheric processes (Ogallo 1993). The factors, which control the space-time characteristics of the unique regional systems, can be classified into two distinct classes, namely natural and anthropogenic (man-made) factors. The anthropogenic forcing on climate is associated with human activities, while the natural factors are associated with solar radiation.

Human activities – primarily burning of fossil fuels and changes in land cover are modifying the concentration of atmospheric constituents or properties of the earth's surface that absorb or scatter radiant energy. These changes in atmospheric compositions are likely to alter temperature, precipitation patterns, sea level, extremes events, and other aspects of climate on which the natural environment and human systems depend.

In their contribution to the third assessment report of the IPCC, 2001, working group 1(WG1) rate the stakes associated with projected changes in climate variables to be high. They argue that numerous earth systems that sustain societies are sensitive to climate and will be impacted by changes in climate variables. Impacts can be expected in sea level changes; the water cycle; air quality; the productivity and structure of natural ecosystems; the productivity of agricultural, grazing and timber lands; and the geographical distribution, behaviour abundance, and survival of plant and animal species, including vectors and hosts of human disease among others. They further state that changes in these systems in response to climate change, as well as direct effects of climate change on humans, would influence human welfare, positively and negatively. Human welfare would be impacted through changes in provisions of and demands for water, food, energy and other material goods that are derived from these systems; changes in opportunities for non-consumptive uses of the environment for recreation and tourism; changes in non-use values; changes in incomes; changes in loss of property and lives from severe climate phenomena and changes in human health. All in all these changes will occur in the people's environment and will affect the different assets they use to form livelihoods that support the economy.

Fresh water is one of the natural resource in Uganda, which is susceptible to changes in climate, but also an asset for livelihoods formation. The natural resource exists in abundance in rivers basins and reservoirs and some of it is retained in swamps, wetlands and even ponds. The water resources according to World Wide Fund for Nature are essential to human health, agriculture, industry and natural ecosystems. International policy documents on water basin management often stress the crucial importance of water to sustain life and development (WWAP 2003). Rosegrant *et al* (2002) points out water basins as providers of water which is essential for growing food, for household water uses including drinking, cooking and sanitation; as a critical input into industry; for tourism and cultural purposes. But most importantly water has been a source of livelihood to many communities that stay near them.

The importance attached to these water resources clearly shows that they require good management because they are an integral part to sustainable development. Their importance and use are related to in some ways to each of the five theme areas; sanitation, energy, health, agriculture and biodiversity as elaborated at the World Summit on Sustainable Development (WSSD) in Johannesburg Aug/Sept 2002.

Furthermore, water is relevant to all three strands of development that is, the social, economic and environmental. When people do not access adequate water, their basic needs like, health, food, security and livelihood are affected. Consequently improving the access of people to water or any other water related resources has the potential to make a major contribution towards improving their well being and eradicate poverty. This is why much of sustainable development is focused on improving the well being of people or getting them out of poverty. Therefore Water resources and the flows that accrue from them like; hydro power, fish, the investments and knowledge (including traditional knowledge) needed to access these resources, and the social and institutional structures that define how they are accessed and managed in Uganda require thorough understanding.

The water sector plays a big role in the economy of Uganda, and there are a number of livelihoods that accrue from this sector. For example, Ugandans are accessing the water basin resources to create a livelihood by getting involved in offshore fishing, fish farming, irrigation agriculture, crafting, recreation and tourism etc. However, their effort to harness these resources to the maximum has often been denied by the resource managers, who have to ensure good resource use. The resource users are not engaged with the managers in decisions on how to use the water resources that often result into conflict.

Several authors like (Phillips *et al* 2006) are debating the link between access to water resources and conflict and people who have little or no opportunity to participate in watershed decisions. Turton *et al* (2007) and references there in stress the importance of effective local stakeholder participation in decision-making processes, and how it affects lives and livelihoods. People participation is one of the doctrines in the Integrated Water Resources Management (IWRM) and highly regarded in Agenda 21 of the United Nations Programme of Action adopted in Rio de Janeiro.

Issues of this nature need to be addressed very fast, because Uganda is one of the countries, which embraced the principles of IWRM as early as 1994. These principles have been embedded in almost all water related policies and legislation today. They are part of management instruments that have been designed to enable the country to achieve the Millennium Development Goals (MDGs) by 2015. Presently the same resources are being threatened by climate change and climate variability (IPCC 2007) hence introducing an additional element of uncertainty about future water resources and their governance.

In other words the management of water, a resource that is increasingly becoming scarce requires an understanding of the science of hydrology as well as an appreciation of social-economic values of communities. Because human well being, ecosystem health and

functions, even economics and politics all depend on how much, when and where water is available.

The study is guided by the assumption that, climate variability has had an impact on water resources from which individuals, households and society accrue sustenance, maintenance especially to earn, gain, get, and make a livelihood. However the level of impact needs further investigations in social-economic terms to understand how this affects present and future livelihoods and management of water resources in Uganda.

1.3 Problem.

Water resources of a country sustain forms of life, food production, as well as general well being and economic development. This natural resource is threatened by climate change and climate variability (Arnell *et al* (2011) and references there in). So far global and regional studies on the impact of climate change on water resources are evidenced for instance in (Arnell 1999; Vörösmarty *et al* 2000; Arnell 2005; Parry *et al* 2007). Climate changes influence precipitation and evaporation patterns and thus indirectly impact on factors like local water availability, water quality, river discharge and the seasonal availability of water supply.

For example, the Government of Uganda, in its initial National communication to the conference of parties UNFCCC revealed that, because of climate change impacting on water resources, Uganda is experiencing water stress, prolonged droughts, reduction in water levels in lakes and rivers which impacted on the generation of electricity, and thus resulting in the interruption of economic activities. Conflict in the cattle corridor, drying up of streams and swamps, the retreating of glaciers on Mt Rwenzori, water scarcity in the dry areas, pollution of water supplies particularly in urban centres, increase in food prices, outbreak of diseases are some of the effects related to water which also negatively affect the economy (GOU 2002). Evaluating these impacts is challenging but necessary because water quality, availability and stream flow are sensitive to changes in temperature and precipitation.

Temperature and precipitation play a vital role in the hydrological resource base, which has a potential to severely impact upon environmental quality, economic development and social security (Arnell 1999). Water resources are part and parcel of the water cycle which is driven by climatic attributes. The future effects of climate variability on water resources will depend on trends in climatic and non- climatic factors. Non-climatic factors include increased demand for water due to population growth, changes in the economy, development of new technology, changes in water shed characteristics, prices, policies, legislation and water management decisions. In addition to typical impacts on water management, climate variability introduces an additional element of uncertainty about future of water resource.

This situation brings into question, “How climate variability has impacted on the water sector in Uganda and the resultant livelihood?” What are the types and characteristics of water resources in Uganda? This study seeks to evaluate the impact of climate variability on the

management of water resources. In so doing, relevance of climate variability on water resources management and its impact on livelihood will be documented.

1.4 Aims and objectives of the study

Aim

To investigate human perceptions on climate change and the impact of rainfall and temperature variability on water resource management and livelihoods in Uganda.

Objectives

To study the long term variations and trends of rainfall and temperature in Uganda.

To analyse the process of livelihood formations and find out human perceptions on climate change in Uganda using a case study.

To assess and characterize water resource potential of Uganda.

To find out the relationship between climate change / variability on lake surface water area.

1.5 Motivation and significance of the study

A number of climate variability studies have been undertaken for Uganda over recent years, though not all focused specifically on the water resources. It is important that the work we undertake builds on these studies. For example, UNDP has produced Climate Change Country Profiles (CCCP) for many countries including Uganda. The CCCP study gives an overview of the general climatic conditions in Uganda, the recent trends in rainfall and temperature, and Global Climate Model (GCM) projections of future climate for Uganda over the 21st century. The IPCC addresses climate change impacts, adaptation and vulnerability in the fourth assessment report. It does not review these issues each on a country-by-country basis but it does provide a useful overview of the literature for Africa and also by sector, including a chapter on fresh water resources and their management. In 2007, Uganda government published the Uganda National Adaptation Programmes of Action (NAPA). The NAPA reviewed the national circumstances and resources of Uganda, examined vulnerabilities to climate change, and then went on to present coping strategies together with implementation arrangements. Hepworth and Goulden (2008) undertook a scoping mission for DFID Uganda to understand the implications and appraise the response of climate change vulnerability, adaptation and mitigation, as well as the role of other institutions involved in climate change in Uganda. It pointed out, the uncertainties surrounding climate change impacts and the lack of capacity to assess or respond to this uncertainty. Oxfam (2008) examined the impacts of climate changes on agriculture, pastoralism and on health and water and their interconnectedness in relation to peoples' livelihoods. Few of these studies have used long term data to detect climate signals and evidences of change. This study intends to

use long term data and determine the implications of the signal to water resources management and livelihood formations.

Chen (1983) presented two perspectives to research in climate and society by showing how both natural scientists and social scientists have generally focused on the “*what if*” side of things. They have raised questions like; *what is that likely to occur-or could be made to occur? What are the underlying causes and important influences, with respect to the earth’s climate?* It is through such approach that natural scientists have speculated and theorized about the possible climate changes, their genesis and the cost on physical and biological systems and even suggest actions to prevent them (Chen 1983).

To him the social scientists have also devoted much effort as they try to establish the costs, benefits, developments that may be triggered by extreme climatic variability. Notably, he argues, that questions like these do begin to delve into issues of “*so what?*” This is one of the questions, which are difficult to answer among other things because of human perception and choice (Chen 1983). But in order to make informed choice, people and governments have to be given information. Therefore, this research is significant in that it will provide information on the performance of water resources, which will enhance individual social responsibility towards the resource. The results will be used to inform policy on water governance in Uganda.

Advances have been made since previous IPCC assessments in the detection of change in biotic and physical systems, and steps have been taken to improve the understanding of adaptive capacity, vulnerability to climate extremes, and other critical impact related issues. These assessments have been carried out at a large scale (and sometimes regional). These advances indicate a need for initiatives to begin designing adaptation strategies and building adaptive capacities. This study strengthens future assessments and reduces uncertainties by ensuring that sufficient information is available for policy making about responses to possible consequences of climate change, including individual households and the economy.

Since Uganda’s climate is subject to annual variability, it presents significant vulnerabilities in the face of global climate change. In the face of the long lead times required for planning, and the conflicting demands placed on policy developers and politicians, it is vital to accurately understand the national consequences of climate change and variability beginning from the house hold which supports the economy.

Taylor & Mackenzie (1992 in Tefera 2006) discuss why many rural development initiatives in Sub-Saharan Africa fall short. They relate it to the fact that insufficient attention and recognition is given to local level specifics and initiatives in solving development problems. Understanding of intricacies, strengths and weaknesses of governance systems and the aspiration of the concerned people is imperative if past failures are to be avoided (Tefera 2006). This study has given due attention to the linkages between governance and the available natural resources, amidst natural changes in the management context.

The water basin analysis is providing local insights and identifying the priorities of water governance that inform higher-level policy and explains how the prevailing external

environments affect livelihoods at the grassroots level. The latter in turn provoke discussions and consultations on how to support livelihoods and mitigate adverse environmental consequences.

The outcomes help organizations and governments to develop guidelines for the orientation, policy and programs contributing to mitigation and adaptation of climate change and managing of water basins.

A study of this nature is of great importance at the international level, the macro level and to the micro level. In that it provides useful information to water planners and managers, irrigation engineer, agronomist and scientists on the main aspects to be taken into account in the water management for social economic benefits. The study informs on how people living on water resources construct their livelihoods amidst external factors like climate variability.

In anticipation of a full range of consequences from and possible responses to climatic variations, the pathways and linkages by which such occurrences are transmitted through society are understood. And since they are dynamic in nature, the pathways shifting overtime are somehow understood (Chen *et al.* 1983).

The study has compiled information on the level of effects that become an essential ingredient for evaluation of alternative strategies. Estimates of aggregate positive and negative inputs provide baseline information by which the benefits of strategies or policies can be assessed. For example cost benefit analysis or cost effectiveness analysis approaches, demand such data for purposes of comparing the costs of strategy implementation to the expected benefit accruing to society.

Information on the level of total effects is important in placing societal problems into perspective. For instance how does climate change fit among the list of priorities of problems to be addressed? As Kenneth Boulding (1980 in Chen *et al.* 1983) suggests, society in general and science in particular, often expends a good deal of effort on seemingly less pressing problems, while the more critical problems are neglected. How climate change problem matches up to other societal problems is a fundamental issue at both national and global scales (Chen *et al.* 1983 and references there in) and outcome on this is evident.

Decision makers requiring information on the full range of possible mechanisms and their effects can draw upon investigations already conducted on human response to natural hazards and to long time climate change. In doing so the study has established the effectiveness of adjusting mechanisms and of the social costs associated with them. Politicians and policy makers will benefit from the re- commendations that will guide them in future decisions relating to water resources, livelihoods and environmental reporting.

The study is a basis for a water management institute whose mission is to improve water and land resources management for food, livelihoods and nature.

1.6 Conceptual base

It is a basic premise of water resource management that managing water resources yields optimal benefits. This means more water, more food, more power, more transport, improved health and the like. These Natural Ecosystem on to which many people depend for their livelihoods are being threatened by climate change. And because the exploitation of these ecosystems is unavoidable, decisions have to be made that will strike a balance between their use and sustenance by following a reliable strategy. In so doing its management requires an understanding of the science of hydrology as well as an appreciation of social-economic values of communities. Such understanding can be best achieved when different players are involved such as scientists (science), the people (society) and the Managers (State). This will then be in line with the Dublin principle (2) of 1992 (Miguel and Gonzalez-Villarreal 1999), which states “*water development and management should be based on a participatory approach involving users, planners and policy makers at all levels*”.

These principles form the core upon which the principles of IWRM have been established though not functional in most countries, simply because good governance was misunderstood (Turton *et al.* 2007). After a decade when the IWRM approaches were adopted, countries are still far away from realizing the potential benefits. It is on this basis that, Turton *et al* (2007) have conceptualized the “Trialogue Model of Governance” that can be applied in various social, political and economic setting to foster consensus among water resources management and policy professionals. In the Model they attempt to justify the interface between the State, Science and Society in achieving good water resources management (Fig 1.1). The study reviewed literature, to find out the extent to which science, state and society have engaged the climatic and non-climatic factors in managing water resources that form a basis for livelihoods (Fig 1.2).

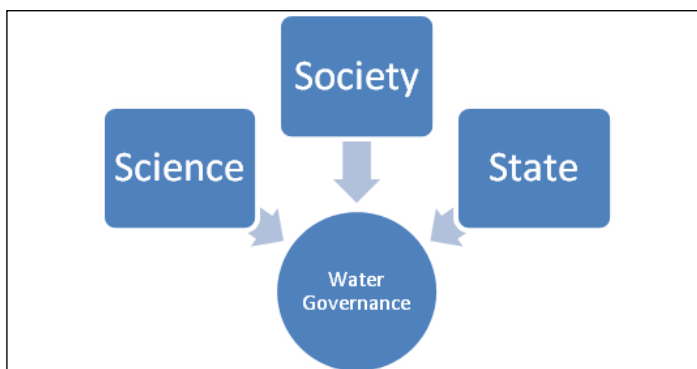


Figure 1.1 A Trialogue Model of Governance (after Turton *et al.* 2007)

The frame work which is presented in the schematic form below has been developed to help understand the approach in which this research has been conceptualized. The frame work is structured around the core elements that are the focus of research (Fig 1.2). The approach is founded on a belief that people require a range of assets to achieve positive livelihood outcomes (DFID 1999). People have to seek ways of nurturing and combining the assets they possess innovatively to ensure survival. But in the process of forming these livelihoods,

factors (climatic and non-climatic) exert influence on the assets. These factors influence the access of assets, livelihood strategy, and the livelihood outcomes in a house hold.

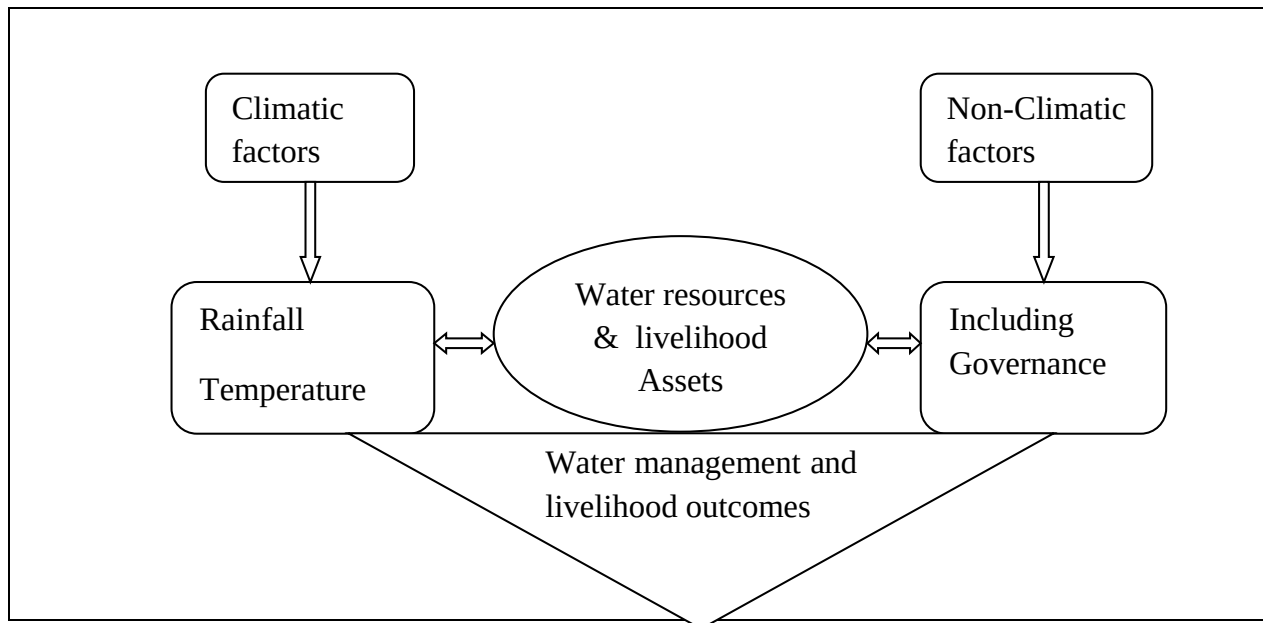


Figure 1.2 Schematic representation of research conceptual framework

People may be involved in different social and economic activities as individuals, but it's at the level of the household that the real impacts of those activities are seen most clearly. The well-being of the household is generally a key objective for most people (Messer and Townsley 2003) especially researchers. The members of a household combine their capabilities, skills and knowledge with the different resources at their disposal to create activities that will enable them to achieve the best possible livelihood assets and outcomes.

The DFID livelihoods framework identifies five core asset categories or types of capital upon which livelihoods are built. For the sake of this research, these assets are divided into six (Baumann & Sinha 2001) namely; human, financial, political, natural, social and physical. Different households will have different levels of access to this range of assets (Whitehead 2002).

A household's access to adequate livelihood assets can be affected by many factors (e.g. climatic and non-climatic) over which households members themselves may have little control. These factors influence the choices that households make about using their assets. They can also destroy assets directly, can force people to abandon their home areas and dispose of assets, prematurely as part of coping strategies. The aim of the frame work described above is to investigate the climatic factors (rain and temperature), their impact on physical, human, financial, social, political and natural (water resources). Non-climatic attributes (demand for water, population growth, changes in economy, technology, watershed characteristics, water management decisions, prices, policies and legislation) impact on the assets and vice-versa. This interaction determines the livelihood strategies and outcomes such as more incomes, increased well being, reduced vulnerability, improved food security, sustainable use of water resource among others. The study aims at assessing a whole range of

influencing factors, but most especially climate variability, and find out its relevance on the livelihoods formations of the people in a household.

The study therefore investigates the characteristics of climate in Uganda especially by following up on the responses that arose from the field study on what household members view as climate change. Through their own observations, respondents noticed changes in temperature and rainfall. Temperature variables like diurnal temperature range, maximum and minimum temperatures have been investigated because respondents view them as changing. Rainfall was also reported by respondents to be changing particularly seasonal distribution. It is the interest of this study to establish whether these observations are impacting on livelihood formations. The study investigates this impact on livelihood formation through the assets available to the households using the DFID framework. A further investigation is carried out on one of the natural assets (water resources) which are central to the wellbeing of individual households in order to understand the impact of rainfall variability on a water body, by studying the lake surface area of Kyoga basin. It is upon this background that the study is cast into a theoretical perspective by reviewing literature that relates to climate and livelihoods as shown in the chapters that follow.

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CHAPTER 2

Theoretical perspectives of climate, climate variability and livelihoods.

This chapter reviews the theoretical perspectives of climate science which underpin the concepts of climate change, climate variability and impacts on livelihoods. The chapter attempts to capture debates and evaluate evidence and discussions regarding climate change, climate variability and its orientation in the world, tropics, Africa, east Africa and Uganda in that order.

2.1 Climate

According to (IPCC 2001b), ‘Climate’ is defined, as the average weather in terms of the mean and its variability over a certain time span and a certain area. Whereas ‘weather’ refers to the fluctuating state of the atmosphere around us, characterized by temperature, wind, precipitation, clouds and other weather elements. Human beings interact with weather and climate on a daily basis while producing food and as they seek health and wellbeing in this world. In order to understand, detect and eventually understand this interaction, it is important to understand the science that determines the climate of the earth and of the processes that lead to climate variability and climate change. The weather variables that affect daily life most directly include temperature, wind, precipitation, humidity, cloud type and the amount of solar radiation. These variables are observed hourly by many weather stations around the earth. These variables however form only part of the reality that determines weather and climate (IPCC 2001b).

Climate varies from place to place depending on latitude, distance from the sea, vegetation cover, geography and other environmental factors (Baede *et al.* 2001). Climate also varies in time, from season to season, year to year, decade-to-decade and even on much longer time scales. The atmosphere and its composition, land and its cover, human activities, the sea, and its processes are other factors, which play an important role in the variability of weather and climate that we experience (IPCC 2001b).

To understand the climate of earth and its variations, and possibly be able to predict the changes for future, one has to understand the climate system and the interactions of the components in the system.

2.1.1 Climate system

A climate system is an interactive process, which consists of the atmosphere, the cryosphere, the lithosphere, hydrosphere and the biosphere, forced by external forcing. Within these components are many physical, chemical and biological interactions that occur on a wide range of space and time scales, making the system extremely complex (IPCC 2001b). The

components in the climate system are described briefly in relationship to Baede *et al.* (2001) in the paragraphs that follow.

The atmosphere, which transcends 10000m above earth surface, is unstable and changes rapidly. It is composed of Nitrogen (78%), oxygen (20.9%) and argon (0.93%), has trace gases such as carbon dioxide, methane, nitrous oxide and ozone, also known as green house gases including water vapour (H₂O) that absorb and emit infrared radiation. The gases, aerosols and clouds found in the atmosphere play an essential role in the earth's energy budget. The hydrosphere is the component comprising all liquid surface and subterranean water (both fresh and saline). It stores and transports a large amount of energy dissolve and store great quantities of carbon dioxide. And there presence greatly influences climate distribution on earth.

The cryosphere, including the ice sheets, continental glaciers and snowfields, sea ice and permafrost, derive its importance to the climate system from its high solar reflectivity (albedo), its low thermal conductivity, its large thermal inertia and its role in driving deep ocean water circulation.

The lithosphere is the hard part of earth made up mainly of soils, rocks and vegetation which control incoming and outgoing radiation. Some of the energy is infrared which heats the atmosphere from below. Some energy facilitates evapo-transpiration from soil or plants back into the atmosphere. The texture of the land surface, which is characterised by both vegetation and topography, influences the atmosphere dynamics such as winds blowing over the land surface that carries dust from the surface into the atmosphere, which interacts with the atmospheric radiation.

The biosphere (marine and terrestrial) plays a central role in the carbon cycle, as well as in the budgets of many other gases, such as methane and nitrous oxide. Other biospheric emissions are the so-called Volatile Organic Compounds (VOC) which may have important effects on atmospheric chemistry, on aerosols formation and therefore on climate.

Many processes take place within and among the components of the climate system outlined above on a temporal and spatial scale which renders the system complex (Baede *et al.* 2001). All the components are further linked by fluxes of mass heat and momentum while the subsystems perform openly and are interrelated. The linkage is illustrated in the diagram below (Fig. 2.1).

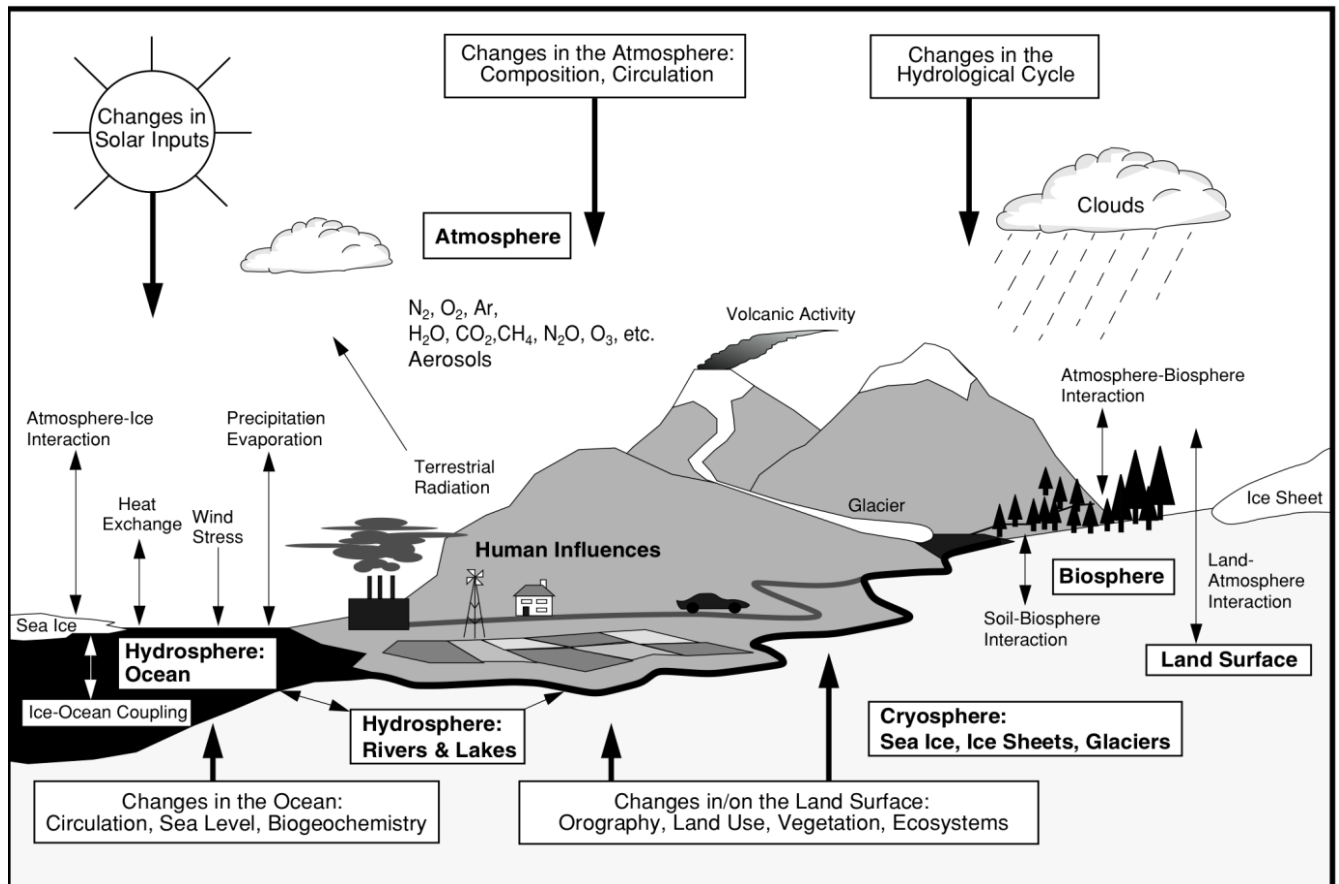


Figure 2.1: Schematic view of the components of the global system (bold), their processes and interactions (thin arrows) and some aspects that may change (bold arrows). Reproduced from (TAR, 2001- Pg 88) in (IPCC, 2001b).

2.1.2 Climate variations

Variations in climate can be well understood by analyzing variations, which are natural, and those that are human induced. Natural variations are driven by the sun, which is the source of energy, for the climate system. The sun sends down solar radiation (shortwave), some of which is reflected back into space by clouds, atmosphere and earth surface and the other is partly absorbed by the atmosphere, but most warms the earth's surface, the land and ocean. The earth's surface returns that, heat to the atmosphere, partly as infrared radiation, partly as sensible heat and as water vapour, which releases its heat when it condenses higher up in the atmosphere (Fig. 2.1). Within the atmosphere are trace gases e.g. green house gases that absorb and emit infrared radiation in all directions, which is also a natural forcing. These gases and clouds trap heat with in the atmosphere and make the earth warm. On the other hand most clouds are bright reflectors of solar radiation and tend to cool the climate system (IPCC 2001b).

Human beings on the other hand propel human induced climate variations. Like other living organism, humans have always influenced their environment, through activities that have led to desirable standards of living. Especially those activities involving combustion of fossil fuels for energy, that produce green house gases and aerosols, that alter the composition of the atmosphere. Other indoor activities, especially have led to the emission of chlorofluorocarbons (CFCs), chlorine and bromine compounds that have impacted on the radiative forcing and also led to the depletion of the stratospheric ozone layer, thus globe warming (IPCC 2007). Land use change, due to urbanization, forestation and deforestation, resource extraction and agricultural practices, affect the physical and biological properties of the earth's surface. Such effects change the radiative forcing and have a potential impact on regional and global climate (IPCC 2001b).

2.1.3 Natural variability of climate

Climate varies naturally on all time-scales (IPCC 2001) as evidenced by glacial and interglacial periods that have alternated as a result of variations in the Earth's orbital parameters in the last million years. Spatial patterns of climate variability are much more pronounced at a regional level than on a global scale because of local variations. Such patterns result from interactions between the atmospheric circulation and the land and ocean surfaces to cause for example the quasi-periodically varying El-Nino Southern Oscillation (ENSO) phenomena and the resulting El Nino and La Nina events which have a worldwide impact on weather and climate especially in the tropics. The following regional patterns of climate will be discussed, tropical climate including Africa and its sensitivity to climate variability and change, east Africa and Uganda.

2.1.4 Tropical climate.

Mcgregor and Nieuwolt (1998), characterize the tropics by the absence of a cold season. The tropics cover more than 40% of the earth's surface, but the tropical circulation often extends beyond these boundaries. Temperature differences between seasons are generally small in the tropics that they are of little consequence. The mean annual range, which is less than 4⁰C, and over the equatorial oceans less than 2⁰C is indicative of this. Spatial temperature differences are also very small in the tropics. Almost everywhere the means for extreme months are between 25⁰C and 30⁰C, because there is a very small difference in the amount of net radiation received between the equator and ten degree latitude. Secondly most of the tropics consist of ocean surfaces, which are great heat storage reservoirs. Tropical climate is further influenced by the overhead position of the sun, cloudiness, altitude, ocean currents and local factors (Riehl 1969). The main influence on diurnal temperature range in the tropics is continentality, followed by elevation and the absence and presence of clouds especially in drier lands.

Because of the size of the tropics and its characteristics, tropical circulation plays a major role in determining the nature of the global circulation at any one time. The meridional circulation of the Hadley cells dominates the low latitudes with ascending branches on their pole ward sides. Return flow to the equator at the surface is in form of the trade winds (Vecchi and Soden 2007). At the centre of the tropical circulation between the two Hadley cells is a wide belt characterized by relatively low surface pressure, rising air movements and convergence of air masses (Lee *et al.* 2009). This zone is known as the Inter Tropical Convergence Zone (ITCZ). Associated with ITCZ is a band of high rainfall on which many low latitude subsistence and cash based agricultural economies depend. The seasonal movement of the ITCZ, which is generally greater over land, is an important determinant of the timing of the onset, duration and cessation of rainy season in many tropical areas (Segele and Lamb 2005). For the African region, the ITCZ displays an almost symmetrical pattern of the movement north and south of the equator, which mimics the annual solar cycle and a zone of maximum surface heating.

2.1.5 Africa's sensitivity to climate variability.

Many sectors like agriculture, health, and water in Africa are sensitive to weather and climate variability. This sensitivity is discussed by several authors found in (Boko *et al.* 2007) who highlight the sensitivity and vulnerability on the environmental and socio-economic aspects of Africa.

For example (Mahli and Wright 2004; Kruger and Shongwe 2004; Conway *et al.* 2004; New *et al.* 2006) have detected a greater warming trend since 1960s in Africa, while decreasing trends in temperatures have been observed in east Africa from weather stations located near water bodies (King'uyu *et al.* 2000). Increase in temperatures is likely to influence the evaporative rates that may heavily impact on water resources of the country.

Rainfall on the other hand exhibits notable spatial and temporal variability (Hulme *et al.* 2005). For example a decline in annual rainfall has been observed in some parts of Africa since the end of the 1960s (Nicholson *et al.* 2000; Chappell and Agnew 2004; Dai *et al.* 2004; Mahli and Wright 2004). There are some regions of Africa that exhibit increased inter-annual variability associated with higher rainfall anomalies and drought (Richard *et al.* 2001; Fauchereau *et al.* 2003; Usman and Reason 2004) including changes in seasonality and weather extremes (Tadross *et al.* 2005; New *et al.* 2006). Such kind of variability may impact on the quantity of surface and ground water resources as well as the related activities like agriculture, tourism and hydropower production.

The water sector is sensitive to changes in climate as evidenced by fluctuations and volatility of lake levels since the 1960s (Riebeek 2006; Conway *et al.* 2005) in Africa. Runoff is an important parameter that contributes to water levels in rivers and lakes. Changes in runoff linked to climate have been observed on the wider continent (de Wit and Stankiewicz 2006; Nkomo *et al.* 2006) though few assessments on underground water and its interactions with climate have been made.

Assessments of health in Africa show that many communities are already impacted by health stresses that are linked to climate change and variability. Such as the resurgence of malaria and links to climate and /or other causal ‘drivers’ of change in the highlands of East Africa (Hay *et al.* 2002a; Pascual *et al.* 2006; Schreck and Semazzi 2004) and other diseases like cholera and meningitis (Molesworth *et al.* 2003, Sultan *et al.* 2005) have also been observed. Of most importance and serious effect on health are the heat waves (Lyon 2009).

Agriculture, which is mainstay of local livelihoods and contributes largely to national Gross Domestic Product (GDP) in some countries, is so sensitive and vulnerable to climate (Mendelsohn *et al.* 2000a; Devereux and Maxwell 2001). This sector is particularly sensitive to periods of climate variability (Usman and Reason 2004), which are further aggravated by periods of prolonged droughts and/ or floods (Mendelsohn *et al.* 2000; Biggs *et al.* 2004; Vogel 2005). It is demonstrated by (Tshiala and Olwoch 2010; Tshiala *et al.* 2012) how climate is impacting on agriculture by influencing the distribution of pests and diseases.

Ecosystems are critical in Africa, contributing significantly to biodiversity and human well-being (Muruiki *et al.* 2005; Biggs *et al.* 2004). The biodiversity that exists particularly outside the conservation areas is threatened by climate variability and change amidst other stresses like fire, invasive species and land use change which interact and produce changes in several African locations (Muruiki *et al.* 2005). Impacts on settlements and infrastructure are (Christie and Hanlon 2001; Reason and Keible 2004; Niasse *et al.* 2004; UNDP 2004) have not been excluded in discussions on how they are suffering from recent extreme climate events. Therefore climate exerts a significant control on the day-to- day economic development of Africa, particularly for the agricultural and water resources sectors, at regional, local and household scales (Boko *et al.* 2007).

2.1.6 Dynamics of East African climate.

East Africa is enclosed between latitudes 5°N- 12°S and longitudes 29° and 42°E (Ogallo, 1988, 1993). Its equatorial position and location on the East African plateau, the general circulation and continental character play a significant part in the nature of East Africa’s climate (Martyn 1992), at the same time making it one of the meteorologically complex sections of the continent (Nicholson 1996). Ogallo (1993) indentifies the major climate parameter, which has the highest space-time variation over the region as rainfall. Temperature however is another important factor that varies as you move away from the equator and also over the highlands. The systems which control the space- time characteristics of rainfall and temperature over the region according to Ogallo (1993) include; ITCZ, Monsoonal wind systems, Subtropical anticyclones, Tropical cyclones, Jet streams, Easterly/Westerly wave perturbations, extra tropical weather systems, El-Nino/Southern Oscillation (ENSO) events, Quasi Biennial Oscillations(QBO), solar forcings, inter seasonal wave, etc. Various studies like (Ogallo 1984; Ogallo 1988; Ogallo *et al.* 1989; Anyamba 1992 and Ogallo 1993) and references there in, shed light on the dynamics of climate in East

Africa. And recently Tierney *et al.* (2013) give a further insight on the influence of Indian Ocean sea surface temperatures on east African rainfall over multi-decadal timescales.

The regional system is also associated with complex topographical features and the existence of many large inland lakes that induce significant modification on the large-scale circulations especially near the surface (Nicholson 1996). The influence of lakes on a variety of scales on the regional weather and climate variability cannot be under estimated. Large lakes are regulators of regional climates (Anyah and Semazzi 2009). The ITCZ is another big influence on the climate of eastern Africa. Martyn (1992) explains that in January when the ITCZ is at around 15°S, east Africa is within reach of the dry north easterly winds blowing down from the Arabian Peninsula and Somalia. On crossing the equator, the winds become north westerly. In April, the ITCZ lies over 5°N when moist air masses of great depth blow off the Indian Ocean at right angles to the Kenyan and Tanzanian coasts and the mountain barriers. In July when the ITCZ has moved to 15° N and an anticyclone has formed over the now much cooler south of Africa, dry, cool southerly and south easterly winds blow over equatorial east Africa. In October as the ITCZ returns south, winds are easterly. Nieuwolt, 1977 in Martyn (1992) observes that Monsoons over east Africa are relatively dry. The advection of moist air masses giving rise to precipitation takes place in the transition seasons, when the ITCZ is crossing into other hemisphere (Nicholson 1996). During the warm ENSO, for example eastern Africa receives abundant rainfall during the ‘short rains’, which shows a strong relationship between ENSO and the eastern African climate (Schreck and Semazzi 2004).

Nicholson (1996) identifies a number of studies like (Rodhe and Virji 1976; Ogallo 1979; Nicholson and Entekhabi 1986) who use spectral analysis to explain inter-annual variability of rainfall; (Johnson and Morth 1960; Nakamura 1969; Davies *et al.* 1985., Minja 1985; Kiangi and Temu 1984) who focused on the influence of the westerly flows on East African rainfall; (Anyamba and Ogallo 1985) who studied the influence of the convergence zones to justify inter-annual variability. Other studies on east African rainfall climate variability like (Atwoki 1975; Cadet and Diehl 1984; Ropelewski and Halpert 1987; Nyenzi 1992; Semazzi and Indeje 1999) have been identified by (Schreck and Semazzi 2004). Clark *et al.* 2003 on the other hand researches on the inter-decadal variability of the relationship between the Indian Ocean zonal mode and east African coastal rainfall anomalies (see diagrams there in for clarity).

Precipitation in east Africa is very variable in quantity as a result of elevation and distance from the sea. It is higher on the Indian Ocean coast, the offshore islands, the lakeshores and the highlands, while places on the lee side of highlands and in basins have less rain. The precipitation regime depends on the atmospheric circulation systems.

Annual rainfall exhibits strong seasonality. The rainfall seasons migrate with the ITCZ, which shifts with the sun’s positions (Ogallo 1984). Close to the equator bimodal distribution of rainfall is well marked with two rainy seasons peaks centred around (March- May and October- November) which are generally known as the long and short rainy seasons respectively (Ogallo 1988). Further away from the equator the distributions are dominantly

unimodal (January- February). In the rift valley and central highlands of Kenya, trimodal distributions are observed at some stations. The third rainfall peak (June-August) is due to moisture incursions from the Congo air mass (Ogallo 1984 and references there in). The highest annual precipitation (> 1000 mm) is recorded in the area affected by the ITCZ. Dry seasons alternate with rainy ones. Where there is only one precipitation maximum, the dry season is in the winter months of a given hemisphere, where as in areas with two rainy seasons they are in the winter and summer months of each hemisphere. In the rainy season, rain falls on 10-20 days a month. There are 150-170 rain days per annum in the wettest areas. In the driest parts of Kenya there are only 20-30 rain days a year, while in basins this figure fluctuates between 50 and 100 (Martyn 1992).

The location of east Africa astride the equator exposes it to comprehensive sunshine associated with high temperatures and high rainfall. At the equator temperatures are predominantly determined by the degree of outgoing long-wave radiation. Equatorial east Africa gets 2500 hours of sunshine a year. The annual solar radiation ranges from 6280 to 7118 MJ/ m². In no month does the daily radiation total fall below 13 MJ/m² (Martyn, 1992). Temperature in east Africa is modulated by thermally induced mesoscale systems associated with orography and large water bodies, like Lake Victoria which has a unique circulation of its own (Schreck and Semazzi 2004; Anyah and Semazzi 2009). Temperatures are highly modified by altitude in East Africa. The maximum temperature can reach 30⁰-35⁰C at lower altitudes but only 20⁰-22⁰C in more elevated situations. Absolute maxima do not usually exceed 40⁰C, and at an altitude of 2600m are no higher than 25⁰C (Martyn 1992). Minima in the warmest places drop to 28⁰-30⁰C, while in elevated places minima falls below 15⁰C and at very high altitudes 8⁰C. Exceptional temperature falls do not go below 5⁰- 10⁰C, or 13⁰C in the warmest places, and 16⁰C on the coast. According to (Martyn 1992) below 0⁰C temperatures are generally recorded only above 2400m above mean sea level (amsl).

Generally, the highest temperatures of the year for Uganda, Kenya and Tanzania are recorded in February, March, November and December. The coolest month of the year is July, or sometimes August. In their investigation King'uyu *et al.* (2000) found evidence of warming in recent years, especially in area extending up to about 5⁰S of east Africa, while south of 5⁰ latitude, night time and daytime temperature trends showed a decrease. A number of authors have reported a decrease in the diurnal temperature range which has been associated with an increase in cloud cover or even decreasing maximum temperature trends (IPCC 1995).

The annual relative humidity at sunrise in this region is 85-95%, and by the afternoon, it falls to 50%, while over the lake and ocean shores it is then 65-70%. The seasonal variation of relative humidity, particularly in the afternoon hours is connected with the atmospheric circulation. Humidity and sunshine are climatic aspects that require further investigation to determine whether they have changed and by what magnitude in east Africa? The climate of Uganda as a region is discussed here below based on recent work found in literature.

2.1.7 Climate of Uganda.

Uganda is often described as a country that experiences an equatorial climate. However, the country's orographic characteristics and the diverse influence of Lake Victoria, Atlantic and Indian Oceans, impose on it a wide variety of climates, ranging from extreme dryness in the northeast up to snowing mountains in the west. This heterogeneity creates a complex scenario for water resource management and the precipitation evolution, which require a more accurate territory analysis in this era of climate change.

Uganda's rainfall exhibits considerable spatial and temporal variability. According to the Uganda Department of Meteorology (DOM), the average annual rainfall over most parts of the country is over 1180mm per annum, which is about 40% higher than the world average of 860mm/yr (UBOS 2008). The country experiences two annual rainfall maxima between March and May (MAM) also known as the long rains and September to November (SON), the short rains (Basalirwa 1995). In the drier parts of the country (especially north east), rainfall between the two maxima is not strikingly different thereby producing a uni-modal type of distribution, characterized by one long dry season followed by one long wet season. In the rest of the country, rainfall has a bi-modal (twin-peaked) pattern with a pronounced dry season between the two rainfall maxima. This pattern is linked to the double passage of the Inter-Tropical Convergence Zone (ITCZ) as it follows the path of overhead sun (Asadullah *et al.* 2008). In response to the overhead position of the sun, the movement to the south of the rain belt makes it the most dominant feature of intra-seasonal variability, because maximum rainfall resides mainly over Uganda (Schreck and Semazzi 2004). Generally, the seasonal pattern follows this bimodal system near the equator and tends to a uni-modal system with distance from the Equator (Conway *et al.* 2005).

The spatial distribution is also influenced by the presence of Lake Victoria as well as the local topography. Recent research has shown that the Indian Ocean, the Red Sea and the coastal water off southern Africa are also moisture sources for Uganda (Gimeno *et al.* 2010). Generally rainfall tends to decrease with the distance from the lake. The highest annual maximum rainfall is experienced around the lakeshore, over the central and western parts of the Lake Victoria basin and on the slopes of Mt Elgon and to a certain extent over the north-western areas. On the other hand rainfall is low over the north eastern and south-western areas and elongated area along the western rift valley running through Lake Albert. Research has demonstrated a positive trend in the rainfall around the northern shores of Lake Victoria, which in future should allow for wetter conditions (Kizza *et al.* 2009). Wetter conditions within the Victoria basin may lead to incidences of flooding and accelerate soil erosion. Further still, small but statistically significant increasing trends of precipitation at low land stations e.g. Mbarara (1904- 1999) and Fort portal (1903 -1978) in western Uganda have been reported by (Taylor *et al.* 2009). The effect of the local topography is an influencing factor on rainfall received particularly in mountainous areas. For example there is a strong orographic effect on the local precipitation in the Rwenzori Mountains. A study by Taylor *et al.* (2009) describes how precipitation on these mountains varies with elevation e.g. at 3290m (amsl) in

the heath-moss forest zone annual precipitation of 2600mm was recorded, whereas at the base of the mountain (1250m) amsl, 1150mm of precipitation was observed. According to Osmaston (1989 in Mölg *et al* 2003) precipitation decreases towards the peak, but values still remain above 1000mm/year.

Climate in Uganda therefore is highly variable depending on distance from the equator, topography, influence from the water bodies and the sea, the effect of approaching winds and other environmental factors. These factors highly influence rainfall distribution and seasonality as discussed below.

Rainfall Seasonality

According to NEMA, (2008) March to May is the main stable rain season over most parts of the country. The probability of normal range of rainfall is generally over 80% except over the extreme north-eastern areas where the probability drops below 70%. The probability of below normal rainfall is low, around 10% over most parts of the country except over the extreme north-eastern areas where it goes up 20%. The probability of above normal rainfall is low, just around 10%, over most areas of the country. October to December is the most variable rain season over most parts of the country. The probability of getting the normal range of rainfall is between 70 to about 80% over the western areas where the main rainy belt for this season is centred but drops to around 50% over most areas of the eastern region and extending into the central parts of the country. The probability of below normal rainfall is fairly high, over 20% over most parts of the eastern region and to above 40% over the north-eastern areas. The probability of above normal rainfall is also fairly high (over 20%) over most parts of the eastern areas. The high variability of rainfall during this season results in high incidences of droughts and floods especially over the Eastern parts of the country.

Temperature variability

Uganda generally experiences an annual mean daily temperature of 28⁰C (Mubiru 2010). Over a year, mean temperatures range from a minimum of 15⁰C in July to a maximum of 30⁰C in February. Highest temperatures are experienced in the north and north-eastern part of the country (GOU 2007) and sustained warming has also been recorded in the southern parts of the country. According to GOU, 2007, the fastest warming regions are the southwest of the country where the rate is of the order of 0.3⁰C per decade (Mubiru 2010). For example, a study by Nsubuga *et al.* (2011) showed that monthly maximum temperatures for a period of 56 years at Namulonge were increasing significantly at a rate of 0.17⁰C per decade. There was evidence that variation of mean monthly temperatures in a year is small ranging between 1⁰C and 2⁰C (Nsubuga *et al.* 2011). According to Mubiru (2010) temperatures in Karamoja sub region have been documented in literature to be high. In the highlands and around mountains, the elevated landmass exerts a local influence in climate producing temperatures that are unique from the lowlands.

2.1.8 Climate, water resources and livelihoods

One of the consequences of a changing climate is the alteration of rainfall patterns (Huho *et al.* 2012). The seasonality, amount, distribution and the timing of rainfall are of particular importance to the population that depends on rain-fed agriculture for their subsistence. There are indications revealed in the IPCC (2001b) that in some parts of the equatorial East Africa, December, January and February (DJF) rainfall may increase by 5 to 20 percent, while June, July, and August (JJA) rainfall may decrease by 5 to 10 percent under the lowest warming scenario. None the less, short term as well as long-term variations in rainfall patterns has important effects on crop and livestock farming (IPCC 2007). For example, seasonal rainfall has been marked by delayed onsets, declining number of rain days and increased intensities altering farming calendars with negative effects on the yields (Huho *et al.* 2012).

Worthy to note are the pastoral activities, especially in developing countries that are weather-dependent. Pastoralism is mainly practised on the dry lands, like those of east Africa. However predictions by climate change models show that, African dry lands will experience rising temperatures and decreasing rainfalls. This could undermine the delicate balance on which pastoral systems depend (Huho 2009).

Increase in the frequency of extreme weather events such as flooding and drought; raise the risk of damage to property and infrastructure. Insurance companies will need to significantly increase the amount of capital they hold to be able to provide insurance cover at a level comparable to that of today (WBGU 2008). Resulting disasters such as floods and droughts have major effects on food provisions, health, economic and environmental losses, and social disorder (Pavel 2003).

Agriculture which is the main livelihood accounts for the biggest share of the economy of African countries. For example over 70% of the labour force in Uganda is in agriculture related activities. It is estimated that, a rise in surface temperature will affect the livelihoods of the 70 per cent of Africans who depend on rain-fed agriculture, hence completing the vicious cycle of poverty (Urama and Ozor 2010).

The availability of optimal water supply for crops determines the level of output obtained. Globally, over 80 per cent of agricultural land is rain-fed and crop productivity depends exclusively on sufficient precipitation to meet evaporative demand and associated soil moisture distribution (FAO 2003). Where these variables are limited by climate, such as in arid and semiarid regions of Africa, agricultural production is extremely vulnerable.

By critically affecting crop productivity and food production, in addition to being a necessity in food production processes, water plays a critical role in food safety. Therefore, food availability, accessibility and nutritional balance will be indirectly endangered by climate change.

The productivity of agricultural, forestry and fisheries systems depends critically on the temporal and spatial distribution of precipitation and evaporation, and especially for crops, on

the availability of freshwater resources for irrigation (Bates *et al.* 2008). Changes in precipitation, and thereby in water availability, influence both productivity and species distribution (Kaiser 2001).

Climate variability affects many important sectors of the economy by influencing the supply of and demand for goods and services (WBGU 2008) because of low yields, resulting mainly from drought and beyond normal rainfall events. The changes can affect the profitability of farming and the affordability of food. For example, the Water Resources Sector Strategy 2003 of the World Bank quotes examples of impacts of climate variability on economic performance. The World Bank, in its 2003 report cites the effect of drought and flood on Zimbabwe and Mozambique in the 1990s as having contributed to a decline in GDP of 11 percent and 23 percent respectively (Pavel 2003). The scale of such losses shows the need for scientists and water managers to have a better understanding of the mechanisms of climate variability and their relationships with hydrological extremes such as floods and droughts. Droughts are estimated to have led to a loss of US\$101 million in GDP US\$36 million in export earnings, and 3,000 jobs in Zambia as a result of restricting hydropower generation from Lake Kariba in the 1990s, while in Mozambique, floods in 2000 cost the economy US\$550 million, or 12 per cent of GDP (Manase 2009 and references there in).

African tropical forests including those in Uganda, may respond more sensitively than savannahs to changes in precipitation, because not only do they depend more heavily on the amount of precipitation, but also on the time of year that the precipitation occurs (Hély *et al.* 2006). Consequently, agricultural activities follow rainfall patterns especially in the tropical regions. For example in Sub-Saharan Africa rain-fed agriculture, which provides food for the populace and represent a major share of the countries' economy follow rainfall pattern closely (UNEP 2008).

Mixed rain-fed systems in the highland perennial systems of the Great Lakes region and in other parts of East Africa are particularly susceptible to climate change. Changes in the primary production of large lakes will have important impacts on local food supplies. Lake Tanganyika currently provides 25-40 per cent of animal protein intake for the surrounding populations, and it is estimated that climate change is likely to reduce primary production and possible fish yields by roughly 30 per cent (Bates *et al.* 2008).

Water resource use for domestic, commercial, industrial and agricultural purposes can trigger numerous conflicts among nations. Competition between water use sectors in the absence of systems regulating such competition can result in a water crisis that may cause water conflict (WBGU 2008). Climate change is anticipated to increase conflicts as a result of struggles for water use if increasing supply to meet growing demand for water resources cannot be assured. The situation is worsened by pressures on natural and human systems, such as population growth (Ozor 2009) associated with property rights.

In Africa and especially semi-arid Africa, pastoralism is the main economic activity. In these areas pastoral communities are transnational migrants who search for water and new grazing lands (Bates *et al.* 2008). With reduced runoff and drying up of rivers, communities will be

forced to trek long distances from their own surrounding to look for water. In drought situations, such pastoralists may come into conflict with settled agrarian systems, and also create pressures and tensions at the new water sources with resultant conflicts (in addition to other effects on livelihoods such as loss in person-hours). One such example is in Nigeria between the Fulani cattle keepers and the settled farming communities. Competition over grazing land and access to water bodies (Ozor 2009) often results in conflict that led to the deaths of several farmers and pastoralists in the region.

The effects of climate change are certain to displace some populations, with a significant increase in the number of environmental migrants over the coming decades. For example, between 1970 and 2004 about 14 per cent and 22 per cent of the populations in East and West Africa, respectively, were affected by the multiple effects of drought, extreme temperature, floods, slides, wave/surges, and wind storm (Raleigh and Urdal 2007). People living in low-lying islands and delta regions face the threat of being submerged by water, thus, the only coping strategy will be to move out of the risk sites to more habitable areas (Ozor 2009). This movement will greatly affect people in many ways, including loss of livelihoods, loss of social systems and values, loss of property and age-long acquired wealth, injuries and sometimes death. At the transit and destination points, migration generates the potential for conflicts of different dimensions, hunger and starvation, and health problems including epidemics (Ozor 2009). This situation is worsened where there are no effective and efficient emergency management services to take care of the displaced people.

Climate change induces health problems as a result of hunger and starvation, water stress, pests and diseases, resource conflicts, injuries and stress from extreme weather events (Ozor 2009). Literature shows that the greatest health burden arising in the regions where vulnerability and population growth are greatest are in sub-Saharan Africa and south Asia (WBGU 2008). Water-related aspects of health include increased cases of cataracts (eye disease) in the arid and semi-arid regions of Africa due to low cloud cover and greater intensity of solar radiation; increased cases of malaria and typhoid due to increased rainfall and temperature; and increased cases of water-borne diseases such as cholera and dysentery due to urban flooding and improper disposal of wastes (Anyadike 2009). Warmer and more humid conditions could enhance the growth of bacteria and mould on many types of stored foods, and this would increase food spoilage and create some specific toxicological health hazards (Ozor 2009). Due to the very large number of people that may be affected, malnutrition and water scarcity may be the most important health consequences of climate change (Bates *et al.* 2008).

Poor health increases vulnerability and reduces the capacity of individuals and groups to adapt to climate change. The World Health Organization (WHO) and UNICEF Joint Monitoring Programme currently estimates that 1.1 billion people (17 per cent of the global population) lack access to water (defined as the availability of at least 20 litres of water per person per day from an improved water source within a distance of 1 kilometre). An improved water source is one that provides 'safe' water, such as a household connection or a borehole. In sub-Saharan Africa, 42 per cent of the population is without access to improved water (Bates *et al.* 2008)

2.2 Livelihoods

This section reviews the literature on livelihoods derived from different social scientist and developmental economic scholars. The concept of “livelihood” is discussed from different viewpoints that help in contextualising the investigation into climate studies. Livelihoods as a composition of assets, the typology of livelihoods and livelihood strategies are presented below.

A livelihood according to Scoones, 1998 ‘comprises the capabilities, assets (including both material and social resources) and activities required for a means of living in (Osborne *et al.* 2008). While Ellis 2000 defines a livelihood as that which comprises: “... the assets, the activities, and the access to these assets that together determine the living gained by an individual or household” (Sunderlin *et al.* 2005). In her work Whitehead (2002) adopts a simple livelihood definition from Bebbington, 1999, as the “diverse ways in which people make a living and build their worlds”. Merrey *et al* (2005) visualizes livelihoods as an approach through which scientific problems of a target group are addressed in an effort to answer the question, as to ‘how people live and make ends meet’. Much of the livelihoods studies have been a result of the adoption of anti-poverty strategies to uplift people’s development. Thus, they centred on rural diversity, on-farm and off-farm livelihoods, poverty and so forth. Researchers wanted to get a perspective on how farm households engage in a portfolio of activities to meet multiple objectives that secure not only immediate well being, but also their capacity to maintain this well-being over time (Whitehead 2002). This study adopts the simple definition from Bebbington 1999 as, “*the diverse ways through which people acquire a means of living and construct their world.*”

Livelihoods research has helped to explain the differences in responses using understandings of endowments, entitlements and capabilities (Osborne *et al.* 2008). As Whitehead 2002 observes, agencies especially those operating in Africa, where livelihood failure has been an issue of concern have devised models that take on board the non-market character of much economic activity and examine how households and individuals interact with the natural environment.

Natural resources management studies are moving the centre of attention from agrarian livelihoods and farming systems, to livelihoods that encompass the whole resource endowment (Birch-Thomsen *et al.* 2001). For example, according to Moser 1998 people’s livelihoods move from being based directly on natural resources to livelihoods based on a range of assets, income sources and outcomes and labour markets, both in rural and urban localities (Whitehead 2002).

Birch-Thomsen *et al* (2001) outlines the importance of putting livelihoods into perspective recently. Study domains in which livelihoods approach has been integrated, include studies of coping in arid and semi arid environments (Reitsma *et al.* 1992; Davies 1996), studies of poverty and environmental change degradation (Reardon and Vosti 1995; Murton 1997; Scoones 1998; Bebbington 1999), studies of changing gender roles (Joekes *et al.* 1994; Francis 1998). In 1998 the British Department for International Development (DFID)

redefined its approach to rural development to include “sustainable rural livelihoods” (Carney 1998; Bryceson 1999). The United Nations Development Programme (UNDP), towards the end of the 1990’s made “sustainable livelihoods” a focus area for poverty reduction (UNDP, 1999). Since then a lot of livelihood research has been done in the last decade that has involved institutions like the Institute of Development Studies (IDS) at the University of Sussex in Collaboration with (DFID), the Overseas Development Institute (ODI) in London, and the University of Leiden in Netherlands (Murray 2002).

2.2.1 Investigations into livelihoods

There are two key questions in livelihood research raised by Murray (2002), ‘How should we do it’? And ‘What is it for’? Murray goes on to suggest the following for both questions. On the first question, he groups the methods into two, the circumspective and the retrospective approach. On the second question he suggests a prospective approach. Out of the three alternatives the prospective approach, is the most important identified by development practitioners (Murray 2002).

Livelihoods have also been investigated using the ‘assets/processes/activities framework (Ellis 1999) also known as the Sustainable Livelihoods (SL) framework. The framework is widely used by the UK Department for International Development (DFID) and presented in (Carney 1998). The DFID SL framework emphasizes a focus on people, their assets and their activities, thus contributing to the design and implementation of country level development strategies (Farrington 2001). Assets in this framework include; human capital, physical capital, social capital, financial capital and natural capital. In pursuing livelihood strategies composed of a range of activities, both the access to assets and the use to which they can be put are mediated by social factors, exogenous trends and shocks (Ellis 1999). The DFID framework illustrated in DFID Sustainable Livelihoods Guidance Sheets (www.livelihoods.org), explains the five fundamental components namely: livelihood context, access, assets, livelihood strategies, and livelihood outcomes.

It is better to understand the nature of resources or assets that people need to access, in the process of composing a livelihood. These assets, households own or are able to gain access to, so that they are able to achieve the best possible livelihood for themselves are; human, natural, social, financial and physical (Bebbington *et al.* 1997; Bebbington 1997; Scoones 1998; Carney 1998) and political (Baumann & Sinha 2001) in nature as represented in the diagram below (Fig.2.1).

This asset hexagon provides a useful starting point for household livelihood analysis. It encourages investigations to take care of the different kinds of assets and resources that are likely to play a role in livelihoods. In the past, development workers focused on the role played by the physical, financial and human capital, natural and social capital was not properly taken into account (Messer and Townsley 2003).

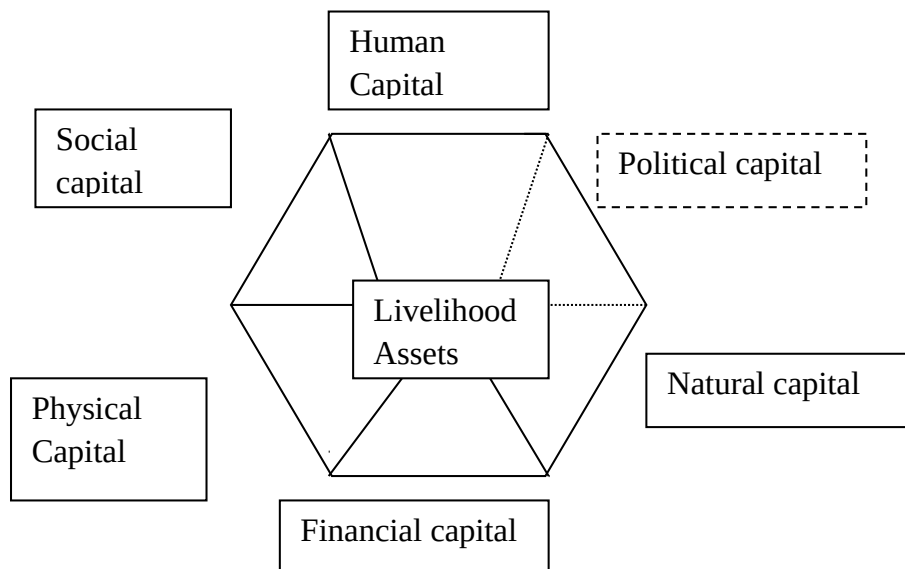


Figure 2.2. Shows the components of assets used in livelihood formation.

The DFID/ODI SL framework, however addresses the social and natural capital assets, to form a pentagon that is used by investigators in livelihood analysis. Baumann & Sinha (2001) examine how far the SL analysis helps in understanding the complex power relations influencing the rightful access to assets and entitlements (see also Farrington, 2001) since power relations have political dimensions. That is why (Baumann & Sinha 2001) suggest the inclusion of the political capital as the sixth asset thus making it a hexagon (Fig.2.1). Concepts in the hexagon have been explained (Messer & Townsley 2003; Carney 1998) as;

Social capital is the way in which people work together, both within the household and in the community. It is abroad term seen by Woolcock, 1998 to encompass the norms and networks facilitating collective action for mutual benefit (Bebbington 1999). While Putman 1993 measured social capital primarily by counting civic organizations. This includes the ability to call on friends or kin of help in times of need, support from trade or professional associations. Social obligations, reciprocal exchange, trust and mutual support are examples of social capital.

Physical capital is formed by economic production. It includes tools and equipment as well as infrastructure such as roads, ports of landing, electricity, irrigation works, housing, market facilities, water supply, health facilities that influence people's ability to earn an adequate livelihood.

Human capital is constituted by the quantity and quality of labour available. At household level, therefore is determined by household size, people's health and ability to work, and the knowledge and skills they have acquired over generations of experience and observation. Human capital contributes to the quality of life in a range of ways which Sen 1997 in (Bebbinton 1999) calls "human capability". The ability to read and write, for instance, enhances people's ability to engage in discussion; to debate; to negotiate; to add their voice to the multitude of voices influencing household, local and national discourse on development

etc. He goes on to argue that these capabilities enhance people's ability to be agents of change. They enhance people's ability to question, challenge, propose and ultimately usher in new ways of doing things (Bebbington 1999).

Natural capital may include assets such as land, water, forest resources and livestock, which are important for the production of food and income. The productivity of these resources may be degraded or improved by human management.

Financial capital on the other hand may come from the conversion of produce into cash, offer of services like labour, income levels, variability over time, distribution within society of financial savings, access to credit, debt levels and cash remittances. It also consists of stock of money or other savings in liquid form. In this sense it does not include financial assets only but also the easily disposable assets.

Political capital (Baumann & Sinha 2001) refers broadly to the ability to use power in support of political or economic positions to enhance livelihoods. Both the legitimate distribution of rights and power as well as the illicit operation of power, which generally frustrates efforts by the poor to access and defend entitlements and use them to build up capital assets, are scrutinized. In its current form according to Baumann & Sinha (2001), the SL analytical framework does not facilitate detailed and rigorous analysis of political dimensions.

These assets are the inputs that make livelihood strategies possible and make livelihoods meaningful and viable hence giving people power (Bebbington 1999).

2.2.2 Typology of livelihoods

Much of the influential writing using the terminology of livelihoods came from the school of (Chambers 1989; Chambers and Conway 1992; Scoones 1998) the notion seems to capture both the objective dimensions of "having to make a living to get by" as well as the subjective dimensions of the conditions in which one lives. Income, expenditure and the experienced quality of life are all somehow implicit in the notion of livelihood (Bebbington 1999).

People for centuries have maintained and sustained their lives by engaging in the following sectors: monetary agriculture, Non-monetary agriculture, mining and quarrying, manufacturing, electricity and water, construction, trade, hotels and restaurants, transport and communication, community services, real estate, government services, technical services, fishing, forestry and migration. Livelihoods can also be multiple and diverse as shown in the study in the Andes by (Bebbington 1999). In Africa for example livelihoods are resulting from a range of activities that include but not limited to; sale of alcohol and cooked food, carpentry, brick making, construction, fish trading, farm labouring, production and sale of crops and livestock, lodging houses, restaurants and bars, crop trading, bicycle repair, iron smith, crafts work, baking, pottery, retail trade (household goods, petro, cement, chicken wire, cloth and other consumer goods), shoe and saddle repairing, knitting and tailoring, traditional healing and medicine etc. Even here one could detect common themes that revolved around issues of access to different resources, different opportunities, means of enhancement and kin and ethnic networks (Bebbington 1999).

2.2.3 Livelihood strategies

Oliver de Sardan 1995 in (Sombalo 2003) defines strategy as a combination of processes (plans, decisions and acts) that an individual or a group of individuals (a firm, a family) develop purposively and which aim at changing, transforming their social, economic and or knowledge and know-how (Sombalo 2003). Yung 1998 states that individuals develop strategies as responses to a changing and uncertain environment, in order for them to duplicate, transform a given lifestyle that corresponds to an objective, as a group or as individuals (Sombalo 2003). Households especially have ensured survival through a portfolio of activities that make them adapt to a wide range of misfortunes and external shock. For example households, may derive a part-livelihood from farming; a part-livelihood from migrant labour undertaken by absent household members and a part-livelihood from a variety of other activities, more or less informal, such as petty trade or beer brewing (Murray 2001). Such multiple livelihoods make risk spreading easier, like when people are spread across space, household members are dispersed, but usually a core adult or group in the rural base is maintained (Francis 2002).

Scoones identifies three broad clusters of strategies to which, especially rural people belong: firstly, those of agricultural either intensification or of extensification; secondly, diversification of income sources; and thirdly, migration which can be local, national or international (Whitehead 2002).

Francis (2002) observes that current thinking about livelihoods rests on an implicit assumption that people follow livelihood strategies using the assets at their disposal in ways that are shaped by the institutional context. She concurs with (Rakodi 1991; Beall & Kanji 1999) when they question the appropriateness of conceptualizing what people are doing in terms of 'strategizing', rather than reacting to systems of power, or situations of crisis. She raises the argument that some people have more resources, and more room for manoeuvre. Others face severe restrictions, and the goals for constructing livelihoods vary. Her research concludes like that of Ellis (2000) that diversification is bi-modal, with very poor households diversifying to survive and the most prosperous households diversifying to accumulate resources.

It is on the basis of this theoretical review that this study has been composed. The review helps in contextualising the study, since it forms part of a larger region. Some of the issues in the review raise interesting aspects that have been investigated. The review reveals that climate exerts a significant control on the day-to-day economic development of African countries, particularly for farming, pastoralism, and water resources at regional, local and household level. There are also indications and projections that temperatures and rainfall will experience changes. It is through this study that we attempt to find out what this means for livelihoods formations. The entire research field is still not fully empirically investigated.

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CHAPTER 3

Methodology

3.1 Research plan and study design

A method is a procedure, or a means to solve problems and to reach new knowledge. Any means that solves this purpose belongs to the arsenal of method.” This chapter describes the various approaches used in selecting study sites, the sampling procedure, collection of data, and how it was analysed. Therefore in order to come up with findings the following design and methods were used. The research design is cross-sectional in nature in that, it was conducted only once and will reveal only a snapshot of point in time (Zikmund 2003).

3.2 Selection of study site.

Prior to the field study, the study site in Uganda was identified and delineated with the use topographic maps (1: 50,000), satellite images, Geographical Information System shape files, and thematic maps (geology, vegetation, population, soil). This gave an understanding of the location and diversity of water resources in Uganda.

Uganda is situated in the eastern part of Africa. It covers an area of nearly 241548 km² having 0.8% of total geographical area of the continent. The exact geographical location lies between 1° 30' South to 4° North latitude and 29° 30' East to 34° East longitude and it is landlocked (Fig.3.1). The country shares a total length of 2698km² of international borders with its neighbours (Uganda National Water Development Report-UNWDR 2005).

Its climate is much influenced by latitude, orographic aspects and the proximity to water bodies. The country has a modified climate characterised by high temperature, high humidity, and high rainfall. According to Köppen's climate classification, Uganda experiences a tropical moist climate, where all months have an average temperature of greater than 18°C and an annual precipitation of greater than 1500mm (Griffiths 1972). The annual variation of mean monthly air temperature is very small, usually 1° to 2° C in the southwest of Uganda and the south-western part of Lake Victoria.

The economic activities on to which the country depends include among others, agriculture, tourism, Industry and services. These are key sectors of the economy, which are controlled by climate. Their percentage share to GDP in 2011 according to UBOS was 24.1% for agriculture, 26.9% for industry and 49.0% for services (MOFPED 2011). Agriculture continues to determine Uganda's success in terms of economic growth and poverty reduction. The sector's share of GDP remains high and it absorbs the largest share of the labour force of more than 73% of the population (NEMA 2008). Uganda has been divided into eight drainage sub-basins, which drain into the Nile. The eight sub-basins, here ranked by area

from the largest to the smallest include: Lake Victoria, Lake Kyoga, Victoria Nile, River Aswa, Albert Nile, Lake Edward, Lake Albert, and Kidepo valley (UNWDR 2005).

At a regional level, Lake Albert and Lake Victoria water management area, which are located to the north and west of the Lake Victoria basin in Uganda (Fig.3.1) was also selected as a study site. The area is traversed by the equator, has a number of water bodies, and varying topography. A dense network of rivers that draw water from the different water catchments into the main water bodies also characterizes it. For this particular study, hydro climatic characteristics of two water management zones were investigated.

Selected scenes were observed and direct scrutiny within these scenes was done in order to get a deeper insight of the interplay between different agents dealing with resources in the study area. Care and thoroughness provided systematic guidelines for probing beneath the surface and digging into the scene. This made the research focused, structured and organized.

For example Namulonge in Busukuma sub-county is one of the sample study site that was selected for investigation (See Fig. 3.1 & 8.1). This is, an area located a few kilometres away from the equator in Uganda, on latitude 0°5' North and longitude 32°61' East. Namulonge is well known for intensive smallholder agricultural practices and is also a research site of the National Crop Resources Research Institute (NaCRI), which strives to develop varieties and farming technology for the people of Uganda. It is rural in nature and most of the residents are either current or past employees of research institute. NaCRI therefore significantly influences agricultural practices in and around Namulonge. Maximum and minimum temperatures as well as rainfall have been recorded at the NaCRI since the late 1940s. These climatic records have been used to analyse the climatic trends of the area at a micro level.

The study also relied on selected scenes from the sub-counties of Katabi, Maddu and Busukuma, found in Gomba and Wakiso districts (See Fig. 3.1 & 8.1). The study villages in each sub-county were chosen based on availability of natural resources, the dominant livelihood and the connection to climate. These sub-counties were selected because they represent a variety of livelihoods patterns in Uganda in a broad sense. Variations in rainfall, proximity to or remoteness from public infrastructure and services and variations in access to non-farm activities were among the other factors that were put into considerations when selecting these areas for field purposes.

Another selected scene for the study is Lake Kyoga, which is part of the upper Nile river basin system found in Uganda. There are 10 districts¹, namely; Apac, Kaberamaido, Kamuli, Katakwi, Kayunga, Kumi, Lira, Nakasongola, Pallisa, and Soroti (Fig.3.1) that contribute water and also benefit from the Kyoga sub-basin. The shallow lake situated in the centre of country was formed by tectonic disturbances, which took place in the lacustrine region million years ago. Population in the Kyoga Water Management Zone (Kwmz) is estimated at about 9.5 million, with agriculture and trade as the major occupations (COWI 2010).

¹ Districts are first level administrative regions in Uganda.

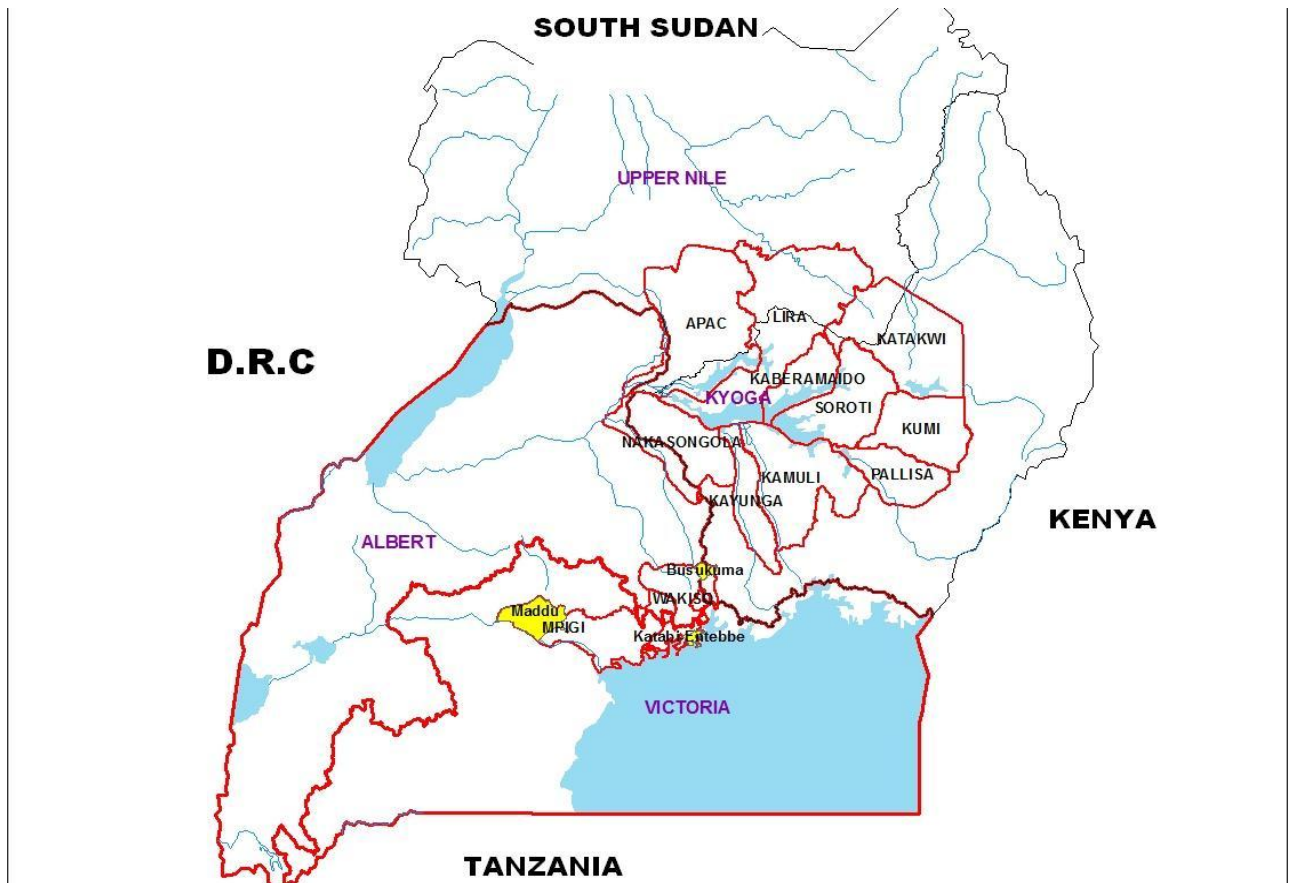


Figure: 3.1 showing the study areas demarcated in red (water management zones, Albert and Victoria the ten districts found around Lake Kyoga) and sub-counties (Maddu, Katabi, Busukuma) represented by yellow.

3.3 Sampling procedure

In this study, a multistage sampling type involving a combination of different approaches of sampling was utilized.

The first stage involved in-depth interviews with an adult member of a household in the 3 sub-counties. The members were sampled using a convenience sample approach, because it is less costly in time and expense. The aim was to develop an understanding and an interpretative framework of the process of household members' interaction with climate and livelihoods.

The second stage involved the use of a convenience sample and judgement approach (Marshall 1996) on individuals in positions of leadership and responsibility of managing natural resources especially the water resources sector. This approach of ensuring that

participants come from a particular background produced a small total sample as shown in table 3.1. The advantage of this approach according to Marshall (1996) lies in its simplicity, but disadvantaged by the fact that it is difficult to determine at the sampling stage whether the informants fulfil the selection criteria.

Table 3.1 Shows the sampling frame used in collecting primary information.

Re/source of information	Contact person	Number of respondents
District local officials	Natural resources officer	3
Sub-county local officials	Natural resources officer and local leaders	9
Key sector principal officers	Principal officers for the water sector.	4
Business sector representatives, like (Diary, fisheries, flower farms, beach manager and boat making).	Managers	5
Households	Household heads	80

Sites were also selected from the four water management zones (Upper Nile, Victoria, Kyoga and Albert) of Uganda. The Department of Water Resource Management (DWRM) delineated these water management zones for monitoring and management purposes. Using a combination of maps, e.g. of the management zones from DWRM, Local government administrative maps from the Ministry of Local Government (MOLG) and census maps with their respective shape files from the Uganda Bureau of Statistics (UBOS), the study areas were then demarcated.

The research team had anticipated finding a number of civil societies and organizations in the study area, which lay claim on addressing issues of climate change or managing water resource. Unfortunately, these organizations could not be traced, and the few organizations, which we found were hesitant to participate in the exercise. And it turned out that some organisations were not effective on ground due to lack of funding. Information was also gathered from targeted members of the business community, whose main economic activity depends on the availability of water and weather (e.g. resorts and hotels). Since the household was our basic unit of study, much of the information was collected from the household survey through interviews randomly.

3.4 Data collection

Time and resource constraints could not permit the research to be carried out on every individual. Therefore different methods and tools were used to gather information. The study basically utilized methods namely; record/document review, survey and interviews to gather both primary and secondary information in two stages, such as;

Climate data

Climate data are the records of observed climate conditions taken at specific sites and times with particular instruments under a set of standard procedures (Lucio *et al.* 2007). Climatic Data was acquired from Government of Uganda's Department of Meteorology (DOM) for further processing. At the department data is collected and archived using climate-computing (CLICOM) format. The CLICOM package is designed for data stored on a long-term basis. It uses a database that organizes and stores input data consisting of numerical input values for climatic study, and descriptive information like the station location, period for which data are available for the station, the climate elements measured, types of instruments used, times of observation, etc. This is a rigorous process to ensure that stored data is of quality. Details on how it works can be found in (King'uyu *et al.* 2000). This data composed of temperature and rainfall observed records for a period of not less than 30 years and in some instances the data set was 70 years long. Daily records were used to generate monthly, seasonal and annual time series for each station. The data set however, had some limitations, which required redress as shown in the results section (4.2.2, 5.2.4.1, 5.2.4.2, 6.2.2.1).

A descriptive or Desktop phase research which was followed involved collection, reviewing and analysis of existing written material like documents, policy papers, academic papers, research reports, evaluation and assessments of programme reports. This phase was necessary to verify perceptions and observations in the exploration phase of the research and to obtain facts and information on climate, water resources management and livelihoods that are empirical domains of the research problem. Holt-jensen 1980 emphasized that, the main aim of integrating the empirical with the deductive research process, is to judge whether there is empirical support via the case studies for the general theories obtained from the literature (Schaller 2001). This implies structuring reality to support or not support the generalizations from the theory. Having intimate familiarity with the research topic and the literature, gave a vantage point while looking at certain aspects of the empirical world. The research began from these vantage points but remained as open as possible to whatever was seen and sensed in the early stages of the research.

Interviewing is one of the most significant sources of information for a case study, which can be organized in form of open-ended, structured questionnaires or focused group discussions (Kakumba 2008). Interviews in this study were face to face because of the advantages (see Babbie 2004; Coldwell & Herbst 2004) that are attributed to them. The questionnaire was used as a structured personal interview on the respondents, simply because, a significant proportion of people were not comfortable with the writing. And many of the interviewees were interrogated while continuing with their daily activities. This technique also ensured a low dropout rate (Babbie 2004).

The interview technique was used to get information from households' members and key informants who included Natural resources officers at (District and sub-county), principal water officers at the ministry of water and environment, and the business managers. It is assumed that these key informants hold positions and have experience or have particular broad or in-depth knowledge about the resource and its management. Through this method a deeper insight of the interplay between different agents dealing with resources in the study area were dug into.

A standardized questionnaire (see appendix) was designed and used to gather data from each of the key informants. The questionnaire is composed of a few open-end and close-end questions. It was used to elicit continuous data and in some situations categorical data was recorded. During the process, data was compared with emerging categories to demonstrate relations between concepts and categories right from the beginning of research not after all the data are collected. In this way the positivist notion of passive observers who merely absorb their surrounding scenes as suggested by (Charmaz 2006) was be dispelled.

In the event that the qualitative data did not illuminate the initial research interests, then we followed leads that we defined in the data, or design another way of collecting data to pursue our initial interests.

3.5 Data analysis

The nature of inquiry demanded both qualitative and quantitative data. It then follows that both the qualitative and quantitative data analysis techniques were applied independently or in combination as deemed necessary. In a bid to move from data to information, data was analyzed using appropriate statistical techniques. Sets of data were analysed using Microsoft excel, SPSS, Matlab, Anclim, TrendTool kit and Envi 4.8 version to establish climatic trends and deduce evidence of change and variability. This process of analysis began after data was collected. During the analysis stage (Table 3.2) several interrelated procedures were performed to summarize and rearrange data in two stages.

The first part involved analyzing climate data from data sets that were acquired from meteorological stations and world data sets (re-analysed). Unfortunately, few long-term climate time series are free of irregularities (Costa and Soares 2009). Consequently, it was important to assess the homogeneity of long climate records before they can be reliably used. This is an important step because non-climatic influences can easily affect the readings while compiling observed data, which may hide the true climatic signals and patterns, and potentially bias the conclusions of climate and hydrological studies. A climate time series is considered to be homogeneous when its variations are caused by variations in climate (Aguilar *et al.* 2003). Adjustment techniques for inhomogeneities have been developed to address both gradual trends and discontinuities. These techniques may be based on 'absolute' or 'relative' methods. Absolute tests apply statistical procedures to each station data separately, while relative procedures use records from neighbouring stations presumed to be homogeneous (Costa and Soares 2009). This study relied on the use of absolute methods using four statistical tests e.g,

- (1) Von Neumann ratios (Sahin and Cigizoglu 2010; Lima *et al.* 2010),
- (2) Cumulative deviations (Sahin and Cigizoglu 2010),
- (3) Worsely's likelihood ratio tests (Pandžić and Lisko 2009) and
- (4) Bayesian procedures (Wijngaard *et al.* 2003).

These tests are well defined in Buishand (1982) and the detailed mathematical formulation of the tests is also discussed in Wijngaard *et al* (2003). Data was not adjusted, because of the uncertainties associated with data manipulation.

Table 3.2 Summary of steps and methods used in the study.

Step	Process	Notes
Delineating surface water in Landsat ETM+/TM imagery.	$M = N \cdot D_{2,5} \cdot W \cdot (P_{L_2} - P_{L_5}) / (P_{L_2} + P_{L_5})$ (Xu 2006)	where P_{L_2} and P_{L_5} are the reflectance's of bands 2 and 5.
Rainfall characteristics analysis	Standard Deviation (SD), Coefficient of Variation (CV) and Percentage contribution to annual total rainfall.	Computed for monthly and seasonal time steps.
Monthly climatic data, obtained from UDM, UBOS (1940 – 2009)	$M_s = \frac{(R_s - \overline{R_s})}{\sigma_s}$ $M_{ry} = (1 / N_j) \sum_{s=1}^{N_s} M_{sy}$ $v(t) = \frac{\sum N_j M_{ry}^2}{J - 1}$ $v(area) = \frac{n - \sum N_j M_{ry}^2}{n - J}$	Normalizing rainfall data series where N_j is the number of regional stations operating in the year j It has to be shown that the geographical variations of (M_{sy}) are small, compared to the temporal variations (Kraus 1977; Nicholson 1986; Türkeş 1996)
Quantifying rainfall deficit for various time scales (using SPI).	$SPI = \frac{x - \bar{x}}{s}$ (Agnew, 2000; Livada and Assimakopoulos, 2007)	Where x is the meteorological variable, $\bar{x}$ is its 3-month average value, with s as the standard deviation.

Drought Severity Index (DSI): Awange <i>et al</i> (2008),	$\overline{S}_m = \frac{1}{3} \sum_{m=1}^3 M_t$	Seasonal means are obtained by averaging the monthly totals for three months of a particular season.
	$A_t = \sum_{m=1}^3 M_t$	While for annual totals, the summation of twelve monthly totals was taken for a given year.
	$P_n = \left[\frac{A_p}{N} \right] \times 100$	Applying Eq. In step (5) and (6), the normal precipitation N - a (30-year) mean is obtained. The normal precipitation is then used to compute the <i>percentage of normal</i> P_n (quartile), where A_p is the actual precipitation.
Precipitation Concentration Index (PCI) Shahid and Khairulmaini (2009)	$PCI = 100 \frac{\sum_{i=1}^3 p_i^2}{\left(\sum_{i=1}^3 p_i \right)^2}$	where P_i is the rainfall amount of the i^{th} month, calculated for each of the stations and for each of the year (period) being considered.
Sen's T test. Partal and Kahya (2006)	$x_j = \frac{\sum_i x_{ij}}{n} \text{ and } x_i = \frac{\sum_j x_{ij}}{m}$ $T = \left[\frac{1}{n(n+1)} \sum_{i,j} (R_i - \bar{R}_j)^2 \right]^{1/2} \left[\sum_{i=1}^n i - \frac{n+1}{2} \right] \left(R_i - \frac{n+1}{2} \right)$	a) x_j and x_i are computed for averages of j^{th} month and i^{th} year as The test statistic T follows an $N(0, 1)$ distribution under the null hypothesis of no trend. If $T > z\alpha$, then a significant trend exists in the time series under consideration. Positive values of T indicate an 'upward trend' and negative values the opposite.

Sen's slope estimation Theil 1950 and Sen 1968 Zhang <i>et al.</i> 2000; Yue and Hashino 2003; Partal and Kahya 2006).	$Q_i = \frac{x_j - x_k}{j - k} \quad \text{for } i=1, \dots, N$	where x_j and x_k are data values at times j and k ($j > k$) respectively. The median of the N values of Q_i is Sen's estimator of slope. If N is odd, then Sen's estimator is computed by $Q_{med} = Q_{(N+1)/2}$ and if N is even, then Sen's estimator is computed by $Q_{med} = [Q_{N/2} + Q_{(N+2)/2}] / 2$.
The Mann-Kendall (MK) (CRCCH 2005).	The test statistic S is: $S = \sum_{i=1}^{n-1} \left[\sum_{j=i+1}^n s \cdot g(R_j - R_i) \right]$ If the null hypothesis H_0 is true, then S is approximately normally distributed with: $\mu = 0$ $\sigma = n(n-1)(2n+5)/18$ The Z-statistic is therefore (critical test statistic values for various significance levels can be obtained from normal probability tables): $Z = s / \sigma^{0.5}$	Where $\text{sgn}(x) = 1 \text{ for } x > 0$ $\text{sgn}(x) = 0 \text{ for } x = 0$ $\text{sgn}(x) = -1 \text{ for } x < 0$ A positive value of s indicates that there is an increasing trend and vice versa. The null hypothesis H_0 assuming that there is no trend in the data is either accepted or rejected if the computed Z_s statistics is less than or more than the critical value of the Z-statistics obtained from the normal distribution table (Kampata <i>et al.</i> 2008).
Linear Regression test (CRCCH 2005):	The regression gradient is estimated by $b = \frac{\sum_{i=1}^n (t_i - \bar{t})(T_i - \bar{T})}{\sum_{i=1}^n (t_i - \bar{t})^2}$ And the intercept is estimated as:	It tests whether there is a linear trend by examining the relationship between time (t) and temperature (T). The test statistic S follows a student - t distribution

	$a = \bar{T} - b\bar{t}$ The test statistic S is: $S = b / \sigma$ Where $\sigma = \sqrt{\frac{12 \sum_{i=1}^n (T_i - a - bt_i)^2}{n(n-2)(n^2-1)}}$	with n-2 degrees of freedom under the null hypothesis (critical test values for various significance levels can be obtained from student's t statistic tables).
Variance	$\frac{\sum_{i=1}^n (T_i - \bar{T})^2}{n-1}$	where T_i is the mean temperature for month i , $\bar{T}$ the long-term mean temperature, and n is the number of months per year (equal to 12).

Different variables were used for analysis to detect variability and trends as found in the different chapters in section two. Arnell 1995 and Pan *et al* (1996) suggest that it is a robust approach when one uses more than one climate field that describes the same variable, so that uncertainty associated with qualitative observed climate data is reduced in (New *et al.* 1999).

Statistical methods: Because of the several disadvantages that may be presented while using graphical methods, an objective approach towards determining the behaviour of any time series is to include some statistical tests to examine the significance of any result observed in the series. The most commonly used methods are the analysis of variance techniques, the use of polynomial functions and methods based on rank statistics e.g. the Mannkendall and Sen's T test (Table 3.2).

In the analysis of variance techniques the study period was divided into some standard sub-period of at least 30 years records also known as 'climatic normals'. The averages of these standard periods were then compared using statistical tests recommended by (Ogallo 1981 and references there in).

Checking and adjusting the data for omissions, legibility and consistency edited data from the field investigations was carried out. Open –ended response questions, which generate a large number of responses, were reduced to general categories of answers and assigned numerical scores. During this process **test tabulation** was also done. This involves tallying of a small sample of the total number of replies to a particular question during the coding process in order to construct coding categories. Raw data was transformed into a form that made it easy to understand and interpret (Rea & Parker 2005). Responses or observations were described first and then averages, frequency distributions, percentages; measures of central tendency were derived using SPSS ver.19 software.

However the measures of central tendency by itself are not sufficient without additional information concerning the extent of variability around it, thus the degree of dispersion associated with central tendency in data was measured. The graphical methods were used to display the visual patterns of data of the respective records. More information can be obtained from a combination of such techniques (del Rio *et al.* 2007) e.g. smoothed and unsmoothed rainfall graphs.

Remote sensing and Geographical Information Systems tools were used especially to analyse landsat images of selected study sites and show the distribution of water resources, and the characteristics of climate attributes. This technique was useful in analysing surface water area of Kyoga basin and also in representing spatial data throughout the study.

The design and research techniques summarised in this chapter is reflected in the different sections that follow in the thesis.

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SECTION 2 LONG TERM VARIATIONS AND TRENDS OF RAINFALL AND TEMPERATURE IN UGANDA

This section comprises 4 chapters that present and discuss the long term variations and trends of rainfall and temperature in Uganda. The four chapters use historical data from the Department of Meteorology (DOM) in Kampala. Rainfall and temperature data was collected over a period of seventy years from observatories around the country distributed in the four management zones. They appear as follows;

- The nature of rainfall in the main drainage sub-basins of Uganda.
- Variability of properties of daily and monthly observed near surface temperatures in Uganda: 1960 – 2008.
- Analysis of mid-twentieth century rainfall trends and variability over south western Uganda.
- Climatic trends at Namulonge in Uganda: 1947- 2009

The fourth chapter presents a study of rainfall trends, temporal variations of rainfall derived from 36 rain gauge stations found in the main drainage sub-basins of Uganda. Characteristics and nature of rainfall in Uganda from 1940 to 2009 is described in accordance with the main drainage sub-basins that form part of water resources management. An analysis of variability and trends in daily and monthly near-surface temperatures in Uganda over a period of 49 years is presented in Chapter 5. For this purpose, daily observed maximum and minimum temperature records from eight selected stations in Uganda were exposed to a rigorous statistical process in order to ascertain the past trend of temperatures. In Chapter 6, a methodology is applied in investigating the spatial variability and trends existent in the mid- twentieth century climatic time series for the period 1943 – 1977 for the western part of the country. Data was collected from 58 observatories found in the Albert – Victoria management zone in Uganda to detect rainfall behaviour in the past. The study serves as a baseline study for future climate studies in western Uganda. Chapter 7 shows results from an investigation at a micro level of rainfall and temperatures in one of the parishes in the study area. Daily-observed temperature and rainfall records were aggregated into monthly means over a period of more than 55 years to establish both seasonal trends and shifts in climate. Study is based on a very small (micro) level using a single station with a long time data series.

CHAPTER 4

The nature of rainfall in the main drainage sub-basins of Uganda. *

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4.1 Introduction

Rainfall, which is the main input to the global hydrological cycle, is one of the most important natural resources that have recently shown significant variations both regionally and globally. Such variation can have profound effects on the availability of water resources, especially those, which derive significant, recharge from rainfall (Ngongondo 2006). Thus it is important to monitor closely the rainfall variation on monthly seasonal and annual time scales in order to manage water resources well. For example 80% of the total catchments of Lake Victoria in east Africa rely on direct rainfall while the remaining 20% comes from the river and underground discharges (Awange *et al.* 2008). Rainfall is also very important for the economic development, disaster management and hydrological planning of a country. This natural resource and the associated variables like temperature, runoff and ground water are commonly used to characterize the climatic state of a region (Kothyari and Singh 1996). Careful assessment of the magnitude and extent of these variables are used as indicators of climatic change. Uganda as a region experiences varied rainfall whose effects are especially noticeable in the eastern part, where drought has been reported to be frequent in the last decades and has drastically altered the landscape. Some areas in Uganda receive rains that have resulted in floods every year, which destroy property worth million of Uganda shillings. This kind of weather has evoked considerable speculations that the country's rainfall characteristics are changing. Detecting rainfall changes over recent decades is needed, together with an appreciation of those characteristics of rainfall supply that are most essential for its effective utilization as a resource and those which are most sensitive to change (Hulme 1992). Uganda's economy is still dependant on agriculture, so extreme events like floods, famine, and drought or crop failure become very critical to the country. Climate change and variability exacerbates the socio-economic woes of Uganda especially in the light of pressures of trying to achieve food security and alleviate poverty. Furthermore, Uganda has just come out of civil war but still experiences political volatility, worsening terms of international trade, rapid population growth and HIV. Variability and trends in rainfall is one of the important aspects of climate change studies (Patra *et al.* 2011) and worldwide there is a lot of literature on both spatial and temporal variation of rainfall. For example, Ruiz Sinoga *et al.* (2011) points out studies of temporal variability and trends in precipitation at both global and regional scales in the last 25 years. Very large spatial and seasonal variability, with implications for water management and risk assessment in the north eastern Iberian Peninsula were revealed by (Lopez-Moreno *et al.* 2009). Zhao *et al.* (2011) used the entropy method to detect the spatial variability of precipitation over temporal scales in Xinjiang which, showed that precipitation was increasing especially in mountainous regions. Rai *et al.* (2010) observed falling trends in temporal scales including aridity index over the Yamuna river basin in India. Moderate to high variations in inter and intra annual rainfall have been identified by Shahid and Khairulmaini (2009) in Bangladesh. While Ngongondo (2006) found out that annual rainfall and groundwater in Mulunguzi river catchment area had declined by up to 15% and 50% respectively, since 1954.

Recent studies of rainfall fluctuations in Uganda e.g. (Nsubuga *et al.* 2011) have demonstrated that total rainfall during the March to May season and the number of wet days

at Namulonge were decreasing. Kizza *et al* (2009) found positive trends at most stations located in the northern part of the Lake Victoria basin especially in the short rains than in the long rains. Nicholson (1996) also revealed that interannual variability of rainfall is remarkably coherent throughout most of eastern Africa especially during the October to December season and a dominant time scale of variability of 5 to 6 years. Phillips and McIntyre (2000) investigated Pacific El Niño-Southern Oscillation (ENSO) and interannual rainfall variability in relation to agricultural management in Uganda. They discovered that, Pacific Ocean NINO3 region sea surface temperatures from July to September are significantly correlated with both August- September and November-December rainfall but with opposite signs. In another related study by Nyenje and Batelaan (2009) about the effects of climate change on ground water system of the upper Ssezibwa catchment in Uganda, found evidence of increasing temperature trends and decreasing trends in river discharge especially from 1990. No significant trends were observed in precipitation, though it is predicted to increase by over 30% and 100% especially in short and long rain seasons in the 2020s and 2080s respectively. The point of departure in this study in relation to previous work is: 1) the wider scope of investigation using stations spread across the country in seven sub-basins; 2) two non-parametric techniques are used in conjunction with other indices to establish trends and characterise rainfall in the different drainage sub-basins. The debate about the different results that are sometimes reported (e.g. GOU 2007) triggered the study presented here. The main contribution of the present work is to build on previous studies by utilizing data spanning seven decades and results would support policy with regard to water resource management under changing climate across Ugandan sub-basins. In this regard, the study aimed at analysing the evolution of precipitation values at different time scales (monthly, seasonal, intra-annual and annual) as well as the spatial patterns of rainfall trends in the main drainage sub-basins of Uganda.

4.2 Data and analysis methods

4.2.1 Study area

Uganda is situated in the eastern part of Africa. It covers an area of nearly 241548 km² having 0.8% of total geographical area of the continent. The exact geographical location lies between 1° 30' South to 4° North latitude and 29° 30' East to 34° East longitude and it is landlocked. The country shares a total length of 2698km² of international borders with its neighbours (UNWDR 2005). Its climate is much influenced by latitude, orographic aspects and the proximity to water bodies. The country has a modified climate characterised by high temperature, high humidity, and high rainfall. The annual rainfall varies from 500mm to 2800mm, with an average of 1180mm (NEMA 2008). The spatial pattern of rainfall in Uganda is complex and arises from the interaction of a number of different forcing factors including; large-scale patterns which are dominated by convective rainfall from the seasonal migration of the Inter-tropical Convergence Zone (ITCZ) as it follows the path of the overhead sun, modulated by the complex topography and the presence of lakes. This leads to two main rainfall seasons: the long rains in March, April and May (MAM) and the short rains in September, October and November (SON).

Generally, the seasonal pattern follows this bimodal system near the Equator and tends to a unimodal system away from the Equator (Conway 2005, Asadullah *et al.* 2008). Inter-annual variability of rainfall correlates with sea-surface temperatures (SST) in the Pacific through atmospheric tele-connections the El Niño/Southern Oscillation (ENSO) phenomenon. Highest totals are generally observed in the mountainous regions in the southwest and east and in the vicinity of Lake Victoria. The lowest rainfall totals are found in the north east of the country on the border with Kenya and Sudan where drought is a common occurrence (NARO 2001). The country is pleasantly cool with a long-term mean temperature of 21⁰ C. Annual temperature range from a minimum of 15⁰C in July to a maximum of 30⁰ C in February. The economic activities that the country depends on include among others, agriculture, tourism, Industry and services. These are key sectors of the economy, which are controlled by climate. In particular, the percentage share of some of these sectors to GDP in 2011 according to UBOS was 24.1% for agriculture, 26.9% for industry and 49.0% for services (MOFPED 2011). Agriculture continues to determine Uganda's success in terms of economic growth and poverty reduction because it absorbs the largest share (73%) of the labour force (NEMA 2008). Uganda has been divided into eight drainage sub-basins, which drain into the Nile as shown in Figure.1 below. The eight sub-basins, here ranked by area from the largest to the smallest are; Lake Victoria, Lake Kyoga, Victoria Nile, River Aswa, Albert Nile, Lakes Edward, Lake Albert, and Kidepo valley (UNWDR 2005).

4.2.2 Data pre-processing

Monthly rainfall data (mm) over the study area was obtained from Uganda Department of Meteorology (DOM) and as well as from the Uganda Bureau of Statistics (UBOS). The raw data sets from DOM are archived as monthly values using climate-computing format. A basic data quality check such as abnormal values in the data sets was assumed in the current study as this was confirmed by DOM staff. Stations considered in the present study were selected based on the length of time and record of areal coverage. In total, 36 Ugandan rainfall stations depicted in Fig. 1 were considered. Some station records commence in the 1925s or 1930s and nearly all cover at least the period 1940 to 1999. Overall, stations over selected sub-basins namely, Albert Nile, Lake Albert, River Aswa, Lake Edward, Lake Kyoga, Lake Victoria and Victoria Nile (see basin characteristics in Fig.4.1) were used for the study. Kidepo sub-basin was dropped because much of its water drains into the neighbouring countries up north.

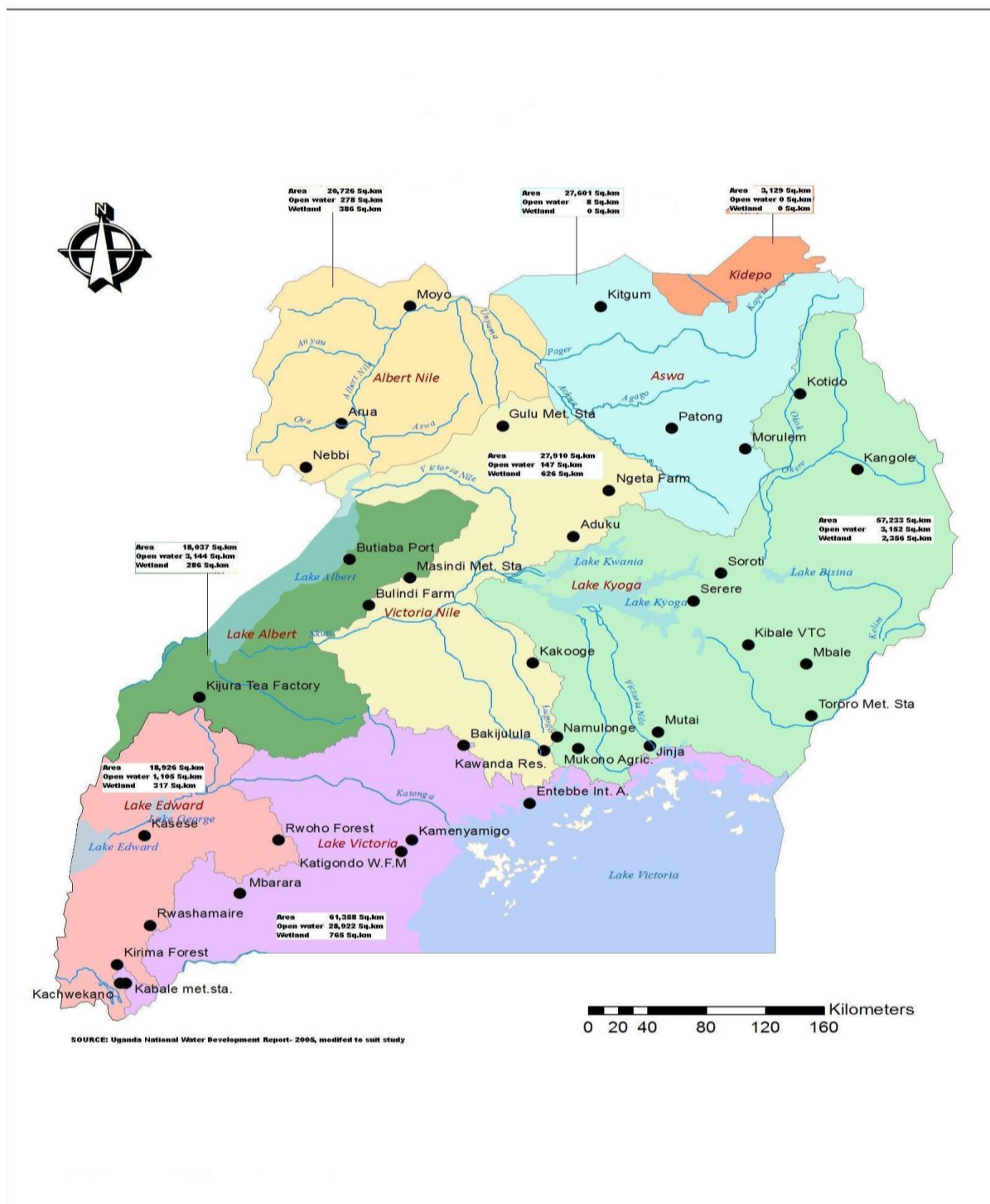


Figure 4.1 shows the distribution of observatories and the size of the main drainage sub-basins of Uganda.

One of the limitations of raw data sets was the presence of missing values. Thus gaps were filled using long-term monthly mean values (i.e., month climatology) of a particular month for that station because in some instances, stations had consecutive missing values (up to a whole year). Using interpolation to fill in the missing data gaps could not be robust. Furthermore, seasonal and annual totals records for each station were derived from the

monthly data records. The series were then normalized to minimize any resultant inhomogeneities in the regional series that may be brought about by varied record length and missing data (Nicholson 1986).

For this study, the original monthly precipitation series were normalized into monthly series (M_{sy}) by subtracting the long term mean $\overline{R_s}$ from the original monthly values R_{sy} and then divide by standard deviation σ_s at each station. This process minimizes the problem of highly diverse means and variability and the randomness of the convective process reflected in the individual station totals (Nicholson 1986). The normalized monthly rainfall anomaly for a given station is;

$$M_{sy} = (R_{sy} - \overline{R_s}) / \sigma_s \quad (1)$$

Rainfall anomaly series were constructed for the seven sub-basins in Uganda (Figure.1) using individual station time series. Annual and monthly totals for individual stations are transformed into regional rainfall departure series in a procedure described by (Nicholson 1986). In the present study, the area-averaged (regional mean climatology or sub-basin climatology) normalized monthly rainfall anomaly (M_{ry}) for a given region/sub-basin was defined as;

$$M_{ry} = (1 / N_j) \sum_{s=1}^{N_s} M_{sy} \quad (2)$$

where N_j is the number of regional stations operating in the year j . The use of regional average, in general, provides a time series that is a better representation of large-scale climatic processes (Partal and Kahya 2006), thus making it easier to deal with one index series in a region. Before one can use the M_{ry} series with confidence for the discussion and analysis of regional month-to-month and year-to-year fluctuations, it has to be demonstrated that it is indeed representative for the region as a whole (Kraus 1977, Nicholson 1986, Türkeş 1996). The validity of regionalization for all series was tested in the present study using correlation coefficients and an analysis of variance (Nicholson 1986). Analysis of variance compares the temporal and spatial variance i.e., investigate if $M_{sy} < M_{ry}$. Kraus (1977) demonstrates that the variance in time can be estimated as;

$$v(time) = \frac{\sum N_j M_{ry}^2}{J - 1} \quad (3)$$

where N is the number of regional stations operative in the year j and J is the number of years of record for the series M_{ry} . The mean spatial variance between rainfall anomalies within the region is estimated as;

$$v(area) = \frac{n - \sum N_j M_{ry}^2}{n - J} \quad (4)$$

where n , the total number of stations years, is calculated as;

$$n = \sum_j N_j = \sum_i J_i \quad (5)$$

The statistical importance of variance estimates (Variance in time/variance in area) was then determined by the F test (Türkeş 1996). Validity of regionalization of all series was also tested using correlation coefficients. Like Nicholson (1986), stations correlating at less than 0.4 with the regional series were dropped (or reassigned) and the regional series recalculated, omitting data for that station. For the 36 stations in the drainage sub-basins of Uganda, correlations are generally between 0.50 and 0.80. Further analyses using regional area – average normalized series was therefore sufficient.

4.2.3 Methodology

Rainfall patterns across the different sub-basins were characterized using statistics such as; mean, standard deviation (SD), coefficient of variation (CV) and percentage contribution to annual were computed for monthly and season-wise viz., December- January- February (DJF), March- April- May (MAM), June- July – August (JJA) and September- October- November (SON). Furthermore, the Precipitation Concentration Index (PCI) proposed by Oliver (1980 in Shahid and Khairulmaini 2009) was used to analyse the annual rainfall distribution. In the present work, PCI is expressed as a percentage in accordance to the following formula (De Luis *et al.* 2000, Ceballos *et al.* 2004):

$$PCI = 100 \cdot \frac{\sum_{i=1}^{12} p_i^2}{\left(\sum_{i=1}^{12} p_i \right)^2} \quad (6)$$

In equation 6, P_i is the rainfall amount of the i^{th} month, calculated for each of the stations and for each of the year (period) being considered. The degree of seasonal concentration of precipitation and the information to compare different climates in terms of seasonality of precipitation regimes are some of the aspects the PCI can be of advantage. The more concentrated is precipitation, the more difficult is water management, irrigation control, soil erosion prevention and rain fed agriculture (Shahid and Khairulmaini 2009). In order to show the spatial distribution of intra- and inter-annual variability or rainfall in Uganda's main drainage sub-basins, PCI and the coefficient of variation of annual rainfall for each of the station is calculated and then interpolated using Kriging method (Shahid and Khairulmaini 2009 and references there in). For mapping of spatial characteristics of rainfall, mean annual rainfall, precipitation concentration index and trends are calculated for each sub-basin. GIS is used for the development of historical rainfall database and calculation of rainfall characteristics at each sub-basin. Raster maps of rainfall characteristics are prepared from regional data using kriging interpolation method.

Using rainfall data computed from equations put forward by Awange *et al.*(2008), seasonal means were obtained by averaging the monthly totals for three months of a particular season, i.e.,

$$\overline{S}_m = \frac{1}{3} \sum_{m=1}^3 M_t \quad (7)$$

While for annual totals, the summation of twelve monthly totals was taken for a given year.

$$A_t = \sum_{m=1}^{12} M_t \quad (8)$$

These were further categorized into the 30-years ‘normal’ in accordance with World Meteorological Organization (WMO) requirement (Awange *et al.* 2008). Using rainfall data computed from equation (7) and (8), the normal precipitation N - typically considered a 30-year mean is obtained. The normal precipitation is then used to compute the *percentage of normal* P_n (quartile) using:

$$P_n = \left[\frac{A_p}{N} \right] \times 100 \quad (9)$$

In equation 9, A_p is the actual precipitation. Using the percentage of normal from equation (9), a Drought Severity Index (DSI) was determined by considering all observations which are less than 25%(first quartile) of the ranked historical records to be dry, while those which are more than 75%(third quartile) are considered wet. Awange *et al* (2008) illustrates severity classification as shown in the scale below:

Wet	> 75%	Near normal	25 – 75%	Drought	< 25%
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Drought seasons and years were identified by observing the years and seasons in which the anomalies were below the drought threshold line (i.e., DSI of 25%).

In order to investigate for the presence of trends in the data sets, Mann-Kendall test was used. This test, which is also known as Kendall’s t statistic, is a non-parametric method that has been widely used to test for randomness against trend in hydrology and climatology. It is a rank based procedure, which is robust to influence of extremes and good for use with skewed variables (Nsubuga *et al.* 2011, Partal and Kahya 2006, CRCCH 2005, Yue *et al.* 2002, De Luis *et al.* 2000). The null hypothesis H_0 of no trend (i.e., the observations are randomly ordered in time) is tested against the alternative hypothesis, H_1 , associated with increasing or decreasing monotonic trends (de Lima *et al.*2010). In this work the null hypothesis is tested at 5% significance level, taken in its two-sided form. This method accounts for missing values, serial correlation and numbers below detection limit that commonly confound trend detection procedures in time series analysis (Hirsch and Slack 1984). The MK statistics has the advantage of making no assumptions about the statistical distribution of variables (Kampata

et al. 2008). Furthermore, the *Sen's T test* was also used for trend analysis. *Sen's T test*, is an aligned rank method having procedures that first remove the block (season) effect from each datum, then sum the data over blocks, and finally produce a statistic from these sums. The aligned rank test is more powerful, its distribution free and not affected by seasonal fluctuations (Partal and Kahya 2006 and references there in). The procedure used in the present analysis was outlined by Partal and Kahya (2006), takes the following steps; x_j and x_i are computed for averages of j^{th} month and i^{th} year as

$$x_j = \frac{\sum_{i=1}^n x_{ij}}{n} \quad \text{and} \quad x_i = \frac{\sum_{j=1}^m x_{ij}}{m} \quad (10)$$

Subtract the monthly average from each of the corresponding months in the n years of data to remove monthly or seasonal effects.

All differences obtained from step 2 are replaced by its ranks, resulting in a similar table with the notation of R instead of X . It is important to note that the integer 1 would be assigned to the smallest difference, whereas the integer nm would correspond to the rank of the highest difference. Hence, R_j refers to the rank of $(x_{ij} - x_j)$, where $i = 1, \dots, n$ and $j = 1, \dots, m$. For each of the t tied values, the average of the next t ranks is assigned.

Calculate the test statistic:

$$T = \left[\frac{12m^2}{n(n+1) \sum_{i,j} (R_{ij} - R_j)^2} \right]^{1/2} \left[\sum_{i=1}^n i - \frac{n+1}{2} \right] \left(R_i - \frac{nm+1}{2} \right) \quad (11)$$

The test statistic T follows an $N(0, 1)$ distribution under the null hypothesis of no trend. If $|T| > z\alpha$, then a significant trend exists in the time series under consideration. Positive values of T indicate an 'upward trend' and negative values the opposite.

The non-parametric method proposed jointly by Theil 1950 and Sen 1968 was used to estimate the magnitude of trends. This approach uses the Sen's slope estimation method by assuming the trend to be linear, such that $f(t) = Q(t) + B$, where Q is the gradient of the linear trend and B is the constant. If a linear trend is present in a time series, then the true slope (change per unit time) can be estimated by using a simple non-parametric procedure developed by Sen 1968 b in (Partal and Kahya 2006). The slope estimates of N pairs of data are first computed by

$$Q_i = \frac{x_j - x_k}{j - k} \quad \text{for } i = 1, \dots, N \quad (12)$$

where x_j and x_k are data values at times j and k ($j > k$) respectively. The median of the N values of Q_i is Sen's estimator of slope. If N is odd, then Sen's estimator is computed by $Q_{med} = Q_{(N+1)/2}$ and if N is even, then Sen's estimator is computed by $Q_{med} = [Q_{N/2} + Q_{(N+2)/2}] / 2$. Finally, Q_{med} is tested by a two sided test at the $100(1-\alpha)\%$ confidence interval and the true slope may be obtained by the non-parametric test. This technique has been used widely to verify the magnitudes of trends, e.g. Zhang *et al* (2000), Yue and Hashino (2003) and Partal and Kahya (2006). Sen's slope is insensitive to outliers or missing data and more rigorous than the usual regression slopes and thus provides us a realistic measure of trends in the data series. The data analyses steps considered in the current study are depicted in figure 2.

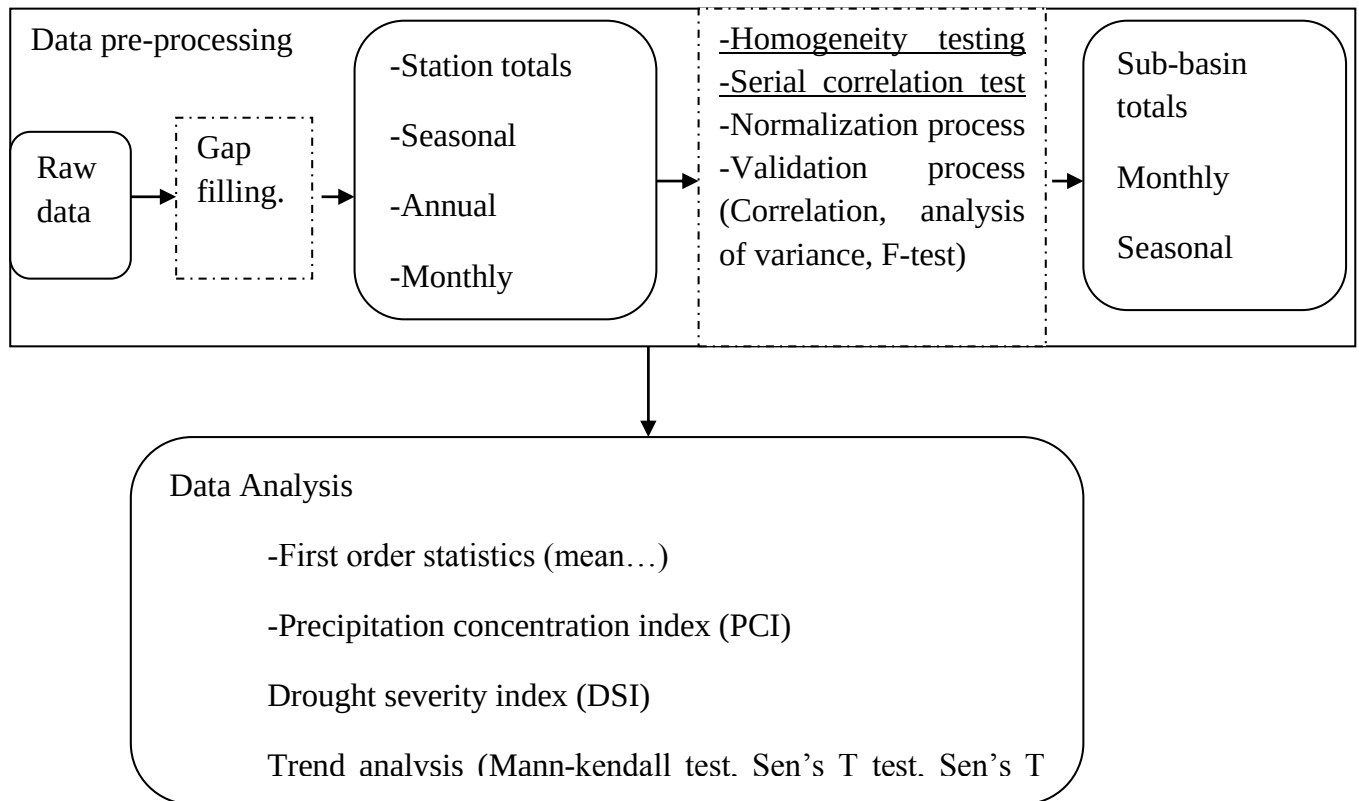


Figure 4.2 Steps in data pre-processing and analysis for the study.

4.3 Results and discussion

For this present analysis a subset of 36 stations is used to derive areally averaged departure series for 7 sub-basins. The locations of these stations in each sub-basin are shown in Fig. 4.1. The highest and lowest values of annual total rainfall, with years of occurrence, for each station in the respective drainage sub-basin are shown in Table 4.1.

Serial correlation effect. Bold figures indicate series, which are serially correlated. Annual series of 18 stations show that data does not come from the same random process. The results reveal a significant serial correlation value in 51% of the 36 stations (Table 4.1). The

locations of the stations with a significant serial correlation were, for the most part, in central Uganda, especially in the Lake Victoria sub-basin.

Rainfall characteristics.

Mean rainfall for the 70 years period was 43842 mm, maximum and minimum rainfall was recorded in 1961 and 1943 respectively, with a coefficient of variation of 7.23%. Cycles are observed in rainfall patterns in Uganda for the period 1940 – 2009. Data shows decades of normal and beyond normal rainfall (Fig. 4.3) during the period of analysis. Three long spans of below normal rain are evident in the 1940s, 1960/70 and 1980s. Other particularly wet periods were experienced in early 1950s, 1960s, late 1970s and the 1990s (Fig.4.3). The contributing factors to the below average annual total rainfall for Uganda have not been established in this study despite the 1980s being drought years which had consequences on food security for the continent (Hulme 1992). The plots show that very high rainfall totals in early 1960s and late 1970s were preceded by relatively low rainfall in Uganda (Fig.4.3).

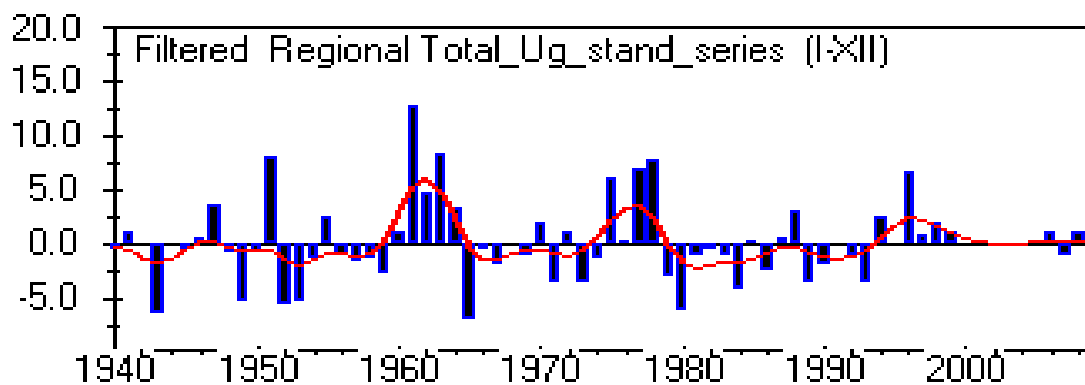


Figure 4.3 Total rainfall (mm) standardised for the period 1940 – 2009 in Uganda.

Average seasonal cycle in precipitation rate from station data for 1940- 2009 over seven sub-basins in Uganda are shown in Figure 4.4. There is a marked contrast in seasonal cycle between sub-basins that lie over and below latitude 2° N (i.e. northern and southern sub-basins). According to Black *et al.* (2003) this contrast is evidence that reflects a strong influence of the southwest monsoon circulation on rainfall in East Africa. The other basins depict low amounts of rain during the southwest monsoon and show a semi-annual distribution of rainfall, which is characteristic of the equatorial zone.

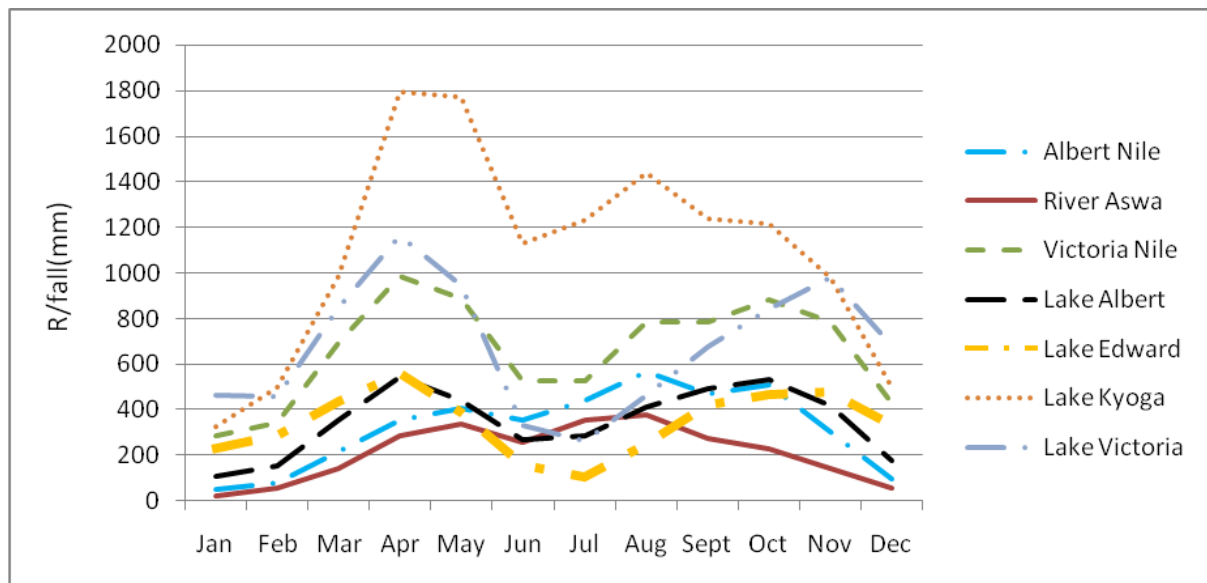


Figure 4.4 Seasonal cycle in Ugandan rainfall between the seven sub-basins.

Mean rainfall. Calculations for station means reveal that Entebbe international Airport recorded the highest mean annual rainfall (1617mm) followed by Gulu meteorological station (1559mm) during the time of analysis. On the other hand, Kangole station shows the lowest mean rainfall (660mm) followed by Kotido(677mm)(Table 4.1). These two stations with low rainfall lie within the Lake Kyoga sub basin in the far north east of Uganda (Figure 4.1). It is also revealed that, 8 stations (Morulem, Kawanda, Kijura, Nebbi, Tororo, Mutai, Kangole, Kibale) had their highest rains recorded in 1961. Six of these stations are within Kyoga sub-basin. Literature has indicated that the 1960s were times of high rains (Nicholson 1996, Kizza *et al.* 2009). Overall 12 stations recorded very high rainfall in the 1960s (Table 4.1). Six stations (Rwashamaire, Mbarara, Kamenyamigo, Rwoho forest station, Moyo and Mbale) also had their highest rains come in 1951(Table 4.1). Four of these stations are located in the Lake Victoria sub basin, and specifically lie within, what is often referred to as 'the dry corridor of Uganda'. This area lies within the rain shadow of the western highlands shielding it from the winds from the Congo basin and also far from the reach of the southeast monsoon winds. These wind types have been identified to be influential in the distribution of rainfall in Uganda (Basarilwa 1995). Their mean annual rainfall ranges between 985mm at Rwoho to 1025mm at Rwashamaire, and their coefficient of variations ranging between 17% and 22%. Mean annual rainfall for most of the stations under analysis exceeds 1200mm. Unlike, Nicholson (1996) the highest mean rainfall during the period of analysis is recorded around the lakes.

Table 4.1 Basic statistical characteristics of annual rainfall data for the 35 stations in the period 1940- 2009.

Drainage Sub-basin	Station	Mean rainfall	Highest total rainfall (mm)	Year of occurrence	Lowest total rainfall (mm)	Year of occurrence	Standard deviation	Serial corr. coeff. (95%)	Von-neumann Ratio (95%)	CV %
Aswa	Morulem	1130	1672	1961	877	1968	15	0.2	1.4	15
	Kitgum Centre	1318	2042	1970	733	1918	21	0.17	1.6	18
	Patong	1233	1920	1978	755	1959	21	0.2	1.4	21
Lake Victoria	Entebbe Int. Airport	1617	2679	1999	1121	2004	24	0.17	1.6	18
	Jinja	1312	1972	1963	871	1953	21	0.3	1.3	20
	Mbarara Met	940	1522	1951	696	1952	13	0	2	17
	Katigondo WFM	1222	2032	1984	753	1967	23	0.3	1.3	22
	Kamenyamigo	1012	1506	1951	569	1992	17	0.2	1.5	21
	Rwoho forest sta	985	1606	1951	540	1981	18	0.3	1.2	22
	Bakijulula	1225	1987	1987	854	1989	18	0.3	1.3	17
Victoria Nile	Aduku Variety	1331	1712	1967	985	1952	13	0.2	1.5	12
	Kakooge Gombol	1013	1695	1947	374	1974	27	0.3	1.2	29
	Kawanda Res	1244	1737	1961	783	1983	20	0.2	1.5	20
	Namulonge Res	1217	1747	1997	674	1989	18	0.3	1.2	17
	Gulu Met	1559	2040	1970	1002	1943	20	0.06	1.8	15
	Ngetta Farm	1447	1930	1963	1157	1973	15	0.09	1.8	13
Lake Edward	Kasese Met	897	1151	1993	676	1991	11	-0.1	2.2	14
	Kabale Met	1021	1477	1945	768	1948	12	0.17	1.6	14
	Kachwekano DFI	1041	1480	1996	707	1960	13	0.24	1.5	15
	Kirima Forest sta	1135	1526	1996	844	1969	13	-0.09	2.1	13
	Rwashamaire	1025	1401	1951	709	1946	15	0.3	1.2	18
Lake Albert	Masindi Met	1329	1733	1972	1014	1983	15	0.19	1.57	13
	Kijura factory	1518	2024	1961	1147	1945	17	0.14	1.6	14
	Bulindi farm	1342	2465	1984	1020	1957	24	0.19	1.6	21

Albert Nile	Arua	1443	1908	1955	1046	1931	15	0.2	1.4	13
	Nebbi UTC	1064	1590	1961	585	1970	20	0.5	0.8	22
	Moyo Boma	1309	1973	1951	875	1970	21	0.17	1.67	18
Lake Kyoga	Tororo Met	1462	1981	1961	879	1949	20	0.29	1.3	17
	Mutai forest	1359	2238	1961	943	1973	18	0.04	1.9	15
	Mukono Agric	1355	2244	1960	772	1972	26	0.5	0.8	23
	Kangole	660	1089	1961	410	1962	14	0.02	2	25
	Serere Agric. Sta	1376	2378	1996	939	1939	19	0	2	16
	Soroti Met sta	1336	2032	1915	851	1957	21	0.1	1.7	19
	Kibale VTC sta	1361	2047	1961	626	1980	21	0.06	1.9	18
	Mbale	1224	1789	1951	807	1927	19	0.16	1.7	19
	Kotido	677	1145	1946	351	1965	16	0.15	1.7	28

Coefficient of variation. Interannual variability according to Hulme (1992) is an important indicator of the reliability of the rainfall resource in Africa. Coefficients of variation for 36 stations have been computed in order to investigate the spatial pattern interannual variability of rainfall totals over Uganda.

The coefficient of variation defined as;

$$CV = \left(\sigma_s / \overline{R_s} \right) 100 (\text{percent})$$

where $\overline{R_s}$ is the long-term mean annual rainfall and σ_s is the standard deviation of annual rainfall totals for station s (Türkeş 1996) is used to represent changes in reliability.

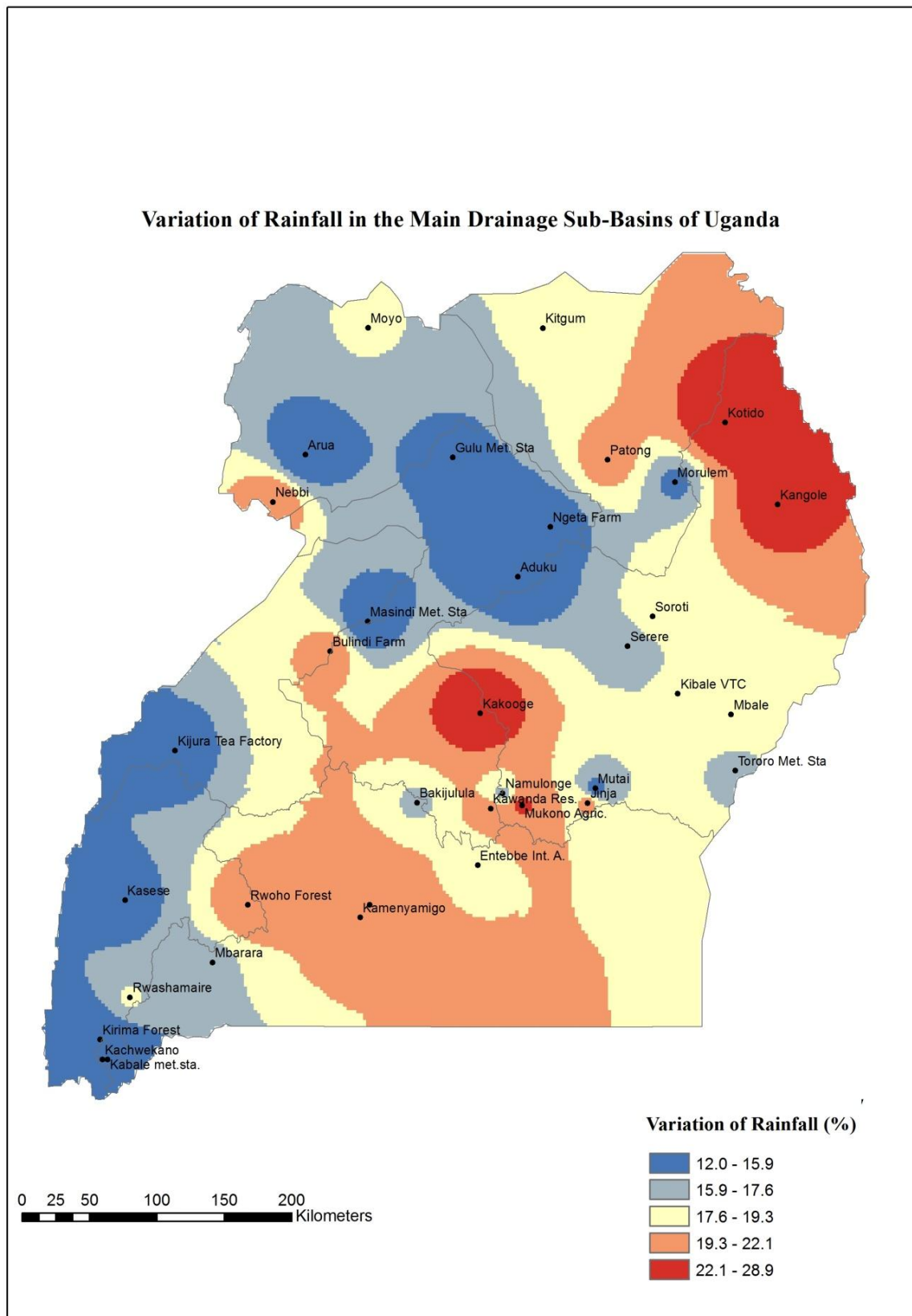


Figure 4.5 Variation of rainfall in the main drainage Sub-basins in Uganda 1940 – 2009. Variability is expressed as percentage of coefficient of variation at rainfall stations.

Figure 4.5 presents this measure of annual rainfall variability change over Uganda. Annual rainfall coefficient of variation for the stations in sub-basins is in the range of 13% to 29%

(Table 4.1). High variations are exhibited at Kakooge, Kotido and Kangole, while Aduku variety, Kirima Forest station, Masindi Meteorological station and Ngetta Farm station showed the lowest variation in rainfall (Figure 4.5). As observed by Türkeş (1996) areas with coefficients over 20% are likely to have more frequent and severe droughts because of the low reliability of the normal rainfall. Low values of coefficients imply high rainfall reliability. Sub-basin analysis indicates that, the coefficients of variation are low (average of 14.8%) in Lake Edward sub-basin compared to other sub-basins, which show a dependable rainfall distribution. Further analysis indicates that rainfall for example at Kakooge has varied more in the last 30 years(1980-2009) than in the first normal (1940- 1969) implying that this station is likely to have more droughts in the future. It is also evident from the map that variability is not coherent, thus the causes of variability are not uniform (the variability is also dependent on e.g., the number of stations used, the interpolation scheme and the topography of the area)

Variations in Sub-basin normalized rainfall series. Before using the sub-basin normalized series for further analysis, the variance analysis was applied to regional data in order to assess whether the series adequately represent the region as a whole. Using the ratios of the variance estimates in time to the variance estimates in the area, it is apparent that all area-averaged rainfall anomalies have coherence in rainfall fluctuations (results not shown). An F- test helps to assess the relative importance of the two components of variance (Nicholson 1986). In most cases according to Nicholson (1986), the limiting value for the 0.01 probability level is about 1.50 or lower. Results from the analysis show that majority of the series had values exceeding 1.50, meaning that there is a 1 % probability that most of the temporal variance in the sub-basin can be accounted for by random fluctuations at a few stations.

Characterizing monthly rainfall. The concentration of the rainfall in a year is an important aspect of climate. Simply because when rainfall distribution is not balanced, it makes water resources planning, plant and crop growth difficult. It is therefore important to investigate rainfall concentration needs using a statistical derived index known as (PCI) that quantifies the relative distribution of the rainfall patterns. Based on Michiels *et al* (1992) approach, two different procedures were used to derive the PCI. In the first procedure, the mean monthly rainfall data set was estimated by averaging the monthly rainfall data over a number of years; afterwards a PCI was calculated (here referred to as Seasonal concentration). In the second procedure, PCI was calculated from rainfall totals of individual years (here referred to as temporal concentration). The PCI permits grouping of data sets according to the derived value. A PCI of less than 10 suggests a uniform distribution, a value from 11-15 denotes a moderate seasonal distribution, a value from 16-20 denotes a seasonal distribution (Michiels *et al.* 1992). An index above 20 represents strong seasonal effects, with increasing values indicating increasing monthly rainfall concentration.

Table 4.2 Showing results from PCI calculations using temporal and seasonal concentration methods.

Sub-basin	1940 – 2009		1940 - 1969		1970 - 1999	
	Seasonal concentration	Temporal concentration	Seasonal concentration	Temporal concentration	Seasonal concentration	Temporal concentration
Albert Nile	10.57	1.44	10.49	3.38	10.70	3.35
Lake Albert	9.71	1.44	9.60	3.37	9.85	3.35
Aswa	10.91	1.46	10.93	3.39	10.92	3.39
Lake Edward	9.62	1.43	9.70	3.35	9.56	3.35
Lake Kyoga	9.76	1.44	9.79	3.37	9.75	3.36
Lake Victoria	9.67	1.44	9.69	3.37	9.73	3.36
Victoria Nile	9.26	1.44	9.25	3.37	9.32	3.35

The application of the first procedure based on the mean monthly rainfall data sets of the seven sub-basins (Table 4.2) results in a PCI, above 10 for Albert Nile and Aswa. This value suggests a uniform to moderate seasonal distribution of rainfall in the northern sub-basins of Uganda. The other 5 sub basins reveal a PCI below 10, suggesting a uniform seasonal rainfall. Temporal analysis for all stations has PCI values, which are below 10, which indicate a uniform concentration of rainfall for the years under analysis. The annual PCIs calculated for individual years are small compared to seasonal concentration index. Because the monthly rainfall of individual years deviates from the long term mean monthly rainfall. Higher values for temporal concentration of rainfall for individual years can also be due to seasonal concentration of the rainfall or to and random deviation from the long term mean monthly rainfall (Michiels *et al.* 1992). Further analysis at 30 year normal (1940-1969) and (1970-1999) also reveals the same pattern, which, further implies that the distribution of rainfall in the sub-basins has not changed with time (Table 4.2).

Since the PCI, like other statistical indices, does not reveal the actual month or season of maximum or minimum rainfall, the examination of sub-basin data set is necessary to identify the period of month (season) with maximum (minimum) rainfall, if there is any.

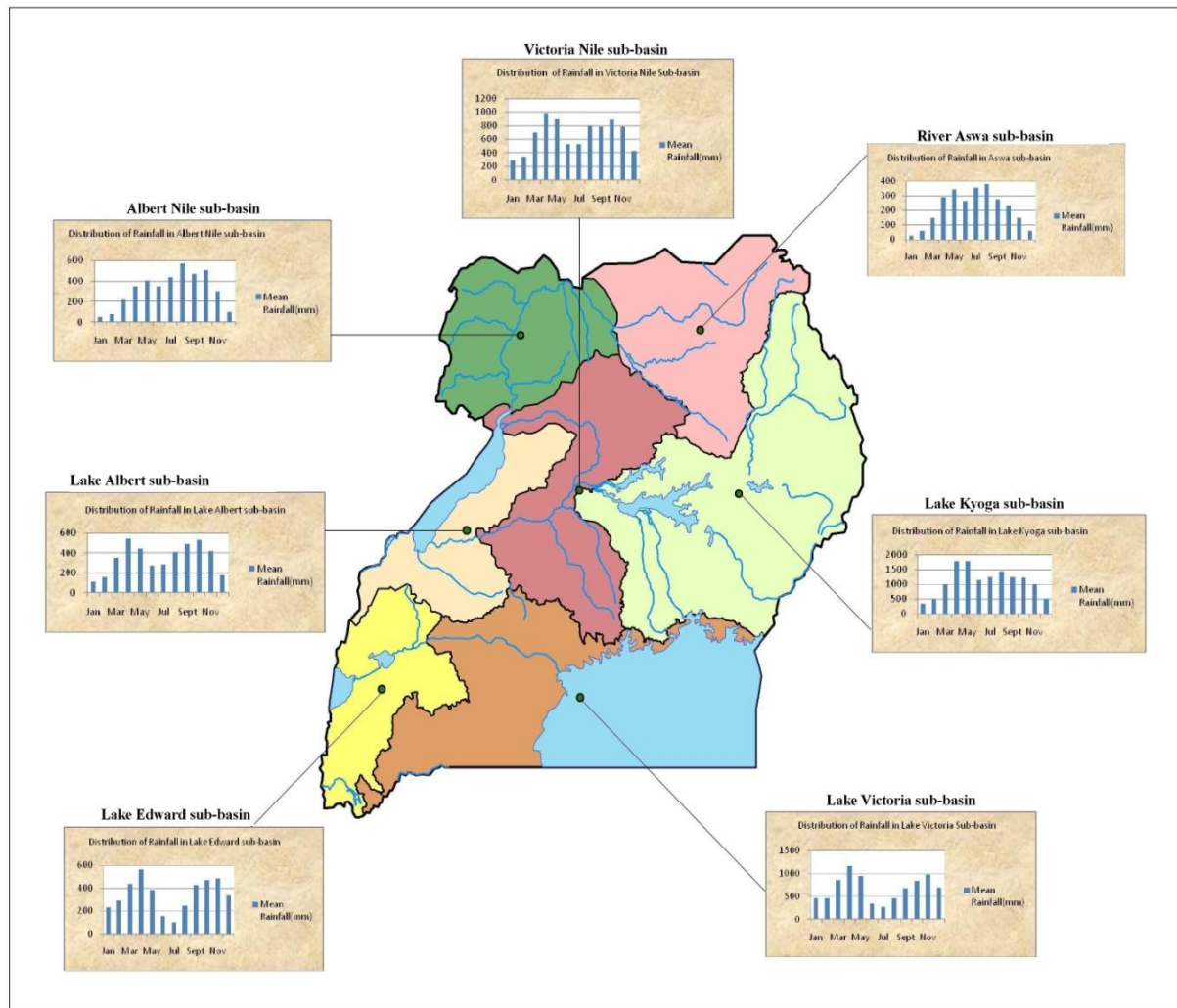


Figure 4.6 Distribution of long term mean monthly rainfall (mm) in the sub-basins of Uganda from 1940 – 2009.

Figure 4.6 demonstrates that there is not a single month without rainfall, which is consistent with the uniform to moderate seasonal distribution derived from the PCI. From the analysis one can conclude from the shape of the mean monthly rainfall plots that rainfall distribution is bi-modal in 4 of the sub-basins; Lake Albert, Lake Edward, Lake Victoria, Victoria Nile located in the west and central part of Uganda and unimodal in the two sub-basins (River Aswa, Albert Nile) which are located in the Northern part of Uganda. Lake Kyoga sub-basin in the central and extending to the east of Uganda, gives a different picture of a well spread distribution of rainfall for a period of 9 months (March to November). The plot indicates two peak periods of rainfall in April/may and August /September. This is evidence of a transition zone between the northern and southern sub-basins. Such a trend could also be attributed to the merging of stations to derive an area-averaged series.

Maximum rainfall in the 4 sub-basins, which experience a bi-modal distribution pattern, is recorded in the MAM and SON seasons. In July and August the 4 sub-basins recorded low

rainfall. Lake Kyoga sub-basin on the other hand, indicates low rainfall during the months of December to February. Peak rainfall for the northern sub-basins (River Aswa and Albert Nile) is in August (Figure 4.6). This kind of rainfall pattern over Uganda is related to the movement of (ITCZ), which brings rainfall approximately 1 month after the sun's path. This, results in a bi-modal rainfall pattern, with the primary rain season occurring in March – May, and a shorter secondary rainy season occurring in October – December (Nicholson 1996, Kizza *et al.* 2009). Phillips and McIntyre (2000) attribute moisture during the OND to the north easterly winds originating in the Indian Ocean. While the northern sub-basins which have peaks in August receive moisture from the Congo/Zaire basin to the southwest.

Visual inspection of plots in figure 4.6 inspired us to examine the contribution of each month to the annual total rainfall in the 7 sub-basins, expressed as a percentage. Five of the sub-basins show that April contributes the highest percentage of rainfall to the annual total received. While, two basins reveal that the biggest percentage of rain is received in August. The analysis also re-affirms that, central and southern sub-basins receive high percentage of rains in the MAM and SON seasons. The Albert Nile and River Aswa sub-basins have a longer wet season (April – October) compared to the rest of the sub-basins. Further explanation underlying the general atmospheric circulation that accounts for the above rainfall patterns can be found in literature by (Ogallo 1993, Basalirwa 1995, Nicholson 1996).

Drought years derived from rainfall anomalies. Drought is a recurring extreme climate event over land characterised by below-normal precipitation over a period of several months to several years or even a few decades (Dai 2011). Drought years from annual and seasonal anomalies of the sub-basins are identified in two climatic normal's i.e. 1940 to 1969 and 1970 to 1999. Literature linked droughts and floods to El Niño/Southern Oscillation (ENSO), Indian Dipole and other large-scale climate system (Ogallo 1988, Nicholson 1996). The study indicates anomalous years that received below and above normal rainfall. The tendency for rainfall to be above average in most of the sub-basins during ENSO years and for drought to occur during the following year (Figure 4.8a-g) is also evident. We also investigated what Nicholson (1996) referred to as seasonal preference for the ENSO related rainfall anomalies. She noted that in east Africa, 'positive anomaly occurs during the short rains of ENSO year and the drought during the long rains of the following year. Our analysis reveals that, the 7 sub-basins experienced drought in the periods 1945/46, 1952-1954 and 1980-1984 (these are depicted in a Table not shown here). Using Nicholson (1996) argument, the years 1942, 1952, 1958, 1964, 1969, 1973, 1979, 1983... should have been drought years. Using the percentage of normal from equation (9), Drought Severity Index (DSI), captures well, the predicted years among others (results not shown). Some of the years revealed by the analysis, were identified as La Niña years by (Phillips and McIntyre 2000).

For the 30 year period (hereafter referred to as climatic normal) and for each season, the occurrences of drought across the respective sub-basins were also investigated. For example, 1943 and 1949 appear as drought years for six sub-basins while 1952/53 appear in five sub-basins. Further still, Albert Nile, Victoria Nile and Lake Victoria had similar drought years in the first climate normal (1940-1969), which is also reflected in the MAM rainfall seasons of Albert Nile and Victoria Nile Sub-basins. The three sub-basins have 62.4% of water

resources when combined. Thus drought occurrence in these sub-basins in future can cause adverse effects on the water distribution within the country.

Mann-Kendall test. Seventeen precipitation variables (i.e. 12 monthly totals, annual and seasonal series) were subjected to the Mann-Kendall test at each sub-basin (Table 3). Significant increasing trends at 0.05 level were revealed in January (14%), October (57%), November (43%) and December (14%). The other months showed increasing and decreasing trends, which were not statistically significant. The SON season on the hand had 43% increasing trends. The number of negative trends exceeded that of positive trends during April, May and August especially in the sub-basins that border with the Equator. This means that the sub-basins are experiencing a reduction in rainfall in the months that contribute the biggest percentage of rainfall. The continued reduction may affect the timing of agricultural activities in the sub-basins in the future.

Monthly total precipitation: During January, only positive trends are detected in all sub-basins. During February, four sub-basins to the north and west of Uganda show positive trend. Negative trends are observed in sub-basins found in central Uganda around Lake Victoria and the Victoria Nile. During March, the sense of trend is positive in the central, east and west and becomes negative for the northern sub-basins (Albert Nile and River Aswa). When it comes to April, the trend behaviour is mixed in such a way that decreasing trends are dominant, with occurrences around the north western, south western and central parts of Uganda. May has more occurrences of decreasing rainfall, with one sub-basin (Lake Edward) showing no trend. June shows mixed occurrences where four sub-basins have positive trends and the trends in the three sub-basins that form the Albert water management zone are decreasing. During July and August, five sub-basins demonstrate increase and decrease in rainfall respectively. Kyoga and Victoria Nile are sub-basins that have shown a non-significant decrease in both months. September is one of those months whose results give mixed trend characteristics. Three of the sub-basins studied have experienced a decreasing trend from May to September when they hit a turning point and start to increase. During October, November and December (OND), homogeneity of direction across the country is detected, similar to what Nicholson (1996) found for most of eastern Africa. In October, four (River Aswa, Lake Albert, Lake Victoria and Victoria Nile) sub-basins; in November, three (River Aswa, Lake Albert and Lake Kyoga) sub-basins and in December, one (Albert Nile) sub-basin demonstrate significant trends at 0.05. Kizza *et al* (2009) also found positive trends in the short rains at most stations located in the northern part of the Victoria basin.

Table 4.3 Temporal Rainfall characteristics in the main drainage Sub-basins of Uganda

Sub-Basins		Albert Nile		River Aswa		Lake Albert		Lake Edward		Lake Kyoga		Lake Victoria		Victoria Nile	
Series variables	Trend tests	Z	Q _i	Z	Q _i	Z	Q _i	Z	Q _i	Z	Q _i	Z	Q _i	Z	Q _i
January	1940-2009	1.42	0.02	2.05	0.01	0.65	0.01	0.08	0.00	1.14	0.04	0.46	0.01	1.01	0.02
	1940-1969	-0.43	-0.02	0.41	0.01	0.43	0.03	-0.48	-0.03	0.11	0.03	-0.64	-0.07	-0.25	-0.04
	1970-1999	1.27	0.04	0.79	0.00	-0.11	-0.01	0.46	0.06	0.71	0.09	0.24	-0.01	-0.29	-0.02
Year of rainfall	MX	1955		1977		1963		1998		1970		1963		1963	
	Mn	1946		1946		1946		1983		1968		1989		1949	
February	1940-2009	0.57	0.00	1.16	0.00	0.46	0.00	-0.37	0.00	0.85	0.01	-0.83	-0.01	-1.22	-0.03
	1940-1969	0.23	0.01	1.11	0.06	-0.43	-0.03	1.27	0.07	1.03	0.26	0.96	0.08	1.25	0.17
	1970-1999	0.05	0.00	-0.92	-0.02	-0.54	-0.04	-0.43	-0.03	0.14	0.02	0.31	0.01	-1.14	-0.11
Year of rainfall	Mx	1969		1968		1979		1979		1978		1964		1964	
	Mn	1945		1946		1962		1997		1962		1989		1946	
March	1940-2009	-0.15	0.00	-0.17	0.00	0.40	0.00	1.36	0.01	0.84	0.02	1.61	0.04	0.27	0.01
	1940-1969	-0.04	-0.00	0.18	0.00	0.89	0.04	0.12	0.00	1.64	0.29	1.21	0.10	2.03	0.19
	1970-1999	-0.04	0.00	-0.40	0.00	0.61	0.04	0.79	0.07	0.50	0.10	-0.03	-0.00	0.43	0.04
Year of rainfall	Mx	1957		1970		1985		1974		1970		1978		1960	
	Mn	1953		1945		1946		1982		1973		1949		1949	
April	1940-2009	-0.49	-0.00	1.54	0.01	0.51	0.00	-1.15	-0.01	0.02	0.00	-0.72	-0.01	-1.88	-0.04
	1940-1969	-1.57	-0.06	0.00	0.00	0.75	0.03	0.41	0.02	0.11	0.01	0.00	0.01	0.71	0.06
	1970-1999	-1.48	0.05	0.43	0.00	-0.89	-0.05	-1.25	-0.11	1.39	0.17	-0.34	-0.02	-0.25	0.03
Year of rainfall	Mx	1947		1946		1963		1982		1947		1963		1966	
	Mn	1969		1969		1945		1999		1969		1952		1945	
May	1940-2009	-1.83	-0.02	-0.41	0.00	0.72	0.00	0	0.00	-0.19	0.00	-0.90	-0.02	-0.43	-0.01
	1940-1969	-1.32	-0.07	-1.03	-0.03	-1.46	-0.08	-0.55	-0.03	0.11	0.04	-1.36	-0.15	-1.32	-0.09

	1970-1999	1.07	-0.05	-2.78	-0.07	-0.62	-0.02	0.11	0.02	-0.25	0.03	-0.17	-0.01	0.61	0.04
Year of rainfall	Mx	1946		1985		1962		1993		1954		1945		1957	
	Mn	1971		1966		1966		1984		1966		1960		1966	
June	1940-2009	-0.29	0.00	0.78	0.00	0.57	0.00	-0.09	0.00	0.17	0.00	0.21	0.01	-0.90	-0.02
	1940-1969	-1.43	-0.08	-1.18	-0.04	-0.68	-0.05	-1.41	-0.06	-0.96	-0.12	0.07	0.01	0.64	0.05
	1970-1999	1.45	0.05	-0.77	-0.00	-0.07	-0.00	-0.11	-0.01	-1.18	-0.14	0.15	0.02	-1.11	-0.06
Year of rainfall	Mx	1957		1985		1943		1972		1950		1974		1972	
	Mn	1952		1965		1949		1999		1960		1990		1952	
July	1940-2009	1.07	0.01	1.81	0.01	0.19	0.00	0.05	0.00	-0.31	0.00	0.41	0.01	-0.72	-0.01
	1940-1969	-0.18	-0.01	-1.57	-0.04	-0.96	-0.05	-2.23	-0.07	-1.57	-0.15	-0.68	-0.05	-1.18	-0.05
	1970-1999	0.30	0.01	0.48	0.00	-0.68	-0.03	-1.68	-0.16	-0.29	0.07	0.03	0.00	-1.57	-0.14
Year of rainfall	Mx	1998		1949		1984		1974		1974		1974		1974	
	Mn	1941		1963		1990		1993		1973		1993		1963	
August	1940-2009	-1.05	-0.01	0.57	0.00	0.73	0.00	-0.31	0.00	-0.84	-0.01	-0.7	-0.02	-1.51	-0.03
	1940-1969	-0.43	0.03	-1.43	-0.03	-1.57	-0.05	-1.59	-0.08	-1.93	-0.24	-1.68	-0.15	-2.64	-0.20
	1970-1999	-1.59	-0.05	-0.59	-0.02	-0.14	-0.01	-1.61	-0.15	-0.29	-0.03	0.03	0.00	-0.79	-0.06
Year of rainfall	Mx	1975		1946		1962		1976		1961		1988		1955	
	Mn	1951		1959		1967		1982		1969		1986		1965	
September	1940-2009	-1.51	-0.00	0.79	0.00	0.59	0.00	-0.80	-0.01	-0.29	-0.00	0.39	0.01	0.62	0.01
	1940-1969	-0.61	-0.02	0.11	0.00	0.04	0.00	-1.95	-0.09	0.46	0.09	0.25	0.01	-0.07	-0.00
	1970-1999	-1.16	-0.04	-2.99	-0.06	-1.28	-0.04	-0.11	-0.01	-0.79	0.10	0.62	0.04	-0.21	-0.02
Year of rainfall	Mx	1955		1973		1961		1992		1983		1955		2007	
	Mn	1965		1982		1953		1993		1957		1957		1963	
October	1940-2009	0.76	0.00	1.88	0.01	1.94	0.02	0.79	0.01	1.09	0.04	2.47	0.05	2.02	0.04
	1940-1969	1.36	0.06	2.36	0.08	2.11	0.11	-1.98	-0.09	2.43	0.36	2.03	0.14	1.89	0.17

	1970-1999	1.23	0.03	-0.38	-0.00	1.71	0.08	2.43	0.12	1.39	0.19	1.25	0.06	1.36	0.12
Year of rainfall	Mx	1965		1983		1965		1983		1972		1961		1961	
	Mn	1943		1943		1947		1963		1979		1943		1947	
November	1940-2009	1.34	0.01	2.08	0.01	2.36	0.03	0.65	0.00	2.05	0.06	1.00	0.03	1.19	0.03
	1940-1969	1.21	0.06	0.39	0.02	1.71	0.10	0.16	0.00	0.68	0.14	1.86	0.25	1.57	0.18
	1970-1999	1.20	0.06	0.39	0.02	1.71	0.10	0.16	0.00	1.89	0.21	1.86	0.25	1.57	0.18
Year of rainfall	Mx	1961		1961		1961		1987		1961		1961		1961	
	Mn	1950		1956		1943		1981		1950		1947		1947	
December	1940-2009	2.11	0.02	0.37	0.00	0.17	0.00	0.13	0.00	0.72	0.02	0.84	0.02	0.30	0.01
	1940-1969	0.93	0.06	0.02	0.01	1.34	0.09	-0.34	-0.02	0.57	0.14	0.79	0.08	0.82	0.07
	1970-1999	3.30	0.08	2.34	0.05	2.41	0.09	1.53	0.08	2.28	0.21	1.60	0.07	1.64	0.12
Year of rainfall	Mx	1951		1951		1965		1963		1951		1951		1951	
	Mn	1953		1943		1971		1970		1952		1952		1952	
Annual	1940-2009	-0.98	-0.03	0.11	0.31	1.56	0.05	-0.69	-0.02	0.44	0.03	1.02	0.09	0.15	0.01
	1940-1969	0.21	0.03	0.11	0.03	0.93	0.21	-0.48	-0.09	1.68	0.73	0.79	0.24	1.36	0.53
	1970-1999	0.96	0.30	-2.13	-0.24	-0.36	-0.04	-1.46	-0.37	0.32	0.24	0.48	0.08	0.25	0.09
Year of rainfall	Mx	1961		1977		1961		1996		1961		1951		1961	
	Mn	1971		1953		1983		1965		1980		1952		1983	
DJF	1940-2009	0.77	0.01	1.21	0.08	0.24	0.00	0.04	0.00	0.61	0.04	0.52	0.02	0.21	0.11
	1940-1969	0.39	0.05	1.21	0.08	0.86	0.13	0.62	0.09	1.16	0.61	0.68	0.12	0.89	0.21
	1970-1999	2.11	0.18	0.52	0.02	0.68	0.06	1.00	0.12	1.75	0.45	1.08	0.09	0.68	0.12
Year of rainfall	Mx	1969		1969		1969		1998		1969		1998		1998	
	Mn	1946		1946		1946		1992		1949		1946		1967	
MAM	1940-2009	-1.62	-0.03	0.44	0.00	1.18	-0.02	-0.12	0.00	0.13	0.00	0.14	0.01	-0.61	-0.03
	1940-1969	-1.21	-0.14	-0.68	-0.04	-0.18	-0.02	0.59	0.07	1.07	0.37	-0.14	-0.02	1.03	0.18

	1970-1999	0.91	0.10	-1.67	-0.12	-0.39	-0.03	-0.86	-0.08	0.68	0.19	-0.17	-0.02	0.57	0.08
Year of rainfall	Mx	1957		1982		1985		1967		1947		1963		1960	
	Mn	1971		1953		1955		1999		1973		1949		2007	
JJA	1940-2009	-0.41	0.00	0.67	0.00	-0.51	-0.01	-0.71	-0.01	-0.58	-0.02	-0.33	-0.02	-1.43	-0.06
	1940-1969	-0.96	-0.12	-1.64	0.11	-1.96	-0.13	-1.62	-0.16	-2.43	-0.52	-1.14	-0.16	-1.64	-0.24
	1970-1999	-0.21	-0.02	-1.67	-0.09	-1.25	-0.11	-2.43	-0.41	-1.18	-0.22	-0.03	-0.01	-1.86	-0.25
Year of rainfall	Mx	1961		1946		1984		1996		1961		1974		1961	
	Mn	1951		1959		1990		1965		1960		1960		1990	
SON	1940-2009	0.78	0.01	2.64	0.03	2.99	0.06	0.56	0.00	1.30	0.06	1.65	0.07	2.07	0.08
	1940-1969	1.07	0.08	1.78	0.12	2.50	0.19	-1.41	-0.11	1.93	0.56	1.75	0.31	1.89	0.33
	1970-1999	1.30	0.07	-2.35	-0.13	1.00	0.07	0.21	0.04	1.28	0.36	-0.20	-0.02	1.03	0.14
Year of rainfall	Mx	1961		1983		1961		1996		1961		1961		1961	
	Mn	1943		1943		1943		1979		1957		1957		1943	
(sub-basin)	SEN's T	-0.31		-3.91		-3.13		-0.91		-1.09		-1.36		0.19	

Climatic normal: To ascertain the changed behaviour of annual, seasonal and monthly rainfall we performed a trend analysis with in a climatic normal and the results are provided in Table 4.3. The analysis shows more positive trends in monthly rainfall totals especially in the second normal. Positive trends were dominant during the OND months and these were equally distributed in the first and second normal. Negative trends are prominent in January and August during the first normal (1940 to 1969). The rest of the months show mixed results of increasing and decreasing trends during the period of analysis. Significant trends for the first normal were evident in Victoria Nile during March, in Lake Edward during July, Lake Kyoga and Victoria Nile during August and Lake Albert sub-basin during November (Table 4.3). Six of the sub-basins experienced significant trends in October except Albert Nile sub-basin. On the other hand, the second normal showed significant negative trends in May and September for (River Aswa), October trends were positive for (Lake Albert and Lake Edward), and in December positive significant trends are evident for the Albert Nile, Lake Albert and Lake Kyoga sub-basins (Table 4.3).

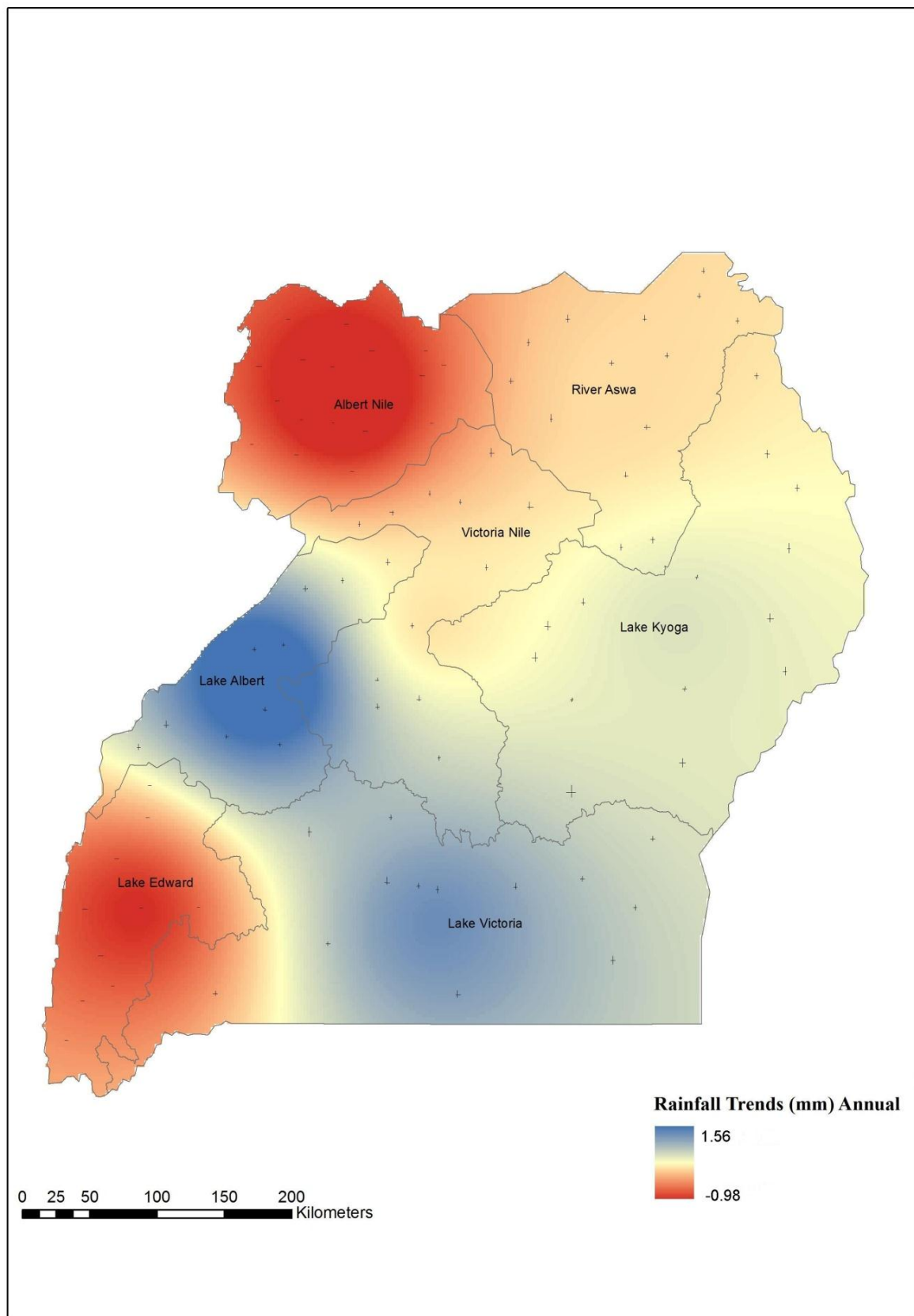


Figure 4.7 shows the spatial distribution of negative (-) and positive (+) trends for annual total rainfall in Uganda's main drainage Sub- basins.

Annual total precipitation: Figure 4.7 shows the spatial distribution of negative and positive trends for annual total rainfall. The majority of the sub-basins have positive trends which are non significant at 5%. Sub-basins showing negative trends are Albert Nile and Lake Edward. From a regional perspective, the decreasing trends are observed in western and north western Uganda. The rest of the regions show an increase in annual total rainfall.

The time-series plots for Albert Nile sub-basin indicate a slight decrease in annual total rainfall with a low-frequency fluctuation (Fig. 4.8a). The normalized rainfall anomalies for Albert Nile sub-basin are characterised by four major wet periods, during the years of 1954 - 1958, 1961-1964, 1976 -1979 and 1997- 1998, and three major dry periods, during the years of 1942 - 1944, 1966 -1974 and 1980 -1994(Fig. 4.8a). The maximum and minimum rainfall was recorded in 1961 and 1971 respectively (Table 4.3).

The time series plot of River Aswa sub-basin (Fig. 4.8b) shows slightly a decreasing trend in annual rainfall with high interannual variability. Three notable periods, during the years of 1942-1945, 1952-1960 and 1964-1968 were dry. Almost all years with in the period 1952-1960 are characterized with negative rainfall anomalies. The wet periods were revealed in the years 1946- 1951, 1961- 1963, 1969-1972, 1976-1978, 1982-1984 with some dry breaks in between of one or two years. The maximal and minimal rainfall values were recorded in 1977 and 1953 respectively (Table 4.3).

The time-series plot of Lake Albert sub-basin (Fig. 4.8c) exhibit high frequency fluctuation. There was a major dry spell during the period 1942-1960. The situation however, reverses to shorter dry years than wet years during the period after 1960. The wettest and driest years were 1961 and 1983 respectively (Table 4.3).

The normalized rainfall anomalies of Lake Edward sub-basin show a high frequency about a decreasing long term mean (Fig. 4.8d). In spite of a spell of wet years during the period 1943-1945, 1974-1978, 1996-1998, one can also detect wet anomalies interspersed with short dry spells of 1 or 2 years, in the period 1954-1974. The sub-basin experienced two long dry periods between 1979-1986 and 1990-1995. Highest rainfall was recorded in 1996, while the lowest in 1965 (Table 4.3).

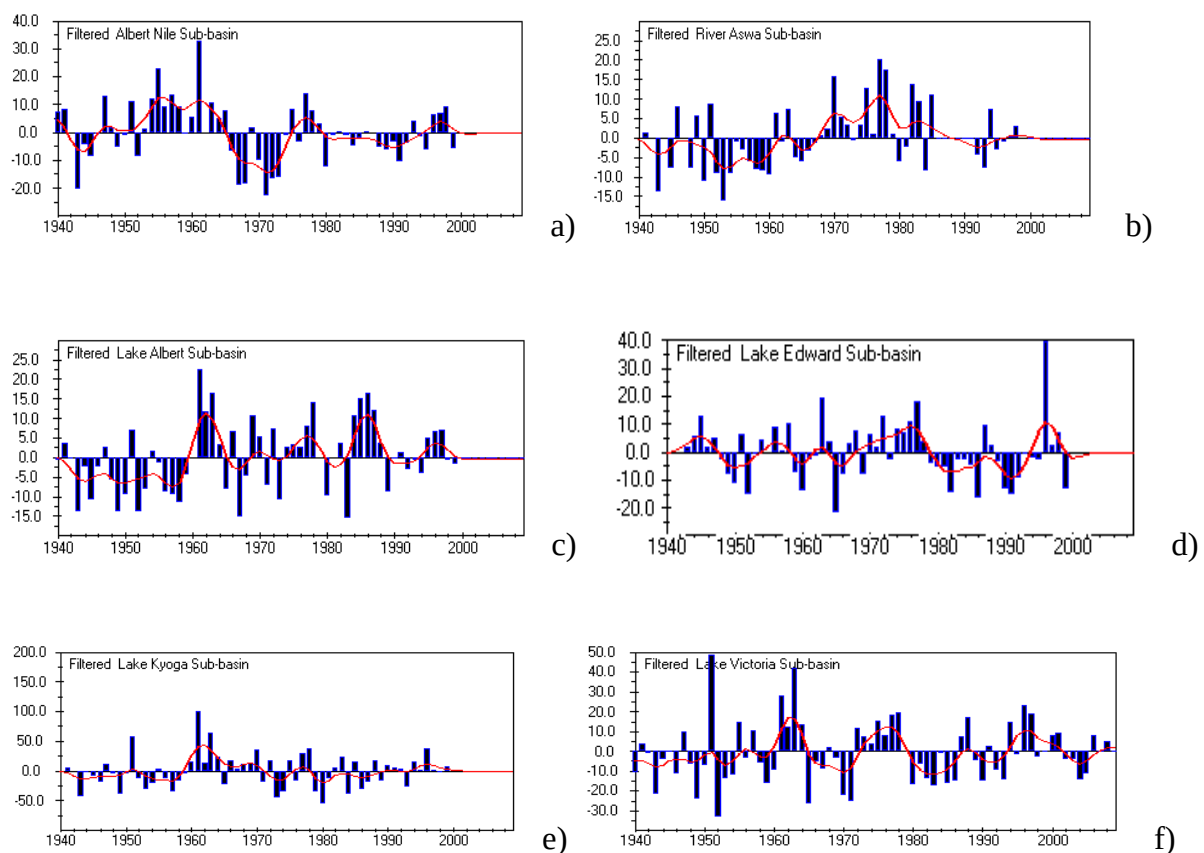
The time series plots of Lake Kyoga sub-basin show a slightly downward trend in annual rainfall with a weak frequency fluctuation (Fig. 4.8e). The sub-basin is characterised by three major dry periods, during the years 1942-1949, 1952-1959, and 1979-1981 and a wet period from 1961-1970, with the exception of two, one year dry breaks in 1965 and 1971 and two year dry break 1975/76. After the 1997/98 wet spell (El-Nino years in Uganda), annual totals have continued to decline. Maximum rainfall was recorded in 1961 and minimum in 1980 (Table 4.3).

A snap short inspection of the time series plot of Lake Victoria sub-basin would give an impression that the normalized rainfall series have equal variation of wet and dry years (Fig. 4.8f). The frequency is apparently low, which tends towards a reduction in annual total rainfall. Sub-basin total rainfall anomalies experienced four major wet conditions during the periods of 1961-1964, 1972-1978, 1987/88 and 1996/97, along with seven dry conditions

during the periods of 1940-1950, 1951-1954, 1958-1961, 1965-1971, 1980-1986, 1989-1993 and 2002-2005. The year 1951 is the wettest on the sub-basin record, with a positive anomaly of +48.4, while 1952 was the driest with a negative anomaly of -33.3.

The time series plots of the Victoria Nile sub-basin depict high frequency of variability (Fig. 4.8g). This is the only sub-basin that has equal periods of wet and dry years. Wet conditions dominate during the periods of 1940-1942, 1951, 1960-1964, 1977-1979, 1987/88, 1996-1999 and 2006/07, with the highest wet anomaly in 1961, where as dry conditions occur during the periods of 1943-1950, 1952-1954, 1968-1972, 1980-1986, 1989-1995, 2004/05 and 2008. The year of 1983 is the driest of the sub basin annual series, with a high negative anomaly of -28.5.

A closer inspection of the above plots (Fig.4.8a-g) reveals consistence in what is found in literature. For example annual series plots above indicate dry conditions in the 1950s and wet conditions in the 1960s. Analysis also shows that, sub-basins like; Albert Nile, River Aswa, Lake Albert, Lake Edward & George, Lake Kyoga, and Kafu-Victoria Nile recorded their highest rainfall in 1961 and 1977. These sub-basins were affected by the incursion of humid Congo air, which according to Anyamba, 1984 played a role in the 1961/62 floods (Nicholson 1996). This study has found out that, dry conditions existed in the early 1980s, 1990s and relatively wet conditions were experienced in the late 1990s (Fig. 4.8a-g).



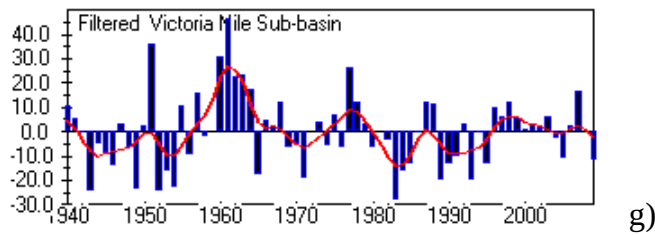


Figure 4.8(a-g) Variations and trends in normalized annual rainfall anomalies series with nine-point Gaussian filter, over the main drainage sub-basins of Uganda.

Seasonal trends. Inspection of the map patterns in (Fig 4.9a-d) and Table 3 reveals an interesting pattern of trend in the seasonal distribution of rainfall. For instance DJF season has positive trends in all sub-basins, although none of the trends is statistically significant at 0.05 (Fig. 4.9a). The respective slopes of change are also negligible, where the highest is 0.11 in Victoria Nile sub-basin (Table 4.3). MAM season, a period which contributes high percentage of rainfall (Fig. 4.9b) revealed mixed trends of decrease and increase which are not statistically significant at 0.05. Four of the sub-basins exhibit positive trends and the three show negative trends. These results are consistent with what Nyenje and Batelaan (2009) found out in their study. They predict a general increase in rainfall, with the greatest increase expected in the wet seasons (MAM and OND). Unlike the rest of the seasons, JJA has more negative trends than positives with slope changes that are negligible (Table 4.3). A positive trend has been recorded in the River Aswa sub-basin during the JJA season (Fig. 4.9c). Maximum and minimum rainfall was recorded in 1946 and 1959 at this basin respectively.

Rainfall trend in the SON season are positive for all sub-basins (Fig. 4.9d), with slope changes that are negligible. This is the only season where positive and statistically significant trends at 0.05, significance level have been revealed at Lake Albert, Lake Victoria and Victoria Nile sub-basins (Table 4.3). Most of the high rains were recorded in 1961 for five of the sub-basins with the exception of two; River Aswa for 1983 and Lake Edward and George for 1996 during the period of analysis. Literature and analysis identify SON as the second wet season which contributes greatly to the total annual rainfall in the seven sub-basins. Down scaled data predicts rainfall increase in this season by over 30%, in the 2020s, over 80% in the 2050s and over 100% in the 2080s (Nyenje and Batelaan 2009). Three years; 1941, 1951, and 1957 which appear in (Nicholson 1996, Phillips and McIntyre 2000) have also been detected in the sub-basins series, as wet years in the scope of analysis.

Trend analysis shows that the only season in which significant rainfall occurs throughout the analysis period are OND. It is also identified that the climatological seasons are DJF, MAM, JJA, and SON. The means of these periods are depicted in Fig. 4.6. Coefficients of correlations between annual and seasonal rainfall departure series for individual sub-basins are presented in table 4.4. Correlations between annual totals and MAM exceed 0.5 for nearly all sub-basins except for Lake Albert sub-basin whose correlations were 0.2. Correlations for SON are above 0.4 and the highest is 0.7 for Lake Edward basin. The correlations are somewhat higher for 4 sub-basins that cover an extensive area in Uganda during the DJF season. The Albert Nile, River Aswa and Lake Edward sub-basins depict correlations above

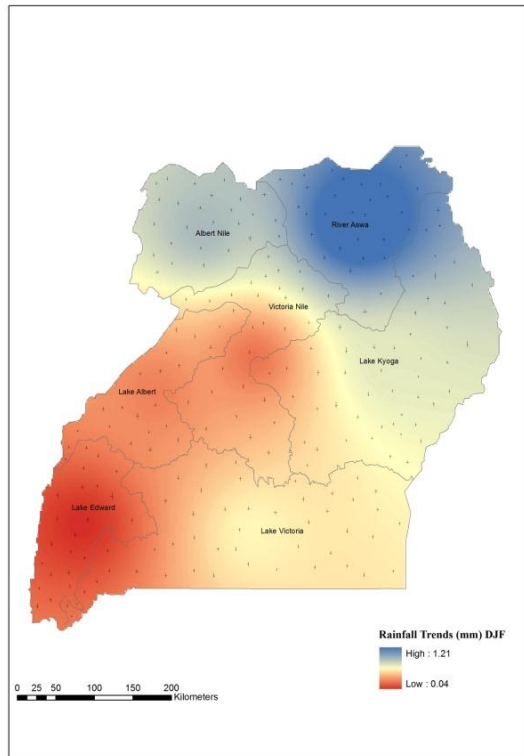
0.5, while the other 4 have low correlations (Table 4.4) during JJA season. Since the three sub-basins have peak rains in August relative to others (Fig. 4.6a, b, and e) is evidence to support the argument that some parts of the country receive moisture from the Congo/Zaire basin to the west (Ogallo 1988, Phillips and McIntyre 2000)

Table 4.4 Coefficients of correlations results between annual and seasonal rainfall departure series for main drainage sub-basins in Uganda.

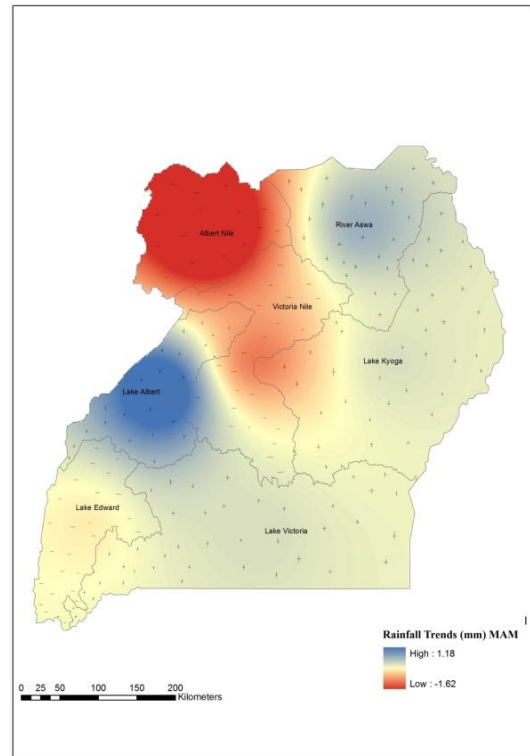
	Albert Nile	River Aswa	Lake Albert	Lake Edward	Lake Kyoga	Lake Victoria	Victoria Nile
DJF	0.6	0.4	0.4	0.6	0.7	0.7	0.5
MAM	0.6	0.7	0.2	0.5	0.5	0.5	0.6
JJA	0.5	0.6	0.7	0.3	0.3	0.2	0.3
SON	0.6	0.6	0.4	0.7	0.4	0.5	0.5

Sen's T test. The Sen's T test results indicate negative trend in six of the sub-basins. The sub-basins that detected negative trends are Albert Nile, River Aswa, Lake Albert, Lake Edward, Lake Kyoga and Lake Victoria. Significant decreasing trends were observed in River Aswa and Lake Albert sub-basins. Results for Victoria Nile sub-basin show a positive trend, which is not statistically significant at 0.05. Results are summarised in table 4.3.

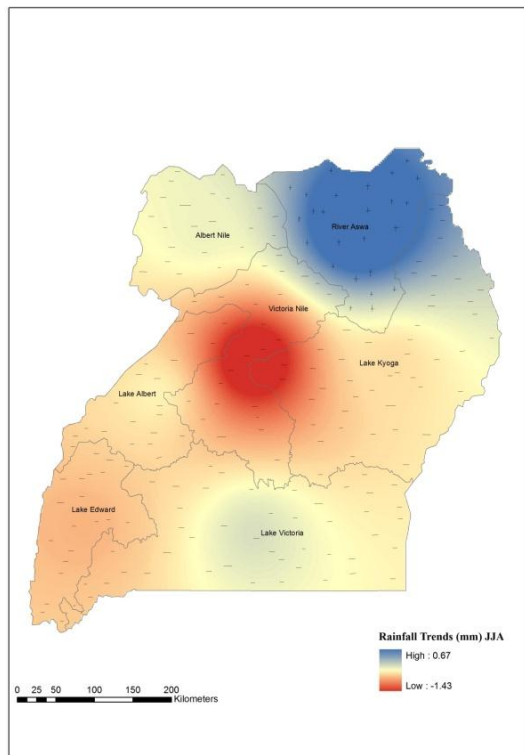
Sen's estimator. The Sen's slopes (Q_i) of all trends in rainfall for the sub-basins are presented in table 4.3, for three temporal periods; 1940-2009 and for the two normals (1940-1969, 1970-1999). They indicate change per unit time of the trends detected monthly, annually and seasonally. Results do not reveal any slope that is statistically significant. It has also been presented that slopes for DJF are positive for all sub basins while those of JJA are negative with the exception of Albert Nile and River Aswa. The rest of the seasons across all sub-basins show slopes with mixed signs. The positive change in the DJF can be attributed to increase in rainfall in December and January. The other months that showed positivity are November and December, with slopes, which were higher in the second climatic normal. However, all these magnitudes of change in all sub-basins are not statistically significant at 0.05. Seasonal slopes for the sub-basins indicate that, magnitude of change was higher in the first normal (1940-1969) than those calculated for the second normal, except for the JJA season in Victoria sub-basin.



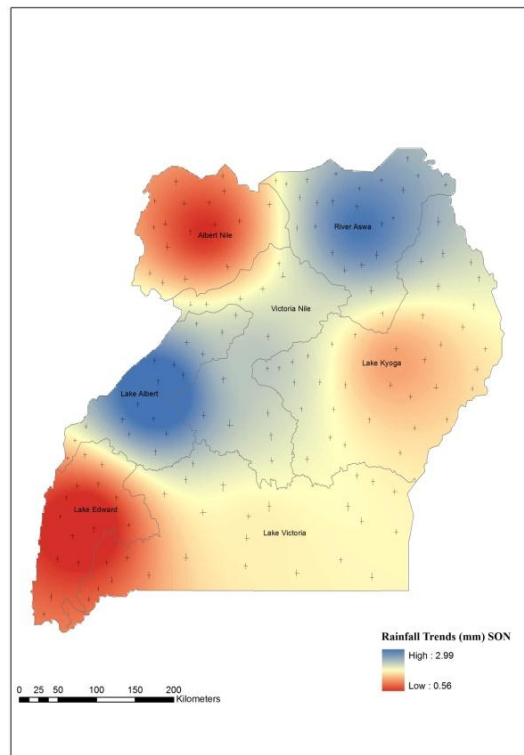
(a)



(b)



(c)



(d)

Figure 4.9(a-d) Shows the spatial distribution of negative (-) and positive (+) trends for seasonal distribution of rainfall for the period 1940 – 2009 in Uganda's main drainage Sub-basins. Magnitude is in mm/ season (not indicated on map).

4.4 Discussion and summary

Conclusions from understanding of the nature of rainfall can be applied to various social and economic spheres to support decision making related to water resources for urban and industrial use, energy planning, tourism, commercial activities and protection of the environment and agricultural production (Sinoga *et al.* 2011). These aspects of the local environment conditions, natural resources and social-economic activities are closely linked. For example, when rains were late and early rains were poor in the East African region in 2010, it created a situation of food insecurity in the region (MOFPED 2011), resulting into hyper-inflation among other factors. But Literature on Uganda's rainfall is scarce and where it is available it is on a small-scale analysis or in less detail, embedded with in East African discussions. As a starting point to help in the decision-making process on water resources availability, the increasing need to know the precipitation behaviour and trends justifies the present work, in a water resource rich country like Uganda.

A study by Guijarro (2002 in Sinoga *et al.* 2011) warns of the tendency of increased spatial-temporal variability in seasonal precipitation and the low statistical significances occasionally found (as a result of the high variability in rainfall) that can lead to underestimating the importance of these precipitation trends. If such trends continue in the sub-basins studied there will be major changes in distribution of water resources, which are critical for economic activities like tourism, energy, industry and agriculture.

Starting out from a wide base of 36 observatories, with homogeneous data and quality contrast, the precipitation trends and the spatial patterns of its evolution in time have been analysed for 1940-2009. Analysis shows decades of normal and beyond normal rainfall, with a marked contrast in seasonal cycles with in sub-basins. Mean annual rainfall is seasonal with much of the rainfall measured during March to May, and although no significant change in annual rainfall can be discerned in Uganda an increase in the variability in the distribution of monthly rainfall can be seen. Variations in annual rainfall are relatively low which imply a dependable rainfall distribution. Plots also indicate that, no single month in Uganda goes without rainfall in the sub-basins. Sub-basins in the north have a unimodal type of rainfall distribution while those in the south have a bimodal distribution with maximums in July to August and March to May respectively. The DSI used in the study informs us of the drought years during the analysis period, which was consistent with previous literature.

From the monthly rainfall variables, October, November, December and January were found to have significant increasing trends as opposed to other months showing positive or negative trend with in the main drainage sub-basins in Uganda. The result of trend analysis of monthly total rainfall especially in October and November is reflected in the SON season, but not in the annual series. There were downward trends in the annual rainfall series, predominantly in north western and south western of Uganda, while the rest of the sub-basins had upward trends.

Results could have considerable implications for society and the economy. Decrease in inland precipitation will cause problems. This is because the reservoirs controlling and storing water

resources are located in the north eastern (Aswa/Kyoga) part of the study region, and a decrease in precipitation in this area could reduce water reserves. These reservoirs (Valley dams) supply water to the pastoralists in times of drought. Studies of trends in rainfall and its evolution provide useful tools for managers and administrators of water resources, especially in areas where periods of droughts can result in major economic losses, and social and political conflict.

Water is probably the country's most abundant resource, and therefore it seems to attract less attention, but if water demand increases and pessimistic predictions about climate change come true then adverse effects have to be faced. These will require efficient water policy actions with in a high degree of hydrological planning that demands appropriate infrastructures and a rational use of the resource.

It is worthwhile emphasizing that the trend results presented in this study were not sufficient to approve climatic change in the main drainage sub-basins of Uganda. Future studies are needed to address the issue of trend attribution and to attempt to establish a linkage between climatic change and the observed hydrologic trends.

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CHAPTER 5

Variability properties of daily and monthly observed near-surface temperatures in Uganda:
1960 to 2008*

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5.1 Introduction

The climate science community agrees that changes in the frequency and intensity of climate events are likely to impact nature and society in future (Zhang *et al* 2005; Easterling *et al* 2003). Unfortunately, such changes are not well documented for some parts of the world, which raises concern amongst scientists, (Easterling *et al.* 2003; Mahli and Wright 2004; New *et al.* 2006; Thornton *et al.* 2007). This is despite of the anticipation that climate change might have a profound effect on developing countries, of which many are located in Africa. Some studies that have documented changes in climate and climate variability and their impacts for Africa include: New *et al.* (2006); Kruger and Shongwe (2004); Mahe *et al.* (2001); King'uyu *et al.* (2000) amongst others. The few regional studies conducted in Africa revealed that observed changes in climate are not spatially uniform (Kizza *et al.* 2009; Mubiru *et al.* 2009; Schreck and Semazzi 2004; Nicholson 1996; Basalirwa 1995; Ogallo 1993; Rodhe and Virji 1976 and Samson 1952) because of geographical and land-surface variations. Nevertheless, profiling these changes has enhanced the understanding of climate in the continent, and contributed to more informed decisions on, and responses to, climate change.

Studies on near-surface temperature changes conducted in Africa, and elsewhere in the world, have demonstrated that it is important to study temperature trends at a regional level. Such regional studies are more detailed and bring out differences between a specific region and the wider surrounding area. For example, various studies (Kafle and Bruins 2009; S.del Rio *et al.* 2007; Cheema *et al* 2006; Domroes and El-Tantawi 2005; Kruger and Shongwe 2004) have identified climate characteristics that are unique to a particular country. These studies have not only informed the scientific community about the climate characteristics of a region, but also formed the baseline for future studies. In general, trend results obtained from annual as well as minimum and maximum temperatures for Africa agrees with international findings on global warming. However, more studies are required for such trends in equatorial locations.

Like most other African countries Uganda has decided to prioritize climate change because of the anticipated impact that it might have in future on livelihoods and social society (GOU 2002; NEMA 2008). In Uganda there are already noticeable observed changes in weather patterns, for example more erratic rainfall in the March to June rainy season that coincides with drought and a subsequent reduction in crop yield. It is also found that rains towards the end of the year are becoming more intense and destructive, bringing floods, landslide and soil erosion (Oxfam 2008). These recent climatic changes are already negatively impacting sustainable livelihoods and food security. Women are the most affected, which hampers their effort to overcome poverty (Oxfam 2008).

A detailed study on near-surface temperature variability and trends in Uganda has not yet been carried out especially to include recent global temperature increases since the 1970s. A primary motivation for undertaking this study is to investigate temperature trends in Uganda during the more recent decades when the global warming signal has intensified consistently,

compared to previous decades. The aim of the study is to explore the variation of, and to try and identify trends in near-surface temperatures, and in particular maximum temperatures ($T_{\max}$) and minimum temperatures ($T_{\min}$) in Uganda by means of a detailed statistical analysis of data gathered at eight meteorological stations over a 49-year period (1960 to 2008). Temporal analyses have been carried out at intra-annual time scales (daily and monthly) using minimums of minimum temperatures ($\text{mn}T_{\min}$), maximums of minimum temperatures ($\text{mx}T_{\min}$), maximum of maximum temperatures ($\text{mx}T_{\max}$), minimum of maximum temperatures ($\text{mn}T_{\max}$). In addition time series of Diurnal Temperature Range (DTR) and Annual Temperature Range (ATR) have also been analyzed.

The study further attempts to document extreme temperature events using a suite of indices. These indices are an outcome from a joint effort by the World Meteorological Organization (WMO) CCI/CLIVAR/JCOMM Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI) (Zhang *et al.* 2005).

5.2 Data and methodology

5.2.1 Study area

As illustrated in figure 5.1, Uganda is located in the east African equatorial area between 1°S to 4°N and 29°E to 35°E (Mubiru *et al.* 2009). The location of the eight temperature stations used in this study is also denoted in figure 5.1. According to Köppen's climate classification, Uganda experiences a tropical moist climate, where all months have an average temperature of greater than 18°C and an annual precipitation of greater than 1500mm (Griffiths 1972). Monthly average temperatures in Uganda vary from 24°C to 30°C , while the annual range of temperature is about 3°C . The annual variation of mean monthly air temperature is very small, usually 1° to 2°C in the south-west of Uganda and the south-western part of Lake Victoria.

Details of the climatic systems that modulate the space-time characteristics of rainfall and temperature over east Africa have been elaborated on in previous studies (Phillips and McIntyre 2000; Ogallo 1993). On a more local scale, Kizza *et al.* (2009), Anyah and Semazzi (2009) and Anyah and Semazzi (2004) recently shed more light on the general circulation and the general climatology of Lake Victoria, which has a significant influence on Uganda's climate. In general, the location of Uganda astride the equator exposes it to comprehensive sunshine associated with high temperatures and rainfall.

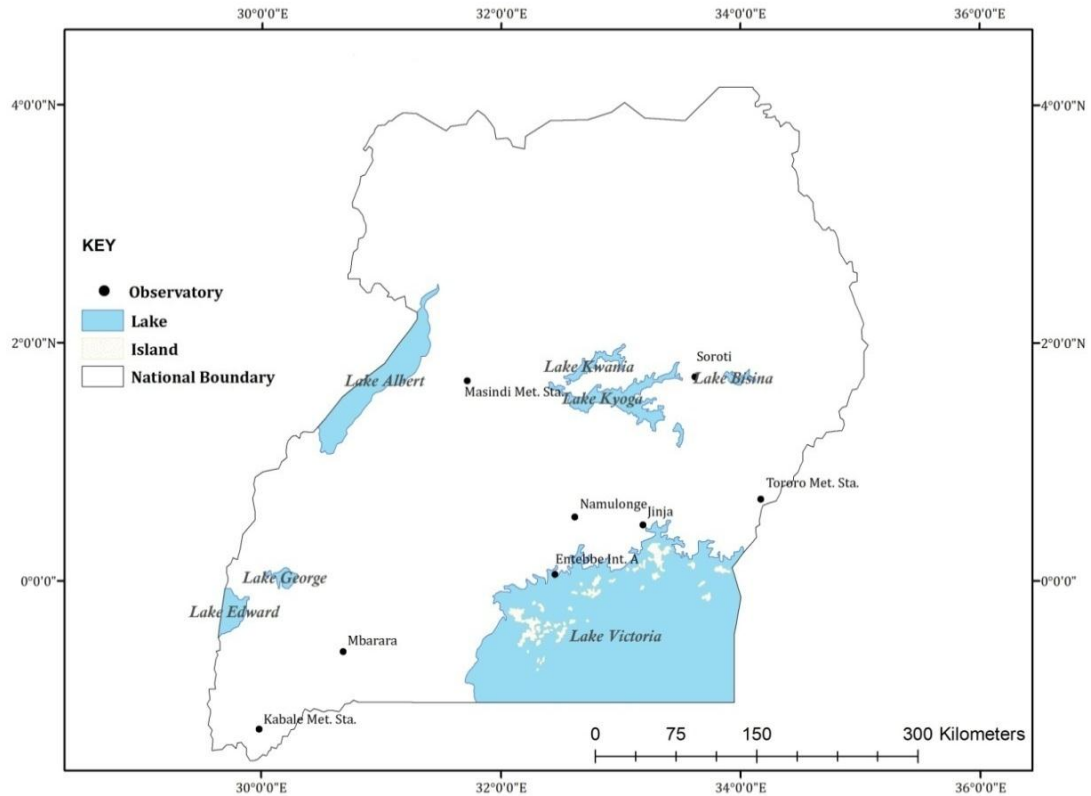


Fig. 5.1 A map of Uganda that is located in equatorial Africa with its lakes and lake islands. The locations of the eight near-surface temperature-recording weather stations used in this study are depicted by black circles.

5.2.2 Temperature data

The near-surface maximum and minimum temperature data used in this study were provided by the Uganda Meteorological Department (UMD) in the Ministry of Water and Environment, Kampala, where collected data are entered and archived using the Climate-Computing (CLICOM) format. Here the data goes through a rigorous process to ensure that stored data are of a highly acceptable quality. Data from eight temperature recording stations were selected (figure 5.1), taking into account the length and availability of data records. The eight stations are fairly well distributed across the country and cover four regions, namely, eastern, western, southern and central Uganda (Basalirwa 1995). Daily temperature records were used to generate monthly and annual means of $T_{\max}$ and $T_{\min}$ at each station. Temperature records that were used meet the WMO required climatological record length of at least 30-years (Table 5.1).

Table 5.1 List of the eight near-surface temperature weather stations, which were used in this study. Note that these stations are located in different climate zones all across Uganda.

Station Name	Station ID/ Code	Longitude	Latitude	Altitude (meters)	Record length
Entebbe International Airport	89320660	32° 45'E	0° 05'N	1155	1960-2009
Jinja	89330430	33° 18'E	0° 45'N	1175	1960- 2000
Mbarara	90300030	30° 68'E	0° 6'S	1420	1960- 2008
Namulonge	89320670	32° 61'E	0° 5' N	1130	1953- 2008
Kabale	91290000	29° 59'E	1° 15'S	1869	1960- 2000
Masindi	88310030	31° 72'E	1° 68'N	1147	1965- 2000
Soroti	88330060	33° 37'E	1° 43'N	1132	1971- 2000
Tororo	89340190	34° 10'E	0° 41'N	1170	1961- 1996

5.2.3 Processing of data

The key outcome for processing the near-surface maximum and minimum temperature data was to detect whether trends in temperature are present in the data records. A trend depicts a consistent long-term change in a time series, which could be identified by the use of either graphical tools or statistical methods (Longobardi and Villani 2010). There are many methods for identifying trends in literature (e.g. Samson 1952; Piccarreta *et al.* 2004; Ghahraman & Taghvaeian 2008; Caloiera *et al.* 2009; Lopez-Moreno *et al.* 2009). In this study graphical and statistical approaches are combined in an effort to identify statistically significant trends in the temperature of Uganda, since it is known that a combination of approaches could yield more information on trends (del Rio *et al.* 2007).

5.2.4 Data limitations

Data used in the study were characterized by the following limitations: (1) Metadata required for homogeneity testing were totally absent. The absence of metadata was a determinant in choosing absolute tests against the more popular relative testing as a method of testing for inhomogeneities. (2) Not all stations had the same data collecting period and some gaps occurred in the data. Both these problems were addressed as discussed below.

5.2.4.1 Homogeneity testing

Trend analyses are limited by the degree of inhomogeneity in data (Aguilar *et al.* 2003). It is important to note that homogeneities in climatic data manifest itself in two ways: (1) as a gradual trend or (2) as a discontinuity (sharp change) in the mean or variance (Easterling *et al.* 1996). There are numerous methods to use in evaluating homogeneity in daily to monthly temporal climate data (Peterson *et al.* 1998). This study restricts the homogeneity analysis to

absolute tests and relies on four statistical methods, namely: (1) Von Neumann ratios (Sahin and Cigizoglu 2010; Lima *et al.* 2010); (2) Cumulative deviations; (3) Worsely's likelihood ratio tests (Pandžić and Lisko 2009) and (4) Bayesian procedures. These tests are well defined in Buishand (1982) and the detailed mathematical formulation of the tests is also discussed in Wijngaard *et al.* (2003). The tests were applied on DTR time series, because they are strong indicators of the degree of climate variability and change (del Rio *et al.* 2007). Lucio *et al.* (2007) also reiterate that inhomogeneity most clearly appear in DTR time series.

5.2.4.2 Estimating data gaps

A study by Stooksbury *et al.* (1999) on the effects of data gaps, as a result of missing data, demonstrated that monthly mean $T_{\max}$ and $T_{\min}$ values could differ by more than $\pm 1^{\circ}\text{C}$ with only a 3-day gap in the data. It is also mentioned in the same study that data of regions that have daily persistence in temperatures are least impacted by data gaps. Uganda is located in the equatorial region of Africa where daily persistence in temperatures is experienced, implying that gaps would therefore have a smaller impact on data analysis. With climate variability and climate trend analyses, data gaps are especially a concern when they occur early or late in the data record, which was not the case for the temperature data used in this study. A number of methods may be used to produce estimated values for data in these gaps, such as the substitution of the nearest neighbour value, the Kriging method, using a derived value or by using the mean value to fill missing data (Jones *et al.* 1999). In this study gaps in the data could not be ignored because the software used for analysis required continuous data. Gaps were therefore filled using long-term daily mean values of a particular month at a particular station. Fortunately, by applying this method the mean value (and trend) of the data was not affected, but it rather ensured that data were continuous.

5.2.5 Calculation of intra-annual temperature variance

The variability of monthly and annual $T_{\max}$ and $T_{\min}$ values obtained from daily values, as well as area averages of these temperatures, were analyzed in this study. The data series therefore contained a complete set of 12 monthly means for each year under consideration, from where the intra-annual variance in temperature was calculated (Micheals *et al.* 1998). These thermometric variables have raised interests amongst scientists like Braganza *et al.* (2004) who argued that changes in mean near-surface temperature could be due to changes in $T_{\max}$ and $T_{\min}$ values, or both (del Rio *et al.* 2007). The intra-annual variance is obtained by:

$$\text{Variance} = \frac{\sum_{i=1}^n (T_i - \bar{T})^2}{n-1} \quad (1)$$

where T_i is the mean temperature for month i , $\bar{T}$ the long-term mean temperature, and n is the number of months per year (equal to 12).

5.2.6 Indices considered in trend analysis

The indices used in the study are part of the suite of 27 indices, mentioned in the introduction. These indices have been computed before for other regions (Easterling *et al.* 2003; New *et al.* 2006). In this study, however, only those indices shown in (table 2) that were considered to be relevant for the region, have been analyzed using Microsoft Excel and a trend software package available at <http://www.toolkit.net.au/trend>.

5.2.7 Construction of area average temperature series

The construction of an area average station temperature series is aimed at providing an overall picture of temperature variation in the eastern, central, southern and western parts of the Uganda. Original monthly temperature series were converted to standardized monthly series (T_{sy}) by subtracting the long-term mean ($\bar{T}$) from the original monthly values (T_i) to obtain anomalies, and then to divide these anomalies by the standard deviation (σ) at each station. This process minimizes the problem of highly diverse means and variability and the randomness of station totals (Nicholson 1986). The standardized temperature for a given station is:

$$T_{sy} = (T_i - \bar{T}) / \sigma \quad (2)$$

The area-averaged (regional mean climatology) standardized monthly temperature (T_{ry}) is defined as:

$$T_{ry} = (1 / N_j) \sum_{s=1}^{N_s} T_{sy} \quad (3)$$

where N_j is the number of regional stations for the year j . The use of regional average, in general, provides a time series that is a better representation of large-scale climatic processes (Partal and Kahya 2006), thus making it easier to deal with one index series in a region.

Table 5.2: Indices used to detect trends in the near-surface temperature data of Uganda.

Descriptive Name	Definition	Units
Hot days	Annual count when maximum temperature $> 25^{\circ}\text{C}$	Days
Warm nights	Annual count when minimum temperature $> 20^{\circ}\text{C}$	Days
Hottest day	Monthly highest maximum temperature	$^{\circ}\text{C}$
Hottest night	Monthly highest minimum temperature	$^{\circ}\text{C}$
Coolest day	Monthly lowest maximum temperature	$^{\circ}\text{C}$
Coolest night	Monthly lowest minimum temperature	$^{\circ}\text{C}$
Cool night frequency	Percentage of days when minimum temperature $< 10^{\text{th}}$ percentile of the (period)	%
Cool day frequency	Percentage of days when maximum temperature $< 10^{\text{th}}$ percentile of the (period)	%
Hot day frequency	Percentage of days when maximum temperature $> 90^{\text{th}}$ percentile of the (period)	%
Hot night frequency	Percentage of nights when maximum temperature $> 90^{\text{th}}$ percentile of the (period)	%
Warm spell	Annual count of days with at least 6 consecutive days when maximum temperature $> 90^{\text{th}}$ percentile (period)	Days
Diurnal temperature range (DTR)	Monthly mean difference between maximum temperature & minimum temperature.	$^{\circ}\text{C}$
Annual temperature range (ATR)	Difference between maximum temperature maximums and minimum temperature minimum.	$^{\circ}\text{C}$

Before using the T_{ry} series with confidence for the discussion and analysis of regional month-to-month and year-to-year fluctuations, it has to be demonstrated that it is indeed representative for the region as a whole (Kraus 1977; Nicholson 1986; Türkeş 1996). The validity of the regionalization for all series is tested using correlation coefficients. Like Nicholson (1986), any station correlating at less than 0.4 with the regional series is dropped and the regional series is recalculated, omitting data for that station.

Effects of errors and lack of consistency at individual stations often reduces when averaging data to calculate regional area series (del Rio *et al.* 2007; Jones *et al.* 1999). Homogeneity tests were applied on both station series and the area average series as discussed in section 2.4.1 above.

5.2.8 Trend analysis

Trends have been analysed using both parametric and non-parametric tests. The Mann-Kendall (MK) is a non-parametric method, which tests whether there is a trend in the time series including climatic data (CRCCH 2005). The n time series values ($X_1, X_2, X_3, \dots, X_n$) are replaced by their relative ranks ($R_1, R_2, R_3, \dots, R_n$) (starting at 1 for the lowest up to n). The test statistic S is:

$$S = \sum_{i=1}^{n-1} \left[\sum_{j=i+1}^n \text{sgn}(R_j - R_i) \right] \quad (4)$$

where

$$\begin{aligned} \text{sgn}(x) &= 1 \text{ for } x > 0 \\ \text{sgn}(x) &= 0 \text{ for } x = 0 \\ \text{sgn}(x) &= -1 \text{ for } x < 0 \end{aligned}$$

If the null hypothesis H_0 is true, then S is approximately normally distributed with:

$$\begin{aligned} \mu &= 0 \\ \sigma &= n(n-1)(2n+5)/18 \end{aligned} \quad (5)$$

The Z -statistic is therefore (critical test statistic values for various significance levels can be obtained from normal probability tables):

$$Z = |s| / \sigma^{0.5} \quad (6)$$

A positive value of s indicates that there is an increasing trend and vice versa. The null hypothesis H_0 assuming that there is no trend in the data is either accepted or rejected if the computed Z_s statistics is less than or more than the critical value of the Z -statistics obtained from the normal distribution table (Kampata *et al.* 2008). Significance levels used in the study are 0.01, 0.05 and 0.10. The MK statistics has the advantage of making no assumptions about the statistical distribution of variables (Mahli and Wright 2004).

For the purpose of cross verification a trend was also identified using the Linear Regression test. It tests whether there is a linear trend by examining the relationship between time (t) and temperature (T). The regression gradient is estimated by (CRCCH 2005):

$$b = \frac{\sum_{i=1}^n (t_i - \bar{t})(T_i - \bar{T})}{\sum_{i=1}^n (t_i - \bar{t})^2} \quad (7)$$

And the intercept is estimated as:

$$a = \bar{T} - b\bar{t} \quad (8)$$

The test statistic S is:

$$S = b / \sigma$$

$$\text{where } \sigma = \sqrt{\frac{12 \sum_{i=1}^n (T_i - a - bt_i)}{n(n-2)(n^2-1)}} \quad (9)$$

The test statistic S follows a student – t distribution with $n-2$ degrees of freedom under the null hypothesis (critical test values for various significance levels can be obtained from student's t statistic tables). The linear regression test assumes that the data are normally distributed and that the errors (deviations from the trend) are independent and follows the same normal distribution with zero mean. Data was tested for normality using a normal probability plot (Chambers 1983). This is a graphical technique for assessing whether or not a data set is approximately normally distributed. Data are plotted against a theoretical normal distribution in such a way that the points should form an approximate straight line. Departures from this line indicate departures from normality. Plots indicated that data points nearly form a linear pattern, implying a normal distribution (plots not shown) making it suitable for a linear regression trend analysis.

5.3. Results and discussions

5.3.1 Homogeneity test of station DTR series.

Homogeneity test results show that, all eight stations used in the study have experienced statistically significant step jumps in their DTR series. Six of the stations showed strong evidence against the H_0 (no change) at a < 0.01 . They include Entebbe, Mbarara, Namulonge, Soroti, Tororo and Kabale. Jinja station DTR series indicate a significant change at 5% significant level, whereas DTR series at Masindi station show a step jump which is not statistically significant at a $= 0.10$. Another outcome of the analysis is that both cumulative deviations and Worsely likelihood tests detected change points at around the same years at almost all stations, except for Masindi which showed a big difference (not shown). All the four tests lead us to a conclusion that the series were not homogeneous and therefore, had experienced significant changes.

5.3.2 Intra-annual variance in $mxT_{\max}$ and $mnT_{\min}$ station temperatures

Analysis of station temperature reveals that, trend of $mxT_{\max}$ for Namulonge station is decreasing (-0.03), while a station like Entebbe depicts an increasing trend (0.70), in the respective period of analysis and both are statistically significant. In contrast Entebbe has decreasing $mnT_{\min}$ (-0.02), which is significant (Table 5.3). Majority of the stations which include; Mbarara, Entebbe, Namulonge, Jinja, Kabale and Masindi reveal that $mxT_{\max}$, have

varied more in the period of analysis compared to what has been experienced in Soroti and Tororo. Great variability in mnT_{min} is also experienced in Namulonge, Soroti, Entebbe, Jinja, Mbarara, Masindi and Tororo (table 3). In comparison to temperatures observed at the rest of the stations mxT_{max} in Soroti are less varied (32%), at the same time Soroti exhibits high variability in mnT_{min} (121%). And Kabale has the lowest of the CV in its mnT_{min} (42%). Overall, Tororo has the lowest variability in its temperature variables.

The study did not venture into finding out the reasons behind this kind of temperature behaviour. There is a possibility that, the trend of temperatures observed at Entebbe and Namulonge stations could be attributed to their location (figure 5.1), intense human activities and influence of urbanization which have modified the local terrain. The study also reveals that, in their second normal, Entebbe, Jinja and Mbarara have experienced more variation in mxT_{max} . More variation has also happened within the mnT_{min} of Entebbe, Jinja, Namulonge and Tororo (Table 5.3). The area average series pattern also demonstrates a general decline of the within-year variance of the monthly temperature means (Table 5.3).

Generally, the mean trend in intra-annual variance is decreasing, but the downward trend is not statistically significant (figures 2a – 2h). The coefficients of variance calculations reveal that maximum temperatures of the area average series are more varied compared to the minimum temperature at these stations of Uganda (Table 5.3).

5.3.3 Trends in extreme temperature and temperature events.

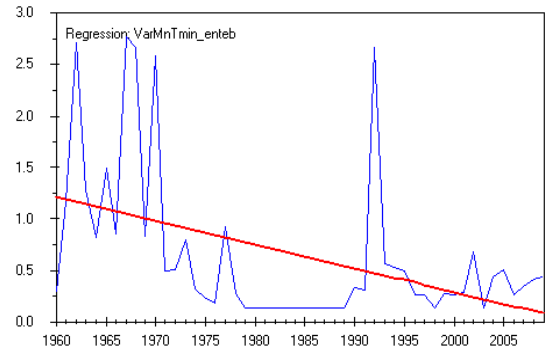
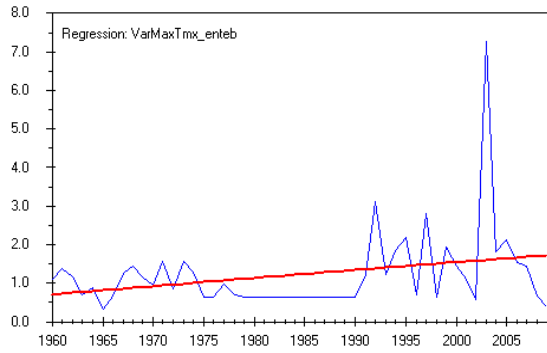
5.3.3.1 Hot extremes (Hot days, Warm nights, Hottest day, Hot night, Coolest day and Warm spells).

The study reveals that, hottest days have increased significantly in the period of analysis at all stations. This positive trend in hottest days signifies that, Uganda is experiencing increased incidents in the extremes of the maximum temperature. This positive trend is strong for Mbarara, Masindi and Kabale (Table 5.4). Furthermore results show that hot days ($>25^{\circ}\text{C}$) have increased significantly at all the stations. The magnitude of change is very strong for Mbarara, Namulonge and Tororo stations. The increase in hot days however for Entebbe and Soroti is not statistically significant. Similarly the coolest day analysis at all the stations depicts a positive trend. The trend is statistically significant at $p<0.01$ for six of the stations, but very strong for Tororo and Masindi (Table 5.4). The increase experienced in Jinja and Entebbe however, is not statistically significant.

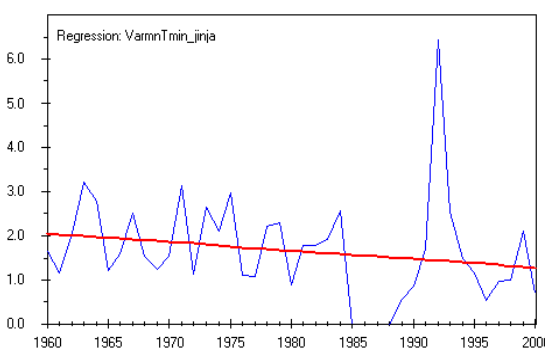
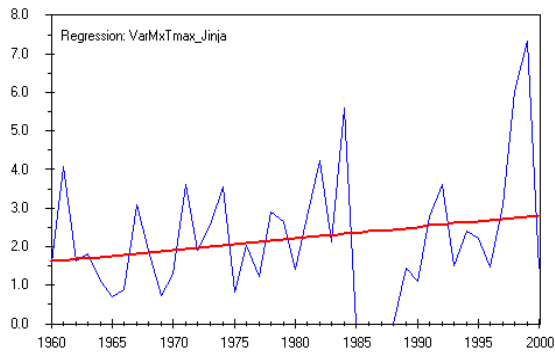
Furthermore, the study has revealed a strong significant positive trend for warm nights in Entebbe and Masindi, while the trend at Namulonge is negative and statistically not significant (Table 5.4). Hot nights have increased over the analysis period at all stations except for Namulonge where the decrease is not significant (Table 5.4). The frequency of hot days is also high at Soroti (38.9%), Tororo (34.5%) and Kabale (33.1%) and lowest at Mbarara (20.4%). The frequency of hot nights is high in Masindi (32.9%) and Soroti (33.3%), while Mbarara shows the lowest of hot night frequencies.

Table 5.3. Showing linear trend results, determination coefficient (R^2) and coefficient of variance (CV), for maximums of maximum temperature and minimums of minimum temperature for station and area average series in Uganda.

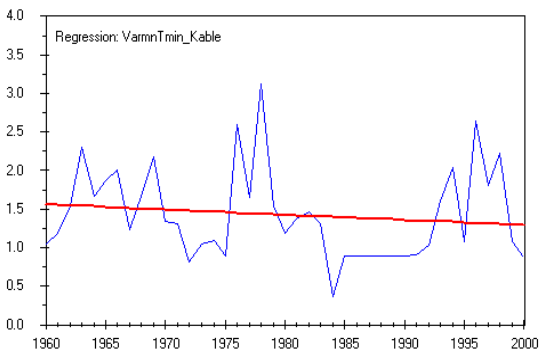
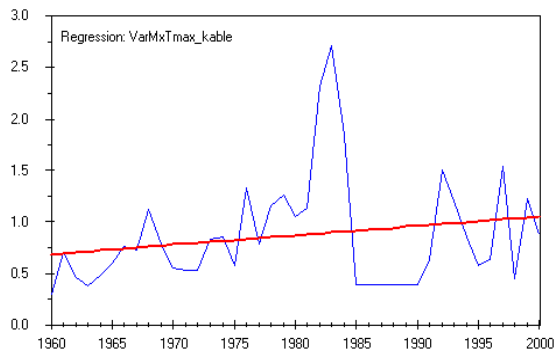
Meteorological Station Name	Period of analysis	Maximums of maximum Temperature (mxT_{max})			Minimums of minimum Temperature (mnT_{min})		
			R^2	CV		R^2	CV
Entebbe	1960- 2009	0.70	0.08	86%	-0.02	0.19	116%
	1960- 1989	-0.02	0.23	37%	-0.06	0.40	113%
	1980- 2009	0.05	0.10	96%	0.01	0.02	125%
Jinja	1960- 2000	0.003	0.05	73%	-0.02	0.04	70%
	1960- 1989	-0.02	0.01	72%	-0.05	0.23	58%
	1971- 2000	0.03	0.02	73%	-0.03	0.03	81%
Kabale	1960- 2000	0.01	0.04	61 %	-0.01	0.02	42%
	1960- 1989	0.02	0.09	67%	-0.02	0.12	42%
	1971- 2000	0.00	0.00	61	0.00	0.00	47%
Masindi	1965- 2000	0.01	0.00	50%	0.00	0.00	57%
	1965- 1994	-0.02	0.01	50%	0.01	0.01	58%
	1971- 2000	-0.00	0.00	49%	0.00	0.01	57%
Mbarara	1960- 2008	0.01	0.02	87%	-0.01	0.07	68%
	1960-1989	-0.01	0.01	65%	-0.02	0.03	73%
	1979- 2008	0.02	0.01	94%	0.01	0.05	52%
Namulonge	1953- 2008	-0.03	0.08	69%	-0.01	0.00	134%
	1953-1982	-0.02	0.01	71%	-0.03	0.04	58%
	1979- 2008	-0.04	0.1	58%	-0.12	0.07	165%
Soroti	1971 -2000	-0.03	0.05	32%	-0.00	0.00	121%
Tororo	1961- 1996	-0.00	0.00	46%	-0.00	0.00	55%
	1961- 1990	-0.01	0.00	46%	-0.02	0.09	58%
	1967- 1996	0.02	0.001	43%	-0.01	0.01	58%
Area average series	1965- 2000	-0.03	0.06	140%	-0.00	0.01	96%
	1965- 1994	-0.04	0.06		-0.01	0.11	
	1971- 2000	-0.05	0.10		-0.00	0.00	



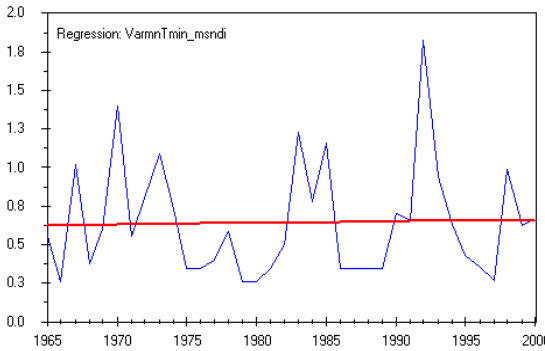
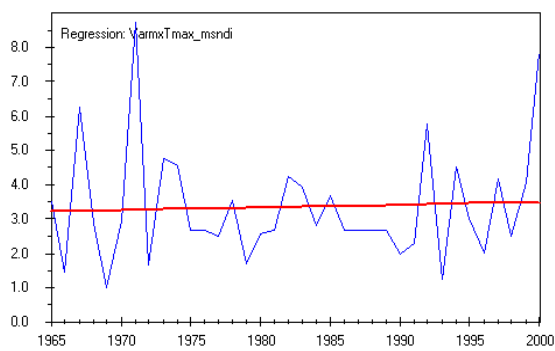
a)



b)



c)



d)

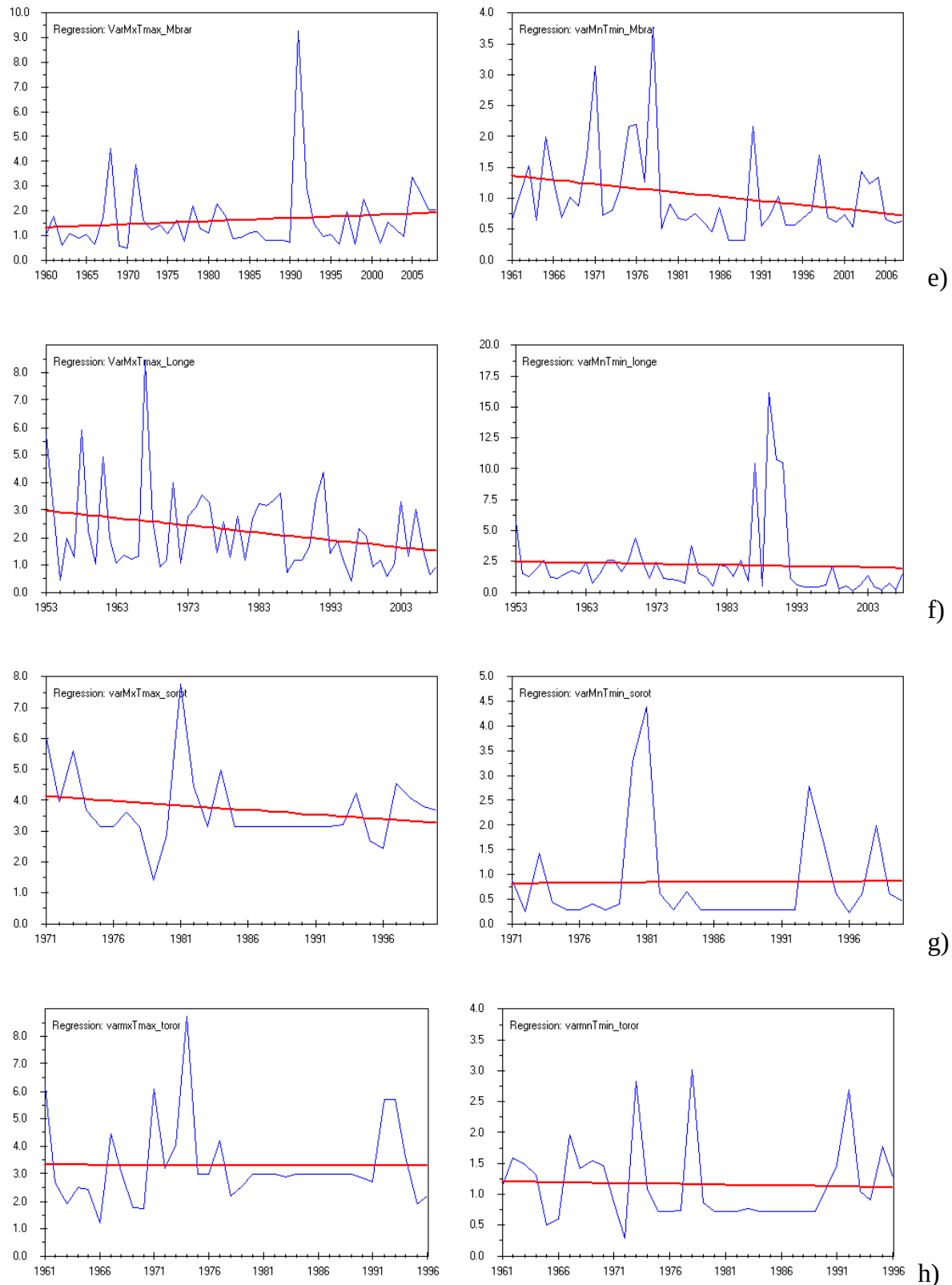


Fig. 5.2(a –h) above show plots for trends in variance for stations in Uganda namely; (a) Entebbe, (b) Jinja, (c) Kabale, (d) Masindi, (e) Mbarara, (f) Namulonge, (g) Soroti, (h) Tororo. Figures on the left represent mxT_{max} , and those on the right represent mnT_{min} .

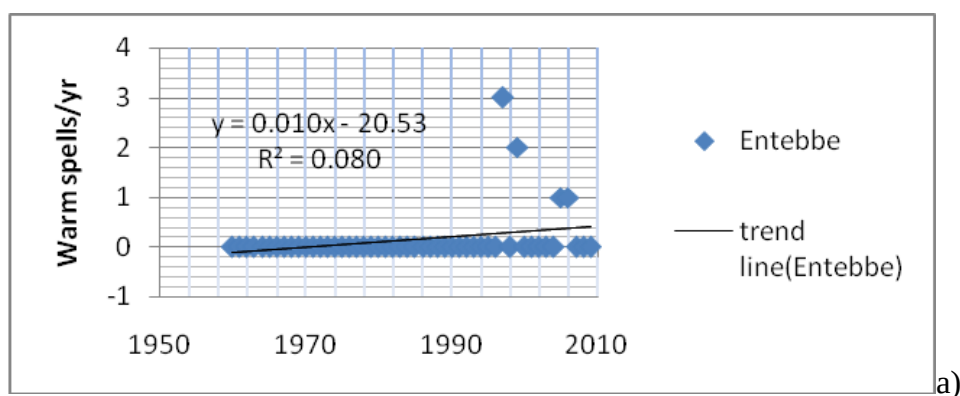
Table 5.4. Trends in hot extreme indices of temperature and Mann- Kendall test for trend (z-statistics) at reference stations in Uganda.

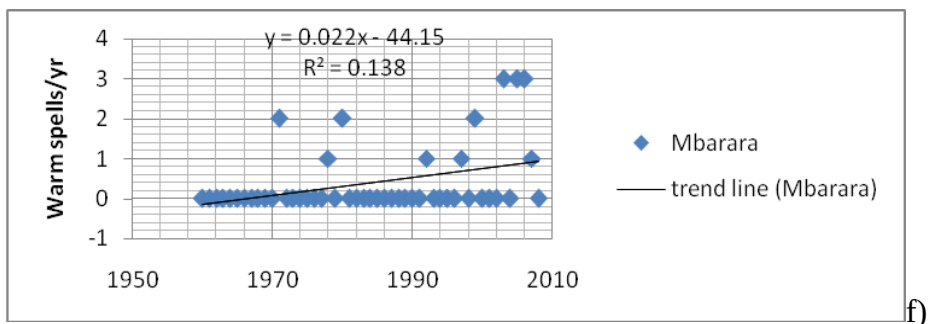
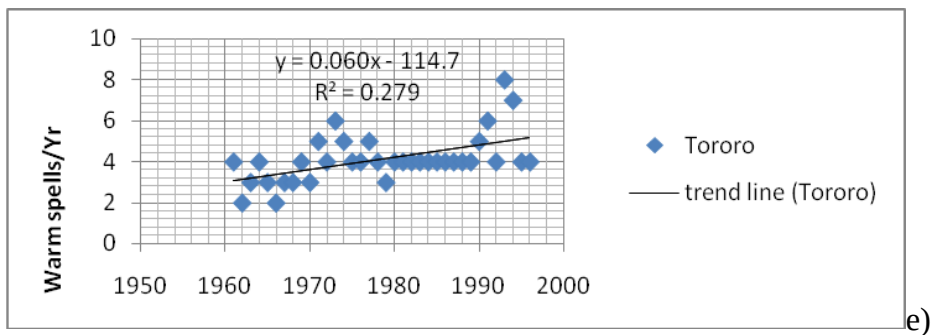
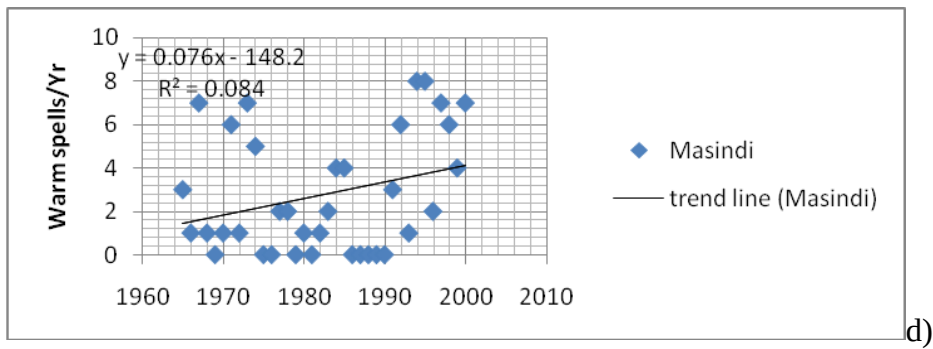
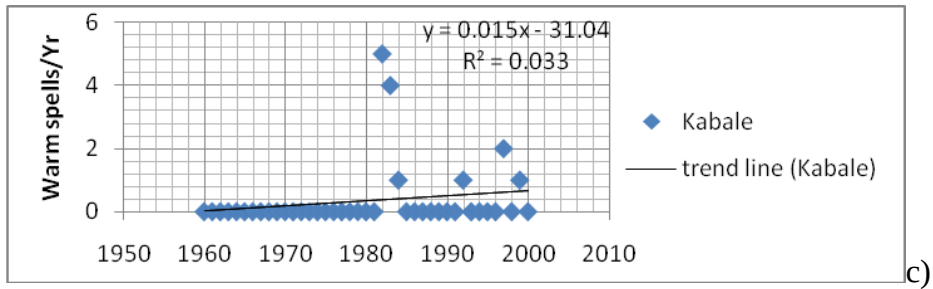
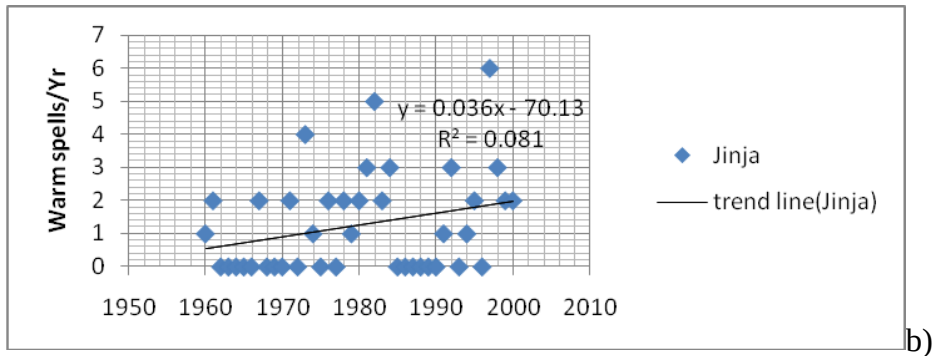
Indices	Unit	Entebbe	Jinja	Kabale	Masindi	Mbarara	Namulonge	Soroti	Tororo
Hot days	Days	0.94 ^d	1.91 ^c	2.41 ^b	2.30 ^b	3.69 ^a	3.94 ^a	0.38 ^d	3.51 ^a
Warm nights	Days	2.97 ^a	1.79 ^c	0 trend	2.87 ^a	0 trend	-0.81 ^d	0.64 ^d	1.64 ^d
Hottest day	⁰ C	2.94 ^a	2.46 ^b	4.42 ^a	5.68 ^a	6.51 ^a	2.53 ^b	3.23 ^a	3.66 ^a
Hot day frequency	%	26.6	25	33.1	28.2	20.4	24.0	38.9	34.5
Hot night frequency	%	21.5	21.95	20.7	32.9	13.4	16.4	33.3	15.5
Coolest day	⁰ C	0.72 ^d	1.46 ^d	2.31 ^a	3.66 ^a	2.97 ^a	2.98 ^a	2.80 ^a	4.05 ^a
Period	Years	1960-2009	1960-2000	1960 - 2000	1965- 2000	1960 - 2008	1953- 2008	1971- 2000	1961- 1996

^aTrends statistically significant at $p < 0.01$; ^bTrends statistically significant at $p < 0.05$

^cTrends statistically significant at $p < 0.10$; ^dNo significant trend

Detailed analysis of maximum temperatures shows that, warm spells have increased during the period of study. Warm spells often occur during the first quarter of every year and their trend is increasing (figures 5.3a-3h). The graphs indicate that, high counts of warm spells have been more apparent after the 1980s at all stations.





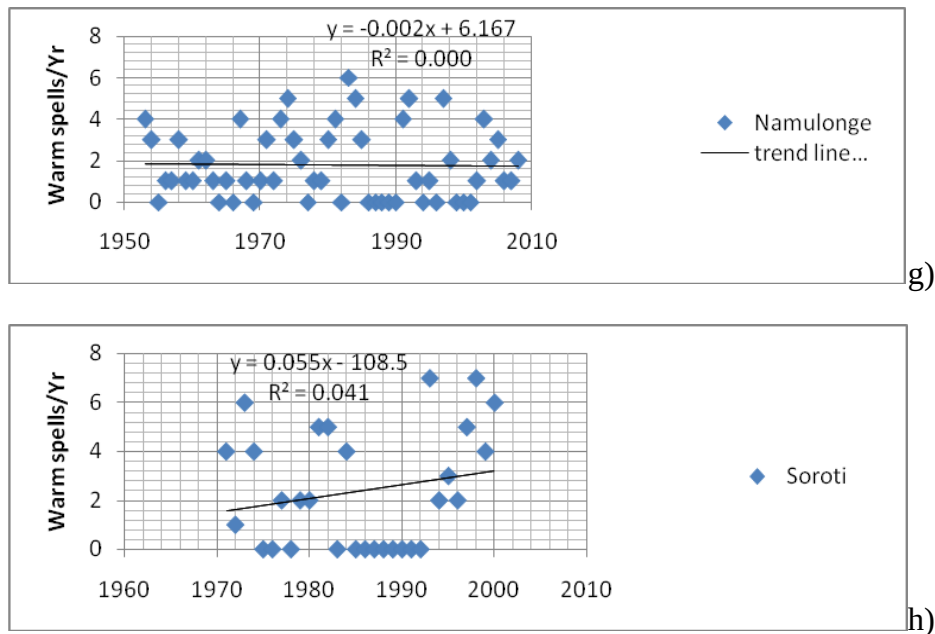


Fig. 5.3 (a-h) shows distributions of warm spells at different stations used for the study.

5.3.3.2 Cold extremes (cool night, cool day, hottest night and coolest night).

The frequency of cool days is high at Soroti (38.9%), Entebbe (36.5%) and Tororo (30.1%), and lowest at Namulonge and Kabale (23%). Analysis also reveals a positive trend ($p < 0.01$) for the coolest nights for all the stations except at Soroti, which reflected a no significant trend (Table 5.5). The magnitude of trend is strong for Mbarara, Entebbe, Masindi and Kabale. Cool night frequency is very high in Kabale (30.3%) and lowest in Soroti (10.3%), which could be partly due to altitude (Table 5.1). Hottest night temperatures for Entebbe, Kabale, Masindi, Mbarara, and Tororo show very strong positive trends at $p < 0.01$ (Table 5.5).

Table 5.5. Trends in cold extreme indices of temperature and Mann- Kendall test for trend (Z-statistics) at reference stations in Uganda.

Indices	Unit	Entebbe	Jinja	Kabale	Masindi	Mbarara	Namulonge	Soroti	Tororo
Coolest night	$^{\circ}\text{C}$	6.31 ^a	3.24 ^a	5.38 ^a	5.54 ^a	6.77 ^a	2.99 ^a	0.55 ^d	3.96 ^a
Cool night frequency	%	12.5	19.3	30.3	17.8	13.5	21.9	10.3	23.4
Cool day frequency	%	36.5	28.9	23.4	27.5	27.0	23.2	38.9	30.1
Hottest night	$^{\circ}\text{C}$	5.19 ^a	1.45 ^c	4.17 ^a	5.75 ^a	6.54 ^a	-1.29 ^d	1.39 ^d	4.73 ^a
Period	Years	1960-2009	1960-2000	1960-2000	1965-2000	1960-2008	1953-2008	1971-2000	1961-1996

^aTrends statistically significant at $p<0.01$; ^bTrends statistically significant at $p<0.05$

^cTrends statistically significant at $p<0.10$; ^dNo significant trend

5.3.3.3 Mean annual Diurnal temperature range (DTR)

Results show that, mean annual DTR trend at six (Entebbe, Jinja, Kabale, Masindi, Mbarara and Tororo) of the stations is negative, but the magnitude for Entebbe and Mbarara is very strong. On the other hand, positive trends are experienced at Namulonge and Soroti at $p<0.01$ (Table 5.6). This finding concurs with Kruger and Shongwe (2004) that, the general global trend for diurnal temperature range has been negative. This decline in DTR resulting from decrease in minimums shows that, temperatures have warmed, which result is not very different from what Nicolls *et al.*, 1996 in (Hulme *et al.*2001) has found to have happened to most of the global surface temperatures.

Table 5.6. Trends in diurnal range of temperature and Mann- Kendall test for trend (Z-statistics) at reference stations in Uganda.

Indices	Unit	Entebbe	Jinja	Kabale	Masindi	Mbarara	Namulonge	Soroti	Tororo
DTR	⁰ C	-6.39 ^a	-0.67 ^d	-1.32 ^d	-1.21 ^d	-4.05 ^a	3.09 ^a	3.76 ^a	-0.84 ^d
Period	Years	1960-2009	1960-2000	1960 - 2000	1965-2000	1960 - 2008	1953- 2008	1971-2000	1961-1996

^aTrends statistically significant at $p<0.01$; ^bTrends statistically significant at $p<0.05$

^cTrends statistically significant at $p<0.10$; ^dNo significant trend

5.3.3.4 Annual temperature range (ATR)

The study also reveals that the trend for annual temperature range ($mxT_{max} - mnT_{min}$) for seven of the stations is negative (Table 5.7). This decreasing trend is strong for Entebbe and Mbarara while stations of Jinja, Kabale, Masindi, Namulonge and Tororo have trends, which are not statistically significant. This implies that the gap between maximum and minimum extremes is reducing which supports the fact that minimums are warming at the studied stations.

Table 5.7. Trends in annual range of temperature and Mann- Kendall test for trend (Z-

Indices	Unit	Entebbe	Jinja	Kabale	Masindi	Mbarara	Namulonge	Soroti	Tororo
ATR	⁰ C	-4.94 ^a	-0.49 ^d	-1.57 ^d	-0.69 ^d	-3.64 ^b	-0.07 ^d	2.05 ^c	-0.94 ^d
Period	Years	1960-2009	1960-2000	1960-2000	1965-2000	1960-2008	1953- 2008	1971-2000	1961-1996

statistics) at reference stations in Uganda.

^aTrends statistically significant at $p<0.01$; ^bTrends statistically significant at $p<0.05$

^cTrends statistically significant at $p<0.10$; ^dNo significant trend

5.3.4 Trends in mean monthly maximum, minimum and mean annual temperature.

5.3.4.1 Area averaged trend

There are 8 available meteorological stations with over 35 years of temperature record for this study. These records have been aggregated into area average annual series following the method in the section 2.7 above. Correlation Coefficients tests show that, station series correlate between 0.1 and 0.9 (Figure 5.4). Series whose correlation was below 0.4 were omitted while generating the area average series for a particular variable.

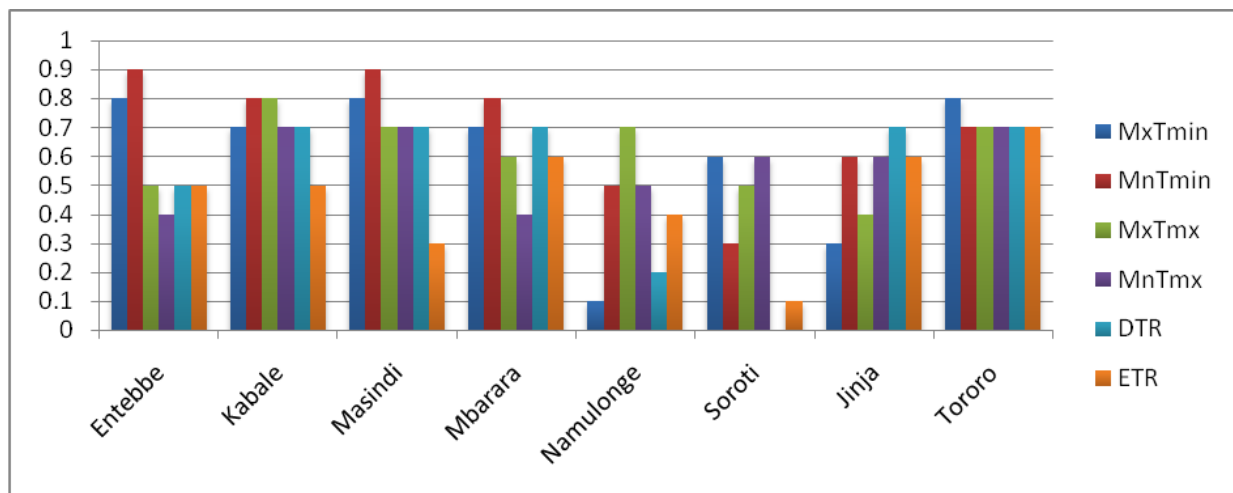


Figure 5.4: Frequency distribution of correlation coefficients between rainfall at individual stations and the corresponding regional average annual series.

Overall, this criterion results in 6 stations for mxT_{min} series, having omitted Namulonge and Jinja; 7 stations for mnT_{min} series, excluding Soroti; 8 stations for mxT_{max} and mnT_{max} series, 6 stations for DTR, without Namulonge and Soroti and ATR not including Masindi and Soroti series.

The analysis indicates that the area average climate series derived for the region has experienced positive trends of mnT_{max} , mnT_{min} , mxT_{max} , mnT_{max} temperature series for the last 41 years. The Z values for the MK statistic reveals that annual series have experienced very strong significant trends in the past decades. There is an indication that both daytime and nighttime hot extremes are increasing. Such a finding is not far from what New *et al.* (2006) has found in their study. Evidence against null hypothesis (H_0) for mnT_{max} , mnT_{min} , mxT_{max} and mnT_{max} for every month is strong and statistically significant ($\alpha < 0.05$ and $\alpha < 0.1$). On the other hand the increasing trends within the minimums (mnT_{min} and mxT_{min}) shows very strong evidence against H_0 . Majority of the months are statistically significant at $\alpha < 0.01$ (table 5.8). The changes are statistically significant except for a few months of the maximum temperatures indicated in bold. It can be concluded for this region that the nights are warming faster compared to the day. This research is not able to explain the cause of such warming, which could be a result of higher humidity levels that can contract the daily temperature range among other factors.

Table 5.8. Trends in monthly maximum, minimum and annual temperature and Mann-Kendall test for trend (z-statistics) of the area average climate series in Uganda.

Indices	Tests	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Minimum Temp Maximum	L.Reg test (σ)	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
	MK test z)	0.67	1.76	1.75	0.88	0.12	1.03	1.62	2.01	1.63	0.57	2.39	2.85	3.17
	Signif.	=0.10	<0.1	<0.1	=0.10	=0.10	=0.10	=0.10	<0.05	=0.10	=0.10	<0.05	<0.01	<0.01
Minimum Temp Minimum	L.Reg test (σ)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	MK test z)	3.44	3.50	3.77	1.72	3.50	6.25	5.57	4.84	4.67	4.3	3.68	4.82	5.93
	Signif.	<0.01	<0.01	<0.01	<0.1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Maximum Temp Maximum	L.Reg test (σ)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	MK test z)	2.04	2.57	2.01	1.85	3.19	2.67	3.79	2.72	3.1	1.92	1.15	1.42	4.50
	Signif.	<0.05	<0.05	<0.05	<0.1	<0.01	<0.05	<0.01	<0.01	<0.01	<0.1	=0.10	=0.10	<0.01
Maximum Temp Minimum	L.Reg test (σ)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	MK test z)	3.75	2.62	2.78	2.50	1.98	3.75	4.1	4.28	4.19	4.01	3.77	3.54	5.01
	Signif.	<0.01	<0.01	<0.01	<0.05	<0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 5.9. Test results for trends on ATR and DTR indices of the area average series

Indices	Unit	Mann-Kendall test	Linear trend test
ATR	$^{\circ}\text{C}$	(S) -231	Sigma: 0.02
		(Z) -2.58	t-statistic: -3.04
		Significant trend at ($\alpha < 0.01$)	Significant trend at ($\alpha < 0.01$)
DTR	$^{\circ}\text{C}$	(S) -138	Sigma: 0.02
		(Z) -1.87	t-statistic: -3.19
		Significant trend at ($\alpha < 0.1$)	Significant trend at ($\alpha < 0.01$)

Tests indicate that ATR and DTR series have statistically significant decreasing linear trends ($\alpha < 0.01$) at a rate of 0.1% per annum. New *et al.* (2006) also found a decrease in DTR trends for countries north of their study region, among which is Uganda.

Bodri and Cermak (2003) observe that climate systems are variable on all time scales, and are better understood when one focuses on changes in climate variability and climate extremes. Simulations of climate predict not only climate warming but also a general decrease in climate variability. Our findings reveal an observed mean trend towards warmer temperature in Uganda, characterized by an increase in the minimum daily temperature. Maximum daily temperatures have increased at a much smaller rate, resulting in a decreasing trend in the diurnal temperature range. This is consistent with the mean global trend which is projected to decrease (Stone and Weaver 2003). The increase in hot nights at most of the stations investigated, will impact on people who have to spend more on cooling facilities. In situations where one cannot afford to purchase a fan, then they will be forced to keep windows open at night to allow cool air into the house. Such a practice will have consequences in that, household members will be exposed to mosquito bites and thus may catch malaria.

The warming trend is likely to exacerbate the constraints on life and livelihood activities, water resources for human consumption and watering of livestock as well as affecting crop water balances. Domestic livestock like other animals have a climate envelope in which they perform optimally. Increase in temperatures will lead to decline in milk and meat production, largely because animals remain in shades instead of foraging (Boko *et al.* 2007). In the tropics and sub-tropics in which Uganda is located, most of the crops are generally assumed to already have reached their highest temperature tolerance levels, and studies indicate that crop yields would be reduced as a result of increases in temperature, hence affecting food security. Additional evidence points to pest incidences e.g. Coffee Berry borer, (Jaramillo *et al.* 2009) increasing in response to a rise in temperatures and this might result in reductions in crop production (IPCC 2007). The response of increased temperatures on water demand and feed resources of livestock is something that should be considered (Thornton *et al.* 2007).

5.4 Conclusions

This study is a first attempt to characterize near surface temperature and its variability in Uganda in recent decades. We have unveiled trends and other properties of temperature at selected stations from the central, eastern, southern and western parts of the Uganda. Data was tested for normality as required to test for linear regression trend analysis, and showed normal distribution. The series were also tested for homogeneity, in which we established that there were not homogeneous, but this inhomogeneity could not be explained because of the absence of historical metadata. Missing gaps in the data set were filled using long term means as recommended by Jones *et al.* (1999) which altered the data set slightly, but means did not change. The study has revealed that maximum temperatures of the region are more variable compared to minimum temperatures. The mean trend in intra-annual variance is decreasing but not statistically significant. There is also evidence in data that warm spells vary per decade which require further understanding. Further analysis to identify abrupt changes can be done using other tests like isotonic regressions (Barlow and Brunk 1972; Dykstra and Robertson 1982), Csorgo and Horvath change point detection (Fergert 1994; Habibi *et al.* 2005) and moving cut data detrended fluctuation analysis (He *et al.* 2012). Since trends in long-term near surface temperature do exist, then government has to take proper actions to deal with the impacts of such trends on industry, fisheries, and agriculture. It also serves to fill the gap in the distribution of temperature trend analyses across the world as well providing useful information to the government of Uganda.

Acknowledgments

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5. REFERENCES

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CHAPTER 6

Analysis of mid-twentieth century rainfall trends and variability over southwestern Uganda.*

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6.1 Introduction

The association between climate, natural resources and socio-economic activities has led to the demand for accurate information on the future of climate and the associated natural systems like the water cycle and its management (Ogallo 1993). This is paramount in water resource planning, agricultural planning, flood frequency monitoring, climate change impacts, environmental assessments and ecology (Ngongondo *et al.* 2011; Michaelides *et al.* 2009; Ceballos *et al.* 2004). Such information is still scarce because of the few studies that have analyzed the relationship of climate patterns and water management among other natural systems especially in the East African region. For example, (Kampata *et al.* 2008, New *et al.* 2006, Schreck and Semazzi 2004, Kruger and Shongwe 2004, Mahe *et al.* 2001, King'uyu *et al.* 2000, Nicholson 1996, Ogallo 1993, Beltrando 1990, Rodhe and Virji 1976, Samson 1952) are among the most recent studies concerning long-term climatological trends that have focused on surface air temperature and precipitation in Africa. From these and other studies, a range of potential climatic impacts on water management for various geographic areas, flood prevention and control, drought management, food and fibre production etc can be hypothesized. When it comes to reviewing germane studies in Uganda, a limited number appear to be available. For example, on the temporal distribution of rainfall in the Lake Victoria basin, Kizza *et al.* (2009) reported that the Lake Victoria basin experienced a predominantly positive trend over the twentieth century. Phillips and McIntyre (2000) investigated the sub-regional significance of El Niño-Southern Oscillation (ENSO) events in Uganda, distinguishing between unimodal and bimodal rainfall zones from 1931 to 1960 for 33 sites. They detected a significant correlation between ENSO events and rainfall seasons. Basalirwa (1995) applied the principal component analysis on monthly records from 102 rain-gauge stations for the years 1940- 1975 to delineate Uganda into 14 homogeneous climatological zones aligned with the spatial pattern of the physical features.

Research focusing on national or regional analysis of climatic parameters has not been exhaustive that is why more studies using different methodologies are recommended (Ngongondo *et al.* 2011). The motivation for this study was to further investigate the temporal and spatial rainfall characteristics including trends for Uganda at high spatial scales, for example, in the Albert-Victoria water management area using old data records. This study fills in the gap for baseline data concerning trend analysis in Uganda, hence the period 1940-1977. Information on whether trends exist in Uganda's rainfall is useful for the Ugandan government to carry out effective water resource planning and management in the future. It will also serve to fill the gap in the map of rainfall trend analyses in the world. Uganda is a small country with a wealth of water resources that are also transboundary. Lack of information on the characteristics of these natural water resources may result in poor decisions on Uganda's economy and human health which are vulnerable to climatic anomalies. As demonstrated, a few studies (Samson 1952; Kizza *et al.* 2009) have been done to investigate trends and variability of rainfall in Uganda. For instance, Samson (1952) investigated trends of East Africa rainfall and used only 14 stations from Uganda to the year 1949. On the other hand, Kizza *et al.* (2009) used six stations found in the Victoria basin of

Uganda to study the temporal variability in the Lake Victoria basin during the twentieth century and only data from 6 stations from Uganda was analysed. The main objectives of this chapter are (1) to describe the spatial patterns of rainfall and concentration, and the inter-annual variability of annual and monthly rainfall concentration for the period 1943 – 1977 using 58 station locations in the Albert-Victoria water management area of Uganda and (2) to analyze the rainfall trends based on both monthly and annual series using parametric and non-parametric tests.

6.2 Dataset and Methodology

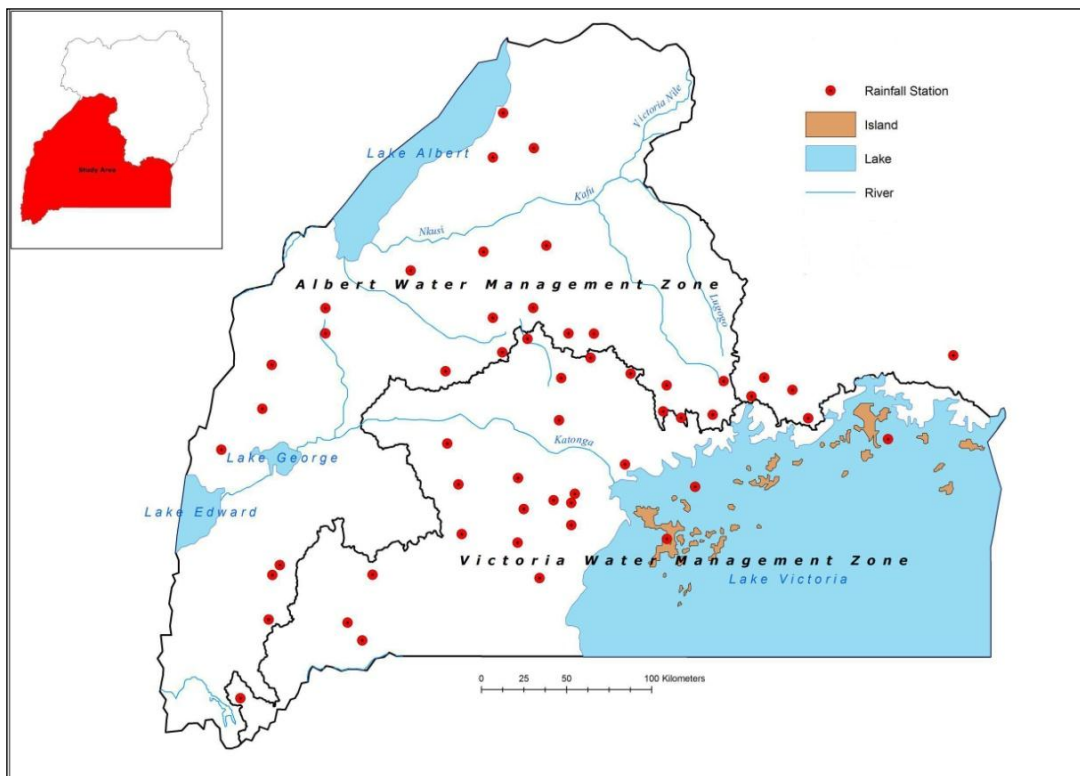
6.2.1 Study area

The Albert-Victoria water management area is located to the north and west of the Lake Victoria basin in Uganda (Figure 6.1). The area is traversed by the equator, has a number of water bodies, and varying topography. It is also characterized by a dense network of rivers, which draw its water from the different water catchment areas into the main water bodies. For this particular study, the Albert-Victoria area comprises two water management zones; the Albert water management zone (here after Awmz) and the Victoria water management zone (hereafter Vwmz).

The Awmz covers an area of approximately 45,000km², which falls into two distinct terrain systems. The North West sloping peneplain found at 1000 – 1200 meters above mean sea level (a.m.s.l) contributes to the Kyoga catchment, and the rift valley catchment which discharges into Lake Albert at a mean lake level of 615m (a.m.s.l). It receives relatively low mean annual rainfall with most parts receiving less than 875mm. Rainfall averages increase towards the highlands, largely due to orographic influence. The Awmz extends to Butiaba in the north which lies at altitude 615m (a.m.s.l), with mean rainfall of 698mm and south wards to Kabale meteorological station found at an altitude of 5400m (a.m.s.l). This Awmz has potential for hydropower production on sites along the Nile River and geothermal power production sites. Population is estimated at about 4.5 million, with agriculture as the major industry albeit with significant fishing activities on Lake Albert and an oil development sector.

The Vwmz covers about 78100km² spread into two distinct terrain systems to the east and to the west direction, such as the gently sloping peneplain of the catchment discharging into Lake Victoria and the rift valley catchments which discharge into lakes Edward and George. The furthest station in the east is Bugiri, elevated at 1185m (a.m.s.l). The Vwmz is characterized by the abundant surface and ground water resources. It has also the highest installed and potential hydropower production potential. Population in this zone is estimated at about 9million with agriculture as the major industry albeit with significant urbanization and moderately active industry and mining sectors.

The major climate parameter which has the highest space-time variation over two water management zones (Fig 6.1) is rainfall. Rainfall determines the spatial patterns of the natural resources and land use activities. Basarilwa (1995) outlines the major systems which control the space-time characteristics of rainfall in Uganda.



known values. The method involves estimating a new value by connecting two adjacent known values with a straight line. A simple linear model can be defined as below:

$$y = \beta_0 + \beta_1 x \quad (1)$$

where β_0 is the intercept and β_1 is the slope. Let the difference between the observed value of y and the straight line ($\beta_0 + \beta_1 x$) is the error ε . It is convenient to think of ε as a statistical error, that is, a random variable that accounts for the failure of the model to fit the data exactly.

$$y = \beta_0 + \beta_1 x + \varepsilon \quad (2)$$

Equation (2) is called a Linear Regression (LR) model. Customarily x is called the independent (regressor) variable and y is called the dependent variable. Because Equation (2) involves only one regressor variable, it is called a simple LR model (Sahin and Cigizoglu 2010).

6.2.2.2 Homogeneity testing

The literature suggests that a change, however minor it may be in the stations environment or observation methods, can artificially alter the mean measurements and make the series suspect (Menne and Williams 2005) or not homogeneous. These inhomogeneities manifest themselves in two basic ways: as a gradual trend or as a discontinuity in the mean or variance (Easterling *et al.* 1996). Inhomogeneities in the statistical properties of climatological variables such as long-term means, trends or standard deviations (Pandžić and Likso 2009) can be detected using absolute and relative homogeneity tests. Buishand (1982) and Peterson *et al.* (1998a, b) have discussed in detail the application of relative and absolute tests. Detailed mathematical development of the tests is also discussed in Wijngaard *et al.* (2003) while Ducre-Robitaille *et al.* (2003) provides a comparison between the techniques.

In this study, homogeneity of the rainfall records has been analysed by five tests including: (1) the von Neumann ratio (V), (2 and 3) the cumulative deviations ($Q/n^{-0.5}$ and $R/n^{-0.5}$) and (4 and 5) the Bayesian procedures (U and A). Three of these tests have been used by Gemmer *et al.* 2004 to analyse precipitation records in China. The same tests have been highly recommended in literature cited by Sahin and Cigizoglu (2010) to be superior when dealing with series with known physical parameters affecting the homogeneity.

6.2.2.3 Test for randomness and persistence

Procedures used to detect trends and variability requires that data should be random and persistence free. Autocorrelation was used to test for such randomness and independence (von Storch and Navara 1995):

$$r_k = \frac{\sum_{i=1}^{N-k} (x_i - m)(x_{i+k} - m)}{\sum_{i=1}^N (x_i - m)^2} \quad (3)$$

where r_k is the lag- k autocorrelation coefficient, m is the mean value of a time series x_i , N is the number of observations, and k is the time lag.

If the calculated r_k is not significant at 5% level, then the Mann-Kendall test is applied to the original values of the time series. Where the calculated r_k is significant, the datasets were smoothed using a 3-year moving average to reveal more persistent trend (Wheeler and Martin-Vide 1992). The smoothened time series may be obtained as:

$$\overline{y}_t = \frac{y_t + y_{t-1} + \dots + y_{t-n+1}}{n} \quad (4)$$

where y is the variable (such as rainfall), t is the current time period (such as the current month) and n is the number of time periods in average.

6.2.2.4 Rainfall mean characteristics

In this study, annual and monthly mean rainfall data was used to calculate rainfall mean characteristics for the area and for each station. We also use the precipitation concentration index (PCI) to evaluate the varying weight of rainfall (daily/monthly), to the total amount rainfall (Li *et al.* 2010) in order to understand monthly heterogeneity of rainfall amounts and its temporal trends. A modified version of (PCI) by Oliver (1980) in De Luis *et al.* (2000) was applied:

$$PCI = 100 \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i \right)^2} \quad (5)$$

where P_i is the rainfall amount of the i^{th} month, calculated for each of the stations and for each of the year (period) being considered. As described in the literature (Ceballos *et al.* 2004; Nel 2009; Ngongondo *et al.* 2011), PCI values below 10 indicate a uniform monthly rainfall distribution in the year, whereas values from 11 to 20 denote seasonality in rainfall distribution. Values above 20 correspond to climates with substantial monthly variability in rainfall amounts (Nel 2009 and references there in). A higher precipitation concentration index value also indicates that precipitation is more concentrated to a few rainy months during the year, and vice versa (Li *et al.* 2010; Zhao *et al.* 2011).

Furthermore, the normalized precipitation anomaly series of annual rainfall (AR) and PCI are used to test for inter-annual rainfall variability. These were normalized using a procedure

proposed by De Luis *et al.* (2000) and references there in. For a given station s , in a given year y , the ratio of each value to the mean for the reference period was defined as follows:

$$AR_{sy} = (R_{sy} - \bar{R}_s) / \bar{R}_s; APCI_{sy} = (PCI_{sy} - \overline{PCI}_s) / \overline{PCI}_s. \quad (6)$$

The absolute values of the anomaly series ($|AR|$ and $|APCI|$) will be used to detect changes in the amplitude of the inter-annual variability of the series.

6.2.2.5 Construction of the area-average rainfall series for regional trend analysis.

This can be achieved by a simple addition or arithmetic averaging of local rainfall values. But for this study, the original monthly precipitation series were converted to standardized monthly series (M_{sy}) by subtracting the long term mean ($\bar{R}_s$) from the original monthly values R_{sy} and then dividing by the standard deviation (σ_s) at each station. This process minimizes the problem of highly diverse means and variability and the randomness of the convective process reflected in the individual station totals (Nicholson 1986). The normalized monthly rainfall anomaly for a given station was computed as in Equation 7:

$$M_{sy} = (R_{sy} - \bar{R}_s) / \sigma_s \quad (7)$$

The area-averaged (regional mean climatology) normalized monthly rainfall anomaly (M_{ry}) for a given region is defined as in Equation 8;

$$M_{ry} = (1 / N_j) \sum_{s=1}^{N_j} M_{sy} \quad (8)$$

where N_j is the number of regional stations operating in the year j . The use of regional average, in general, provides a time series that demonstrates large-scale climatic processes (Partal and Kahya 2006), thus making it easier to deal with one index series in a region.

Before one can use the M_{ry} series with confidence for the discussion and analysis of regional month-to-month and year-to-year fluctuations, it has to be demonstrated that it is indeed representative for the region (Kraus 1977; Nicholson 1986; Türkeş 1996). In other words, it has to be shown that the spatial variations of (M_{sy}) are small, compared to the temporal variations of the whole region as represented by (M_{ry}). Kraus (1977) demonstrates that the variance in time can be estimated as follows:

$$var(t i m e) = \frac{\sum N_j M_{ry}^2}{J-1} \quad (9)$$

where N is the number of regional stations operative in the year j and J is the number of years of record for the series(M_{ry}). The mean spatial variance between rainfall anomalies within the region is estimated as follows:

$$v(area) = \frac{n - \sum_j N_j M_{ry}^2}{n - J} \quad (10)$$

where n , the total number of stations years, is calculated as follows:

$$n = \sum_j N_j = \sum_i J_i \quad (11)$$

The statistical importance of variance estimates (Variance in time/variance in area) is determined by the F test (Türkeş 1996).

6.2.3 Trend analysis

Approaches used for detecting trend in the time series can be either parametric or non-parametric. The most popularly used non-parametric test is the Mann-Kendall (MK) test (Mann 1945; Kendall 1955). It has been widely used for different climatic variables in various trend studies including those of (Kampata *et al.* 2008; Kizza *et al.* 2009; Ngongondo *et al.* 2010; Rai *et al.* 2010; Nsubuga *et al.* 2011). The MK test at a significance level of 5% has been applied to study the temporal trends of the following: a) total annual rainfall, and its coefficient of variability, b) month to month total rainfall and c) seasonal total rainfall (December to February, March to May, June to August and September to November) series.

For purposes of cross verification, a Linear Regression test was also carried out to identify whether there is a linear trend by examining the relationship between time and the variable of interest. The complete mathematical description of these methods can be found in CRCCH, (2005) and studies mentioned above.

The linear regression test assumes that the data are normally distributed and that the errors (deviations from the trend) are independent and follows the same normal distribution with zero mean. Data was tested for normality using a normal probability plot (Nsubuga *et al.* 2011). This is a graphical technique for assessing whether or not a data set is approximately normally distributed. Data are plotted against a theoretical normal distribution in such a way that the points should form an approximate straight line. Departures from this line indicate departures from normality.

Rainfall is one of the main variables that define the climate of a region so its spatial characterization is highly relevant. Spatial patterns of rainfall means, variability, trends and PCI across the area were investigated using ordinary kriging interpolation method (Ngongondo *et al.* 2010; De Luis *et al.* 2000). This method is robust in sparsely sampled regions (Ngongondo *et al.* 2010 and references there in) and the study area is such an ideal case for such a method. Normalized time series associated with September-October-

November (SON), March-April-May (MAM) and annual data were spectrally analyzed using spectral power density embedded in MatLab software package at 95% significance level.

6.3. Results and discussions

6.3.1 Quality control and homogeneity

Most of the stations used in the study had a certain percentage (5% -15%) of missing data. A threshold of not more than 10% missing data was set for the first step which resulted in the selection of 70 meteorological stations for study. A linear regression method explained in section 2.2 above was then applied to make the series complete. Thereafter only 58 stations, including those with missing data of not more than 5% were used for further analysis.

Annual series of rainfall at these stations were tested for homogeneity to reveal the following results. Nine of the stations (Rwashamaire, Kigorobya, Bugoye, Kisomoro, Kyembogo, Kijura tea Factory, Kyegegwa, Masindi, Nalweyo Gombolola) were identified by four of the tests as being not homogeneous. Three of the stations (Bumagi, Kabasanda and Kakumiro variety T.C) were found to be inhomogeneous by 3 of the tests. Three stations (Kawanda, King's College Budo and Nkozi Experimental farm) were rejected by two of the tests and only one station (Matete) was found to be inhomogeneous by one test at 5% significance level. Results show that majority of the station annual series were homogeneous. Stations, which were found not to be homogeneous by 3 or more tests at 5% significance, were only analyzed at station level and excluded from regional analyses. This decision was based on reasons, which can be found in literature such as (Easterling *et al.* 1996; Peterson *et al.* 1998a, b; Costa and Soares 2009; Domonkos 2011) and others. Therefore, for further analysis, the following station annual series were not used in generating a regional average rainfall series that represents the region namely; Bumagi, Kabasanda, Kigorobya, Bugoye, Kisomoro, Kyembogo, Kijura, Masindi, Nalweyo, Kakumiro, Kyegegwa, and Rwashamaire (Table 6.1).

6.3.2 Serial correlation

Examination for autocorrelation was applied on annual, monthly and seasonal series for each of the individual stations and tested for their significance at the 10 % significance level. The 10% significance was given preference, because real inhomogeneities might remain unrecognized at a lower significance level (Tu *et al.* 2005). Results showed that annual rainfall series data for 14 stations (shown in Table 3) did not come from a random process. The 14 annual series were then exposed to a smoothing process using equation 4, so that they can meet the independent identical distribution criteria, and thus run the Mann-Kendall test directly.

6.3.3.1 Annual rainfall series.

The key statistics of the data set used in the study is shown in Table 6.3. The maximum annual rainfall amount of rainfall (2004 mm) was observed on Bumagi- Ssesse Islands located in Lake Victoria, while the least mean annual rainfall (698 mm) was reported at Butiaba H.M station found along Lake Albert (fig. 6.4a). The highest recorded rainfall within the analysis

domain occurred at Bumagi (2636 mm), while the least was recorded at Maddu (178 mm). In the 1960s, particularly 1961, at a majority of the stations (not shown), above average rainfall was recorded. For example, the highest rainfall for 18 out of the 58 stations occurred before 1960. The lowest recorded values are more concentrated in the 1970s (21) and 1950s (16). This is in agreement with Nicholson (2000), finding below average rainfall in equatorial latitudes in the 1950s and 1970s and a reversed pattern in the 1960s.

Table 4.1 Showing stations that have been rejected by different homogeneity tests. *Italicized figures show results from a test that are not homogeneous at a 5% significance level.*

R/fall station	Test for randomness	Von.Neumann ratio	Cumulative deviations			Bayesian procedures	
	r1	v	q/n ^{-0.5}	Year.Δ	r/n ^{-0.5}	U	A
Bugoye	0.68	0.6	2.0	1964	2.1	0.98	4.61
Bumagi Sese	0.18	1.5	1.3	1962	1.6	0.54	3.28
Kabale met.sta.	0.10	1.7	0.9	1956	1.1	0.43	2.38
Kabasanda	0.27	1.9	1.4	1964	1.5	0.67	3.44
Kakumiro Var.T.	0.04	1.9	1.4	1968	1.4	0.59	3.25
Kawanda Res.	0.14	1.7	1.3	1960	1.3	0.45	2.37
Kigorobya	0.76	0.7	1.4	1961	1.5	0.50	2.31
Kijura Tea Fact	0.22	1.2	1.4	1961	1.4	0.88	5.64
Kings Col. Budo	0.19	1.4	1.1	1973	1.4	0.38	2.78
Kisomoro	0.81	0.2	2.1	1964	2.1	1.67	9.54
Kyegegwa	0.18	1.4	1.1	1956	1.14	0.52	3.26
Kyembogo Farm	0.19	1.7	1.6	1967	1.6	0.74	3.75
Masindi Met.sta	0.73	0.5	1.7	1961	1.8	0.63	3.01
Matete Gombol	0.15	0.4	1.0	1975	1.3	0.09	1.23
Nalweyo Gomb	0.88	0.2	2.4	1961	2.4	2.11	10.3
Nkozi Exp Farm	0.24	2.0	1.5	1960	1.9	0.53	2.56
Rwashamaire	0.25	1.9	1.5	1964	2.2	0.55	3.29

3.3 Rainfall regimes of annual, seasonal and monthly rainfall series.

6.3.3.2 Monthly rainfall series

Analysis shows that Bumagi Sese station had the highest mean monthly rainfall in most of the months, followed by Nyabyeya and Kisomoro in the analysis domain (Table 6.2). On the other hand, Butiaba H.M. meteorological station experienced the lowest mean monthly rainfall in the majority of the months. Much of this rainfall is received from September to February at Butiaba. January and February are the months in Butiaba having more than 100% coefficient of variability, which signifies high variability in rainfall. A summary of mean monthly rainfall with the corresponding coefficients of variation and station is shown below (Table 6.2). It is evident from the table that months with high mean rainfall have low coefficients of variations while months with low mean rainfall have high coefficients.

A close look at the series of the stations Bumagi and Butiaba reveals a contrasting distribution pattern despite the fact that, both stations lie close to a lake. Butiaba recorded lower amounts of rainfall in each month compared to Bumagi Sese. Comparison of mean annual rainfall at the two stations reveals that Butiaba recorded rainfall close to 3 times less than what was received at Bumagi station during the analysis period (Table 6.3). The distribution of rainfall recorded at Butiaba station shows a fairly distributed rainfall pattern throughout the year (Figure 6.2). On the other hand, the records for Bumagi Sese show a distribution which brings out the two seasons of high rainfall and also the seasons of low rainfall distinctively (Figure 6.2). Both stations recorded high peak rainfall in April, and receive a considerable amount of rainfall every month.

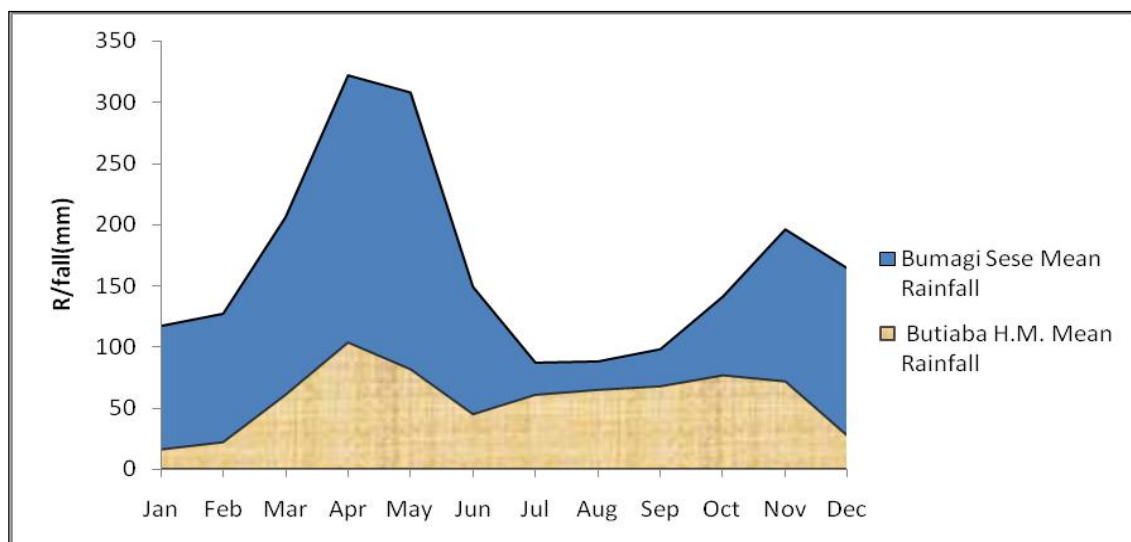


Fig 6.2 Showing distribution of mean monthly rainfall (mm) for Butiaba H.M station and Bumagi Sese station 1943- 1977.

6.3.3.3 Seasonal rainfall series

Seasonality of rainfall has been described through the monthly rainfall total as a percentage of the total annual rainfall (Nel and Sumner 2006; Nel 2009). Results indicate that annual

rainfall in the Albert-Victoria area is seasonal, with 39% and 37% of the annual rainfall occurring in MAM and SON seasons respectively. On average the MAM and SON totals accounted for 76% of the mean rainfall in the water management area. Evidence of this seasonality was also reported by Ogallo (1984), Basalirwa (1995), and Nicholson (1996) and later used by Phillips and McIntyre (2000) to delineate Uganda into sites of un- and bimodal rainfall distribution patterns. Beltrando (1990) attributed this distribution pattern to the seasonal movements of the ITCZ.

Table 6.2 Summary of mean monthly maximum and minimum rainfall with their corresponding coefficient of variation at a station.

Variable	Mean maximum rainfall	Coefficient of variation %	Station	Mean minimum rainfall	Coefficient of variation %	Station
January	117	50	Bumagi	16	111	Butiaba
February	127	59	Bumagi	22	106	Butiaba
March	206	39	Bumagi	61	64	Butiaba
April	322	28	Bumagi	57	47	Kyegegwa
May	308	34	Bumagi	56	89	Lyantonde
June	149	45	Bumagi	16	125	Rwoho
July	118	49	Nyabyeya	17	102	Kiteredde
August	163	39	Nyabyeya	37	74	Katera
September	188	34	Nyabyeya	67	54	Butiaba
October	222	45	Kisomoro	77	58	Butiaba
November	196	52	Bumagi	72	82	Butiaba
December	164	55	Bumagi	7	68	Bakijulula
Annual	167	18	Bumagi	58	22	Butiaba
DJF	139	33	Bumagi	22	80	Butiaba
MAM	278	24	Bumagi	57	42	Butiaba
JJA	169	20	Kakumiro	25	69	Lwengo
SON	186	29	Kisomoro	58	22	Butiaba

The area experienced a bimodal seasonal distribution of rainfall, with maxima occurring one month after the two transitional seasons (fig. 6.3) marked with two (long and short) rainy seasons (Beltrando 1990)

Our analysis revealed that April recorded the highest percentage of rainfall (15%), followed by October and November with 13% and 12% respectively, towards the annual rainfall amount for the region (figure 6.3). The months of June and July recorded the lowest percentages of rainfall (5%), while January recorded the second lowest of 6% in the Albert-Victoria region. However, at the level of a water management zone, June and July's monthly percentage of total rainfall is 5% and 4% respectively (figures 6.3). The rainfall of the wettest month (April) is 3 times the rainfall received in January, June and July, (figure 6.3). As observed by Martin-Vide (2004), the occurrence or not of one of these high amounts can change the character (dry or rainy) of any given month, season or year. This can lead to considerable uncertainty in the average pluviometric contributions, which in turn has environmental and social repercussions.

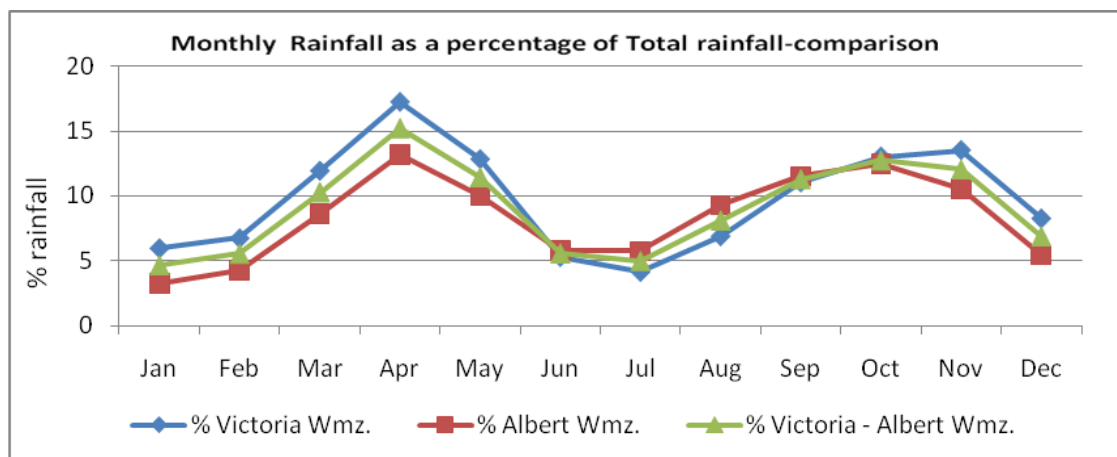


Figure 6.3 Shows seasonality through monthly rainfall totals as a percentage of the total annual rainfall.

6.3.3.4 Annual rainfall variability.

Measures of variability about the mean are of critical importance to water resources. According to Nel and Sumner (2006), the greater the variability of annual rainfall, the more difficult and expensive management of water resources becomes. In this study, interannual variability of each station was established using the mean coefficient of variation (CV). The coefficient of variation for the annual rainfall series for the stations is in a range of 30% and 12% for Kawungera and Rwashamaire stations respectively (Table 6.3). The average CV is 19% indicating that, rainfall does not vary greatly from one year to another. Further still, the CV is low for high rainfall stations and high for low rainfall stations (Figure 6.4b). This, according to Rodhe and Virji (1976) indicates high reliability and low reliability at those

stations respectively. In the studies of De Luis *et al* (2000) and Türkeş (1996) it is noted that, areas with coefficients of variation higher than 30 % are likely to have more frequent and severe droughts and floods. Records available do not reveal occasional flooding in this part of Uganda. A closer study of Figure 6.4 reveals that a significant decrease in rainfall associated with an increase in interannual variability was detected in the areas commonly referred to as the “dry corridor” of Uganda. This is one of the most densely cattle- populated areas in the country, which demands high quantities of water and grass. Increase in interannual variability poses a threat to the pastoral activity. Rainfall variation is also a threat to Uganda’s water resources. The combination of low (high) rainfall and abstraction, results in low (high) flow of rivers, lowered (high) ground water and the drying of wetlands. This in turn has detrimental impacts on fresh water ecosystems and water quality. Scarcity of regular water sources will encourage the use of alternative sources like rainwater harvesting to supply drinking water, water for industrial purposes and animal and wild life. If such rainfall characteristics are maintained in the future, it may adversely affect the availability of water resources and associated economic activities.

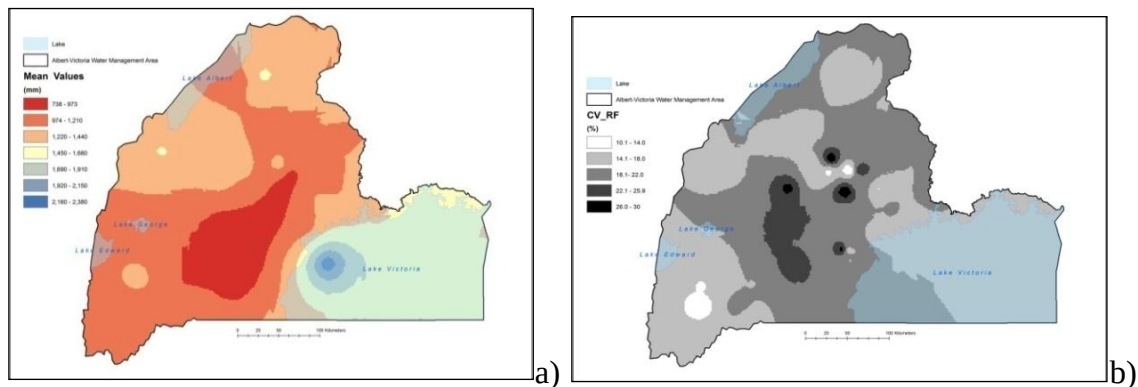


Fig. 6.4 Annual rainfall of Albert-Victoria water management area (1943- 1977). (a) Mean annual rainfall. (b) Spatial distribution of interannual variability of annual rainfall

Table 6.3 Spatial distribution, mean rainfall, rainfall variability and basic statistical characteristics of selected rainfall stations in the Albert-Victoria water management area in Uganda.

R/fall station	Mean annual Rainfall	Highest rainfall (mm)	Lowest rainfall (mm)	Slope	T	PCI	Cv% R/F	Cv% PCI	R/fall (Z)	PCI- (Z)
Bakijulula	1207	1622	946	3.8	1.15	10	14	8	1.21	0.03
Bale Gombolola	1295	2348	802	14.9	3.7	10	21	11	4.39	-1.28
Bugaya	1324	2010	995	1.9	0.53	10	16	10	0.89	-0.21
Bugiri	1388	2252	765	-1.9	-0.24	10	26	8	-0.02	-0.47
Bugoye	1035	1401	676	-10.2	-3.00	10	20	30	-2.03	0.69

Bukuya	1047	1517	112	-1.9	-0.42	10	26	32	0.31	1.16
Bumagi Sese	2004	2636	1293	11.2	1.88	10	18	10	2.78	-0.51
Bushenyi	1278	1854	934	1.3	0.26	10	17	9	0.84	0.54
Buta	1094	1863	544	-16.8	-3.17	10	29	12	-4.2	0.15
Butemba	1113	1436	395	-0.12	-0.04	10	19	13	0.51	-0.19
Butenga	999	1772	620	2.19	0.44	10	27	12	0.67	-1.32
Butiaba H.M	698	1077	400	3.50	1.36	10	22	15	1.08	0.82
Buvuma island	1596	2132	1077	8.81	1.97	10	17	13	1.69	-2.30
Entebbe Vet.Lab	1602	2324	1097	-1.15	0.22	10	17	11	0.6	-2.12
Kabale met.sta.	1017	1313	768	5.66	2.10	10	15	11	1.72	-1.18
Kabasanda	1323	1947	953	-11.5	-2.76	9	20	4	-2.16	-4.71
Kakumiro Var. T.c	1315	1780	926	8.44	2.58	10	15	11	2.15	-1.63
Kalagala	1174	1488	761	-3.08	-0.98	9	13	22	-0.58	1.22
Kalungu	1049	1597	743	-8.01	-2.46	10	19	19	-3.72	0.77
Kasagama	734	1109	328	-1.51	-0.56	10	22	32	-0.48	-0.37
Kassanda	851	1087	561	-4.5	-1.68	10	19	13	-0.62	-1.36
Katera Sango Ba	1184	1530	873	1.15	0.34	11	15	10	0.31	-1.74
Katigondo WFM	1080	1486	844	-1.48	-0.47	10	16	10	-0.57	-1.81
Kawanda Res.st	1256	1737	820	8.73	2.02	9	20	9	2.09	-1.84
Kawungera	922	1688	423	15.9	4.13	10	30	16	4.06	-1.08
Kigorobyia	1145	1550	530	7.78	1.78	10	21	11	1.83	-0.78
Kijura Tea Factory	1487	2024	520	14.5	3.64	10	18	19	3.52	-1.19
Kings Coll. Budo	1225	1656	497	-5.83	-1.54	9	18	16	-0.86	0.45
Kisomoro	1444	1843	822	-18.9	-4.01	10	17	15	-4.36	1.39
Kitabi Seminary	1341	1788	1113	2.89	0.98	9	13	5	1.47	-0.47
Kitalya Prison Far	1137	1465	844	-3.74	-1.11	10	15	8	-0.85	-0.82
Kiteredde Mission	1029	1600	572	-3.38	-0.83	11	22	17	-0.95	1.19
Kyegegwa	1303	1647	198	-9.32	-2.78	10	27	24	-2.4	1.76
Kyembogo Farm	1303	1923	963	-9.32	-2.78	10	17	15	-2.77	1.39
Lwemiyaga	914	1622	669	4.04	1.00	10	24	13	0.62	2.65
Lwengo Gomb.Hq	895	1253	314	-5.83	-1.54	11	22	25	-1.27	-0.48

Lyantonde Disp.	793	1287	529	-11.8	-4.45	10	24	11	-2.79	1.09
Maddu	888	1239	178	-3.07	-0.82	10	21	16	0.34	0.14
Masaka Fore sta.	1159	1691	900	10.6	3.12	10	18	13	2.68	-1.38
Masindi Met.sta.	1315	1584	1097	5.03	2.39	10	10	9	1.95	-1.71
Matete Gombolo	861	1576	568	1.82	0.51	10	21	11	-1.29	1.96
Mbarara Met.sta	955	1522	696	3.61	1.19	10	18	9	1.69	-0.95
Moniko Estate	1494	1972	1103	5.45	1.52	9	15	8	1.45	-0.99
Mpigi Agric Sta.	1258	1712	925	-2.66	-0.71	9	16	10	-0.85	0.98
Mubende 2nd or	1224	1647	766	-5.69	-1.80	10	15	10	-1.95	-0.48
Mugalike W.F.M	1281	1651	701	10.6	3.43	10	17	14	3.09	-0.99
Mukono Agric Sta.	1384	2098	912	-10.5	-1.49	9	25	9	-1.39	-1.36
Nakabango	1223	1888	785	-2.15	-0.56	10	18	11	0	-0.39
Nalweyo Gombol	1219	1661	951	13.1	6.60	10	15	12	4.35	-0.65
Namanve	1348	2220	944	3.64	0.84	9	19	9	0.99	0.19
Namungo	1170	1564	749	1.71	0.63	10	13	11	0.42	-1.78
Ngongwe Cof Nur	1501	2027	940	-1.97	-0.39	9	16	23	-0.24	0.85
Nkozi Exp Farm	1086	1503	728	4.16	1.42	10	16	11	1.57	-1.33
Nyabirongo	1135	1422	410	2.58	0.75	10	17	17	0.09	0.74
Nyabyeya	1518	2145	1125	-4.34	-1.03	10	15	12	-0.95	-1.44
Rwashamaire	1010	1228	709	-3.02	-1.32	9	12	13	-1.74	1.12
Rwoho Forest sta.	1059	1606	669	1.13	0.23	10	21	9	0.69	2.64
Sembabule	810	1159	501	-2.43	-0.91	11	19	11	-0.74	1.04

6.3.3.5 PCI and Coefficient of variation of PCI series.

Interannual distribution of rainfall amounts in space and time shows that stations in the study area have concentrations values between 9 and 11, which denote a moderate to seasonal rainfall distribution (table 6.3). The interannual variability in the distribution of rainfall is low to moderate. There are eleven stations located in Vwmz with a stable monthly rainfall regime where the mean PCI <10 (table 6.3). The study does not reveal any evidence of stations with high concentration in the regime (mean PCI >20). There is a close relationship between amounts of rainfall and concentration of indices. For instance, stations with higher mean rainfall had relatively lower concentrations indices and vice versa. Ngongondo *et al.* (2011)

also revealed this characteristic in Malawi, which could partly be explained by the climatic systems such as the ITCZ that are experienced near the Equator.

The coefficients of variation of PCI ranged from a minimum of 4% at Kabasanda to a maximum of 32% at Bukuya. Rainfall concentration is an important factor affecting erosivity and desertification (De Luis *et al.* 2000 and references there in) in that it may promote sediment yield transport and thus affect the sustainability of ecosystems like that of Lake Victoria and Lake Albert. A detailed study on trends in the seasonal distribution of rainfall is much needed to assess fully the potential effects of changes in rainfall pattern on ecosystem dynamics. This is important because, literature from organizations like WMO, UNEP and IUCN have found that severe drought can degrade and destroy wetland ecosystem through changes in water availability which causes deterioration in habitats (in Enete and Ezenwanji 2011).

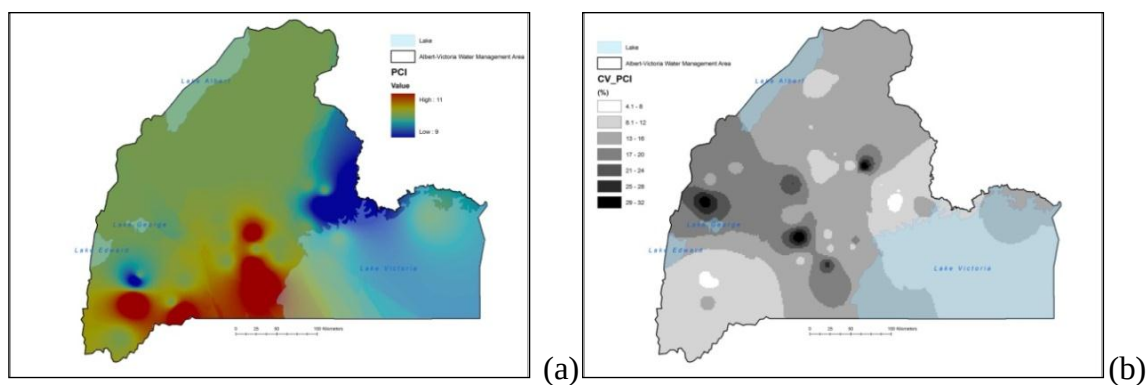


Fig. 6.5. Annual Precipitation Concentration Index (PCI) in the Albert-Victoria region(1943-1977) a) Mean annual PCI (b) Spatial distribution of interannual variability of PCI.

Since the precipitation concentration index, like other statistical indices, does not reveal the actual month or season of maximum rainfall, the examination of the station data set is necessary to identify the period (season) of the year with maximum rainfall, if there is any (Michiels *et al.* 1992). Mean monthly rainfall over a period of 35 years for the stations in the two zones is shown in Figure 6. This figure demonstrates that there was no single month without rainfall, which is in agreement with the uniform to moderate seasonal distribution derived from the PCI value (Table 6.3 and Figure 6.5) Variability in the region is owed to topography and the presence of Lake Victoria, which exert a great influence to the extent of not having a real dry month (Beltrando 1990). Furthermore, shapes of the mean monthly rainfall data for the two zones (Figure 6.6b, 6.6c) show a bimodal rainfall distribution (depicting the expected seasonality), with a period of maximum rainfall in MAM and SON.

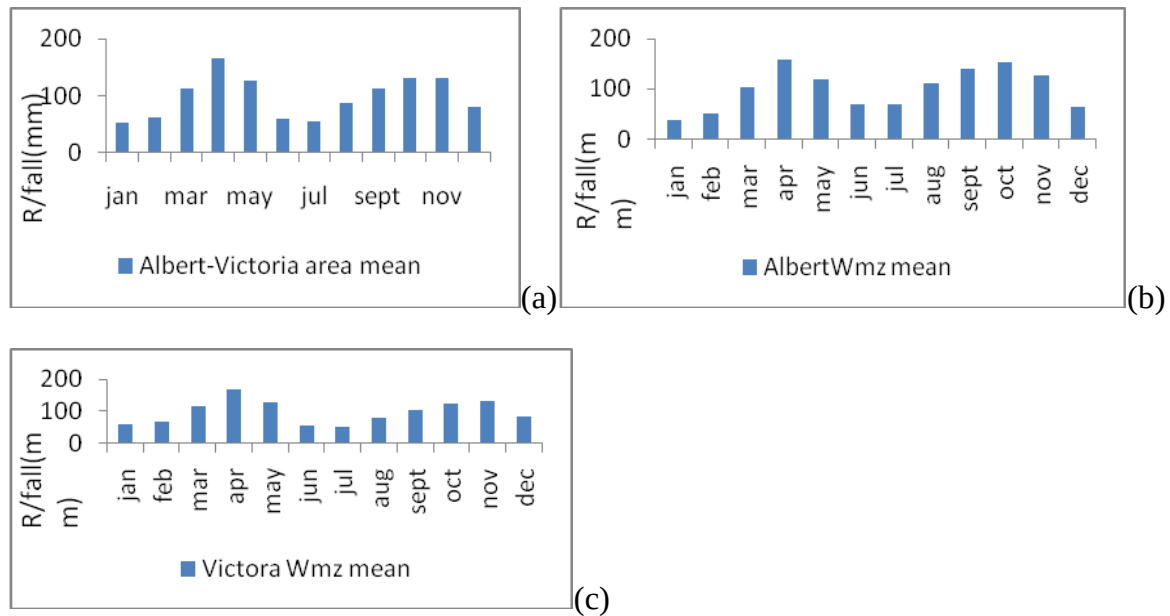


Fig. 6.6 a – c Show distribution of mean rainfall (mm) in a) Albert-Victoria wma, (b) Albert and (c) Victoria water management zones in Uganda.

6.3.4. Trend in rainfall elements

6.3.4.1 Monthly Precipitation Concentration index (PCI) trends.

We observe that majority of the stations [34(59%)] experienced negative PCI trends and of which 11(32%) were significant. Positive trends were recorded at 23(40%) stations, out of which 4(17%) are statistically significant (Table 6.3). A calculation of the correlation of coefficient (-0.4) revealed there is a relationship between rainfall trends and PCI trends. For example, PCI values are high in places where rainfall trends are decreasing and which are experiencing increasing variability (Fig.6.7a).

6.3.4.2 Annual rainfall trends.

Mixed results are detected in the rainfall trends of the stations under the analysis domain. For example 31 stations have positive trends of which 8 are statistically significant at 5% level. Negative trends were found at 26 of the stations and only 6 stations were statistically significant at a 5% level. Furthermore, our analysis shows that annual rainfall at Nakabango station had no trend (see Table 6.3). The stations, Bale Gombolala, Bugoye, Bumagi, Buta, Kalungu, Kawungera, Lyantonde, Masaka forest station, Kisomoro, Kyembogo, Kijura Tea Factory and Nalweyo Gombolola, had very strong rainfall trends at 99% significance level (Fig. 6.7b).

6.3.4.3 Monthly rainfall trends.

Monthly rainfall trends were calculated for January to December. Negative trends (which were not significant at $\alpha = 0.05$) were dominant for the most of the months. The percentage of trends for the respective months and seasons recorded at the 58 stations is shown in the Table 4. The study reveals that August has the highest number of stations (46) which recorded

a negative trend and 9% of these were statistically significant, followed by September with 40 stations. In January, February and November over 40 stations recorded positive trends, of which 20.7% were significant at 5% level. The highest percentage of significant (positive and negative) trends for monthly rainfall is in April, May and August with 15.5%. Trends recorded in July in the analysis domain are substantial but not significant. January and February have the least number of stations experiencing significant trends, accounting for only 5.2%. Results also show that 38 stations experienced negative trends in the MAM season, while 41 stations recorded a positive trend during the SON season (Table 6.4). The MAM season has 20.7% of trends recorded as significant, while eight stations exhibit positive significant trends in the SON season. The distribution of DJF, MAM, JJA and SON trends at studied stations is shown in Table 6.4, which presents the trend analysis results of monthly and annual data for the Albert-Victoria water management area.

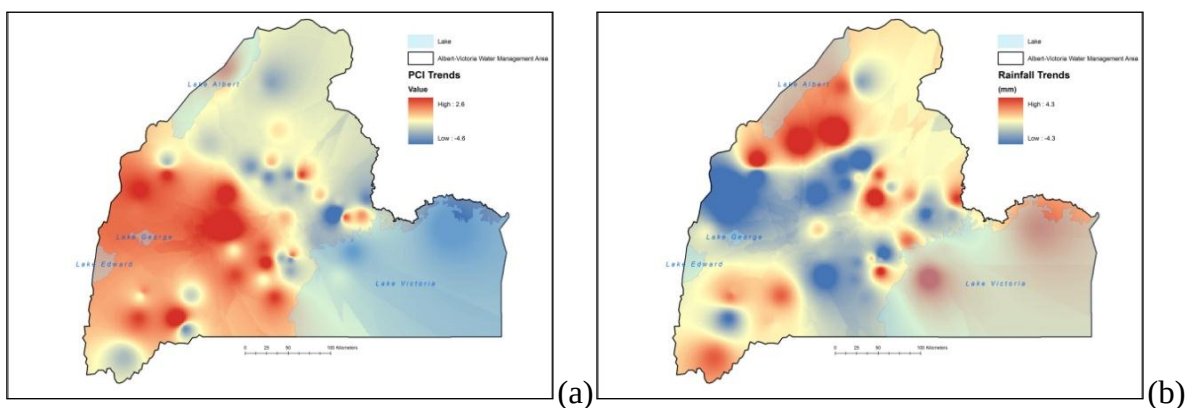


Fig.6.7 (a & b). Observed trends in annual Precipitation Concentration Index (PCI) and annual rainfall for the period 1943-1977 in the Albert-Victoria wmz

6.3.4.4 Regional trend

Based on the procedure described in the construction of the area averaged series section, 12 monthly series on to which a trend analysis was then performed to discover a possible regional behaviour. Before using the regional mean normalized series for trend and spectral analysis, the variance analysis has been applied to the regional data in order to assess whether regional monthly series adequately represents the region as a whole. Using the ration of the variance estimates in time to the variance estimates in the area, it is apparent that majority of the area-averaged monthly anomalies tend to vary in a statistically coherent manner over the rainfall regions. Tests on the series showed that, the geographical variations (v-area) between different places with in the region are small, compared to the temporal variations of the whole region as represented by (v-time). Results for the *F* test for February, July, October and November are not statistically significant at 5% level.

Table 6.4 Summary of trend test results for monthly rainfall in Albert-Victoria water management area in Uganda (Number of stations=58).

Variable/Trend	Number of stations with - ve trends	Significant - ve $\alpha = 0.05$ level	Number of stations with + ve trends	Significant + ve $\alpha = 0.05$ level	Significant trends (%)
January	14	0	41	3	5.2
February	12	0	45	3	5.2
March	25	0	31	5	8.6
April	35	5	22	4	15.5
May	34	6	33	3	15.5
June	25	0	32	4	6.8
July	32	0	24	0	0
August	46	4	11	5	15.5
September	40	4	17	1	8.6
October	30	0	27	6	10.3
November	8	0	49	6	10.3
December	43	2	14	0	3.4
Dec-Jan-Feb (DJF)	23	1	34	3	6.8
Mar-Apr-May (MAM)	38	9	19	3	20.7
Jun-Jul-Aug (JJA)	32	2	24	1	5.2
Sep-Oct-Nov (SON)	16	2	41	8	17.2
Annual	26	6	31	8	24

Table 6.5 presents the trend analysis results of monthly and annual data for the Albert-Victoria water management area. An overall inspection of the table indicates that the regional Mann-Kendall statistic was mostly found to be significant in February and December (shown in bold). The indication from the linear regression test statistic also validates the outcomes of the Mann-Kendall test in the same region.

Table 6.5 Results of regional trend analysis: t is linear regression test statistic and z is the Mann-Kendall test statistic. Bold figures indicate significant values at the 5% significance level.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
Year of max. R/fall	1947	1964	1951	1964	1946	1973	1973	1975	1945	1947	1962	1961	1962
Year of min. R/fall	1965	1946	1943	1976	1966	1971	1971	1973	1968	1957	1943	1943	1956
Slope	0.01	0.01	0.01	-0.0	-0.0	0.0	0.0	0.0	-0.0	-0.0	0.0	0.0	0.0
T	0.85	2.1	1.5	-0.8	-1.3	0.9	0.9	0.2	-1.9	-1.8	1.8	2.4	1.9
Z	0.13	0.2	0.2	-0.1	-0.1	0.1	0.1	-0.1	0.2	-0.2	0.2	0.2	0.2

	DJF	MAM	JJA	SON
Year of maximum. R/fall	1963	1951	1975	1961
Year of minimum. R/fall	1946	1943	1960	1957
Slope	0.0	-0.0	0.0	-0.0
T	2.8	-0.1	0.9	-0.9
Z	0.3	-0.0	0.1	-0.1

The yearly fluctuation in total rainfall for Albert-Victoria water management area is shown in figure 6.8a-e using normalized annual series. A close scrutiny of figure 6.8(e) shows a pattern whereby rainfall recorded for most of the years was below the regional annual mean. The period from 1951 to 1959 was the longest to have recorded rainfall below the annual mean. Nicholson (2000) found out that during the 1950s, the equatorial latitudes of Africa experienced drier conditions contrary to the subtropical latitudes. It is evident from the figure that 1961 to 1964 recorded heavy rainfall, maximum being recorded in 1962. Re occurrence of extreme rainfall events like those of 1960s, can result into storm water discharges from combined sewer and surface water overflows, fluid erosion leading to mobilization of stored runoff of agricultural fertilizers and pesticides, animal wastes and manure. Heavy rains can also lead to the weakening or failure of dams (Enete and Ezenwanji 2011).

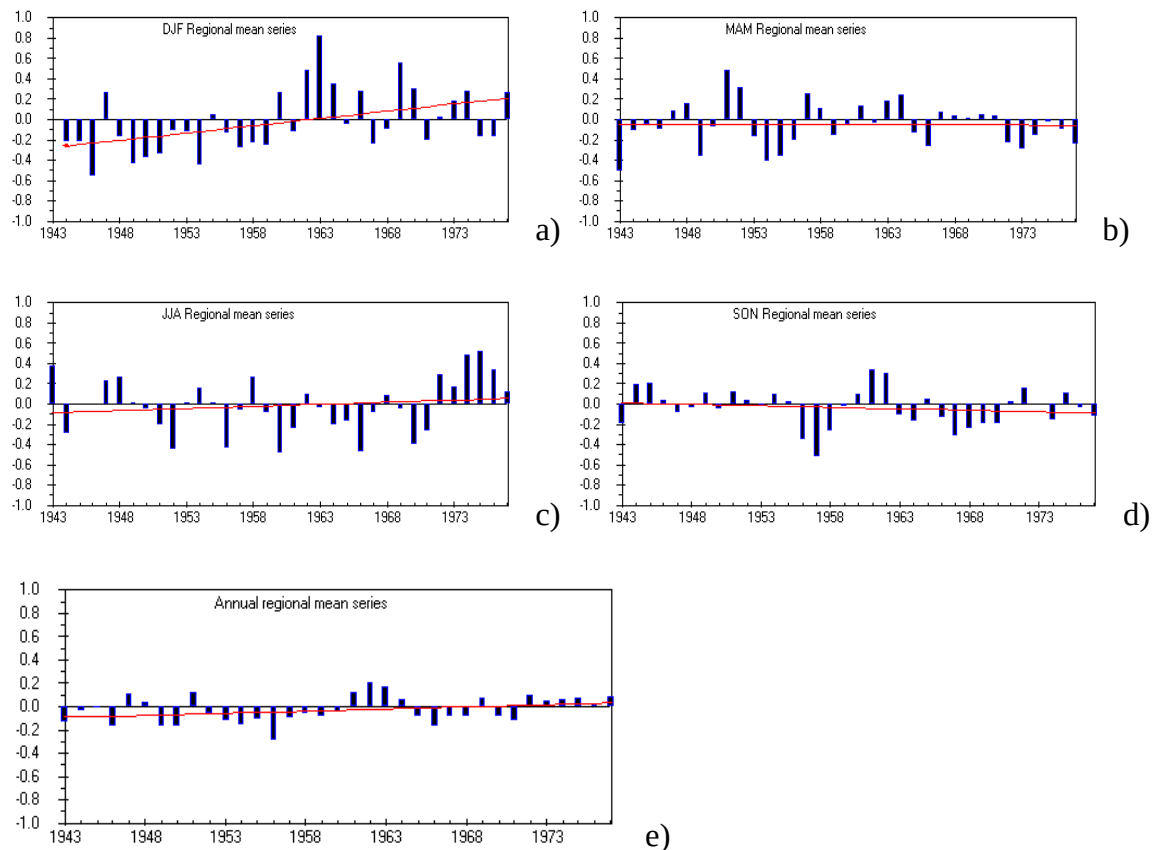


Fig. 6.8 (a-e). Shows the climatology and seasonal mean trend pattern for the Albert- Victoria water management area from 1943 to 1977

Years of anomalously high rainfall can be identified in all plots such as total annual rainfall for 1947, 1951, 1961, 1962, 1963 and 1972 in (fig 8). For MAM rainfall, the years that have high rainfall include; 1951, 1952, 1957, 1961, 1963 and 1964, while for the SON rainfall, the years are 1944, 1945, 1951, 1954, 1961, 1962, 1972 and 1975. Despite the few differences in studying rainfall trends, Kizza *et al* (2009) also found out that 1951 and 1963 of the MAM season and 1951, 1961 and 1972 of the SON season received anomalously high rainfall. In line with future projections of changes in total annual precipitation in the tropics (IPCC, 2007) increased precipitation levels and extreme variation may cause damage (flooding, soil erosion, mass movement) in highland areas. JJA is the season in Uganda expected to have low amounts of rainfall. However, the plots show that 1943, 1947, 1948, 1958, 1972, 1973, 1974, 1975, 1976 received rainfall far above the average in the JJA period of analysis. A closer examination of the DJF plot shows that for about 18 years, there was less than average rainfall recorded in the first part of the analysis period (before 1962) and thereafter, rainfall records showed mixed fluctuations every year of below and above the mean rainfall (figure 8).

The long term productivity and competitiveness of Albert-Victoria water management area's economic activity (agriculture) is at risk if increased variability aggravates water availability especially in the central low lands of the study area. The variability in rainfall could reduce the yields of major food staples such as cereals. Significant rainfall trend may require shifts to new varieties that are more tolerant to rainfall changes. Inter-annual or inter seasonal rainfall variability represents a major challenge to the rain dependent agricultural producers and the

water managers. This may disrupt the growing conditions and result in crop failures with serious implications for food security, water availability and agricultural productivity. Rainfall variability also influences the manner in which the factories plan input production and affects both inputs and outputs (Molua 2006).

Spectral analysis using fast Fourier transform shows that the total annual series has peaks at 0.5, 2.6, 6.5 and 10 years. The MAM series has peaks at 3.5, 6.3 and 10.8 years, while the SON series has peaks at 3.8, 6.7 and 10.5 years. Generally the spectral analysis of the time variations associated with these components (fig.6. 9) reveals a major periodicity around 3, 6 and 10 years. Other studies have shown that 5-6 years is a major periodicity over East Africa (Beltrando 1990 and references therein; Kizza *et al.* 2009). This time period has been associated with the ENSO phenomenon explained by Nicholson (1996 in Kizza *et al.* 2009).

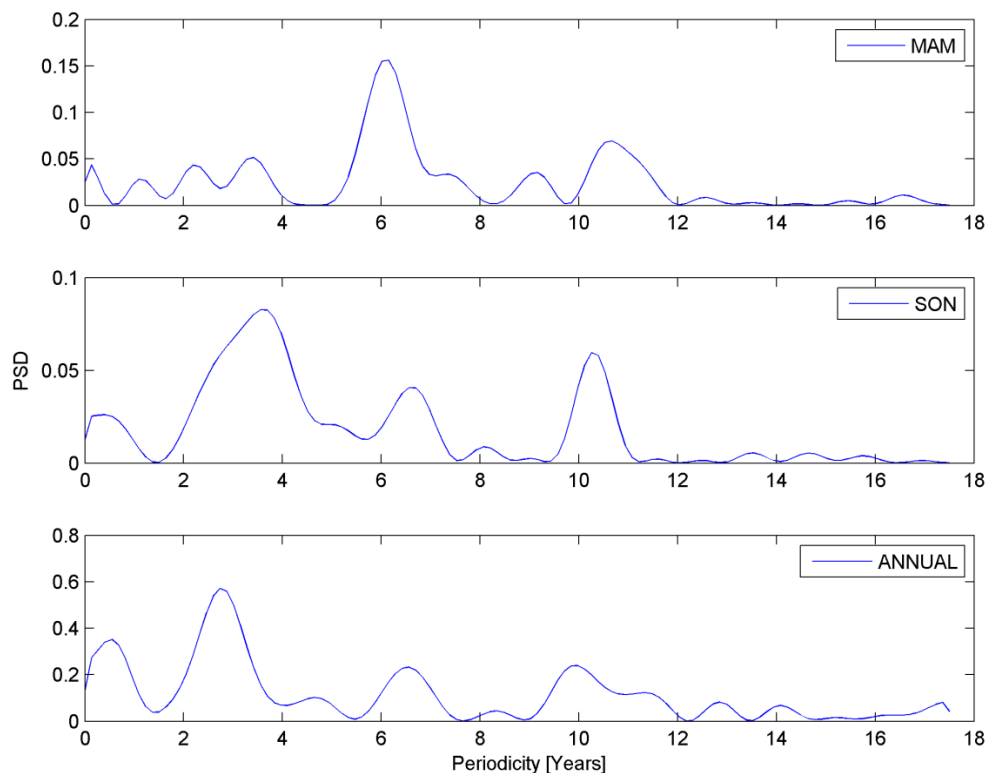


Fig 6.9. Power density of the normalized regional time series associated with the components for MAM, SON and Annual series.

6.4. Conclusions

This study investigated the spatial and temporal characteristics of various rainfall variables at 58 stations in Uganda's Albert-Victoria water management area. We highlight the following key points from the results of the study after basic data quality control and analysis.

Most of the stations that were available from the Department of Meteorology had a certain percentage of missing data. We applied quality control steps that enabled us to end up with 58 station series of rainfall. Serial correlation for annual series was high for 14 stations.

These series were smoothed so that they can meet the distribution criteria and enable the running of the Mann-Kendal test directly. Majority of the station series were homogeneous; those station, which were inhomogeneous were not used in the analysis of the area average (regional) series.

Different homogeneity adjustment techniques naturally produce different results, which make the decision on what technique to use rather difficult (Peterson *et al.* 1998a, b). However, two different adjustment versions can lead to similar results and improve the reliability of the data for many uses. We found evaluating the breaks detected as well as the attempt to correct the series from artificial steps to be poor, because of the lack of metadata support. A homogeneity-adjusted time series is not the same as a pristine time series that is homogeneous without needing adjustments. Many approaches can make average adjustments, since one may not be able to determine the level of bias a change introduces at a particular station given its site and microclimate (Peterson *et al.* 1998a, b).

Results show that stations close to Lake Victoria recorded high amounts of rainfall. The rainfall distribution is bi-modal, with maximums experienced in the MAM and SON seasons of the year. Annual rainfall is seasonal in that 39% and 37% occur in MAM and SON seasons respectively. Spectral analysis of the time component reveals year periods around 6 and 10 years which is a characteristic of the annual, MAM and SON series. April recorded the highest rainfall, while January, June and July recorded the lowest rainfall. Average CV is 19%, which signifies low variability in analysis domain. The coefficient of variation is low for high rainfall stations and vice versa. Interannual variability of rainfall distribution is low to moderate. Analysis also reveals that PCI values lie between 9 and 11 which denote moderate to seasonal rainfall distribution. The coefficient of variation for PCI rainfall series was in the range of 4% to 32%. Furthermore 63% of the stations experienced negative trends and only 32% were significant. Also noted was the close relationship between rainfall trends and PCI trends. It has also been demonstrated through mean monthly rainfall that, there was no single month without rainfall. Results also revealed that, 12 stations had very strong trends at 99% significant level. Non-significant negative trends at 95% were dominant in various months and seasons recorded in the region.

At a regional scale, positive and non-significant trends in monthly rainfall occurred in the analysis domain whereas negative trends are noted for the months presumed to be of high rains (Table 6.5). The increases in rainfall totals for some months (February and December) are also reflected in the DJF significant trends for the area (Table 6.5). The area generally did not reveal significant trends in the mid twentieth century at a 5% significance level. Empirical studies do not provide information on the causal factors of detected trends. The authors are aware that a 30-year period is not enough to encompass fully any climatic variability signal. Therefore, the observed changes should be considered with caution.

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CHAPTER 7

Climatic trends at Namulonge in Uganda: 1947-2009. *

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7.1 Introduction

It is known that temperatures and rainfall are regarded as parameters of climate with large spatial and temporal variations (Ogallo 1993) and are useful to consider in climate change studies (Kafle and Bruins, 2009). That is why a great deal of work has been done over the last three decades in detecting changes in monthly total rainfall and mean temperatures in the various parts of the world (Aguilar *et al.* 2005 and references there in). New *et al.* (2005) also indicates studies documenting such changes at a global, regional and national scale. Regional studies concerning some analysis of maximum and minimum temperature trends have been outlined by (Del Rio *et al.* 2007). In Africa (King'uyu *et al.* 2000; Hulme *et al.* 2001; Kruger and Shongwe 2004 and references there in; Mahe *et al.* 2001; Mahli and Wright 2004; Schreck and Semazzi 2004; Domoroos and El-Tantawi 2005) amongst others have conducted national and regional studies of recent trends and variability in monthly climate. However, there has been little work done on rainfall and temperature related trend studies in Uganda, primarily because of a difficulty in obtaining data. With climate change a reality (Kruger and Shongwe 2004) it is important to update and inform on observed climatic trends from this part of the world, where livelihoods are greatly dependent on climate. Such results may assist in planning for agriculture, food security, livelihoods and water supply and management and can also be of great value to mitigate possible impacts on society, the economy and the environment. Important to note is that rainfall and temperature have a direct influence on water resources, plant growth and livelihoods (IPCC 2007).

Ogallo (1984, 1988, and 1993) give detailed descriptions of the systems that modulate the space and time characteristics of rainfall and temperatures over the East Africa, including Uganda. At the equator temperatures are predominantly determined by the degree of outgoing long-wave radiation, or heat emission from the Earth's surface. The most important systems responsible for Uganda's rainfall include; (1) Inter-Tropical Convergence Zone (ITCZ), (2) subtropical anticyclones, (3) monsoonal winds and (4) the moist westerly winds from Congo. Local influences such as large water masses, human activities and topography also play a role (Basalirwa 1995; Nicholson 1996; Beltrando 1990). A combination of these factors and especially the bi-annual propagation of the ITCZ across the region results in four broad rainfall seasonal patterns over most parts of East Africa and Uganda as recognized by the East African Meteorological Department in 1963 (Basalirwa 1995). For example, December to February is generally dry, when the ITCZ is located to the south. Any rain during this time is locally driven (e.g. by Lake Victoria's lake/land breeze) effect. March to May is commonly known as the "long rains" season, which is modulated by synoptic scale circulation associated with the ITCZ and the Mascarene anticyclone (Basalirwa 1995; Nicholson 1996). The Mascarene anticyclone is a belt of high pressure cell over the Indian Ocean, which is the driving force behind the southeast monsoon, whose full force is usually felt during July and August. June to August is a general dry season except for parts in northern Uganda where rains are associated with the influx of the moist westerly Congo air mass modulated by the Atlantic anticyclone.

The September to November season, also known as "short rains" season is the second rainy season and is also associated with meridional ITCZ propagation. Because of these systems

most of Uganda has a mean annual rainfall, of 1200mm (Nicholson 1996). Previous studies provide some evidence that a bimodal rainfall regime dominates in the south of Uganda, while a unimodal distribution is more apparent above 3° North (Komutunga and Musiitwa 2001).

The main objectives of this present study is to identify possible statistically significant trends in both temperature(maximum and minimum) and rainfall over Namulonge area during recent decades when the global warming signal is intensified.

7.2 Data and methodology

7.2.1 Study site description and general climatology

According to “Busukuma sub-county council three year development plan 2009 -2012”, Namulonge is one of the villages in Busukuma parish, Busukuma sub-county, Kyaddondo county in Wakiso district of Uganda. Namulonge is an area located just a few kilometres away from the equator in Uganda, on latitude 0°5' North and longitude 32°61' East. The area lies approximately between 900 – 1340m (AMSL). Topography is undulating, characterized with flat-topped hills, dissected by broad valleys that are occupied with swamps. This location exposes Namulonge to an equatorial climate characterized by comprehensive sunshine associated with high temperature. Namulonge village has 424 households and a total population of 1743 people of which 835 are female and 908 are male (2009 estimate). Namulonge is well known for intensive smallholder agricultural practices and is also a research site of the National Crop Resources Research Institute (NaCRI), which strives to develop varieties and farming technology for the people of Uganda. It is rural in nature and most of the residents are either current or past employees of research institute. Agricultural practices in and around Namulonge are therefore significantly influence by NaCRI. Maximum and minimum temperatures as well as rainfall have been recorded at the NaCRI since the late 1940s.

In view of the dependence of the area's population on climate for its economy, the following question is frequently asked: “Is Namulonge in the process of drying out and cooling down or vice versa?” such a question is bound to arise simply because some recent literature suggests that equatorial African countries might warm up to 1.4°C above the current temperature by the 2050s (Hulme *et al.* 2001). Some natives (through personal communication) believe that, in the recent years, rainfall is less than what it was 30 to 40 years ago and temperatures are warmer. Samson (1952), however, points out that one cannot rely on human memory alone, and that it is more desirable to find answers through science, especially with scientists continuously informing society that future weather might become increasingly unpredictable and extreme (Cheema *et al.* 2006). It is therefore important that the climatology of Namulonge is analyzed and understood, with the objective of identifying changes in historical climatic data at an early stage. When we find the changes that have happened in the past from the data, we will be able to explain and project similar events in future and also mitigate the impacts they are likely to have on society.

7.2.2 Temperature and rainfall data

Meteorological data for Namulonge has been recorded on a daily basis at the (NaCRI). It is then kept with the Department of Meteorology in Kampala, where it is entered and archived using climate-computing format. Data was then quality checked using visual inspection of temperature and rainfall plots. For this study monthly means of rainfall as well as minimum and maximum temperatures were loaded into the Microsoft Excel data manipulation system and AnClim(v5.108) software (Stepanek 2007) for analysis and graphical output. A number of time series were derived namely; average monthly maximum temperature (Tmax), average monthly minimum temperature (Tmin), and average monthly total rainfall. Analysis was carried out for time periods of all years 1947-2009 for rain, 1953-2008 for temperature.

7.2.3 Seasonal trends

In order to further understand the intra seasonal change, rainfall and temperature records were analyzed for the four seasons; December-January-February (DJF); March-April-May (MAM); June-July-August (JJA); September-October-November (SON). Nicholson (1986) also found these four seasons to be appropriate for Africa.

7.2.4 Trends in climate normal's

In order to quantify whether trends appear particularly severe during a particular time interval of the reference period, time series are further divided into the following two partially overlapping 30 year periods: temperature (1953-1982 & 1979-2008), rainfall (1947-1977 & 1978-2009). Such climatic periods also referred to as climate normal, have been used in the work of (Longobardi and Villani 2009; Cheema *et al.* 2006; Piccareta *et al.* 2004; and Ogallo 1981). The second climatic normal from about 1979 is very important to the scientific community and research fellows. This period represents the most recent years or climate normal for studying climate change. Similarly the period lies with the WMO recommended baseline period for climate studies. This is the period in which a number of studies on Uganda (Kizza *et al.* 2009; Mubiru *et al.* 2009; Basalirwa 1995) among others have been conducted to understand climate variability and change. For example, Kizza *et al.* (2009), investigated the temporal distribution of rainfall in the lake Victoria basin on seasonal to annual time scales, using an updated dataset with records covering a period 1903- 2006 to test the presence of significant trends in rainfall data. Their results showed that positive trends dominated mostly stations located north of the basin. They also found out that, the 1960s experienced pronounced rainfall in the basin, at the same time seasonal rainfall analysis showed that the short rains tend to have more trends than the long rains. On the other hand Mubiru *et al.* (2009) using a historical data set of daily rainfall and temperature from 37 representative stations across ten agricultural production zones of Uganda, generated the characteristics of the seasons based on a monthly time scale and changes in land cover in relation to climate and farmers perception to climate change and the coping strategies used in response to climate change. They were able to find that monthly total rainfall and rain days were decreasing and found no evidence in data that rainfall was increasing or decreasing on the annual time scale. They also established that maximum temperatures were increasing,

though the minimums of the daily maximums changed faster than the minimums. None of these studies however, has been able to carry out an in-depth study on a single station in an area as important as Namulonge to understand its climatic trends in history. In this respect, trends of maximum and minimum temperature and rainfall for 1st climate normal and 2nd climate normal were established.

7.2.5 Trend analysis

With the aim of trend detection and cross verification, both parametric (linear regression analysis) and nonparametric (Mann-Kendall tests) statistical procedures are applied on historical data of two variables. Temperature and rainfall trend of each month is then calculated. Also data has been analyzed for presence of trends for the four seasons in order to understand the intra-seasonal change. In order to make the results more understandable graphs are drawn. The procedure for carrying out the Mann-Kendall statistic (s) is explained by (Piccareta *et al.* 2004, CRCCH 2005; Modarres & Vicente de Paulo Rodrigues da Silva 2007; Kampata *et al.* 2008; Caloieroe *et al.* 2009; Kizza *et al.* 2009; and Longobardi & Villani 2009) among others. The Mk test is applied by considering the statistic S as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_k) \quad (1)$$

where x_i is the data value at time i , n is the length of the data set and $\text{sgn}(z)$ is equal to +1, 0, -1, if z is greater than, equal to, or less than zero respectively. The null hypothesis is that (H_0 = no trend) for a given level of significance. The mean $E(s)$ and variance $V(s)$ of the statistic S were obtained as:

$$E(s) = 0, \quad (2)$$

$$\text{VAR}(S) = \frac{1}{18} \left[n(n-1)(2n+5) - \sum_{p=1}^q t_p(t_p-1)(2t_p+5) \right] \quad (3)$$

Here q is the number of tied groups (sample data with the same value) and t_p is the number of data values in p^{th} group. The values of s and $\text{Var}(s)$ are used to compute the test statistic Z as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{VAR}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{VAR}(S)}} & \text{if } S < 0 \end{cases} \quad (4)$$

The presence of a statistically significant trend is evaluated using the Z value. A positive (negative) value of Z indicates an upward (downward) trend. To test for either an upward or downward monotone trend at p significance, H_0 is rejected if the absolute value of Z is

greater than $Z_{1-p/2}$, obtained from the standard normal cumulative distribution table. In this work significance levels of $p = 0.05$ were applied.

A linear regression test was also used to test for trend in this study. This is a parametric test that assumes that the data are normally distributed. It tests whether there is a linear trend by examining the relationship between time(x) and the variable of interest (Y). The regression gradient given by is estimated as:

$$b = \frac{\sum_{i=1}^n (X_i - \bar{X})(Y_i - \bar{Y})}{\sum_{i=1}^n (X_i - \bar{X})^2} \quad (5)$$

And the intercept is estimated as:

$$a = \bar{Y} - b \bar{X} \quad (6)$$

The test statistic S is:

$$S = \frac{b}{\sigma} \quad (7)$$

Where $\sigma = \sqrt{\frac{12 \sum_{i=1}^n (Y_i - a - bX_i)^2}{n(n-2)(n^2-1)}}$

The test statistic S follows a student-t distribution with $n-2$ degrees of freedom under the null hypothesis (critical test statistics values for various significance levels can be obtained from Student's t -statistic tables). Equations shown above were sourced from trend user guide (www.toolkit.net.au/trend-CRCCH 2005).

7.3 Results and discussion

Climatic trends of rainfall, maximum temperature, minimum temperature and average temperature of each month has been discussed below. Monthly average temperature and rainfall of the studied station with their linear trend values and statistical significance are shown in Table 1. Data was tested for normality using a normal probability plot (Chambers 1983) on line <http://www.itl.nist.gov/div898/handbook/eda/section3/>. This is a graphical technique for assessing whether or not a data set is approximately normally distributed. The data are plotted against a theoretical normal distribution in such a way that the points should form an approximate straight line. Departures from this line indicate departures from normality. The result which justifies normality is indicated in the normal probability plot below (Figure 7.1). The points on this plot form nearly a linear pattern, which indicates that the normal distribution is a good model for the data set with $p = 0.000$.

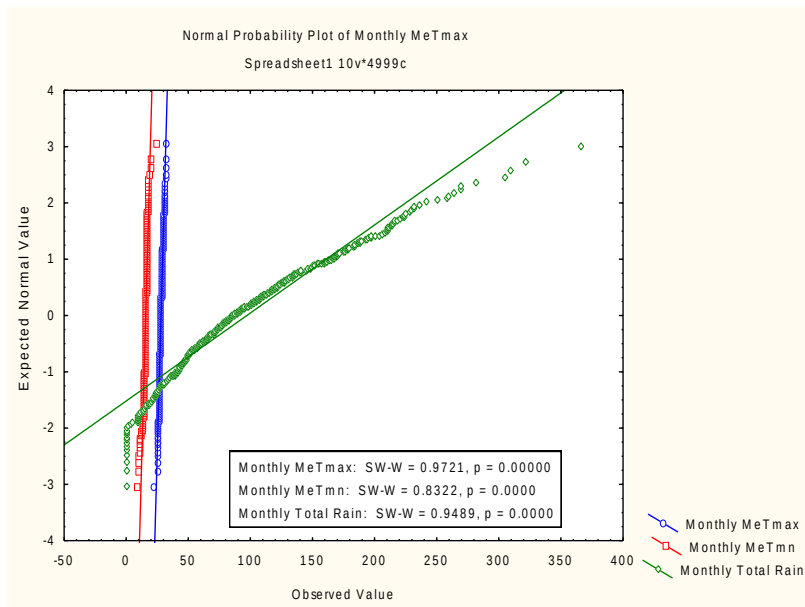


Figure 7.1 Normal probability plot of climatic data used in analysis

7.3.1 Temperature trends

Figure 7.2(a) & 7.2(b) show the minimum and maximum temperature anomalies of Namulonge during the period 1953-2008. The figure also reveals that mean monthly minimums are decreasing after the 1970s (Fig.7.2a). On the other hand figure (7.2b) illustrates that mean monthly minimums are decreasing, which is indicative of a warming in minimum temperatures since the 70s. The station showed little annual variations during the study period.

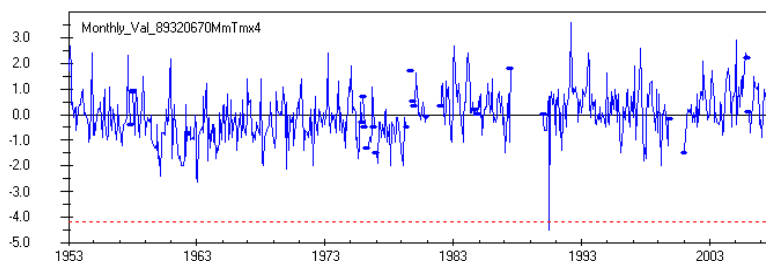


Figure 7.2(a) Monthly mean maximum temperature anomalies of Namulonge (1953 – 2008) values are expressed as a departure from the long term mean.

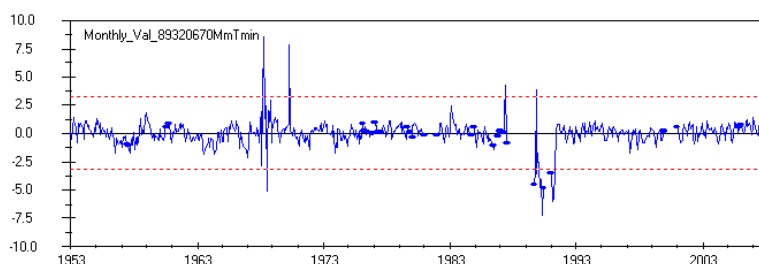


Figure 7.2 (b) Monthly mean minimum temperature anomalies of Namulonge (1953- 2008), values are expressed as a departure from long term mean.

7.3.1.1 Maximum temperature trends

The analysis shows that the trend of maximum temperature for each month from January to December is increasing (Table 7.1). The increase in trend is statistically significant in the months of April to September and December. While October to November and January to March the trend for maximum temperature is positive, the increase is not significant at 5% confidence level. This finding is not far from what Hulme *et al.* (2001), observed about the warming trends in Africa, where warming in JJA and SON was larger than that of DJF and MAM. February recorded the highest average maximum temperature of 29.5⁰C followed by March with 29.1⁰C (Table 7.1) in this period of analysis.

High peaks of temperatures were experienced in 1992 and 1993 while 1990 recorded cooler maximum temperature (Figure 7.2a). The lowest average maximum temperature recorded was in July (26.9⁰C). A closer look at the average maximum temperatures show that the second climate normal has been warmer compared to the first climate normal (Table 7.1). This finding is in line with IPCC (2001a) findings that, the 1990s were the warmest decade experienced in (Domroes and El-Tantawi 2005). The trend for maximum temperatures is increasing significantly with in all the four seasons, but out side the 5% confidence level (Table 7.2).

These findings compares well with what New *et al.* (2006) found out in their study of daily temperatures and precipitation from fourteen south and west african countries over the period 1961-2000, which excluded Namulonge station but came to a conclusion that temperatures were warming in most of the regions analyzed. This also indicates that day time temperatures were increasing.

7.3.1.2 Minimum temperature trends

The analysis reveals that minimum temperature trends in months of November to February and June to September were positive while those for March to May and October were negative. The trends for most of the months were non significant at a 5% confidence level, with the exception of April and July whose trends were significant at a low confidence level. Lowest average minimum temperature were experienced in January and July, and the highest of the minimums were recorded in April and May (Table 7.1). Higher peaks of the minimums are evident in 1968 and 1970 while the lowest of minimums were recorded in 1989/90/91 period (Fig. 7.2b) after which they started to increase. According to Oxfam (2008), minimum temperatures have been rising faster than maximum temperatures in Uganda. The report reveals that minimum temperatures rose from about 1960 -1982, then declined, and rose again since 1990s, which results are not far from the findings of this study. Trends in minimum temperature are significantly negative in the MAM season at a rate of -0.25 per decade, while the other three seasons are experiencing positive trends (Table 7.2). The increasing trends are only significant in the JJA season and insignificant for DJF and SON. These notable changes have a low level of confidence except the SON, which lies in the 5% confidence level.

The trend in minimum temperature for the whole study period however, shows an increasing trend of 0.001 which is not significant ($t = -0.020 < 0.05$) confidence level. Minimum temperatures in the area were high, with a mean of 15.9°C in the first climate normal, and have shown a slight decrease in the second climate normal with a mean of 15.7°C. January and July have experienced the lowest minima in both climate normals (Table 7.1).

7.3.2 Rainfall trends

Rainfall trend is decreasing for most of the months except for January, September and December, though this negative trend is not statistically significant, at a 5 % confidence level. The analysis further reveals that on average, maximum rainfall received in the last sixty-three years, was recorded in April with a mean monthly total of 153.79mm, followed by November with 139.2mm (Table 7.1). Indeje *et al.* (2000) point out that, as much as most parts of East Africa are experiencing dry conditions, the Lake Victoria basin, central and western Uganda are among the few areas that receive significantly high rainfall during the month of April. Average rainfall for the 1st climate normal (1947-1977) is greater than the 2nd climate normal (1978 to 2009) for most of the months, except May, September and October (Table 7.1). The rainfall trend per decade shows the same characteristics.

The increase in Rainfall during the months of September, December and January was experienced in the second normal (1978-2009). The average rainfall of April is 156.7 mm per year, which is highest among all months and in both normals (Table 7.1).

The first climate normal (1947-1977) recorded a mean annual rainfall of 1269 mm, with the highest amount of total rain being 1635mm in 1951, while the lowest total annual rainfall received for this first climate normal is 964mm in 1952. Namulonge recorded a lower mean annual total rainfall (1147mm), lowest maximum (1475mm) and low minimum total rainfall (676) in the second climate normal compared to the first climate normal. This is in line with findings by New *et al.* (2006) that indicated a decrease in the regions' averaged total rainfall although not statistically significant. Comparison of two normals of rainfall is clearer from figure 7.3.

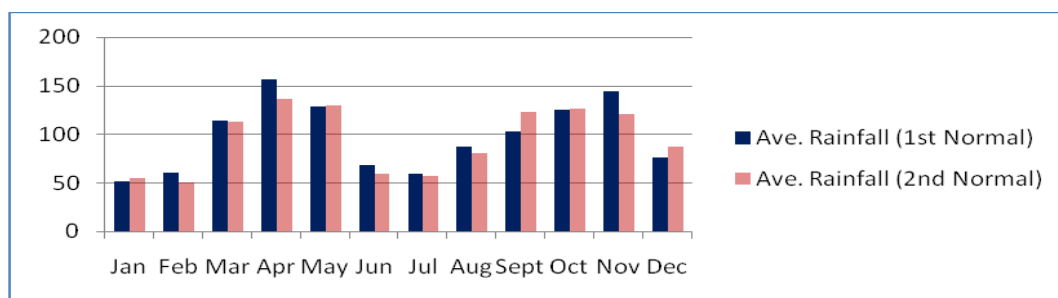


Figure 7.3. Two normals of Rainfall verses months (1947 – 2009)

The month of May receives on average the highest rainfall of 34.7 mm (Table 7.1). The average total amount of rainfall received in Namulonge for the period 1947 to 2009 was approximately 1198 mm, which is very close to what Basalirwa (1995) and Nicholson (1996) found out to be the average annual rainfall for east Africa. The years, which recorded total

amounts of rainfall below 1000mm, were 1949, 1952, 1983, 1985, 1986, 1987, 1989, 1991, 1995 and 2005 (Fig. 7.4).

The year during which, the lowest total with 675.6 mm was recorded, nearly half the average of rainfall received in east Africa was 1989. Years from the analysis that recorded total rain above 1500mm include 1951, 1961, 1962, 1963, 1964, 1968, 1997 (Fig. 7.4). Four of these years (1951, 1961, 1963, and 1997) are also indicated in Kizza *et al* (2009), as years that received anomalous rain. Nicholson (1996) on the other hand pointed out that 1951, 1963, 1968, were years of high peaks that corresponded to Pacific El Nino/Southern Oscillation (ENSO). The plot of Namulonge shows that, 1961 and 1997/98 were years of high rainfall. These rainfall peaks compare very well with flood/El Nino events in East Africa as characterized by (Schreck and Semazzi 2004).

The analysis also shows that the 1960s were the wettest years at this station, which confirms earlier findings that during this time many east African lakes rose by over 2 meters because of the rain that was received during those years (Ogallo 1993; Nicholson 1996; Nicholson and Yin 2001).

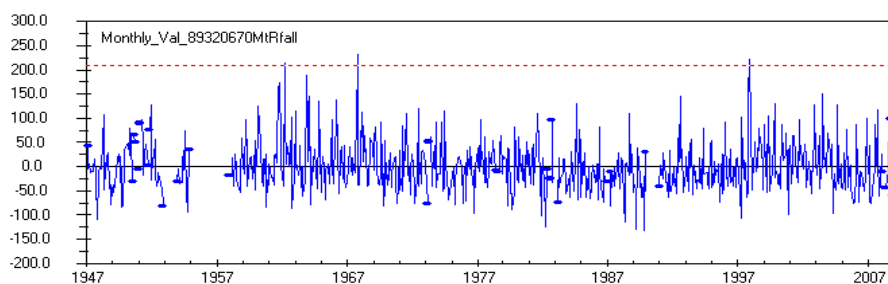


Figure 7.4 Monthly mean total rainfall anomalies of Namulonge (1947 – 2009), values are expressed as a departure from long-term mean.

DJF and SON seasons have experienced a positive rainfall trend (0.047 and 0.254 respectively), while MAM and JJA show a decreasing rainfall trend. The trend is only significant for MAM (-6.63), while the rest of the seasons the trend was non significant at a 5% confidence level (Table 7.2).

The MAM season contributes a larger percentage (38.3%) to the annual total rainfall amounts received in Namulonge. This result collaborates with what (Nicholson 1996; Ogallo 1993; Indeje *et al.* 2000) found out in their studies on East Africa rainfall. They were of the view that much of this high rainfall is modulated by local factors rather than large-scale factors during this season. On average MAM and SON rainfall totals account for 72 % of the mean rainfall in Namulonge. This results is close to what Kizza *et al.* (2009) found in their study. Mean rainfall for annual total, DJF, MAM, JJA, SON are 100.2, 68.0, 140, 72, 122 mm respectively.

Table 1. Monthly linear trend values and their statistical significance levels for temperature and rainfall of Namulonge.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Period
Max.temperature trend ⁰ c	0.000	0.016	0.008	 UNIVERSITEIT VAN PRETORIA UNIVERSITY OF PRETORIA YUNIBESITHI YA PRETORIA	0.028	0.023	0.022	0.010	0.006	0.022	1953-2008		
MKRank stat. (Tkrit_95%)	- 0.029	0.125	0.016	0.202	0.259	0.327	0.343	0.322	0.291	0.090	0.063	0.282	
Max. temperature trend(1 st Normal) ⁰ c	- 0.016	0.012	0.002	0.004	-0.016	0.010	0.004	- 0.001	0.034	0.007	-0.033	0.018	1953-1982
Max. temperature trend(2 nd Normal) ⁰ c	- 0.022	- 0.014	-0.044	0.012	0.039	0.014	0.027	0.005	-0.008	0.036	0.025	0.036	1979 - 2008
Max. temperature trend/ 10 yrs ⁰ c	0.005	0.171	0.083	0.147	0.176	0.263	0.291	0.229	0.222	0.103	0.069	0.225	
Ave. maximum temperature ⁰ c	29.11	29.57	29.12	27.73	27.26	27.25	26.93	27.50	28.10	28.11	28.00	28.30	1953-2008
Ave.Max temp (1 st Normal) ⁰ c	28.99	29.28	28.89	27.51	26.98	26.80	26.30	27.12	27.82	28.01	27.85	28.01	1953-1982
Ave. Max temp (2 nd Normal) ⁰ c	29.28	29.97	29.44	27.99	27.58	27.80	27.47	27.99	28.49	28.20	28.14	28.63	1963-2009
Mean monthly Max. Tmax trend.	- 0.010	0.009	-0.005	0.001	0.016	0.018	0.024	0.022	0.021	0.016	0.001	0.018	
MKRank stat. (Tkrit_95%)	- 0.062	0.049	-0.069	0.034	0.206	0.136	0.229	0.170	0.15	0.079	-0.129	0.149	
Min. temperature trend ⁰ c	0.011	0.002	-0.012	-0.038	-0.021	0.008	0.022	0.008	0.006	-0.002	0.000	0.01	1953-2008
MK Rank stat. (Tkrit_95%)	0.185	0.079	-0.186	-0.359	0.204	0.147	0.241	0.105	0.136	-0.043	0.022	0.206	
Min. temp trend (1 st Normal) ⁰ c	0.003	0.025	0.000	0.017	0.020	0.004	0.004	0.009	0.013	0.021	0.010	- 0.027	1953 - 1982
Min. temp trend (2 nd Normal) ⁰ c	0.039	0.030	0.002	-0.028	-0.013	0.004	0.044	0.006	0.015	0.012	-0.014	0.044	1979 - 2008
Min. temperature trend/ 10 yrs ⁰ c	0.119	0.019	-0.129	-0.384	-0.218	0.079	0.223	0.083	0.069	-0.025	-0.011	0.103	
Ave. minimum temperature ⁰ c	15.28	15.53	16.16	16.43	16.44	15.82	15.29	15.47	15.62	16.04	16.17	15.44	1953-2008
Ave. Min temp (1 st Normal) ⁰ c	15.17	15.67	16.45	17.00	16.85	15.67	15.03	15.41	15.58	16.18	16.11	15.32	1953 - 1982
Ave. Min.temp (2 nd Normal) ⁰ c	15.31	15.39	15.84	15.91	16.03	15.89	15.36	15.53	15.67	15.95	16.20	15.50	1979 - 2008
Mean monthly Min. T min trend.	0.030	0.025	-0.002	-0.023	-0.006	0.034	0.039	0.030	0.025	-0.018	0.024	0.038	
MKRank stat. (Tkrit_95%)	0.221	0.190	-0.013	-0.245	-0.018	0.418	0.313	0.232	0.292	0.096	0.231	0.338	
Ave. Maxi-min temperature ⁰ c	23.63	24.00	23.56	23.39	23.20	22.80	22.12	22.20	23.39	22.34	22.83	22.32	1953-2008
Rainfall trend	0.246	-	-0.522	-1.562	-0.218	-	-	-	0.704	-0.007	-0.305	0.237	1947-

(mm)		0.267				0.291	0.283	0.211					2009
MK Rank stat. (Tkrit_95%)	0.087	-0.057	-0.080	-0.274	-0.076	-0.140	-0.162	-0.118	0.103	0.003	-0.010	0.021	
Rainfall trend (1 st Normal)(mm)	0.615	-0.274	-1.249	-0.995	-0.342	0.503	0.145	0.202	0.515	-0.031	1.862	-0.329	1947-1977
Rainfall trend (2 nd Normal)(mm)	0.404	1.29	-0.420	0.441	-0.987	-0.121	1.263	-0.134	2.61	0.603	0.202	1.260	1978-2009
Rainfall trend/ 10 yrs(mm)	2.466	-2.673	-5.222	-15.626	-2.187	-2.916	-2.830	-2.111	7.048	-0.077	-3.058	2.376	
Average rainfall(mm)	54.86	61.04	114.26	153.79	128.99	66.61	60.67	82.05	114.89	125.96	139.16	87.08	1947-2009
Ave. Highest rainfall(mm)	21.30	22.77	33.04	32.78	34.77	24.81	21.42	25.04	31.94	30.38	33.08	28.65	1947-2009
Ave. Rainfall (1 st Normal)(mm)	51.26	60.21	113.61	156.35	128.20	68.61	59.69	86.98	102.82	125.07	144.05	76.15	1947-1977
Ave. Rainfall (2 nd Normal)(mm)	54.59	50.83	113.38	136.48	129.24	58.79	57.06	80.84	122.50	126.00	120.82	86.83	1979-2008
Deviation of rainfall (mm)	38.32	42.84	45.32	64.14	50.92	34.53	48.00	43.25	56.52	48.21	80.11	56.55	

A closer analysis shows that the annual trend for rainfall is decreasing. This may have severe impacts on soil moisture and agricultural production over Namulonge in future, given the fact that the cropping system and planting time depends highly on rainfall distribution (Phillips and McIntyre 2000). The decrease is however statistically non significant at a 5% confidence level, with a decadal trend of -0.841 during the period 1947- 2009 (Table 7.2). This station does not fall in the 67% of the cases which had significant positive trends as established by (Kizza *et al.* 2009).

The Mann- Kendall test was applied to detect trends in annual wet days. A negative trend of -2.36 per year was observed at Namulonge station. This trends is statistically significant at $p < 0.05$. The annual distribution of wet days during the period of study are shown in figure 7.5, which also reveals that there were more wetter days in the earlier years of the series than in the latter period after 1990.

Table 7.2. Seasonal linear trend values and their statistical significance levels for temperature and rainfall for Namulonge, including those of January to December.

	DJF	MAM	JJA	SON	JAN-DEC
Monthly total rainfall trend	0.047	- 0.663	-0.252	0.254	-0.084
-Mann- Kendall stat Tkrit_95%	0.021	-0.172	-0.154	0.129	0.055
-Trend / decade	0.477	-6.631	-2.518	2.541	-0.841
Monthly maximum temperature trend	0.017	0.013	0.026	0.013	0.017
-Mann- Kendall stat Tkrit_95%	0.223	0.228	0.378	0.218	0.378
-Trend / decade	0.176	0.133	0.259	0.132	0.172
Monthly minimum temperature trend	0.009	-0.024	0.013	0.003	0.001
-Mann- Kendall stat Tkrit_95%	0.214	-0.244	0.267	0.074	-0.020
-Trend / decade	0.097	-0.258	0.130	0.029	0.009
Monthly mean minimum T min	0.028	-0.010	0.034	0.010	0.016
-Mann –Kendall stat. (Tkrit_95%)	0.298	-0.045	0.406	0.287	0.288
-Trend / decade	0.280	-0.102	0.343	0.101	0.162
Monthly mean maximum Tmax	0.011	0.004	0.021	0.012	0.011
-Mann –Kendall stat. (Tkrit_95%)	0.102	0.032	0.262	0.108	0.229
-Trend / decade	0.105	0.042	0.214	0.119	0.108

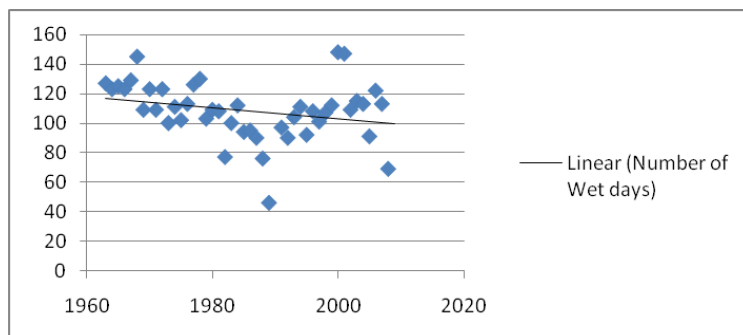


Figure 7.5 Showing the distribution of wet days during the period 1960 - 2009.

7.3.2.1 Trends in interannual and intra-annual rainfall

To study rainfall trends in the Kwazulu-Natal Drakensburg region of South Africa, Nel (2009) considered data at each station for the period 1955-2000 as an arithmetic mean for the region. To test for trends in annual rainfall, data for the period 1947-2009 were considered to

calculate the arithmetic mean for the station, and this mean for each year was plotted. Mean annual rainfall for Namulonge ranges from 49 to 149 mm (Fig 7.6). A negative linear trend(-0.18) in mean annual rainfall was detected which is not statistically significant at 5%.

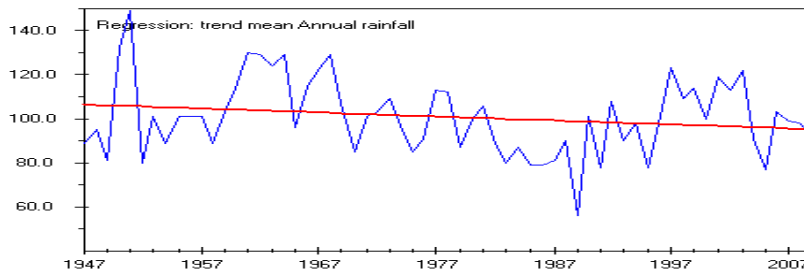


Figure 7.6 Time series of mean annual rainfall for Namulonge for the period 1947-2009

Rainfall in Namulonge is seasonal, and seasonality can be described through the monthly rainfall totals as a percentage of the total annual rainfall(Nel and Sumner 2006; Nel 2009). The intra-annual rainfall depicts a positive trend for the period 1947-2009(Figure 7.7). Knowledge of interannual and intra-annual rainfall distribution of rainfall can be of great importance when looking at ways to solve regional water resources problems(Schulze 1979 in Nel and Sumner 2006).

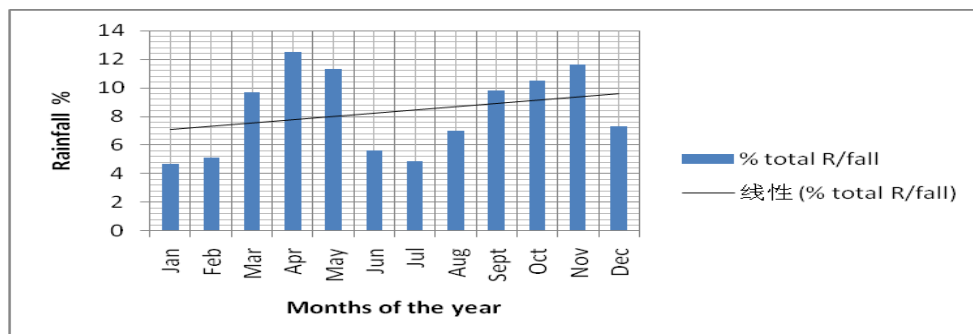


Figure 7.7 Monthly rainfall as a percentage of total rainfall, 1947-2009

7.4 Conclusions and recommendations

This chapter presents the first attempt to analyze climate characteristics of Namulonge in the past half century. The analysis for this study was based on data obtained from the Department of Meteorology in Kampala-Uganda. The choice of the statistical approach used in this study is in line with those used frequently by other scholars to explain climatic trends elsewhere in the world.

Results show monthly maximum temperatures for the period under consideration have been increasing significantly (Table 7.2). The second climate normal has been warmer than the first climate normal of the period under study at this station. IPCC (2001), observed that global average surface temperatures were increasing since 1976, at a rate of 0.15°C per decade, this study has established that maximum temperature has been increasing significantly at a rate of 0.17°C/decade (Table 7.2). Records indicate that 2005 was the

hottest of all years with a mean monthly average of 32.8⁰C. It is evident that variation of mean monthly temperatures throughout the year is very small ranging between 1⁰–2⁰C.

It is also evident from the 56 year record that mean annual minimum temperature was increasing but did not show a statistically significant trend. However the minimums of the minimum temperatures reflect a statistically significant trend which is increasing. This implies that, the nights were warming, especially from the 1990's (Figure 7.2b) which is an indication of global climate change. Warming temperatures are likely to impact on the livelihoods of the people, their health and water resources among others. For example Vectors, pathogens and hosts that cause disease survive and reproduce within certain optimal climate conditions, so changes in these conditions can modify greatly these properties of disease transmission (NEMA 2007). Increased precipitation may increase the presence of disease vectors by expanding the size of existent larval habitat and creating new breeding grounds. Furthermore increases in local temperatures may have detrimental effects on sensitive development stages of plants such as flowering, thereby reducing grain yield and quality.

Riebsame *et al.* (1995) argues that elevated temperatures may enhance evaporation losses, unless they are compensated by increased precipitation, even runoff is likely to be further reduced (IPCC 2007). Muchena and Iglesias (1995), in Abraha and Savage (2006) through simulations have concluded that temperature increase of 2⁰ or 4⁰ C reduced maize yields which show that crop production is significantly affected by climatic variables, which are a driving force for crop growth. Given this argument, the increasing temperatures may impact water resources in and around Namulonge and also alter crop water balances.

Rainfall is decreasing especially in the MAM season. MAM and SON are wet seasons with average rainfall ranging between 110 and 155 mm. These seasons are separated by two seasons of low rainfall. Over the first 30 years higher rainfall was recorded compared to the recent 30 years. Analysis shows that the early 1960s were the wettest years on record.

The results from this study can be ably interpreted in the context of other impacts, which Orindi and Eriksen(2005 in Nema 2007) have noted, meaning that it is likely that constraints on livelihood could be exacerbated.

The majority of Ugandan farmers, like those in Namulonge, practice rain-fed agriculture which is sensitive to fluctuations in weather and conditions. Declining rainfall may lead to crop failure, increasing temperatures and reduced rainfall can even lead to scarcity of water resources for human consumption and watering of livestock. Increases in temperatures may lead to decline in milk and meat production, largely because the animals remain in shade instead of foraging. Crop water balances may be affected through changes in precipitation and other climatological elements such as the increase in evapotranspiration(IPCC 2007). The impacts of land degradation at Namulonge and the surrounding areas are already quite severe. The population growth, human settlements, transport, agriculture, utilization of trees for energy and other human activities are probably responsible for the anthropogenic forcings.

The climate systems in Namulonge are still complex and not fully understood. Some studies like that of King'uyu *et al.* (2000), have come up with results that indicate a significant rise in night time temperatures at several locations. Climate model simulations also anticipate increase in rainfall with in Namulonge region where as this study shows that rainfall is on the decrease at the station. Further research into the underlying local factors that influence climate is therefore required. Future studies ought to investigate aspects of urbanisation among others on temperatures. A study on the possible impacts of climate change on food crops like maize, beans, potatoes, bananas and commercial activities like poultry, fish farming and flower farming that are carried out in the area is also required.

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SECTION 3 ANALYSIS OF CLIMATE CHANGE PERCEPTIONS AND LIVELIHOOD FORMATIONS IN UGANDA USING A CASE STUDY.

This section comprises a single chapter on the analysis of climate change perceptions and livelihood formation using a case study.

The chapter reports on the survey, which was carried out in three sub-counties of Uganda to establish people's opinions on climate change and variability, evidences thereof, and the implications on livelihood formation. These sub-counties were selected because they represent a variety of livelihoods patterns in Uganda in a broad sense. The procedure described here, was not designed to make inferences about the larger populations from which the respondents were drawn. But statistical representation of the findings does not represent populations in the sub-counties that were studied nor for Uganda as a whole. A methodology is followed to acquire data from house holds using a questionnaire on a number of respondents. The purposive field work selection procedure from districts to sub-counties and households set out to identify and describe a range of livelihood patterns that were likely to contain within them the experiences of a substantial proportion of households in Uganda. Livelihood assets are examined using sustainable livelihood tool to determine how people are responding to impacts of climate change/variability. Analysis consisted of established mixed qualitative and quantitative techniques to explore patterns in the livelihood data, coded thematic narrative and interpreted using frequencies.

CHAPTER 8

Climate change and livelihood formation, evidence from three case studies in Uganda.

8.1 Introduction

The reason why climate change has become a point of focus in livelihoods formation is because; developing countries depend on activities, which are climate sensitive, and are estimated to have disastrous impacts (IPCC 2007). Developing nations already are faced with climate change challenges. Thus any new challenge brought about by climate change is likely to be felt primarily through intensification of the impacts that people are already facing (Nuorteva *et al.* 2010).

The majority of the people living in and around the Uganda's Lake Victoria, the largest fresh water body in Africa, engage in livelihood that are highly dependent on water and other natural resources. The most dominant livelihoods in the area are farming, fishing and trade, influenced by the climate and the presence of the lake. People are dependent both directly and indirectly on the surrounding natural resources, and consequently their livelihoods are closely connected to the variability and productivity of the natural resource base. As observed by Ellis and Bahiigwa (2003) almost any aspect of the way, people go about gaining a living is worth investigating.

Ultimately the question addressed in this chapter is: What factors and conditions lead to households choosing a form of livelihood? The factors affecting such decisions will vary considerably among different households, according to their access to different types of assets (e.g. financial, human, physical, social, political, and natural) and according to the needs and priorities of individual households. The following sections use evidence from case studies in Wakiso and Gomba district to address this question. Country literature reviews produced by national researchers provided the main source of secondary data for the study. In addition, local information was obtained through a review of national policy documents, district and local by-laws, NGO reports and other literature about the study area. This was complimented by discussions with relevant district and local authorities. Qualitative and quantitative primary data were captured through a combination of focus group discussions and questionnaire survey.

8.2 Methodology

8.2.1 Theoretical framework

People may be involved in different social and economic activities as individuals, but it's at the level of the household that the real impacts of those activities are seen most clearly. Household here is defined as people living under the same dwelling unit and eating together. This is the unit of analysis whose well-being is generally the key objective. Within this unit members combine their capabilities, skills and knowledge with the different resources at their disposal to create activities that will enable them to achieve the best possible livelihood outcomes and assets. There are five core asset categories of capital identified by DFID's livelihoods framework upon which livelihoods are built. For the sake of this research, these assets are divided into six (Baumann & Sinha 2001) namely; human (e.g. skills, knowledge, good health and ability to labour), financial resources (e.g. savings, access to credit, bank loans, remittances, pensions), political (e.g. policies, structures, institutions), natural (e.g.

land, water, vegetation, biodiversity environmental services), social (e.g. networks, civil society, groups, trust, social relations) and physical (e.g. basic infrastructure including transport, shelter, communication, energy). The types of assets available to people, and the way in which assets are combined and managed, depends on local context. As a result different households will have different levels of access to this range of assets (Whitehead 2002) which they combine to form a livelihood.

A household's access to adequate livelihood assets can be affected by many factors (e.g. climatic and non-climatic) over which households members themselves may have little control. In a way each household will respond differently to these factors of accessing livelihoods. Different motivators and barriers influence livelihood responses and these responses will be different at different levels and scales (Osbahe *et al.* 2008). The different motivators and barriers influence the choices that households make about using their assets. For example they can destroy assets directly, can force people to abandon their home areas and dispose of assets, prematurely as part of coping strategies. The frame work is used to investigate the climatic factors (rain and temperature), their impact on physical, human, financial, social, political and natural (in particular water resources). Non-climatic attributes (demand for water, population growth, changes in economy, technology, water-shed characteristics, water management decisions, prices, policies and legislation) impact on the assets and vice-versa. This interaction determines the livelihood strategies and outcomes such as more incomes, increased well being, reduced vulnerability, improved food security, sustainable use of water resource among others. The study aims at assessing a whole range of influencing factors, but most especially climate change and climate variability, and find out its effects on the livelihoods of the people in a household.

8.2.2 Field research in the Lake Victoria basin area

This chapter builds on the field research that investigated livelihood formation and climate change in two districts found around the Lake Victoria basin area. The research was conducted in January – February 2010 in sub-counties of Katabi, Maddu and Busukuma. The study villages in each sub-county were chosen based on availability of natural resources, their dominant livelihood and the connection to climate. These sub-counties were selected because they represent a variety of livelihoods patterns in Uganda in a broad sense. Variations in rainfall, proximity to or remoteness from public infrastructure and services and variations in access to non-farm activities were among the other factors that were put into considerations when selecting the areas for the field study. The location of sample sub counties can be ascertained from the Uganda map given in figure 8.1. Detailed description of the study areas is given in the section 8.3.1 that follows.

The research focused on general livelihoods in the lake basin area. The main method used in the field research was an interview technique using a questionnaire on respondents from household and key informants.

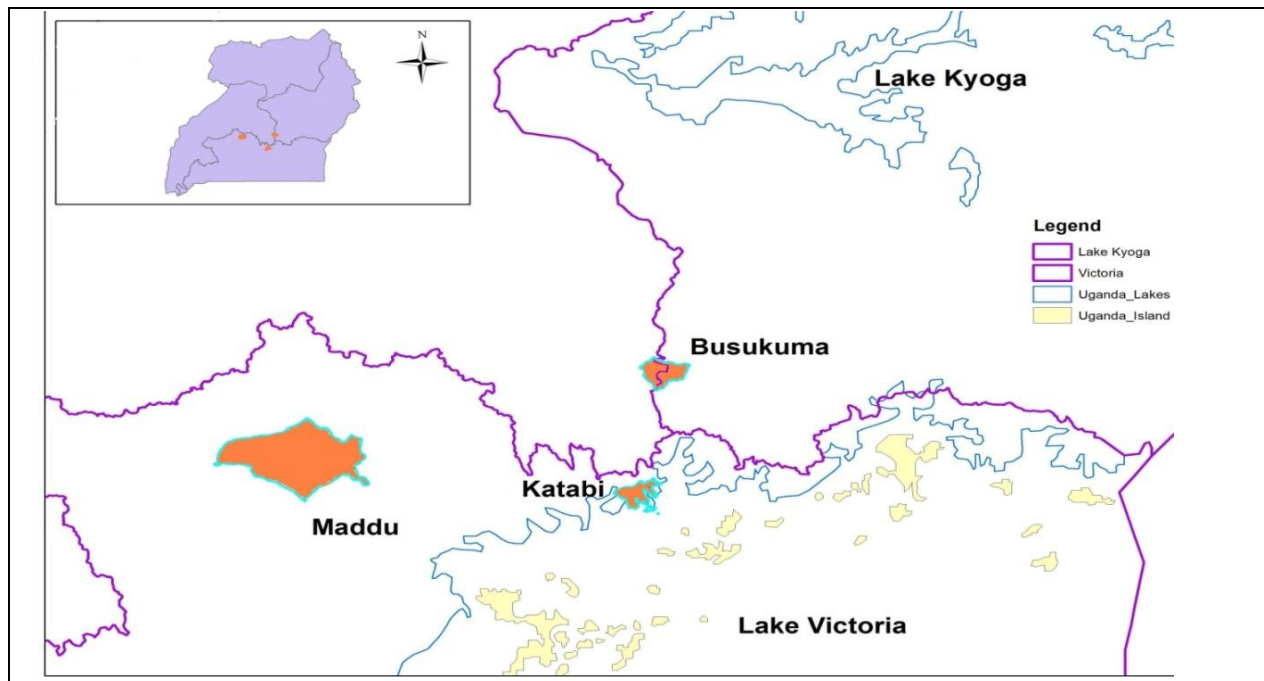


Figure 8.1 Locations of sample sub counties used in the field research

Key informants included persons with a key position in the management of natural resources. All together 70 interviews were conducted with three key informants from each sub-county. Interviews were first conducted with the natural resources managers in order to get a general understanding of the sub-county and its livelihood patterns. The other respondents were randomly selected depending on their availability in spite of the different livelihood sources. Interviews were conducted in a loosely semi-structured manner following certain pre-determined themes, while also allowing space for free-flowing discussions. The informants were encouraged to elaborate on their answers, and to explain the reasons and meaning behind their views.

The main issues discussed in the interviews included the respondents' awareness of climate change, understanding of household livelihoods, livelihood assets, governance, recollection of past environmental shocks and stresses among others. Also other social-economic sources of challenges were investigated as will be indicated in the discussion.

The qualitative interview method, as pointed out by Nuorteva *et al.* (2010) was chosen because it enables large amount of personal reflections to be included in a rather short time period. While the selection of the sample respondents cannot really be considered to represent the views of the entire districts, it does allow the inclusion of various accounts, observation and opinions from different sub-counties and livelihood backgrounds.

Besides the actual field research, previous research and literature regarding the livelihoods in Uganda were reviewed to get a better understanding of the overall circumstances in the area and to help focus the research. The review was done on previous research conducted by authors (e.g. Hepworth and Goulden 2008; Ellis and Bahigwa 2003; Smith *et al.* 2001) among others.

Like in the work by Ellis and Bahiigwa (2003), the procedure described here, was not designed to make inferences about the larger populations from which the respondents were drawn. The purposive field work selection procedure from districts to sub-counties and households set out to identify and describe a range of livelihood patterns that were likely to contain within them the experiences of a substantial proportion of households in Uganda. Further still, statistical representation of the findings does not represent populations in the sub-counties that were studied nor for Uganda as a whole. Analysis consisted of established mixed qualitative and quantitative techniques to explore patterns in the livelihood data, coded thematic narrative and interpreted using frequencies.

8.3 Results

8.3.1 Background to the case study areas

The two case studies Katabi and Busukuma are located in Wakiso district, while Maddu is located in Gomba district². The sub-counties³ lie on the shores of Lake Victoria, the greatest fresh water lake on the African continent also found in Lake Victoria water management zone (Vwmz). These districts in which the sub-counties are situated are endowed with forests, range lands and wetlands which form a major resource base for the districts. For example wetlands cover 16% of the total land area, in these districts, with the major portion lying along Lake Victoria fringes (MWE 2011). Due to the increasing population, natural resources are under pressure, which makes them susceptible to degradation. The landscape belongs to the Buganda surface classification, lying at an approximation range of about 900 to 1340 meters above mean sea level. The districts are characterised by flat-topped hills with steep slopes, and broad valleys occupied by swamps. Climatic is warm and wet with high relative humidity. Rainfall pattern is bi-modal with two wet seasons in the year. The districts have two rainfall seasons, with the long rains occurring from March – May and the short rains in September – November. The remaining months are generally dry. The mean annual total rainfall is 1320mm while mean surface temperature is 22⁰C (see climatic characteristics depicted in table. 8.1, figures 8.2, figure 8.3 and figure 8.4). According to respondents, the weather patterns have become more erratic in recent years. The soils are generally of high productivity and are mainly sandy clay soils, the dominant types are red gravel loams with occasional reddish brown sandy loam and yellowish sands with quartz gravel (NEMA 2008). Much of the vegetation has been removed to allow for settlement (Katabi and Busukuma) and cropping in Maddu. The majority of people resident in the areas of study are from Baganda ethnic group. The main environmental concerns are bush clearing, tree cutting, overgrazing, brick making, and charcoal burning.

The location of the study areas is advantageous because they are close to Kampala, the capital city of Uganda. Since the major source of livelihood is agriculture, agricultural commodities easily find their way into the market. The marketing system is based on hyper markets, where a number of farmers bring their products like surplus food crops, livestock and cash crops

² First level of administration

³ Second level of administration

once a week to a strategic market town in each parish which brings traders from further afield to transact. The mean household size in 2002 was in the range of 4.1 and 4.6 persons for the case study area (UBOS 2009). The field study revealed a mean household size of 5.8 persons with a Std. Dev of 2.7.

Table 8.1 Showing rainfall characteristics of stations in the study area

Met. Station	Sub-county	Mean rainfall	Highest total rainfall (mm)	Year of occurrence	Lowest total rainfall (mm)	Year of occurrence	Standard deviation	CV %
Entebbe Int. Airport	Katabi	1617	2679	1999	1121	2004	24	18
Namulonge Res	Busukuma	1217	1747	1997	674	1989	18	17
Maddu	Maddu	888	1239	-	178	-		21

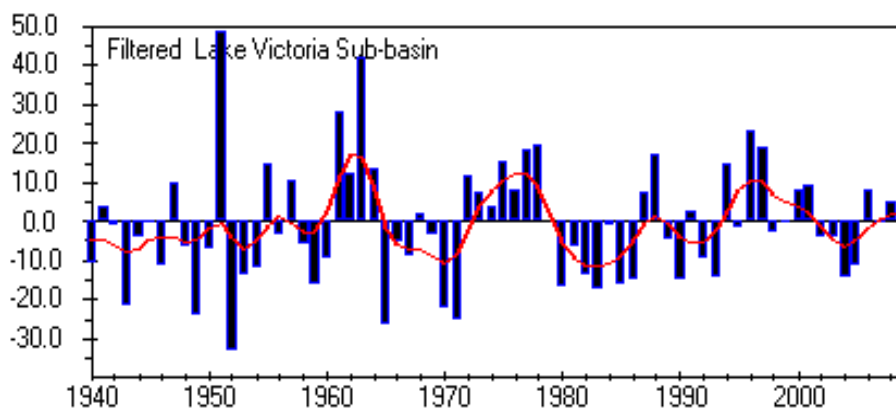


Figure 8.2 Annual rainfall patterns for Lake Victoria sub-basin in Uganda

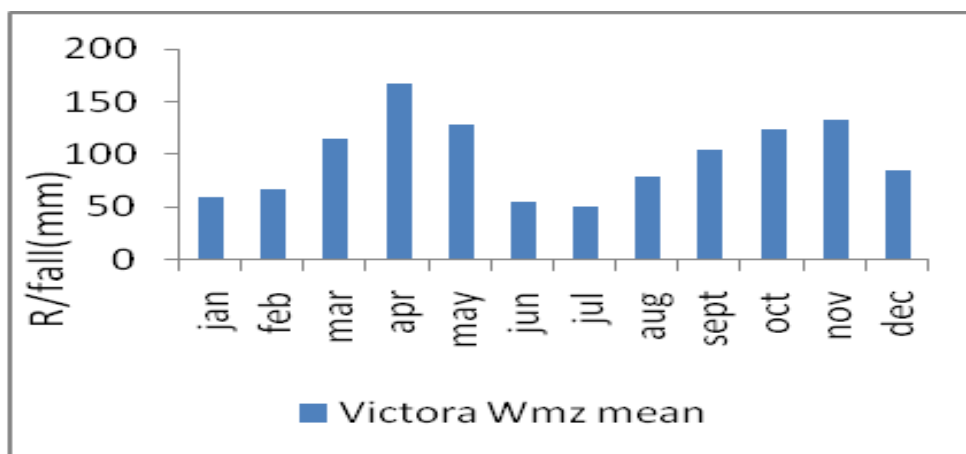


Figure 8.3 Monthly mean rainfalls for Lake Victoria water management zone in Uganda.

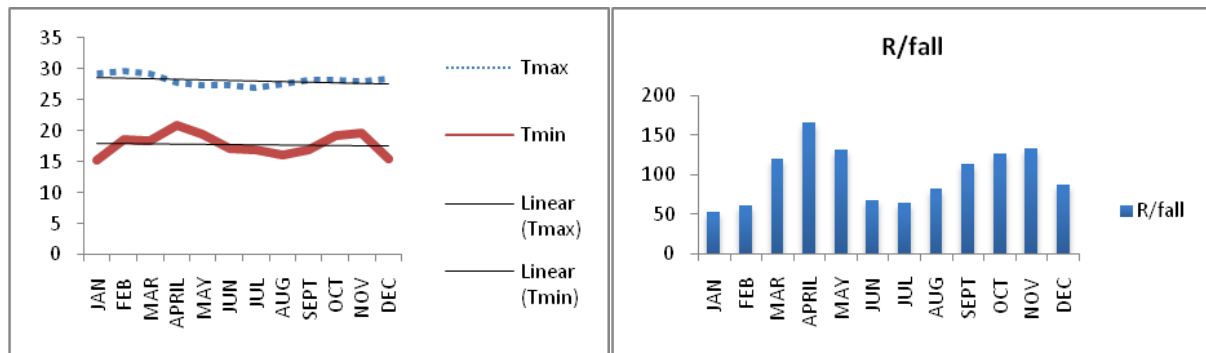


Figure. 8.4 Monthly average maximum and minimum temperatures (left) and rainfall (right) at Namulonge over a 63-year period (1947 to 2009).

Climate change awareness in the area of study

It was in the interest of the study to establish the level of awareness respondents had on climate and climate change. Climate change can bring both positive and negative impacts on different livelihoods and also expose them to unfamiliar conditions (Osbahe *et al.* 2008). It emerged that 96% of the respondents had heard about climate change and 38% were informed through the media, 20% from the internet, and 17% through other sources. Government officials had done little to inform the respondents about climate change since only 2% could testify to that effect. It was also noted that 8% of the respondents claimed to know about climate change through personal experience, observation, own knowledge and detection. Further interrogation generated the following information on climate change awareness as shown in the table.8.2 below.

Respondents also revealed that, in the last 10 to 20 years they have noticed a number of changes that include high temperatures during the day, infrequent hail storms, fog was rear, droughts were frequent, the nights are warmer, it was raining a lot in January, there were few rain days in the year but whenever it rains it was intense and most importantly rainfall was erratic and unevenly distributed.

While answers about the recent climatic changes were diverse, answers regarding coping were quite consistent. Most interviewees were coping by changing lifestyle, diversifying to activities that are less prone to weather, watering food crops, have changed the type and style of clothing, at night they use light or no bed covers and also keep windows open to let cool air in the house.

Table 8.2 Showing percentage of respondents who strongly disagree, Disagree, Agree and strongly agree to questions that relate to climate change awareness.

Statements that determine climate change awareness	Strongly disagree	Disagree	Agree	Strongly agree
The world climate is changing	2	-	38	61
Uganda's climate is changing	2	3	62	34
Change in climate did not affect their livelihoods	32	53	11	5
Change in climate was not going to affect their livelihoods	40	50	4	6
Other factors other than climate change were affecting their livelihood	3	18	66	13
No climate change evidence in Uganda	31	57	5	8
Climate change would impact majority of livelihoods	2	8	39	51
Climate change is impacting on the economy of Uganda	5	-	44	52
Weather seasons have changed	3	-	43	54
Experiencing longer droughts	3	11	60	26
Experience frequent floods	7	37	43	13
Experience high temperatures	3	10	44	43
Experience more rain days in a year	7	62	24	7
More warmer days in a year	-	11	73	16
Morning temperatures are warmer than they used to be	2	22	68	9
Night temperatures are higher	-	6	67	27
Night temperatures are colder	14	77	8	2
Change in biodiversity	4	9	64	23
Species behaviour and life has changed	2	5	74	19
Living standards will decrease	-	-	47	52
Experience food shortage	2	2	31	66
Increase in infectious disease	-	7	52	40
Few problems would arise because people would adopt	33	52	14	2
Experience better weather	51	45	5	-
A hydro-political situation will emerge	10	15	61	15
Experience less hydro power	3	10	71	16
Few people would be involved in climate controlled activities	12	24	39	24

Respondents raise one coping method of watering plants, which has not been very common especially in these parts of Uganda. Much of the farming in Uganda is rain fed, and farmers have always relied on rainfall to grow food for own consumption and cash crops to generate income. This could explain why, close to 85% of the respondents disagreed with the question that, climate change has nothing to do with the way they secured their livelihood (see Table 8.2) above. We are informed by Kinsey (2002) that households that rely on rain fed farming especially in Africa face fluctuations in annual income and demonstrate how components of income move in response to variations in rainfall. Households therefore try to reduce the effect of an income shock by diversifying in or out of agriculture or both including irrigation.

The field study also shows that, interviewees were diversifying and getting involved in activities which are less prone to weather changes. Climate is an important natural resource, which according to the interviewees influences livelihood formation in Uganda. The study shows that 90% of the respondents agree that changes in climate will impact on the majority of livelihoods, while 96% agreed to the statement that climate change was already impacting on the economy of Uganda. Table 8.3 shows correlations of responses from sample households on the impact of climate on livelihoods. With such perception from most of the respondents, they are not going to wait for disaster to happen, hence the diversity in their livelihoods. Generally diversification concurs with cause and motivation continuum across families at a particular point in time (Ellis 1998) whereby some causes are either locations specific or disaster driven. Diversification of livelihoods sources has been put forward as one of the strategies households employ to minimize household income variability and ensure a minimum level survival (Idowu *et al.* 2011).

A livelihood according to (Idowu *et al.* 2011) is a bundle of activities households engage in to generate livelihoods and achieve a certain level of livelihood security. Livelihoods in Uganda have evolved based on the availability and opportunities afforded by the natural resource base. Market forces also play a major role in the evolution of livelihoods. These main sources of livelihoods are, however, commonly supported by diversity of secondary livelihoods. For the purposes of this study (and at the great risk of oversimplification) the main sources of household livelihoods are characterised as; subsistence farming, employment income, business enterprise, cottage industry, property income and family support. However, the main activities that support livelihoods in sample households identified by respondents were (see also figure 8.5);

Table 8.3 showing correlations of responses from sample households on impact of climate on livelihoods.

	The change in climate has nothing to do with the way I secure a livelihood	Climate change is not going to affect livelihoods	Climate change will impact on the majority of livelihoods in Uganda	Climate change is impacting on the economy of this country
Pearson Correlation	1	.625**	-.376	-.376
The change in climate has nothing to do with the way I secure a livelihood Sig. (2-tailed)		.000	.002	.002
N	66	65	64	64
Pearson Correlation	.625**	1	-.407**	-.407**
Climate change is not going to affect livelihoods Sig. (2-tailed)	.000		.001	.001
N	65	68	65	65
Pearson Correlation	-.138	.003	.322	.322
Climate change will impact on the majority of livelihoods in Uganda Sig. (2-tailed)	.281	.979	.010	.010
N	63	65	64	64
Pearson Correlation	-.376**	-.407**	1**	1**
Climate change is impacting on the economy of this country Sig. (2-tailed)	.002	.001		
N	64	65	66	66

** . Correlation is significant at the 0.01 level (2-tailed).

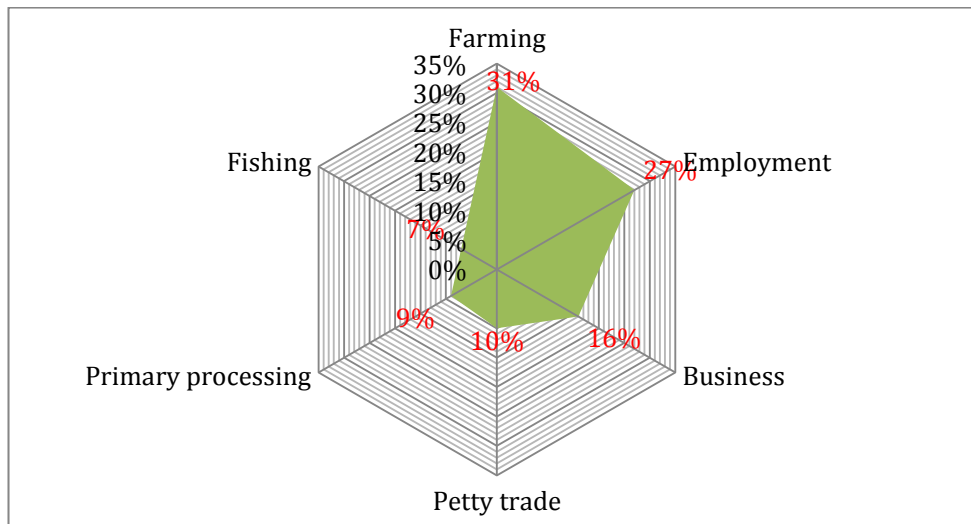


Figure 8.5 showing the percentage of households who identified a particular activity as the main source of livelihood.

Farming i.e. crop, animal, pasture, poultry and bee keeping (31% of households)

Employment i.e. banking, labour provision, teaching, machine operators, domestic workers (27% of households).

Business i.e. metal fabrication such as blacksmith, welding and fittings, masonry, timber products, vehicle mechanics, real estate, services, house letting, barbering, hair plaiting, plumbing, painting, repair services for watches, radio, food preparation and vending (16 % of households).

Petty trading i.e. consumables, cash crops, alcohol, herbal products, retail in industrial products, charcoal trade, selling clothes (10 % of households).

Primary processing i.e. quarrying, brick making, woodwork like carving and carpentry, handicrafts, sand mining (9 % of the households).

Fishing i.e. fish farming, fish catch, boat making, fish gear (7 % of households).

Other sources of livelihoods include providing laundry services, cycle-transport (boda-boda), construction, repairing equipment and tour operators. Households were also asked to mention those activities, which support livelihoods in the community they live in. This was done to validate the above-mentioned main activities. It was found out that, 28% of households identified self employment and trade related activities to be the main activity, followed by farming at 19%. Fishing is at the bottom of the list with 3% of the households naming it as an activity that supports livelihoods. Statistical correlation for these answers and responses from the households' main activity was 0.17, which is weak.

It should be noted that in all the three sample sub-counties, households pursue diverse livelihood strategies. Agrarian based activities play an important role in the livelihoods of the rural (Maddu) and semi-rural (Namulonge) households. In contrast to Maddu and Namulonge, farming activities comprise a much smaller proportion of livelihood activities in

Katabi, with fishing and fish-related employment and trade the primary source for most households. At the same time livestock rearing plays a big part in the economic aspect of Maddu, and it is also important as a buffer against market and climatic shocks. Furthermore, livestock is an asset that can be quickly liquidated in circumstances that are sudden or those which require big expenditure such as medical care, school fees or bride price. So respondents invest in animals to enable them cover expenditures in the future.

During the field exercise, respondents were asked, whether someone else contributed to their livelihood? About 60% of households in all three sample areas indicated that friends and family as supporting. 2% of households identified the Community Based Organisations (CBOs), Non-governmental Organisations (NGOs) and Faith Based Organisations (FBOs) contribute, while 20 % of households did not have anybody else contributing to their livelihoods. Remittances and other transfers scarcely register in the livelihood portfolios of the sample households, though they are a critical source of income for the country. Remittances play an essential role in Ugandan households, for they provide a buffer against failing agricultural production in cases of climatic and/ or market shocks and to some it is a vital income stream. However, remittances do not appear to enhance opportunities for income diversification. They help to assure subsistence, but do not necessarily facilitate wider investment in either agriculture and or trade, but highly reflect in both self and wage employment.

The main livelihood problems identified through the questionnaires from the sample households were categorised (here ranked in order of importance) as;

Economic, including but not limited to competition in business, high costs of doing business and living, capitalisation, low prices, low supply of produce, price fluctuations, limited funds, scarcity of raw materials, poverty, little pay, increasing demand, delayed payment...etc.

Lack of natural resources, such as; shortage of fish, lack of land, land shortage, water shortage, scarcity of herbs, deforestation, diseases/pests, decreasing soil fertility, etc.

Weather related problems like drought, shortage and unreliable rainfall and weather related disasters.

Enabling environment i.e. corruption, high taxes, cost of doing business, theft, cheating, policy and institutions and low business relationship (partnerships).

Poor technology and technological changes were also of great influence in forming livelihoods. Respondents cannot afford to purchase, maintain and match the current developments in technology.

Access to infrastructure including transport costs, thick vegetation, poor roads, electricity cost and lack of market were challenging livelihood formation.

The following sections examine the influence of capital assets, the governance environment and climate variability on a household's decision to form a livelihood.

8.3.2 Capital assets

Assets determine the economic activities of a household in a given context. The context as indicated by Winters *et al.* (2009) includes natural forces, such as natural disasters, weather patterns, pests, human forces, the state and civil society. An intervention that improves a household's asset position is likely to increase its ability to take advantage of opportunities to produce outcomes such as income, food security and investment spending.

Natural capital is the term used for the natural resource stocks from which resource flows and services useful for livelihoods are derived (DFID 1999). Natural capital is very important to communities, which, derives all, or part of their livelihoods from resources based activities. Examples of natural capital in the study area included; water resources, soils, forests, sand and clay, animals, rock and pasture. These resources were available to the community in the study area and have been listed according to their importance in the provision of livelihoods.

Human capital represents the skills, knowledge, ability to labour and good health that together enable people to pursue different livelihood strategies and achieve their livelihood objectives (DFID 1999). Human capital is required in order to make use of any of the five other types of assets, to achieve positive livelihood outcomes. But this is determined by the size of the household, education levels, experience, age, occupations and gender (Morse and McNamara 2012). The study investigated whether people in the three sample study area were able to invest in their own human capital by attending school. Education is important in raising economic efficiency and competitiveness and to fighting poverty (Yúnez-Naude and Taylor 2001). Recent literature depicts education as a contributing factor to diversification by rural households in developing countries (Ellis 1998). The study revealed that, 50% of the respondents had attended post secondary education, and of these (21%) were graduates (Fig. 8.6). The capacity of a household to engage in off-farm work or otherwise diversify its income sources is commonly associated with its level of education attainment, wage rise and other opportunities corresponding with educational achievement. A lack of education is an obstacle to participating in many non-agricultural activities (Winters *et al.* 2009).

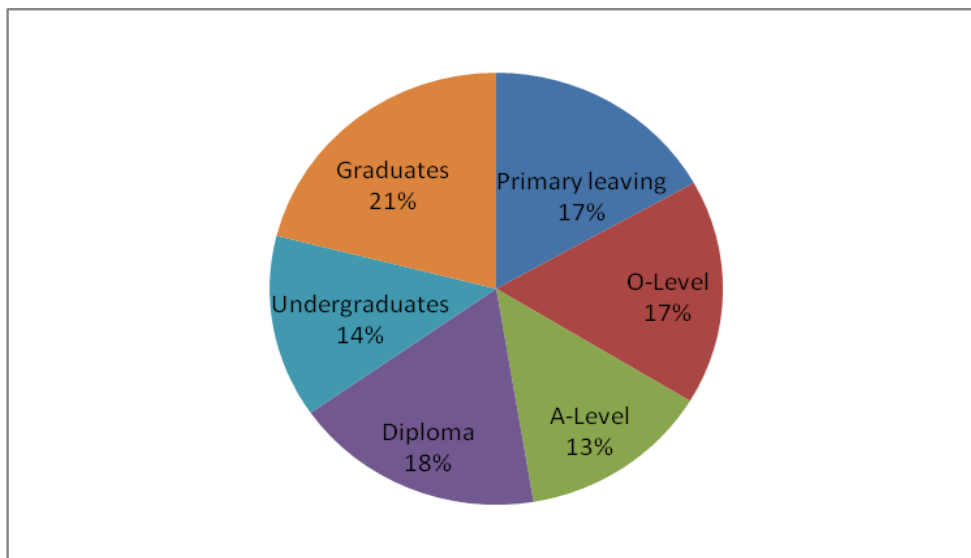


Figure 8.6 Level of education attained by respondents in the study areas.

Human capital provides labour for the various enterprises engaged in by a household. It was the aim of the study to find out whether the knowledge acquired was relevant to existing livelihoods? Having in mind that formal education was not the only source of knowledge for human capital, we had to establish what type of skills, experience and training the respondents had and the purpose it serves? From the analysis it became evident that, 32% of the respondents had technical skills, 22% management training, and the least represented was banking and finance (Fig. 8.7). The study also found out that 70% of the interviewees were utilising their skills and training to form a livelihood. Only 19 % of the respondents were not using their skills and training to make a living. Among the reasons that were advanced for not using their skills and training included; having found alternative livelihoods that were more profitable e.g. poultry; others felt that they were being under employed in the industry in which they had trained; some few had decided to join politics, thus abandoning their training. Job scarcity, capital accumulations are the other reasons why respondents were not using their skills and training. When members differ in terms of education, even their sources of livelihoods differ.

The study was not able to establish differences of education with in a household. But as Morse and McNamara (2012) demonstrate, intra-household differences in education and training are an important factor that affects, especially off-farm sources of income. The level of education and school attainment has a strong bearing on the productivity of a given population. In Uganda individuals who have gone to higher education according to Newman and are likely to engage in non-farm enterprise than those without education according Canagarajah (1999 in Smith *et al.* 2001). In this regard we can anticipate that since universal primary education was introduced in Uganda, there is a chance in future to see more non-farm activities mushrooming. Education as well as accumulated years of schooling of the diverse household members can influence household investment allocations to the various activities, as well as proceeds to those investments per activity (Yúnez-Naude and Taylor 2001).

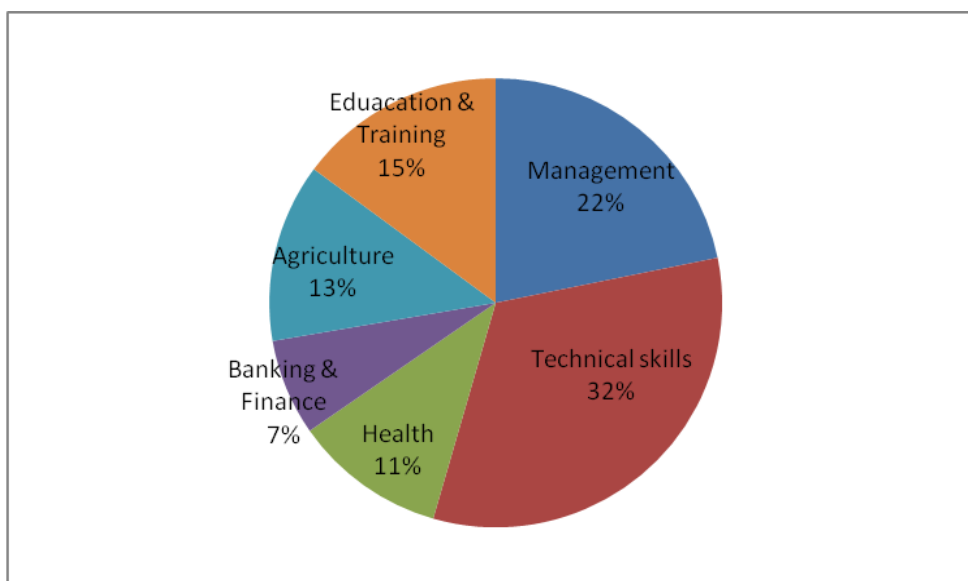


Figure 8.7 Categories of skills, training and experiences held by respondents in percentages.

Financial capital Consists of stocks of money or other savings, including income levels and its variability over time plus its distribution within society of financial savings, access to credit and debt levels. Across all sample study areas, income from different sources of activities for majority of the respondents (53%) was in the range of U.shs 18000 and 900000 (\$100 - \$500) per month and very few people in the study area benefitted from remittances. The other sources of finance that are available to the interviewees include, micro-finance credit schemes, bank credit, rotating credit and savings schemes, and government intervention scheme known as ‘prosperity for all’ (a.k.a Bona-baggaggawale) in a descending order. The study also established the importance of these schemes in supporting livelihoods. It turned out that respondent’s ranked micro-finance credit schemes to be more important than the others, while insurance was ranked as the least important in supporting their livelihoods. Smith et al., 2001 where they observe that microfinance institutions that were opened up in 1990s had grown from 50 to 250 by 1999, support this revelation in literature. In 2010, Uganda had 2115 providers of microfinance facilities with 952,331 loans amounting to \$398,998,047 of total deposits (UBOS 2010). Climate change was affecting the way respondents were accessing finances in that, it has created a situation of uncertainty that limit loan access (13%) and loan repayments were becoming hard to pay back by (10%) of the respondents. Never the less a considerable number of interviewees (6%) did not realise any influence of climate change on the way they access finances. Financial service provision is still hampered by poor physical and communication infrastructure and by a weak legal system that makes it hard to penalise defaulters (Smith *et al.* 2001). A big percentage of the respondents spent their income on feeding, taxes, education, transport and electricity in that order of ranking. It was observed that low-income earners (Ushs1800 - shs18000 or \$1 - \$10) were not spending on education and health, which are considered to be basic human needs.

Physical One way of establishing the relative wealth of a community and households in particular is to catalogue physical assets, though it is not an easy task. In terms of ‘productive assets’ especially the tools used in formulating a livelihood is summarised in table 8.4. Also provided are the percentages of how the tools are accessed.

It is evident from the table that majority of the interviewees own mainly tools and equipment used in agriculture, which are basic. Very few respondents hire or depend on loaned equipment. The percentages of hiring and loaning rise as the equipment needed requires heavy capital investment. With such basic tools and equipment livelihood formation is slow, and what is left for the majority is to depend on what nature offers which makes them vulnerable.

Access to infrastructure is likely to increase opportunities in livelihoods formation. According to Winters *et al.* (2009) infrastructure such as electricity, markets, and proximity to a road, railway or urban centre increase the probability of being involved and or diversifying a into a livelihood. There is a strong influence of access to infrastructure and proximity to urban areas, as well as positive correlation between access and non agricultural wage employment.

Table 8.4 List of basic tools and equipment used in livelihood formation and how they are accessed in the study areas under consideration.

Tool(s)/ Equipment	Owned %	Hired %	Shared %	Loaned %	Free %
Panga	67	1	4	-	-
Hoe	66	3	3	-	-
Cooking utensils	60	1	-	-	-
Furniture	56	1	-	-	-
Bicycle	47	1	-	-	-
Spray pump	27	3	3	-	-
Fishing hooks	11	3	1	-	-
Oxen	11	4	3	-	-
Fish nets	10	1	3	1	-
Boat	7	4	4	1	-
Tractor	6	17	-	-	-
Sewing machine	6	3	3	-	-

Social According to Harris and de Renzio (1997 in Bebbington and Perreault (1999), the term social capital has been used to refer to family and kinship relationship, social networks or associational life related to groups or organisations, cross-sectoral linkages or networks that link organisations of state, market, and civil society around problem-solving tasks. Building endowments of social capital may be a means through which households might be more efficient in building and using other forms of capital and more effective in making claims on natural resources. For example, social capital may enhance the protection of natural capital from degradation by externalities through acts of protests, as well as from overuse by members by enforcing rules, fines and any other sanctions (Bebbington and Perreault 1999 and references therein). Such organisations may also be a means for accessing different forms of capital and for shifting the way in which the state allocates resources. They may also affect the incomes that people can derive from natural resources use by increasing both the prices paid to rural people for their products as well as the productivity of resources use. It is further observed that, social capital in the form of networks of social sanctions can enhance both the level of human capital formation and the social uses to which that human capital is put.

Social capital is an important aspect of the study areas in Uganda and can take many forms, ranging from kinship, social groups, organisation, political contacts, and patronage. A summary of how households by percent, felt linked to other households or individuals in the

community is provided in the breakdown that follows. For example, 66% of the interviews were linked to other households because of kinship (blood relation), while 63% linked with individuals and households in the community because they belong to the same social group. Interviewees who were linked to other households because of patronage were 51%, to organisations were 36%, and only 24% were based on political contacts.

These linkages according to the field interviews were of importance in providing mutual assistance (74%), traditional ceremonies and decision making (64%), raising capital (44%), pooling labour (39%) and only 19% of the respondents felt that linkages with others were important during climate disaster management periods. This low percentage including that of abating crime is not common occurrences. Usually climate disasters happen on a large scale, so neighbouring households in the same community would not help each other unless when help comes from relatives in cities in form of food and clothing. The high percentages in the first three linkages can be attributed to the fact that, they do not demand money. Such assistance comes from social groupings, relatives and patrons in form of mobilisation, representation and ceremonies (weddings, funerals, religious etc) where most people are obliged to attend. People who need to raise capital are often affiliated to organisations where they take membership so that they can benefit from funds as loans in form of micro-credit. As discussed by Osbahr *et al.* (2008) social structures provide social stability by binding individuals in a group together and also connect people from differing social and economic strata.

Political Access to assets and entitlements are widely governed by power relations that have political dimensions, but their workings are at times informal and concealed. Examples of illicit use of political capital are abundant and are found in the relations among the respondents especially the elites, local officials and elected representatives and between them and outsiders such as in the tendering process and district service commissions which hire staff. Administrators and members of local government have a key role in determining who benefits. This power is exogenous and it can be built up according to (Baumann and Sinha 2001). He further explains that, the ability of the poor to press their claims depends on how they can build up this power in relation to that of others, and deploy it in counteracting the illicit use of power by others (usually the elites). In order to establish the political dimensions, in all sub-counties, households were asked whether they participated in any organisation, cooperative, political party or pressure groups. It was explained that the type of information of the institution on which an opinion was sought to understand whether it was enabling the household member in forming a livelihood. Results from this exercise are as follows:

8.3.3 Vulnerability

Vulnerability is seen as a high degree of exposure to risk, shocks and stress (Ellis, 1998). The phenomenon varies over time and space, depending largely on the changing processes through which individuals, households and larger social groups fulfil their immediate subsistence needs and invest in medium- and long term reproduction of their social system (Le Sage and Majid 2002). Vulnerability analysis along this line requires identifying specific

physical, economic and social resources that are accessed and how they are used to form a livelihood.

In the Lake Victoria basin area where the study area is located, climatic vulnerability is characterised by high mean annual rainfall, compounded by low variability in its spatio-temporal distribution. In addition, the past few decades have shown a definite trend for increasing temperatures and reduced precipitation. Hence, livelihood strategies are geared towards coping with a high degree of uncertainty, minimising risk and meeting subsistence needs. This has implications for individual time preferences and investment decision-making amongst most people in Uganda.

Access to rural livelihoods is mediated and affected by institutions, shocks and economic trends (Ellis 2000; Kgathi *et al.* 2006). In study area land tenure systems for the establishment of livelihoods have resulted in reducing access of the local communities to their land and its natural resources. In addition, the introduction of cordon fences by large scale farmers and land owners has had an adverse effect on livelihoods as it reduces access of communities to water, pasture, fishing and gathering. There is no empirical evidence on the impact of changes in land tenure institutions on access to livelihoods in Uganda as yet.

The common livelihood shocks in the study area include drought, diseases (animals, crops and humans), floods, desiccation of river channels (primarily due to natural geographical shifts in the flow of water) and civil unrest. Desiccation of river channels in Ggomba has adversely affected access of the local communities to water resources for both human and livestock. The impact of shocks on livelihoods in the study area is also demonstrated by the occasional migration of pastoralists from Gomba into the northern districts close to Lake Kyoga, which causes civil unrest.

Household members from the study area specifically identify the crises they have faced in the past to include: crop failures, legal problems, disease, conflict over natural resources, death of family member, theft, and extreme temperatures. Climate related crises (e.g. temperature, drought, floods and storms) are least mentioned by households. However, among the climatic related crises, extreme temperatures were ranked highly followed by drought. Disease followed by death top the general list of crises that have befallen households in the study area.

The study investigated further on how households dealt with the above crises. The use of modern farming practices is the most cited by households as a mitigation measure to deal with the crises. Since majority of the households are involved in agricultural activities either as a main livelihood or as an alternative livelihood strategy modern farming practices are highly integrated in livelihood formation.

Seeking medical help is mentioned as a second way to overcome the crises in the households that were studied. Other mechanisms of overcoming the mentioned crises include; seeking legal redress, seeking security and help, health living, borrowing from independent financial providers' e.g. microfinance, resorting to trade instead of farming, mutual understanding, diversifying to other forms of livelihoods.

Digressing deep into households' vulnerability, respondents were asked whether they had experienced changes economically, socially and environmentally and how these households' had dealt with these changes in the past. The past in this aspect is 10 to 20 years, though it could have been longer, but the memory of respondents for a long period beyond twenty years could not be guaranteed.

Series of economic changes in the households have occurred in the past 10 to 20 years. Such changes include; low production of food and animal products; declining incomes and scarcity of jobs; a shift in activity from farming to trade; inflationary tendencies coupled with high costs of transport, taxes, goods and services and living costs. Respondents are dealing with these profound changes in a number of ways, such as; getting involved in multiplicity of income generating activities in order to meet their personal needs. Other respondents have resorted to migration (urban, overseas) especially the young in search of a livelihood. In order to circumvent the food problem, the urban households are depending on supply of food from relatives in rural areas. This will require a member of the household to visit the relative on a weekly basis to participate in cultivation and on return come home with food. Modern ways of farming (such as hybrid animals, crop varieties, fertilisers) have been adopted by the respondents in order to maximise production. Households, involved in businesses are soliciting loans to capitalise them and also tap into other business ventures especially those which are not climate dependent. The same respondents who are in business have experienced high taxation, inflation and competition among each other when carrying out work. In order to cope, they have resorted to selling their products at high prices so that they can maintain their profit levels.

There are number of social changes that have occurred to the households in the three sample study areas. The fact that households were not relating with neighbours as freely as they used to in the last 10 to 20 years was a challenge that was mentioned by many. Respondents felt that their social relationships with waning, everyone was looking after their own and they could not even extend forms of gratitude to them. This was followed by the fear for technological dependence, migrations and high dependence on family members. Conflict over natural resources especially land is another social change observed in the last 10 to 20 years. Land is expected to be closely linked to agricultural production, including both crop and livestock production. It has indirect value in other economic activities and serves as collateral for credit which links land to livelihood activities. In general, respondents without access to some land on average, focus on other economic activities other than agriculture.

A number of other variables besides the key assets are also likely to influence the option of livelihood. For example amount of labour available can lead to a stretch of livelihoods, or even the age and gender of the household head, which reflects the stage of life and opportunities available to the head. The amount of investment the household has previously made also matters as does the level of social capital of the household. Finally, the local context including the functioning of markets, availability of common property resources and local government policy, are all influence household decisions making with respect to livelihood activity.

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SECTION 4 ASSESSING AND CHARACTERISING WATER RESOURCES OF UGANDA AND THEIR RELATIONSHIP WITH CLIMATE CHANGE.

This section has two Chapters on water resources and their relationship with climate change/variability in Uganda.

Chapter 9 reviews the characteristics, availability, governance, demand and importance of present day water resources in Uganda as well as describing the various issues, challenges and management of water resources of the country. This review is drawn from secondary sources, because much of the literature is found in policy papers, government and international organisations documents and work embedded in documents produced by consultants. The findings from these secondary sources are compared with those findings from climatic data. Deeper insight is presented in Chapter 10 which draws on climate characteristics and water resources to establish the potential impact that may arise by detecting changes in surface- water area of Lake Kyoga basin using remotely sensed imagery. Since the nature of water resources distribution is transboundary, several issues and challenges arise because of the geopolitical nature of Uganda. These issues are further aggravated by climate change, climate variability and population growth among others. Climate change is expected to impact on rainfall and water availability, which impact can be detected from lake surface water area. The findings from analysis are correlated with hydrological data from literature to support the results.

CHAPTER 9

Water Resources of Uganda: An Assessment and Review.*

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9.1 Introduction

Of all the renewable resources, water has a unique place. It is essential in sustaining all form of life, food production, promoting economic development and for general well being. Water is impossible to substitute for most of its uses, difficult to de-pollute, expensive to transport but a manageable natural resources, capable of diversion, transport, storage and recycling (Kumar *et al.*2005). Water resources are divisible into two distinct categories: the surface-water and ground water resources. Each of these categories is a part of the earth's hydrologic cycle derived from precipitation. Surface and groundwater resources of the country not only play a major role in domestic water supply, watering livestock, industry, hydropower generation, agriculture, marine transport, fisheries, waste discharge, tourism, and environmental conservation. That is why it is considered indispensable for all forms of life by Kundzewicz *et al* (2007) in almost all human activities.

Water resources are conceived as a dynamic phase of the hydrologic cycle, which is influenced by climatic, physiographic and geological factors. For example physiographic factors, including geological aspects influence the occurrence and distribution of water resources. While orography influences rainfall and other climatic variables like temperature, humidity, and wind, that in turn affects evapo-transpiration, which determines the totality of water resources (Kundzewicz *et al.* 2007). Therefore, the study of water resources requires an understanding of the climatology among other aspects, of a region. Since direct rainfall is the most important source of water resources in Uganda, therefore, understanding the spatial and temporal variability of rainfall is paramount when estimating water availability (Asadullah *et al.* 2008).

Uganda is well endowed with water resources with almost 15% of the country covered by fresh water. The rural water subsector reform report for Uganda in 2004, identified water resources as comprising of rainfall, surface water run-off, rivers, lakes, wetlands and groundwater. The total renewable water resources are estimated by FAO-AQUASTAT to be about 66km³/per year corresponding to about 2,200m³ per capita per year (NEMA 2008). Both and more of these water resources are shared by other riparian states shown in the table 9.1 below that are part of the Nile Basin. In a regional context, the whole of Uganda's water resources is part of the Nile. Uganda is a downstream riparian to Burundi, Democratic Republic of Congo (DRC), Kenya, Tanzania and Rwanda and an upstream riparian to South Sudan, Sudan and Egypt.

Since the nature of water resources distribution is transboundary, several issues and challenges arise. These issues are further aggravated by climate change, climate variability and population growth among others. The current water management practices in Uganda may not be robust to cope with these impacts and the increasing water use requirements. With rapid growing population and improving living standards the pressure on Uganda's water resources is increasing and per capita availability of water resources is reducing day by day. Due to spatial and temporal variability in precipitation the country faces the problem of floods, landslides and droughts. The quality of surface and ground water resources is also deteriorating because of increasing pollutant loads and non-point sources. Climate change is

expected to impact on rainfall and water availability. Currently, the data collection, processing, storage and dissemination have not received the deserved attention. All these aspects require an assessment of the current water resources status. Much of the literature on water resources is scattered and embedded in policy documents, strategic plans and reports produced by consultants and international organisations.

The review therefore, focuses on the character, potential, governance, challenges, availability and demands of water resources of the country using secondary data sources.

Table 9.1 The major shared water bodies and river courses of Uganda.

Water resource	Countries sharing	Basin wide
River Nile	Uganda, South Sudan, Sudan, Egypt	Burundi, DRC, Egypt, Ethiopia, Kenya, Rwanda, South Sudan, Sudan, Tanzania, Uganda, Eritrea
River Achwa	Uganda, South Sudan,	Uganda, South Sudan,
River Kagera	Tanzania, Burundi, Rwanda, Uganda	Nile Basin Riparian States Burundi, Tanzania Rwanda, Uganda
River Semliki	DRC, Uganda	Nile Basin Riparian States
River Malaba	Kenya, Uganda	Kenya, Uganda
River Sio	Kenya, Uganda	Kenya, Uganda
Lake Victoria	Uganda, Kenya, Tanzania	Nile basin Riparian States
Lake Albert	DRC, Uganda	Nile Basin Riparian States
Lake Edward	DRC, Uganda	DRC, Uganda
Sango bay swamp	Tanzania, Uganda.	Kenya, Burundi, Rwanda

9.2 Hydrology of Uganda

9.2.1 Surface water resources

Uganda is a landlocked country that occupies 241,550.7 km² of land. Open water and swamps constitute 41,743.2 km² of area and area under land constitutes 199,807km²(UBOS 2009). With about 15% of total land area of wetlands and open water, including the annual water supply of 66km³ in form of rain and inflows, one would conclude that, Uganda is fairly

well endowed with water resources. Water availability has determined the local water resources, the land -use potential and influenced the population distribution.

Open water sources are mainly in the form of rivers, swamps and lakes whose drainage falls into eight main drainage sub-basins(UN-WWAP 2006). These include; Lake Victoria, Lake Kyoga, Victoria Nile, Lake Edward, Lake Albert, River Aswa, Albert Nile and Kidepo Valley (Fig 9.1). The yield from these sub-basins, dominates the water resources potential with in Uganda. Major water bodies include lakes Victoria, Kyoga, Albert, George, Edward (Table 9.2) and another 149 smaller lakes spread across the country covering an area of 38,500 km². The lakes are interconnected by a river system, which developed as a result of river reversal and ponding that formed the two major lakes (NEMA 2008 and references there in). In the northeastern part of the country, many of the watercourses are seasonal. The main river basins of Uganda are shown in the Figure.9.1 below.

The most prominent hydrological feature in Uganda is Lake Victoria, which is the second largest fresh water lake in the world with an area of 69,000 km² is drained by River Nile. The 130 km stretch of the Nile from Lake Victoria to Lake Kyoga is termed the Victoria Nile. Lake Kyoga is drained through the Kyoga Nile which, after a relatively flat reach downstream from the lake, enters a series of rapids and falls before it flows into Lake Albert at a level 410 m lower than Lake Kyoga (NEMA 2008). The plateau immediately to the north of the Rwenzori drains to Lake Albert via the Muzizi River.

In Lake Albert, the Nile is joined by river Semiliki which drains Lakes George & Edward found in the rift valley and a high rainfall area at the bottom of Rwenzori Mountains. Lakes George & Edward are connected through the Kazinga Channel. The Nile flows from Lake Albert with a gentle slope to the Sudanese boarder. This reach of the river is called the Albert Nile (NEMA 2008).

Major rivers in Uganda include the Nile, Ruizi, Katonga, Kafu, Mpologoma and Aswa. The rivers and lakes of Uganda are within the upper part of the White Nile Basin, with the exception of those in the tiny northeastern catchment of Kidepo, which drains into the Lake Turkana basin in Kenya (Figure.9.1). The northwestern slopes of Rwenzori watershed in Uganda drain to Lake Edward via the Ishasha, Chiruruma, Nchwera and Nyamweru rivers, and also by several streams, which enter the western flowing part of the Katonga River. The northeastern part of the Virunga range watershed however, drains directly to Lake Victoria via a series of swampy lakes and streams culminating in the Kibaler River, which enters Lake Victoria through the swamps at Sango Bay.

The Ugandan slopes of Mt. Elgon and the central highlands along the Kenyan border drain via rivers with swampy valleys or seasonal floodplains to Lake Kyoga, while the north eastern highlands and most of the northern plateau drain directly to the Bahr el Jebel in Sudan via the Achwa River that also joins the Nile (NEMA 2008).

Because of warping of the landscape, many of the perennial streams of the plateau are clogged with swamp. About 10 percent of the country is covered by swamps, of which one third is permanently flooded. In the south and west of the country, swamps occupy the steep

V-shaped valley bottoms, while in the north swamps mainly consist of broad flood plains. In the east they exist as a network of small, vegetated valley bottoms in a slightly undulating landscape.

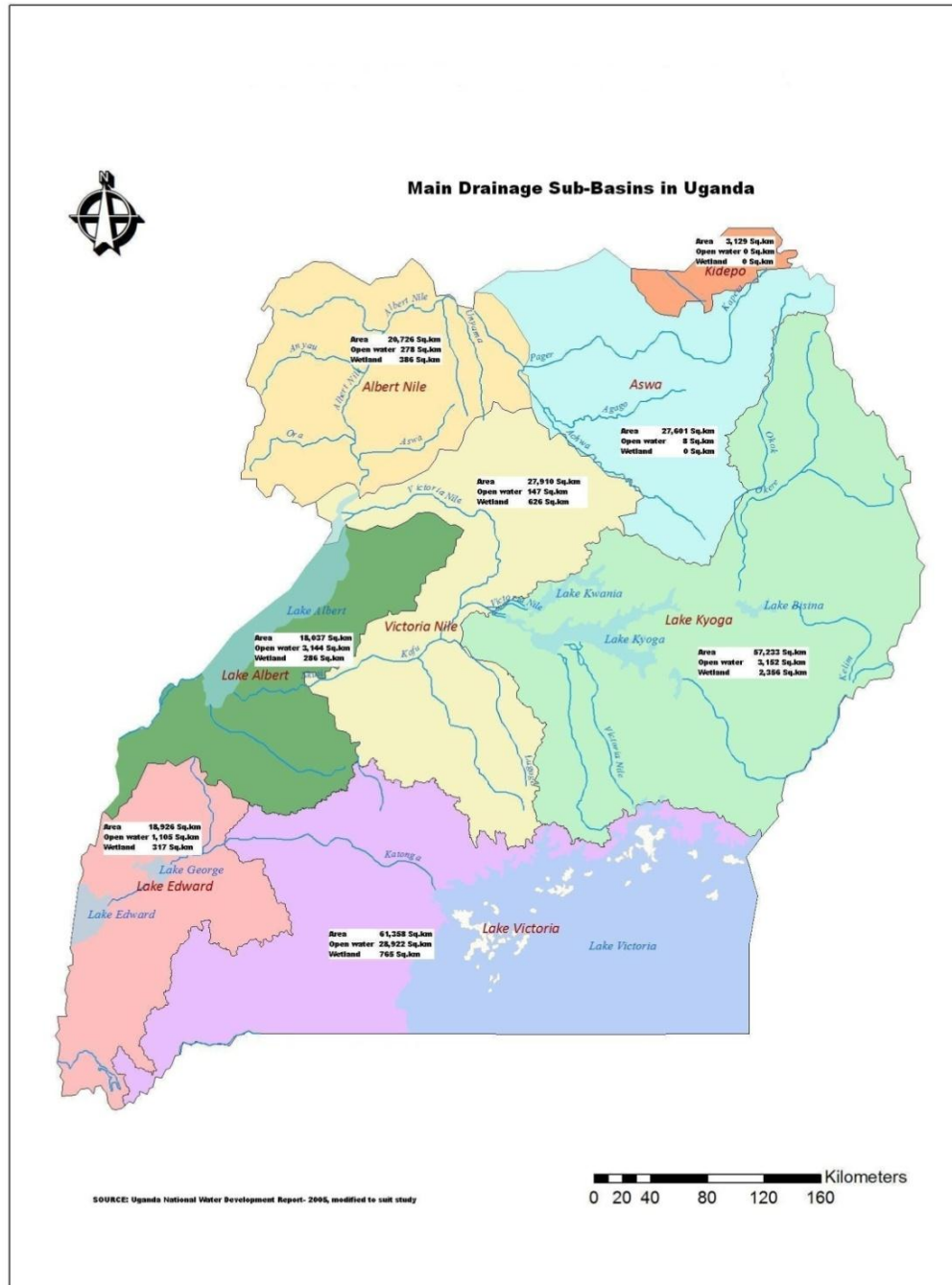


Figure 9.1 Main drainage sub-basins in Uganda including rivers and lakes.

9.2.2 Wetland Resources

There are basically two broad distributions of wetland ecosystems in Uganda: (a) the natural lakes and lacustrine swamps found around major lakes; and (b) the riverine and flood plain wetlands which are associated with the major river systems in Uganda. They cover about, 29,000 km², or 13% of the total area of the country. Wetlands comprise swamp (8,832 km²), swamp forest (365 km²) and sites with impeded drainage 20,392 km² (NEMA 1998). Hence, are regarded as areas of seasonally flooded grassland, swamp forest, permanently flooded papyrus, grass swamp and upland bog. By 2008, wetlands around major drainage basins had declined considerably except for Kidepo (Table 9.3).

	Surface area (km ²)	Area in Uganda (km ²)	Mean Elevation above sea level (m)	Maximum depth (m)	Volume in Uganda (km ³)	Mean depth (m)
Lake Victoria	68800	28655	1134	84	1237	40
Lake Albert	5659	2850	618	56	80	25
Lake Kyoga	2636	2636	1034	10.7	7.9	3
Lake Edward	2324	638	912	117	16.8	34
Lake Kwanja	540	540	1033	5.4	2	4
Lake Wamala	250	250	1290	9	1.2	4
Lake Bisina	150	150	1030	N/A	0.5	N/A
Lake George	228	228	914	7	0.8	2.4
Lake Bunyonyi	61	61	1974	39.3	0.2	
Lake Kachira	39.6	39.6	1235	4.8	0.2	
Other 149 minor lakes		2453			7.2	
Total		38500.6			1353.8	

Table 9.2 Major Lakes of Uganda and their associated characteristics.

Source: UN-Water, 2006 in (NEMA, 2008)

This decline has been generally observed around Lake Victoria and Edward drainage basins (MWE 2011). The decline according to the Uganda water and environment sector performance report of 2011 is largely attributed to encroachment for expansion of urban centres, settlement, industrial developments and extension of agricultural land. With the exception for Sango Bay, the bulk of Uganda's wetlands lie outside protected areas.

Wetlands perform a number of functions, such as; mitigate the effects of both floods and droughts, provide fish resources, support cropping and grazing along their margins. They are areas of high biodiversity and productivity as well as valuable refuges and sources of food

like fish. Furthermore they are active biological filters in the treatment of effluents, but due to this function they are also sensitive to the accumulation of pollution (Smith *et al.* 1995).

Table 9.3 Changes in wetland coverage by drainage basin between 1994 and 2008

Drainage basin	1994 (Area km ²)	%	2008 (Area km ²)	%	% Change
Albert Nile	1736.3	6.21	1255.2	4.71	27.7
Aswa	3,028.0	10.83	2,168.9	8.24	28.4
Kidepo	168.1	0.60	197.2	0.74	-17.3
Lake Albert	2,838.6	10.15	2,421.7	9.20	14.6
Lake Edward	1,671.1	5.97	1,096.3	4.16	34.4
Lake Kyoga	15,008.3	53.67	11,028.5	41.92	26.5
Lake Victoria	7,167.6	25.63	3,310.2	12.58	53.8
Victoria Nile	5,786.3	20.69	4,829.4	18.35	16.5

Source: MWE, 2011- modified to suit study.

9.2.3 Yield of rivers

All of Uganda's rivers ultimately reach the Nile. The flows of the Nile are highly variable from year to year. This annual variability has been monitored and reported in previous studies as evidenced in figure 9.2. The plot shows the long-term variations in flows of river Nile monitored at Jinja, Masindi Port and Panyango. Flow records show that the flow increased from 1960s, after which a steady decline is observed at all monitoring points. The long-term average outflow of water from Lake Victoria has been 840m³/s and the range of outflows is between a minimum of 345m³/s and a maximum of 1720m³/s. At the 95% monthly reliability level, the flow of the Victoria Nile is of the order of 495m³/s according to the 2004,WRM subsector reform study report.

Using annual rainfall data series for the period 1940 to 1999, a Drought Severity Index (DSI) for the drainage sub-basins in Uganda was computed. A DSI uses temperatures and rainfall information in a formula to determine the severity of wetness or aridity for a particular region (Kim and Valdés 2002).

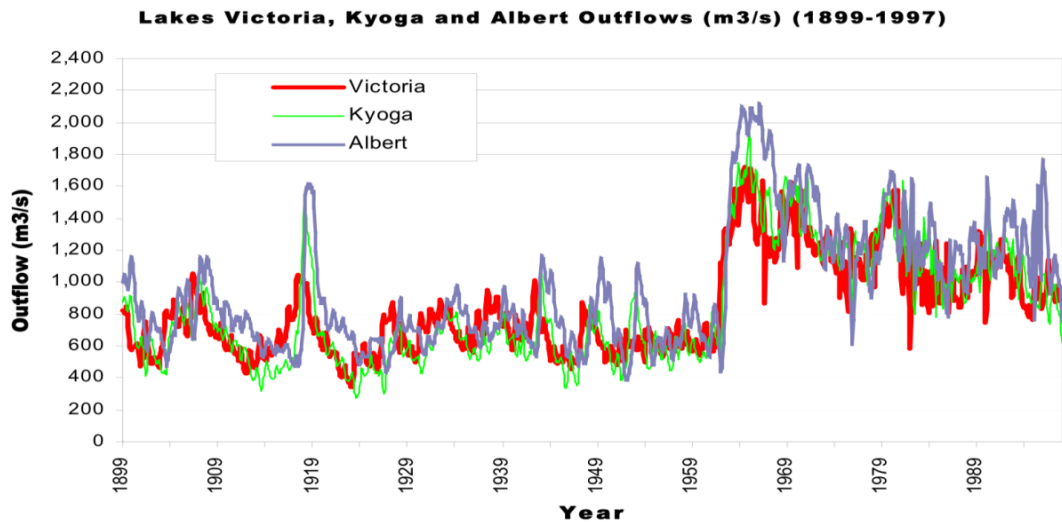


Figure 9.2 Long-term variations in river Nile Flows. (Figure adopted from WRM subsector reform study report 2004)

Drought seasons and years are identified by observing the years and seasons in which the anomalies in rainfall are below the drought threshold line (i.e. DSI of 25%). The drought years were then used in the analysis process to compare those times of drought in the drainage basins and long-term variations in river Nile flows. Results presented in table 9.4 have been compared with plot in figure 9.2, which was produced by DWRM. There is a close correlation between DSI and the river Nile outflows monitored for 1899- 1997 period.

Following steps in Awange *et al.* (2008) one can discover the years and seasons when the sub-basins were experiencing droughts. It is evident from plot (Fig.9.2) and table 9.4 that, the early 1940s and 1950s in the first climatic normal were years of below normal rainfall. The situation is similar in the second normal when the early 1980s were drought years, consequently affecting the outflow of the river Nile. This re-affirms the fact the main source of water for the water resources in Uganda is rainfall and the whole of Uganda's water resource is part of the Nile.

Series variables	Climatic Normal	Albert Nile	Lake Kyoga	Lake Victoria
Annual	1940-1969	1943,1949,1952,1953, 1954,1965	1943,1949,1953,1957,1958, 1965	1943,1946,1952,1953,1959,1965
	1970-1999	1971,1983,1984,1989, 1993	1973,1974,1979,1980,1984, 1986, 1993	1970,1971,1980,1982,1983,1985

Table 9.4 Drought years for selected drainage sub-basins in Uganda.

Annual rainfall data for the period 1940 to 1999 was exposed to *Sen's T test* to establish the behaviour of rainfall trends in Uganda. This is a non-parametric method that is used to test for randomness against trend in hydrology and climatology. The aligned rank is robust, distribution free and not affected by seasonal fluctuations (Partal and Kahya 2006). The

results of *Sen's T test* applications to annual rainfall of the main drainage sub-basins are shown in table 9.5. The Sen's T test results indicate negative trend in six of the sub-basins, namely; Albert Nile, River Aswa, Lake Albert, Lake Edward, Lake Kyoga and Lake Victoria. Significant decreasing trends were observed in River Aswa and Lake Albert sub-basins. Results for Victoria Nile sub-basin show a positive trend, which is not statistically significant at 0.05.

Table 9.5 Trend Results for the main drainage sub-basins. Sen's T-test was applied using area average rainfall data

Sub-Basins	Rain series	Albert Nile	River Aswa	Lake Albert	Lake Edward	Lake Kyoga	Lake Victoria	Victoria Nile
Year of.. Rainfall	Mx	1961	1983	1961	1996	1961	1961	1961
	Mn	1943	1943	1943	1979	1957	1957	1943
SEN's T-test	Area mean	-0.31	-3.91	-3.13	-0.91	-1.09	-1.36	0.19

Despite Uganda's significant water resources, their spatial and temporal variability often renders many parts of the country water stressed over long periods of the year. Water resource management sub-sector reform study of 2004 showed that, districts in the north-eastern and south-western parts of the country have the least per capita water availability and that by 2015 more than 75% of the country will be water stressed (Figure.9.3). The methodology used in computing the water availability only considers the runoff generated within each district. It is used here to give a picture of the average yield of major catchments in Uganda.

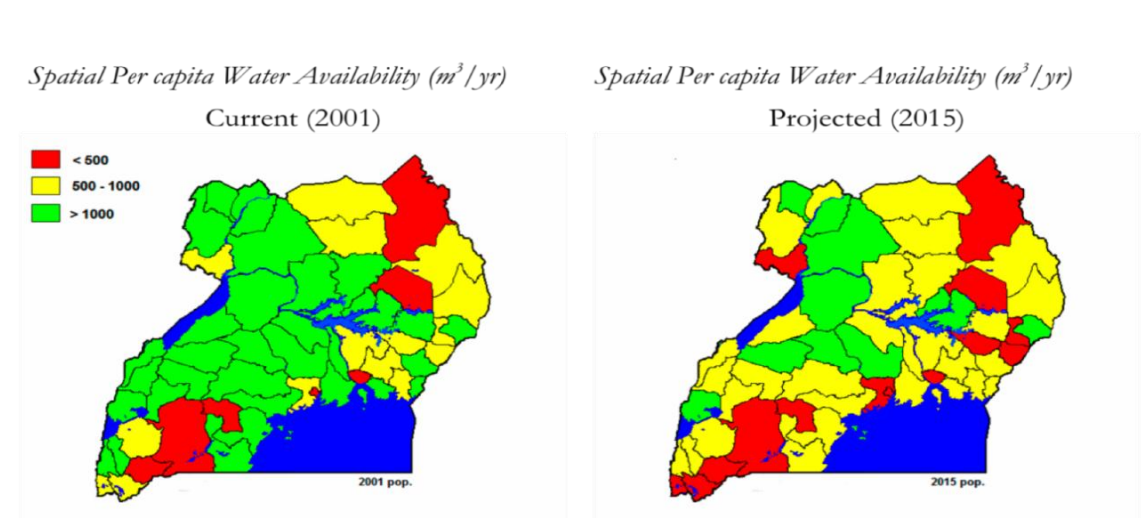


Figure 9.3 Spatial per capita surface water distributions (m^3/yr). Source: WRM Sub-sector Reform study report, 2004.

For example the southwestern and northeastern parts of the country have the lowest annual run-off ($< 1 \text{ litre/s/km}^2$). These are semi- arid areas receiving very low rainfall. The Lake Victoria basin has the highest run-off ($> 10 \text{ litres /s/km}^2$). Mean annual rainfall calculated for the different drainage sub-basins during 1940 to 2009 is depicted in figure 9.4. Analysis supports the correlation between rainfall and run-off generated by each sub-basin and represents the average yield of major catchments in Uganda.

A recent study by DWRM (2011) in the Victoria water management zone, on the Rwizi, Wamala and Victoria catchments concluded that, reduced water levels occur annually in the dry season with in the three catchments. The lowest levels are witnessed at the end of every dry season, until the rains set in. The study revealed that, the rains that follow the drought periods are not high enough to recharge the water resources to the original high levels. This however paints a bleak picture especially when the rainy seasons become unpredictable so that a proper hydrological forecast can be made (DWRM 2011).

9.3 Status of water availability

The Directorate of Water Development (DWD) and National Water and Sewerage Corporation (NWSC) have been tasked to ensure that water is availed to Ugandans. DWD provides water to NWSC, which distributes it to the consumers. Approximately 66% of Uganda's population had access to safe water supplies as of July 2010 (MWLE 2010). Available information from NWSC shows that there has been a steady increase in total water production e.g. from 46.7 million m^3/yr , in 2000/01 to 72.14 million m^3/yr in 2009/10 financial years. Comparing the water requirements with the available renewable freshwater, Uganda is underutilising the current renewable freshwater for consumptive purposes (FAO 2005).

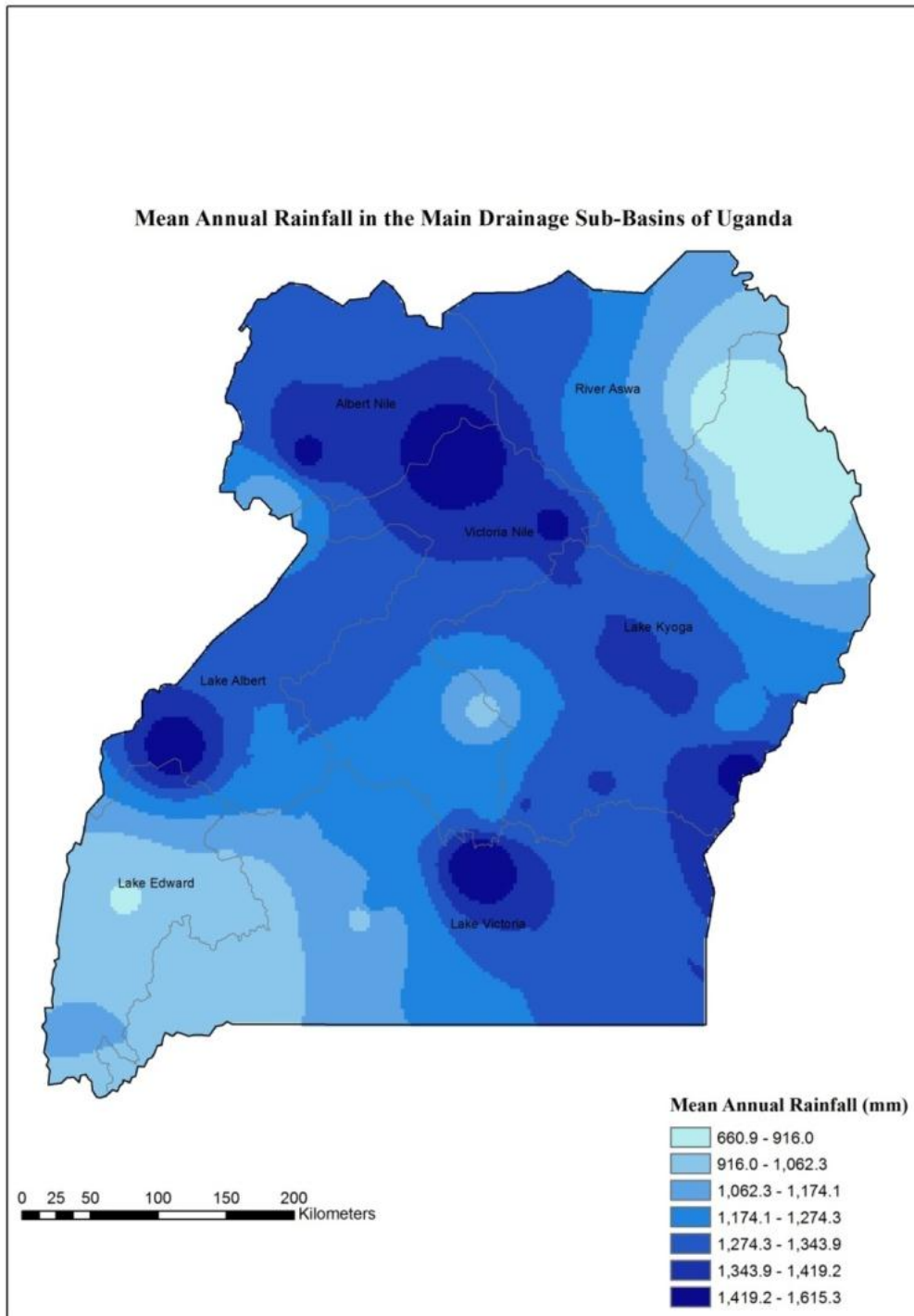


Figure 9.4 Distribution of mean annual rainfall in the main drainage sub-basins in Uganda 1940- 2009.

For example, the country was using only 1% of its fresh water by 2005, of which, domestic water supply accounted for about 51%, agriculture 41% and industry 8% of the total water withdrawal (NEMA 2008). The use of water all over the world is a function of population change, food consumption, economic policy, technology, lifestyle and societies views of the value of freshwater ecosystem. Since Uganda has one of the fast growing populations (3.2%),

its demands will lead to increased water withdrawal. Withdraw per capita rose from 12m³/yr in 2002 to 21m³/yr in 2008 (Fig. 9.5).

Percent change is equivalent to 112% in a period of seven-year. Notable changes were realized in domestic withdrawals from 45% to 51% while industrial withdrawals fell by 7%. According to NWSC annual reports total volume of water sold increased from 31.2 million m³/year in 2002/03 to 47 million m³/ year by June 2010.

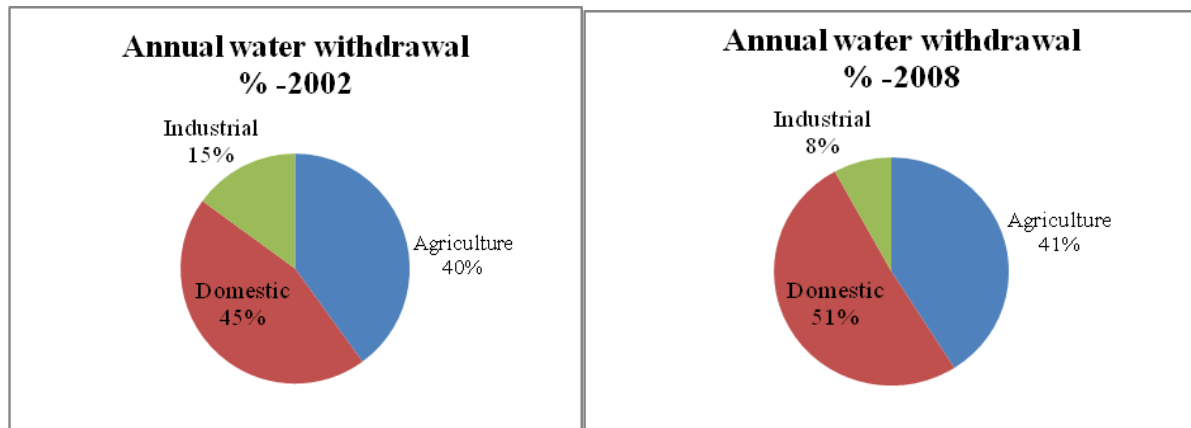


Figure 9.5 Water withdrawals in Uganda. Data was sourced from WRMD quarterly reports, joint water sanitation sector program support, DWRM.

Much of the total water produced is sold to domestic consumers (48.9%), industrial and commercial enterprises (25.4%), institutions and governments (20.8%), and (4.8%) was sold via public standpipes by 2010. This positive trend shows how effective the organizations have been in achieving national targets. The major water sources are protected springs, deep boreholes, rain water harvest and shallow wells.

9.3.1 Groundwater Occurrence

The primary source of freshwater for drinking and irrigation in the world is groundwater. Ground water supplies 75% of all safe sources of drinking water in Africa (Mileham *et al.*, 2009). In Uganda for example, 61% of the country's water is from a ground water source. Several studies, like (Taylor and Howard 1996; Tate *et al.* 2004; Tindimugaya 2006; Mileham *et al.* 2009; Nyenje and Batelaan 2009) have assessed ground water occurrence in Uganda from different perspectives at a catchment scale.

According to the Monitoring and Assessment Division report 2011, the available ground water resources of Uganda were estimated in 2010 during the National water resources study to be as shown in table 9.6 for the different basins. The report produced a map of estimated exploitable groundwater resource per district. This exploitable ground water represents the proportion of renewable resources that can be exploited on a sustainable basis without seriously affecting the environment.

The Victoria Nile and Kyoga basin have sustainable ground water, which is more than 36 mm/yr, while Kidepo has the least amount of sustainable ground water equivalent to 6.3

mm/yr (Table 9.6). This is a true reflection of the catchment size from which these basins draw water (Figure 9.1).

9.3.2 Groundwater Development

Groundwater is the major source of water supply in the rural, semi-arid and arid areas in Uganda. Groundwater development has been ongoing since the 1930s through construction of deep boreholes, shallow wells and protected springs. There are approximately 24660 deep boreholes, 16162 shallow wells and 24844 protected springs and 15123 rural water harvest tanks in the country constructed mainly for rural domestic water supply (DWD 2010). In the 1990s ground water development was intensified to provide for town water supply. For example, 782 small towns were identified for the provision of piped water by June 2006, and 70 % of this water was to be provided by ground water sources like the deep boreholes (Mileham *et al.* 2009). Boreholes and shallow wells are normally installed with hand-pumps with capacity of 1m³/hour and their yields are usually low. Ground water has advantages like, good quality water that requires little or no treatment costs, can easily be operated and managed by users, which makes investment and operational costs to be low than those of surface based systems. Boreholes with yields greater than 3m³/hour are thus normally considered for installation with motorized pumps for piped water supply.

Table 9.6 Average sustainable groundwater for major river and lake basins in Uganda.

River Basin	Area km ²	Land area km ²	Sustainable ground water (mm/year)
Lake Edward	18946	17855	20.3
Lake Victoria	61886	32924	24.7
Lake Albert	18079	14882	23.7
Victoria Nile	27961	27807	39.9
Lake Kyoga	57236	53899	36.1
Albert Nile	20727	20484	24.4
Aswa	27637	27635	17.3
Kidepo	3229	3228	6.3
Miscellaneous	5716	5679	15.0

Source of data: Monitoring and Assessment Department, DWRM, 2011.

In 1996 GoU initiated groundwater assessment studies, to fully understand the nature, extent and reliability of the country's groundwater resources. The study has provided Information on the distribution and behaviour of aquifers, groundwater recharge, aquifer vulnerability to

pollution, impact of motorized abstraction on groundwater resources and a conceptual model of groundwater dynamics has been developed.

For example, assessment in three catchments namely Ruizi, Wamala and Victoria concluded that, groundwater resources were declining. The causes of decline according to the monitoring and assessment department of the DWRM report, includes among others; climate change/global warming, changes in land-use, especially deforestation, unsustainable water withdrawals, poor catchment management, prolonged droughts, reduced rainfall in the catchment (see table 9.5). This information, though still scanty, forms the basis for the current groundwater resources planning and management in these catchments. An analysis in order to understand the climatic variables in the catchments is thus justified.

9.3.3 Groundwater recharge

Recharge assessments have recently been carried out in Apac in the north, Mbarara in the west, Wobulenzi in the centre, Nkokonjeru in the mid-east and Hoima in mid-western Uganda. Groundwater recharge estimates obtained using the various methods range between 90 and 220 mm per annum and accounts for 7% and 20% of the average annual precipitation in Uganda (Tindimugaya and Nakalyango 2005). Mileham *et al.* (2009) applied dynamically downscaled climatological data on a soil moisture balanced model to estimate ground water recharge and runoff in southwestern Uganda along river Mitano. His results under the A2 emissions scenario, for the period 2070 – 2100, relative to 1960 -1990 indicated an increase in precipitation (14%) and a modelled potential evaporation (53%) and a substantial increase in rain intensity (Mileham *et al.* 2009). Hydrological projections also gave a rise to increases in recharge (53%) and runoff (137%). These figures indicate that groundwater recharge in Uganda is quite high compared to current abstraction volumes and will not be a limiting factor in groundwater development for a few years to come. However, there is a need to carry out more detailed recharge and water balance studies in the country to ensure that groundwater development is carried out in a sustainable manner.

9.3.4 Ground water potential

The potential of groundwater in various areas of the country is exhibited by presence of deep boreholes, shallow wells and springs.

9.3.4.1 Deep Boreholes

Deep borehole potential can be assessed by a means of a number of borehole parameters such as regolith thickness, aquifer yields and rest water levels. Uganda is characterised with a clayey regolith especially in the upper layers where relatively low permeability dominates. The regolith thickness across the country can be described as low to medium varying between 20 - 45m. This leads to medium to high ground water potential through provisional storage. Aquifer yields on the other hand vary from one part of the country to another according to the formation in which they are drilled and their degree of fracturing and weathering. For example, potential yield from deep aquifers were estimated to be above 3 m³/hr in the southwest, southeast, northwest and along the eastern border of the country during the

AQUASTAT survey (FAO 2005). In large areas of central parts of the country potential yields are between 2 and 3 m³/hr, while in some areas it is below 1 m³/hr (FAO 2005). Rest water levels also give an indication of the groundwater potential of an area. Shallow water levels (<20m) indicate that the aquifer has high potential for yielding groundwater while deeper water levels indicate the reverse. Rest water levels (static water levels) in the country vary between 1 and 45 m below ground level. Deep borehole technology is the predominant technology used in Uganda. Approximately 38% of the population access safe water from deep boreholes (DWD 2010).

9.3.4.2 Springs

Springs occur either where the flow of unconfined groundwater is interrupted by an impermeable formation or where the head of confined groundwater is released by flow to the surface. There are 2 major types of springs in Uganda namely: Contact and Fracture springs. Fracture springs are usually very susceptible to contamination and drying up while contact springs are more reliable.

9.3.4.3 Shallow Wells

The potential of shallow wells is quite high, especially in the valleys. Their potential is favoured by the thick regolith that is fairly coarse grained. From Uganda's experience, shallow wells are a very reliable source of water supply to the communities although precautions need to be taken to ensure that they are not contaminated. Springs and wells are a major source of water for the country. Through DWD, shallow wells have been constructed and improved to provide good quality water especially in the south western, western, and central parts of the country where they provide water to many homesteads. In urban centres many of these springs are contaminated with faecal materials. For example, 85 % of the protected spring wells in Kampala are still contaminated with faecal matter (see Daily Monitor 17.04.2013, <http://www.monitor.co.ug/News/National/One-in-200-city-wells-is-safe---KCCA/-/688334/1750352/-/fmbtlt/-/index.h>) yet more than 90 percent of slum dwellers, get their water from these springs.

9.4 Water resources sector development trends

Much of the national documentation refers to a series of development plans, strategies and action plans which were planned and executed to varying degrees of success, without an explicit sector policy framework in 1980s. In the 1990s a number of guidelines were prepared and studies undertaken by the Government which paved the way for the review of water legislation and sector policy development process. Since then, GoU has taken major steps to rationalize water resources management, development and the delivery of Water and Sanitation Services (WSS). The development is aligned to achieve the millennium development goal (MDG) on water estimated at 62% by 2015 (UBOS 2006).

To achieve the set targets, the GoU has reformed the water and sanitation sector in order to ensure that services are provided and managed with improved performance that is cost effective. In this regard reform studies were carried out that resulted in development of Sector

Strategic Investment Plans (SIPs) with appropriate policies and strategies like (see GOU 2009):

The rural water and sanitation SIPs which aim at increasing the safe water supply coverage to 77% or 95% by 2015.

The urban water and sanitation reform SIPs that intend to provide 100% urban population with safe water supply and sanitation by 2015.

The water for production SIPs, which expects the participation of the private sector and farming community in financing this regard.

The water resources management SIPs, whose objective is to promote integrated water resources management and development at both national and local levels.

The strategies above required a Sector Wide Approach to Planning (SWAP). SWAP framework for the WSS sector was adopted at the second GOU/Donor review for the water sector in September 2002. The move towards sector wide approach called for GoU/donors to promote; uniform fund disbursement rules, uniform and stronger fund accountability rules, common indicators, joint appraisals and reviews. Since then reviews have been carried out every year to monitor progress in the water sector.

The National Water Policy (NWP) adopted in 1999 was another development that set the stage for water resources management and improving water supply and sanitation in Uganda. It promotes a new integrated approach to water management that guide the allocation of water and the associated investments. This new approach is based on the continuing recognition of the social value of water, while at the same time giving much more attention to the economic value of water. Key aspects in NWP include; application of a participatory demand driven approach to planning which promotes user ownership and management of services, backed by measures to strengthen local authorities and private institutions in implementing and sustaining water and sanitation programmes.

The NWP embraces international and regional resolutions, declarations and guidelines because more than 90% of Uganda's waters are trans-boundary or river courses. This therefore means that the use and development of Uganda's water resources is controlled by international laws and principles and colonial agreements. Totally dependent on the Nile, therefore, Uganda's approach to the water resources development and management is a critical element within the Nile Basin and hence requires clear trans-boundary policy and institutional frameworks within the country and also legal and harmonized laws with riparian states.

The current strategic framework for the development and management of water resources in Uganda recognizes two important principles. First, water is fundamental, to achieving the national objective of poverty eradication through the promotion of rapid economic growth, good health, food security, and social equity (GOU 2001). Secondly, within the regional context, according to the ministerial policy statement, cooperative development of the trans-

boundary water resources e.g. R. Nile, R. Kagera, R. Malaba, Lake Victoria and others can serve as a catalyst for a broader range of cooperation and economic integration.

9.5 Water resources utilization in Uganda

Water for Agriculture/irrigation: Rain fed agriculture is the most practiced land use method in the country. Currently this practice is threatened with climatic variability and a fast growing population, which are impacting on food security levels. The increase in population has increased the need to raise crops in areas that do not get enough rainfall. As a result national policy on agriculture has plans to achieve increased agricultural production per unit area e.g. through a more efficient use of land and water resources which will improve food security. A Food and agricultural report study in 1987, estimated the irrigation potential in Uganda to be more than 280,000 ha. If fully developed a water demand of 2.7billion m³/year will be required from Uganda's water resources hence, placing a considerable demand on the national and trans-boundary water resource like the river Nile.

The Shared Vision Program (SVP) on efficient water use for agricultural production was tasked to establish a forum to assist stakeholders at regional, national and community levels to address issues related to efficient use of water for Agricultural production in the Nile basin and link it with the trans-boundary water policy. This program provides the appropriate linkage under the Transboundary Water Resources Program (TBWRP) being formulated with NBI-SVP for improved agricultural Production.

Water for power: Most waterpower is used to generate Hydro-Electric Power (HEP), which is used to light homes and to run factories. A study by Nile Basin Capacity Building Network (NBCBN) in 2005 estimated the hydrological resources to have a power production potential of over 2500MW, of which over 2000MW is mainly concentrated on river Nile and the rest is scattered in parts of the country. By 2005, less than 10% of this potential was exploited (NBCBN 2005). Of the 2000MW potential along the river Nile, 630MW (31.5%) have been tapped, and the unexploited potential is well over 1300MW (ERA 2009).

Installed capacity stands at 853MW including thermal and hydropower plants, of which HEP contributes 602.5MW. This shows that power supply of Uganda is almost totally dependent on hydropower. Unfortunately, installed capacity is grossly inadequate to meet the current and rapidly increasing demands. For example in 2008, the number of consumers by type was recorded at 347,433 for domestic small general service; 28,810 for commercial small general service; 324 for Large industrial; 1,194 for general-medium industrial and 195 for street Lighting (Figure 9.6). During financial year ending 2010/2011, total Umeme customers were 457808 (UMEME 2011). Given the current economic growth of 7%, domestic power demand is expected to increase to 1130MW by 2023 (New Vision 2012). One of the national development plan objectives is to increase power generation to between 780MW and 820MW, as well as increase rural electrification to 10% and promote efficiency programmes and renewable sources countrywide.

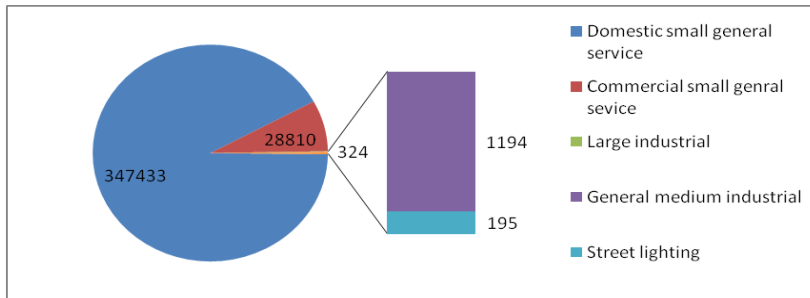


Figure 9.6 shows number of electricity consumers by type in Uganda in 2008.

The main sites that have been identified for the development of major HEP schemes are all located downstream along the river Nile. The non-Nile river small-scale hydropower potentials exist along the rivers draining Mt. Elgon, the extreme southwest of Uganda, rivers draining west Nile near Arua and the rivers draining the Rwenzori Mountains (NBCBN 2005). The country has a big potential for medium, small and micro hydropower stations.



Plate 1. An aerial view of one the HEP scheme at the Bujagali Hydro power plant in Jinja Uganda. The hydro-plant can now fully generate 250 megawatts of power.

The national policy provides for regional co-operation for optimum hydropower development. For example, the Nile Basin Power Trade of NBI-SVP has the objectives of establishing the Institutional means to coordinate the development of regional power markets and improve access to reliable and low cost power among the Nile Basin countries. In order for Uganda to fully exploit her hydropower potential on the Nile, this program will be the main avenue for the linkage for cooperation under the trans-boundary water policy and to also promote the benefit-sharing concept. Development of large schemes on the Nile should be the right way to go by the government of Uganda, because the markets are available in the region.

Water for industry: The role of water for example in industry contributed 24.2% in 2008/2009 to the total Gross Domestic Product (GDP) and increased to 26.9% in 2010/2011(MOFPED 2011). Water is highly consumed in the construction industry, which is a major activity according to (UBOS 2009). For example activities like construction,

manufacturing, mining and quarrying that consume a lot of water contributed 12.3%, 7.5%, and 0.3% of the total GDP in 2008/09 respectively. Water, is vital in transforming industry and eradicating poverty, consequently will be in high demand given the trend of economic growth.

Water for fish: Inland water bodies support a thriving fishing industry in Uganda. Fish catches vary from place to place, with the largest yields associated with major lakes and rivers (Table 9.3). According to UBOS (2009) fishing activity was worth 2.9% share of the GDP by 2008/09 fiscal years and many people are indirectly dependent on this industry. Fish is often a large part of diet of people living in the country and abroad. Tonnes of fish are also harvested from wetlands and ponds on fish farms (see Plate 11). Fishing activities have become so popular that are fast increasing in importance and numbers that are exerting pressure especially on the quality of water resources.



Plate 11. Fish harvest from a fish pond in Uganda.

Water for transport: People depend on water transport to carry goods for use and trade from one region to another, using boats, ferries and ship. Water transport links Ugandans living on islands with the mainland and also those involved in trade across borders towards DRC, Tanzania and Kenya. This activity has impact on the quality of water resources, which will necessitate further inquiry.

Water for environment and tourism: Development of tourism is a high priority area and is dependent on the natural beauty and quality of the environment, including wetlands, range lands, lakes, rivers and the associated sceneries like the waterfalls, beaches and rare fauna species provide an array of tourism activities. The splash and flow of water in the streams, hot springs, geysers and fountains also soothes and inspires many people who love being near water. Many of the recreational places in Uganda provide water sports, such as swimming, fishing, Water rafting and sailing. People also enjoy the beauty of a quite lake, a thundering waterfall (like those at Karuma, Kabalega and Budhagali) or even roaring surf.

Business community in Uganda has built recreational areas along the lakes, such as Entebbe, Lutembe, Sesse-Kalangala, Kigo, and Jinja where local tourism is flourishing. These

facilities generate huge financial and socio-economic benefits for the country. For example in the year 2008, a total of 844,000 tourists to the country were recorded, of which 144,000 declared their purpose of visit as leisure and holiday. And about 138,000 persons (foreign and national) visited the national parks in 2008, 190,000 in 2010 and 208,000 in 2011. Between 2010 and 2011 the industry grew by 9.4% and contributed 21% to GDP in 2011, earning the country US \$ 805 million in 2011/12 financial year (Daily Monitor News paper 26.09.2012).



Plate 111. Water rafting on the river Nile. The activity is a popular touristic attraction.

Water for Sanitation: This is a field of public health that is necessary to control and prevent disease. It includes personal cleanliness, sewerage treatments, waste disposal systems, water treatment and so forth. Sanitation deteriorates where water conditions are poor and uncertain which directly affects the well being of communities. Likewise sewerage and sanitation service requirements increase in step with improvements in water supplies and have important health implications. Because water, health and sanitation are set targets for 2015 MDGs, African Development Bank (ADB) financed water and sanitation projects to small towns and rural areas in Uganda to the tune of USD 28 million and USD 60 million respectively (ADB 2010). Government of Uganda (GoU) has also signed agreements in 2012 to finance projects to improve health services delivery and access to water and sanitation in both urban and rural areas worth USD 155.8 million of investment (ADB 2012). This development is expected to put more pressure on the water resources of the country as discussed in sections above.

Water supply: Water supply is a key factor of production in e.g. manufacturing industry, power generation, mining, construction and agriculture. It sustains the natural environment; therefore its quantity and quality are important indicators of what the country has achieved. Access to water has levelled off at 64% for rural and 77% for urban areas but set targets are 100% and 77% for urban and rural areas respectively by 2015.

The challenges faced with Uganda with regard to water supply issues are: to ensure that water for both human and livestock consumption is available in sufficient quantities and quality all the time; that the demand is quantified; water is used efficiently and sanitation is promoted;

and shared waters and watercourses are used and developed to meet this demand in particular with regard to the new strategy of bulk water supply.

9.6 Climate change and water resources

The changing climate in Uganda presents very serious national challenges and risks to water resources which impact on various sectors such as agriculture, tourism and energy, which support the economy and the wellbeing of its people. Significant impacts of climate change are manifested in form of droughts, variations in groundwater and surface water levels, melting of ice caps, incidences of diseases, high temperatures and wild fires. For example, Awange *et al* (2008) identified eight seasonal droughts within the Lake Victoria basin in the period between 1990 and 1999. Study analysis has also established drought years and seasons in the various drainage sub-basins in Uganda (Table 9.4). Prominent was the 2004/5 drought period when the water level in Lake Victoria dropped by a meter below the 10 year average (Kull 2006). Droughts significantly affect the country's water resources, hydropower production and agriculture.

Climate variability is also reflected by the cycles observed in rainfall patterns in Uganda for the period 1940 – 2009. Analysis shows decades of normal and beyond normal rainfall (Fig 9.7) during the period of analysis. Three long spans of below normal rain are evident in the 1940s, 1960/70 and 1980s. Other particularly wet periods were experienced in early 1950s, 1960s, late 1970s and the 1990s (Fig.9.7). The contributing factors to the below average annual total rainfall for Uganda have not been established in this study despite the 1980s being drought years. Such drought years, as noted by Hulme (1992) have had consequences on food security for the continent.

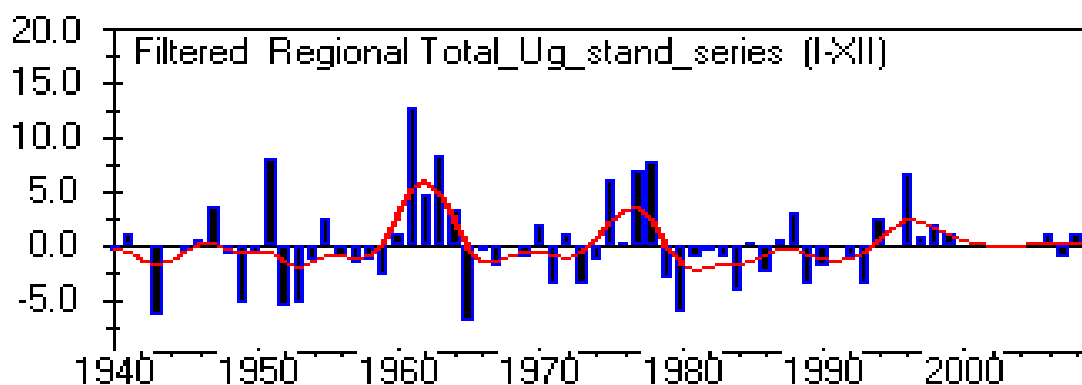


Figure 9.7 Regional total rainfall (mm) for the period 1940 – 2009 in Uganda.

From a hydrological perspective, rain is the main source of water to Ugandan water resources. For example Lake Victoria, which is the largest water resource with a big influence on Uganda's climate, has displayed large and rapid changes in responses to rainfall anomalies. And a number of studies highlighted by Tate (2004) and Nicholson *et al* (2000) have concluded that the lake is a sensitive indicator of climate change. A substantial body of research demonstrates that lakes are good sentinels of global climate change, simply because they are sensitive to environment changes and can integrate changes in the surroundings (Adrian *et al*. 2009). Models on Sensitivity of Lake Victoria levels, predict a fall in levels

during the 2021 – 2050, and levels will pick up by 2070-2099 time horizons in both emission scenario. This circumstance is explained by the predicted decrease in direct rainfall with a corresponding increase in lake potential evaporation by 2021 -2050 (Tate *et al.* 2004). There is a significant correlation between lake rainfall series and lake levels (Mistry and Conway 2003), which requires further study on Ugandan lakes and also relate this variation to livelihoods of the populace.

Melting glaciers of late have attracted the attention of hydro-meteorologists for their contribution as a source of water into Uganda's drainage system. The interaction between glaciers and climate represents a particular sensitive process on the water resources of Uganda. Mölg (2003) cites a number of authors who have comprehensively studied the effect of this interaction in the Rwenzori catchment area. Recent research in the 1950s, 1990s and 2000s indicate that the area covered by alpine glacier has reduced from 7.5km² in 1906 to 1km² in 2003 on Rwenzori Mountains (Taylor *et al.* 2009). Between 1955 and 1990, Rwenzori ice caps according to the MWE (2011) have retreated by 40%. This implies that the water reservoirs for Uganda in the ice caps are tremendously reducing. This retreat is attributed to anthropogenic changes, whose behaviour still requires thorough investigations.

The effect of deglaciation on water resources has been investigated by Taylor *et al.* (2009) to determine the impact of glacial melt on river discharge during the dry season and the risk of flooding during the rainy season. Their finding, also held by Kaser *et al.* (2004) showed that current glacial recession has a negligible impact on alpine river flow since melt water discharges contribute less than 2% of the total discharge to River Mubuku (the principal river receiving melt water discharges) at the base of Rwenzori Mountains during both dry and wet seasons. Consequently the effect of melt water has insignificant impact on the water resources, but may have adverse effect on tourism of Uganda. Melting of ice caps of the Rwenzori is expected to have an effect on water catchments downstream and eco-tourism as well as the overall economy (MWE 2011).

The effects of climate change on ground water recharge and base flow in Uganda has been investigated for instance in upper Ssezibwa catchment by Nyenje and Batelaan (2009), using global climate models. Projections from their study indicate that rainfall will generally increase, from 20% to 100% by the 2080s. Simulations from the same study showed an increase in recharge, base flow and total flow in the future. The mean annual daily discharge is expected to increase by 40 – 100% from the current 1.47 m³/s in the coming 20 to 80 years (Nyenje and Batelaan 2009). Such a trend is an assurance on the availability of water in the many years to come, assuming population growth is kept at a minimum.

Studies about the impact of climate change on water resources in Uganda are still very few where as water resources cover almost 15% of the country. These water resources also support a number of livelihoods, which are likely to be impacted by changes from change in climate. Thus there is a need to investigate and understand how water resources will respond to climatic changes in Uganda.

9.7 Water governance in Uganda.

Water governance is seen as a range of political, social, economic and administrative systems that are in place to develop and manage water resources and the delivery of water services at different levels of society (UNDP 2000; GWP 2002). The manner of allocation and regulatory process and interaction in the management of water resources that embraces formal and informal institutions (Rogers and Hall 2003) including poverty eradication (Turton *et al.* 2007) are a focus of governance. Some of the necessary conditions for good governance are inclusiveness, accountability, participation, transparency, predictability and responsiveness. A major challenge is to understand how all these different processes in concert will determine certain policy outcomes as climatic changes affect water resources and how change in governance regimes occur? Currently Climate change and the related increase in extreme weather events have exposed the vulnerability and lack of resilience of water resource management regimes. And policies to accommodate the prospects of climate and global change are inadequate. For instance policies tend to focus on standard policy solution like liberalization and pricing of water services, which have had counter-productive results. There are fewer policies that are meant to intervene in circumstances where the impact of climate change on water resources is still being investigated. This renders the conditions under which management has to perform increasingly unpredictable.

Generally, the broad strategies in Uganda for implementing activities and programs in the water and environment sector are articulated in the Poverty Eradication Action Plan (PEAP) of 2001. PEAP is the basic planning framework for the formulation and implementation of all sector policies, strategies and programs. It identifies water, sanitation and environment as one of the priority areas for poverty eradication. The strategies are embedded in the three pillars, namely; to increase production and competitiveness of Uganda's products to attain increased household incomes including water for production and water resources management; Strengthening security, conflict resolution and disaster management (includes water for security in North- eastern Uganda and provision of water and sanitation services; and human development among others.

Implementation of the PEAP is guided by a comprehensive sector policy and legal framework for management of the water and sanitation sector. These include;- the 1995 Constitution of the Republic of Uganda, Local Governments Act Cap 243, Water Act Cap 152, and accompanying regulations, Water Resources Regulations of 1998, Waste Discharge Regulations of 1998, Water Supply Regulations of 1999, Sewerage Regulations of 1999, National Environment Management Authority Act Cap. 153, National Water & Sewerage Corporation Statute Cap 317, the 1995 Water Action Plan, National Water Policy of 1999, National Environment Management Policy of 1994, National Health Policy and Health Sector Strategic Plan of 1999, National Gender Policy of 1997 and the 2006 Community Mobilisation and Empowerment Strategy.

Since Uganda ascribes to international water conventions and declarations, it has prepared a Water Action Plan (WAP). The WAP is a flexible and dynamic framework for the protection and development of Uganda's water resources in conformity with the Water Act.

The government of Uganda further developed a water policy that provides for the overall policy framework for water resources management and development. The objective of the water policy is *“To manage and develop the water resources of Uganda in an integrated and sustainable manner, so as to secure and provide water of adequate quantity and quality for all social and economic needs of the present and future generations with the full participation of all stakeholders”* (NWP 1999).

The National Water Policy further identifies a need to enhance co-ordination and collaboration between water and sanitation sub-sectors, so that they both adequately address environmental health and sanitation issues. This is done through the Water Policy Committee (WPC), Water Sector Working group (WSWG), Donor Forum, Non-Government Organisations (NGOs) forum under the umbrella of Uganda Water and Sanitation Network (UWASNET), Sector reviews by GoU and Donors and District Water and Sanitation Committee (DWSC). The policy also acknowledges the need for cooperation on transboundary water resources management issues and promotes decentralization of water management functions. Water supply and sanitation, water for agriculture, hydropower and industrial use are priorities for allocation of water through planning and operation of systems.

The key player in water governance is the Ministry of Water and Environment (MWE), which has the overall responsibility of setting national policies and standards, and priorities for water development and management. It also monitors and evaluates sector development programmes to keep track of their performance, efficiency and effectiveness in service delivery. Under the Ministry there are three agencies for water sector namely; DWRM and DWD as the lead agencies responsible for managing water resources, coordinating and regulating all water and sanitation activities and providing support services to local Governments and other service providers respectively. The Department of Environmental Affairs (DEA) is the other agency, responsible for environmental policy, regulation, coordination, inspection, supervision and monitoring of the environment and natural resources as well as the degraded ecosystems and mitigating and adapting to climate change. Equally important is the National Water and Sewerage Corporation (NWSC) an autonomous parastatal established in 1972, and recognised by NWSC statute of 1995, is responsible for the delivery of water supply and sewerage services.

The other players in governance are Ministry of Finance, Planning and Economic Development (MoFPED) mobilises funds, the Ministry of Health (MoH) is responsible for hygiene and sanitation promotion for households, the Ministry of Education and Sports (MoES) is responsible for hygiene promotion and sanitation in primary schools, the Ministry of Gender, Labour and Social Development (MoGLSD) is responsible for gender responsiveness and community mobilisation, the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) spearheads agricultural development. This includes the use and management water for production including Irrigation, animal production and aquaculture at farm level. Local Governments (Districts, towns, Sub-Counties) are empowered by the Local Governments Act 1997 for the provision of water services. Communities are responsible for demanding, planning, contributing cash to operating and maintaining rural WSS facilities. While (NGOs) and Community Based Organisations (CBOs) are active in the provision of

water and sanitation services, training of communities and local governments, hygiene promotion as well as advocacy and lobbying.

Since 1993, Uganda has been undergoing a decentralization of responsibilities from central government level to district local government level. This shift of responsibility has had a profound impact on the players in the Water Supply and Sanitation (WSS) sector. Districts became the main implementation agents and the human dimension is being emphasised in governance issues. Governance also needs to be evaluated to determine its response in a changing climate.

9.8 Catchment based water resources management

There is a lot of diversity presented in literature relating to the implementation of Integrated Water Resources Management (IWRM), especially in developing countries (Agyenim and Gupta 2012; Horlemann and Dombrowsky 2012; Anderson *et al.* 2008; Biswas 2008). This diversity is attributed to differences in institutional set up, governance structures, legal framework and level of development (Funke *et al.* 2007). The framework of IWRM stipulates that water resources are better managed at a catchment unit. This is why the WRM sub-sector reform study in Uganda recommended a paradigm shift from a centralized to a catchment based water resource management. Catchments are part of the four main management zones namely; Victoria, Kyoga, Albert and Upper Nile water management zones. The management zones are further divided into drainage sub-basins from which water resources are monitored and managed. It is in these sub-basins that catchment management will be implemented. Currently catchment based water resource management is being piloted to understand how best it can be implemented in Uganda.

A pilot study on river Rwizi catchment area located in Victoria water management zone has revealed some aspects in the initiation of catchment management. Such aspects include the identification of threatened wetlands systems, integration of catchment management issues in district development plans, promotion of community participation, forestation, dissemination of weather outlook/forecasts among others (Sewagudde 2011).

One of the key lessons learnt during piloting was, IWRM is better embraced in an area that is experiencing serious water resources problems. Secondly, because the process requires involvement of multiple stakeholders for its success, it involves a great deal of consultations and consequently substantial amounts of funds are required. Involving political, administrative and technical representatives in catchment management structures was found to be a viable aspect.

9.9 Water Resources Management Challenges and Issues

The uneven spatial and temporal distribution of water resources in Uganda is a big challenge to their management. For example, there are increasing incidences of water use conflicts in the water scarce parts of the country, especially in the cattle corridor. The frequent migration of pastoralists from place to place in search of water not only poses a security threat but is

also a major health hazard as diseases are transferred from one part of the country to another in this process.

There is also increasing pressure on water resources due to rapid population growth, increased urbanization and industrialization, uncontrolled environmental degradation and pollution. A combination of some of these factors has been cited to be responsible for the recent landslides in eastern Uganda. This pressure still remains a big challenge to the sustainable management and development of country's water resources.

The frequent recurrence of extreme weather events (floods and droughts) and increasingly erratic rainfall are a big challenge to the management of Uganda's water resources. The variability in seasonal rainfall, has significantly affected the different socio-economic activities that are heavily dependent on rainfall.

Ground water is presently the major source of rural domestic water supply and is planned as the main source of water for small towns (40 completed and 80 new ones) and rural growth centres (which approximate 800) up to 2015. Some of the aquifers however, are limited in yield, extent, hydraulic characteristics, and recharge is low in certain parts of the country. The availability and quality of groundwater for larger rural water supply projects is a significant future challenge. Given the limitations of ground water supplies, it would appear that groundwater abstractions for many large projects in say irrigation and municipal water supplies may not be sustainable.

There is still little knowledge on how climate change will impact on this important resource. Given the increasing demand for water and the high rates of population growth of 3.2%, it is of utmost importance that an analysis of the hydrological impacts of climate change especially in Uganda are intensified.

Despite all the above planned developments, there is still very limited knowledge of the country's groundwater resources, making it difficult to guarantee sustainable groundwater development for the current and future needs.

Groundwater recharge varies considerably across the country and is extremely sensitive to land use and the amount and intensity of precipitation falling in a given area. However, due to inadequate data and resources, very few groundwater recharge assessments have been carried out in Uganda and thus recharge estimates for most areas remain unknown.

Government should be aware that, the development of hydropower schemes, though a non-consumptive use creates reservoirs, which have adverse effects and environmental consequences on water resources. These include; Siltation / sedimentation and aquatic weed encroachment in the reservoir, diminished downstream river discharge, eutrophication in reservoirs due to domestic and industrial waste, increased loss of water due to evaporation and others.

The unique geographical location of Uganda in the Nile Basin, i.e. being a lower and an upper riparian state imposes constraints and responsibilities to the country (HDR 2006). As a

country it would be affected by the use of the water both in quantity and in quality by the riparian countries.

Another setback in Uganda's effort especially to exploit HEP potential is the current colonial agreement of the agreed curve policy (NEMA 1996). This colonial agreement has been rejected by Uganda even though the main beneficiaries of the agreement are still upholding it. It is therefore expected that regulation of Lake Victoria with a more scientific friendly policy supported by Decision Support Systems (DSS) may overcome this problem.

The challenges that Uganda faces in this respect include: failure to regulate Lake Victoria with a better regulatory policy, fluctuation of levels of lake Victoria and other equatorial lakes in the Nile Basin due to climatic change and variability, maintenance of water quality to be free of aversive weeds, sedimentation etc.

9.10 Conclusion

Priority of Uganda's water resources utilization and development is given to domestic water supply for both human consumption and livestock. Rural domestic water demand is by far greater than the urban demand because about 80% of the country's population is rural (UBOS 2009). Currently the rural population is dependent on ground water development or rainwater harvesting to meet their needs. Given the MDG water targets and GoU water development programmes, Uganda will resort to the utilization of the watercourses and the shared water bodies to satisfy rural water demand sooner than later. The water supply sector is under expansion and small-scale irrigation is being promoted and may in the future be of increased importance, but rainfall, which is a major source of water, is on a decrease as water demand increases. Detailed assessments are thus necessary on ground water resources, groundwater recharge and water balance.

Statistics from UBOS (2009) show that, rate of access to domestic water for rural and urban water populations had levelled off at 63% and 77% for the year 2007/2008. The water and environment sector performance report of 2012 indicates that access percentage of people within one kilometre (rural) and 0.2 km (urban) of an improved water source was 64% and 68% respectively. Major source of water for the country are protected springs, deep boreholes, shallow wells and rainwater harvesting. The new national strategy of bulk water supply is to meet rural settings demands including demands of water for livestock (WSS sector working group report 2006). The biggest challenge is that this demand is not quantified, not forgetting that Uganda is both a downstream and an upstream riparian state.

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CHAPTER 10

Detecting changes in surface-water area of Lake Kyoga basin using remotely sensed imagery in a changing climate. *

*Submitted for review to Theoretical and Applied Climatology.

10.1 Introduction

The need for a change detector that will automatically correlate and compare two sets of imagery taken of the same area at different times and display the changes and their locations to the researcher was articulated as early as 1964 (see Shepherd 1964). According to Singh (1989), change detection is the process of identifying differences in the state of an object or phenomena by observing it at different times. It involves the skill of quantifying temporal effects using multi-temporal data sets. The detection of these changes is important in providing information as to what and where the changes have occurred and to analyse these changes e.g. in order to manage natural resources better. Change detection research, should be able to provide information on area change and change rate, spatial distribution of changed types, change trajectories and accurate assessment of change detection (Lu *et al.* 2004). Change detection has diverse applications such as land use change analysis, monitoring expanse of cultivation, deforestation, forestation, changes in vegetation phenology, seasonal changes in pasture production, damage assessments, crop stress detection, disaster monitoring, flood invasions (Schäfer and Lundström 2012), snow melt measurements, water body change (Nath and Deb 2010; Mouchot *et al.* 1991), drought (Shamsipour *et al.* 2011), wetland change, forest fire, urban change, land use and land cover change, landscape change and other environmental changes. The basic principle in using remote sensing data for change detection is that changes in land cover manifests in changes in radiance values (this radiance ought to be above the background radiance changes attributed to land cover change arising from other factors such as, a) differences in sun angle, b) differences in atmospheric conditions, and c) differences in soil moisture (see Singh 1989 and references there in).

Water mass as a feature in a remotely sensed imagery, has a unique spectral response compared to the surrounding landscape. In the optical range water has a distinctively low spectral response, and this property has been utilized for water body extraction (Xu *et al.* 2009). In radar images water body lies in dark areas because of its low backscattering coefficients, and it holds some self-similar texture features (Zhaohui *et al.* 2009). This technique of change detection using remote sensing can be applied in water resource monitoring studies. Monitoring changes in water resources, using Landsat images has become increasingly important in the past years for reasons pertaining to uncertainties surrounding climate change effects, development of transport routes, and need for timely information for monitoring and management purposes (Nath and Deb 2010). Globally, water resources have been hit the hardest for instance due to temperature increase, reduction in precipitation, increased evaporation, and conversion of land cover which can alter a basins response to rainfall events which can lead to reduction in surface-water area. Consequently this impacts on water volume, variability of river discharges and the seasonal availability of water supply (Alcamo *et al.* 2007).

Significant work has been done to extract water body information using satellite images in the past, Ouma and Tateishi (2006) study in the East African Great Rift Valley. Reviews about the various methods used for the extraction of water information from remote sensing imagery can be found in (Nath and Deb 2010; Lu *et al.* 2004). Four methods (i.e. supervised segmentation, decision tree, spectrum-photometric and Normalized Difference Water Index

(NDWI) model) are commonly used by researchers for water body extraction research. In this study the NDWI approach reported in Xu *et al.* (2009) was considered due to its simplicity and effectiveness in extracting water body information especially with both vegetated cover and water mass common in most water basins in Uganda. The NDWI approach reported first in Mcfeeters (1996) and later used by Ouma and Tateishi (2006) is derived from green and near infrared red channels spectral signature as given in Equation 1. In these portions of the electromagnetic spectrum, water bodies will absorb almost all-incident radiant flux while the land surface reflects significant amounts of near- and mid-infrared energy

$$NDWI = \frac{G_r - e^{-eNnI}}{G_r + e^{-eNnI}} \quad (1)$$

In Equation (1), Green band and NIR bands correspond to band 2 and band 4 respectively of the Landsat TM imagery. The green band is preferred to the red band because the green band is relatively insensitive to the background components such as soil (Ji *et al.* 2009). In Equation (1), the presence of water bodies will be denoted by high NDWI values than the other landscapes, because water has a high reflectance in NIR channel and it can restrain the information of forest, farm and grass (McFeeters 1996; Xu 2006; Xu *et al.* 2009).

The main aim of the current work is to investigate the changes in areal coverage of surface-water in the Lake Kyoga basin between 1986 and 2010 using Landsat TM and ETM+ imagery. Specifically the objectives of the study were a) to characterise the climatic conditions of Lake Kyoga basin between 1940 and 2009, b) analyse the changes in areal surface-water coverage in Lake Kyoga basin using appropriate water index derived from Landsat imagery of 1986, 1995 and 2010 and c) investigate the linkage between climatic parameters and surface-water area.

This study contributes towards understanding the manifestations of climate variability on communities and could therefore support climate change adaptation and mitigation strategies for the benefit of the vulnerable poor in communities. Furthermore, extracting water body information from remotely sensed data is one of the important means of water resources macroeconomic monitoring, flood disaster monitoring and wetland protection. Additionally, accurate extraction of water resources information from remotely sensed images is a significant means for the surveying and dynamic monitoring of water resources (Xu 2006).

10.2 Study area

Lake Kyoga is part of the upper Nile river basin system found in Uganda. The basin is surrounded by 10 districts (administrative regions) namely; Apac, Kaberamaido, Kamuli, Katakwi, Kayunga, Kumi, Lira, Nakasongola, Pallisa, and Soroti (Figure 10.1, bottom left). The shallow lake situated in the centre of country was formed as a result of up warping, which led to river reversal that filled up the basin that is now Lake Victoria. Due to the gradual increase in water into Lake Victoria, the Victoria Nile outlet at Jinja began to overflow filling the central depression, which is the present Lake Kyoga. According to the Uganda National Water Development Report (UNWDR) of 2005, Lake Kyoga has a surface

Lake Kyoga sub-catchment has streams entering the lake from the south such as Sezibwa and Victoria Nile and also from the north;

Mpologoma dominated by Mpologoma – Malaba river systems and lastly

Kwania, which covers L. Kwania and the wetland systems found around Amolatar, Dokolo and Apac.

The table 10.1 below shows the breakdown of the main rivers and their annual water contribution to Lake Kyoga basin.

River	Catchment area	Contribution (m ³)/ year
Victoria Nile	Principal inflow from south	25.6 billion
Mpologoma	Southeast	610 million
Okere	Northeastern part	373 million
Sezibwa	The south	217 million
Omunyal	The north	40 million

Source of figures used in the table is from Ramsar documentation on wetlands in Uganda.

Direct precipitation over the major lakes amounts to about 6 billion m³/yr while the mean annual outflow from the system is 27 billion m³. Ramsar documentation points out that Lake Kyoga margins are fringed by *cyperus papyrus*, which often detaches to produce floating islands, because of the substantial changes in water levels. The swamps are dominated by papyrus, but seasonal floodplains carry grasses with some trees in less deeply inundated areas. The lakes of the complex support important commercial fisheries in which *Latesniloticus* constitutes 60 –70 % of the total annual catch. The small lakes are however, fished only by artisans including crocodiles have been hunted for their skins and are at the point of extinction.

10.3 Data and Method

10.3.1 Data

The land cover index was derived from the 30 x 30 m resolution of Landsat images obtained from USGS sites GLOVIS (<http://glovis.usgs.gov/>) and EarthExplorer (<http://earthexplorer.usgs.gov/>). In the analysis, Landsat imagery scenes (path 171, row 059) acquired on January 1986, 1995, and 2010 covering part of Kyoga drainage sub-basin in Uganda were considered. The decision to base our analysis on the month of January was based on the need to use scenes acquired during minimum rainfall events, as during this period, the quality of the images is not compromised due to the effects of cloud cover.

Secondly, soil moisture could be minimal during this period and therefore any index calculated from the satellite images would not be affected by background noise (soil moisture). Further still to overcome the changes that may be brought about by radiance changes caused by other factors like the sun angle, satellite scenes acquired for the same season of the year were selected.

10.3.2 Image pre-processing

Image pre-processing comprised of the following steps: a) converting optical band data to top of atmosphere reflectance values, b) extracting the area (region of interest), and c) visual image analysis where pixels were well aligned.

10.3.3 Method

In the present study we propose to estimate changes in areal water bodies by using the Modified NDWI (MNDWI) based on TM and ETM+ spectral bands. The MNDWI (see Equation 1 in Table 10.2) is particularly suitable since it can enhance open water features while efficiently suppressing and even removing built-up land noise, vegetation and soil noise (Xu 2006). The MIR is a middle infrared band such as TM band 5 and as reported in Ji *et al.* (2009) is a suitable index for delineating surface water bodies from Landsat TM/ETM+ imagery because it is least sensitive to the sub-pixel non-water components. In the present work, MNDWI used to assess the changes in the open water types: lakes and rivers e.g., existing within Lake Kyoga drainage sub-basin.

In order to account for the observed changes in surface water bodies in Lake Kyoga basin, the basin's climatic characteristics was analysed using the historical, monthly precipitation data. In particular, the SPI described in McKee *et al.* (1993) can be applied to quantify the rainfall deficit at various time scales. In this study, the SPI was calculated for the different temporal scales e.g., December, January and February (DJF) of observed rainfall totals (Table 10.2, step 4). In the analysis, an averaging period of 3 months was used to account for lag and cumulative effects of precipitation (Shamsipour *et al.* 2011). The resulting SPI series was further categorized into the 30-years 'normal' in accordance with World Meteorological Organization (WMO) requirement and then computed using equations put forward by (Awange *et al.* 2008).

Using the percentage of normal (equation in step 7- Table 10.2), a DSI is determined by considering all observations which are less than 25 % (first quartile) of the ranked historical records to be dry, while those which are more than 75 % (third quartile) are considered wet. Awange *et al.* (2008) illustrates severity classification scale as: Wet (> 75%); 25 < Near normal < 75%; Drought < 25%.

Drought seasons and years are identified by observing the years and seasons in which the anomalies in rainfall are below the drought threshold line (i.e., DSI of 25%). Table 10.2 depicts some of the equations utilized in the present study.

Table 10.2 Summary of steps and methods used in the study.

	Step	Process	Notes
1	Delineating surface water in Landsat ETM+/TM imagery.	$M = N \cdot D_{L_{2,5}} \cdot (P_{L_2} - P_{L_5}) / (P_{L_2} + P_{L_5})$ (Xu, 2006)	where P_{L_2} and P_{L_5} are the reflectance's of bands 2 and 5.
2	Rainfall characteristics analysis	Standard Deviation (SD), Coefficient of Variation (CV) and Percentage contribution to annual total rainfall.	Computed for monthly and seasonal time steps.
3	Monthly rainfall data, obtained from UDM, UBOS (1940 – 2009)	$M_{sy} = (R_{sy} - \overline{R_{sy}}) / \sigma_{sy}$ $M_{ry} = (1 / N_j) \sum_{s=1}^{N_j} M_{sy}$ $v(t) = \frac{\sum N_j M_{ry}^2}{J - 1}$ $v(area) = \frac{n - \sum N_j M_{ry}^2}{n - J}$	Normalizing rainfall data series where N_j is the number of regional stations operating in the year j It has to be shown that the geographical variations of (M_{sy}) are small, compared to the temporal variations (Kraus, 1977; Nicholson, 1986; Türkeş 1996)
4	Quantifying rainfall deficit for various time scales (using SPI).	$SPI = \frac{x - \bar{x}}{s}$, (Agnew, 2000; Livada and Assimakopoulos, 2007)	Where x is the meteorological variable, $\bar{x}$ is its 3-month average value, with s as the standard deviation.
5	Drought Severity Index(DSI): Awange <i>et al</i> (2008),	$\overline{S_m} = \frac{1}{3} \sum_{m=1}^3 M_t$	Seasonal means are obtained by averaging the monthly totals for three months of a particular season.
6		$A_t = \sum_{m=1}^{12} M_t$	While for annual totals, the summation of twelve monthly totals was taken for a given year.
7		$P_n = \left[\frac{A_p}{N} \right] \times 100$	Applying Eq. In step (5) and (6), the normal precipitation N - a (30-year) mean is obtained. The normal precipitation is then used to compute the <i>percentage of normal</i> P_n (quartile), where A_p is the actual precipitation.

10.4 Result and discussion

10.4.1 Climatology

Rainfall is the main source of water over the Lake Kyoga drainage sub-basin. An analysis of the climatic conditions over the basin for the period 1940 – 2009 is given here. Table 10.3 shows the meteorological stations that were used in the analysis and the associated rainfall characteristics. Values in bold denote station series which were serially correlated, implying that annual series of 2 stations show that data does not come from the same random process. During this period of analysis, Serere agricultural research station, found in the centre of the basin recorded the highest total rainfall in 1996. Five of the nine stations recorded the highest rainfall in the 1960s. Kotido meteorological station in the far north of the zone has the highest rainfall variability of 28% followed by Kangole (25%). Within this period of analysis Kangole received its highest total rainfall in 1961 and the following year 1962 it recorded its lowest total.

Table 10.3 Characteristics of annual rainfall data for Lake Kyoga drainage sub-basin between 1940- 2009.

Station	Mean R/fall	Highest total R/fall (mm)	Year of occurrence	Lowest total R/fall (mm)	Year of occurrence	Standard deviation	Serial corr. coeff. (95%)	Von-neumann Ratio (95%)	CV %
Tororo Met	1462	1981	1961	879	1949	20	0.29	1.3	17
Mutai forest	1359	2238	1961	943	1973	18	0.04	1.9	15
Mukono Agric	1355	2244	1960	772	1972	26	0.50	0.8	23
Kangole	660	1089	1961	410	1962	14	0.02	2.0	25
SerereAgric.Sta	1376	2378	1996	939	1939	19	0.00	2.0	16
Soroti Met sta	1336	2032	1915	851	1957	21	0.10	1.7	19
Kibale VTC sta	1361	2047	1961	626	1980	21	0.06	1.9	18
Mbale	1224	1789	1951	807	1927	19	0.16	1.7	19
Kotido	677	1145	1946	351	1965	16	0.15	1.7	28

Annual precipitation data recorded in Kyoga sub-basin from 1940 – 2009 show decades of normal and beyond normal rainfall. Three long spans of below normal rains are evident in the 1940s, 1960/70 and 1980s in both basins (see Fig. 10.4). Other particularly wet periods were experienced in early 1950s, 1960s, late 1970s and the 1990s (not shown here).

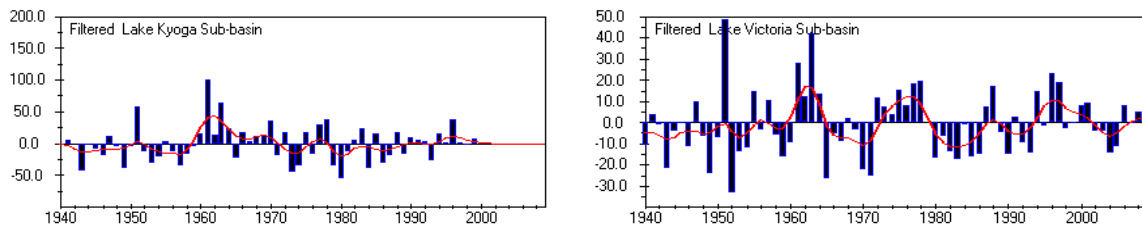


Figure 10.2 Regional total rainfalls (mm) for the period 1940 – 2009.

The Lake Kyoga drainage sub-basin is wide with some mountainous topography at its edges, which can cause variation in climate, thereby producing spatial heterogeneities in temperature and precipitation. So a degree of disparity in SPI values between the stations should be expected. Figure 10.3 shows that there is a remarkable consistency in the SPI for the month of January in most years within the basin. As observed, most parts of the basin experienced drought conditions (negative SPI) in the month of January. In some years the basin experienced relatively wetter conditions as a whole, with the SPI indicating positive rainfall anomalies. Generally the SPI for January shows that much of the sub-basin experienced drought conditions, despite a few wetter years in the 70-year period (Fig. 10.3). There are years for instance (1953, 1957, 1959, 1962, 1969, 1970, 1971, 1973, 1974, 1977, 1985, 1998, and 1999) when January received above normal rainfall.

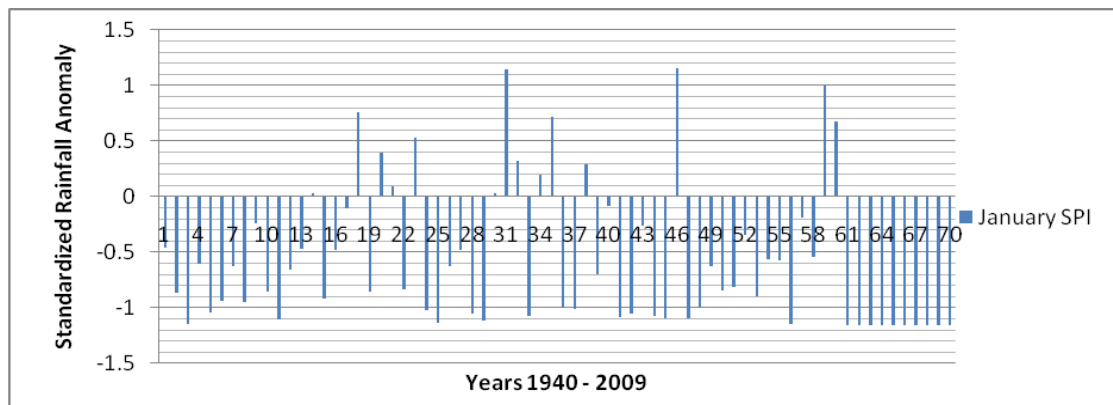


Figure 10.3 Standardized annual precipitation anomalies for the area average January series of Kyoga drainage sub-basin using the DJF base period.

10.4.2 Satellite derived changes

In remotely sensed studies, data analyses rely on the spectral signature to identify and characterize the object plus other techniques to categorize and group objects (Mouchot *et al.* 1991). In this respect, Green band (B2), and middle infrared band (B5) of TM/ETM+ have been employed in MNDWI model to measure the extent of surface-water area and its variation in January over different years. Figure 10.3, illustrates the areal extent of surface-water over the Lake Kyoga basin.

Table 10.4 Percentage change of surface water area for the different classes in the Kyoga basin.

Year of detection	No water	Low water	Moderate water	High water
1986	50%	41%	2.4%	6.4%
1995	49.7%	41.6%	2.6%	5.98%
2010	46.5%	43.8%	0.8%	8.7
% Change	7%	6.8%	65%	36%

Analysis reveals that, class of no water has declined steadily by 7%. Regions of low water have increased by more or less the same percentage of 6.8%. The moderate water class was high in 1995 and declined by 65% by 2010. High water class shows an increase of 36% from a low percentage in 1995, implying that areas that were not under water in 1986 (Fig. 10.4) have been covered by water in 2010. Visual inspection of the images for 1986 shows a detaching Lake Kyoga from the Kwania lake water system, which is evidence of low water in the basin. By 2010, water had occupied the areas that seemed detached as seen in the same figure 10.4.

The increase in surface-water area that was detected may be attributed to the reduction in the wetland size in the two basins (Kyoga and Victoria). According to NEMA (2009), reduction in the wetlands around the study area was 26.5% by 2008. Other water resource developments like the construction of Nalubaale power dam along the Victoria Nile created another water outlet from Lake Victoria into the basin, which may have led to the increase in surface-water area in the receiving basin. There are also records of frequent floods around the basin recently, which is evidence that the basin is undergoing hydrological changes.

The available observational records and historical information show that variations in the level of east African lakes are closely related to previous trends in rainfall patterns (Anyah and Semazzi 2004). The DSI values, presented in Table 10.5 illustrate the drought seasons/years in both Kyoga and Victoria drainage sub-basins in Uganda. Because Lake Victoria basin is part of the Kyoga catchment, a change in the water regime in one basin is reflected in the amount of runoff received in another. There is a degree of correlation between the drought years in the sub-basins in the first normal (30 years) than in the second normal during the period of analysis (Table 10.5).

In particular, the 1986 drought event is captured well by the surface-water area change analyses indicated by the 50% and 41% of no and low water coverage respectively, while the area under high water was 6.4%. Awange *et al* (2008) also identified 8 drought seasons within the Lake Victoria basin period between 1990 and 1999. But because of some limitations in data and differences in spatial coverage of the two studies, our results slightly disagree with those reported in Awange *et al* (2008). Another prominent drought period was

the 2004/5, when the water level in Lake Victoria dropped by a meter below the 10 year average (Kull 2006).

Table 10.5 Drought years for selected drainage sub-basins in Uganda

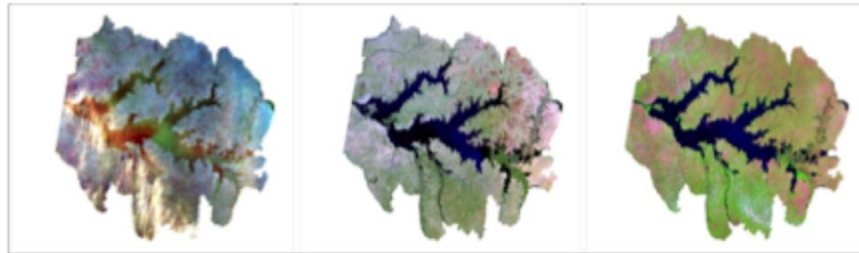
Series variables	Climatic Normal	Lake Kyoga	Lake Victoria
Annual	1940-1969	<u>1943</u> , 1949, <u>1953</u> , 1957, 1958, <u>1965</u>	<u>1943</u> , 1946, 1952, <u>1953</u> , 1959, <u>1965</u>
	1970-1999	1973, 1974, 1979, <u>1980</u> , 1984, 1986, 1993	1970, 1971, <u>1980</u> , 1982, 1983, 1985

10.4.3 Vulnerability

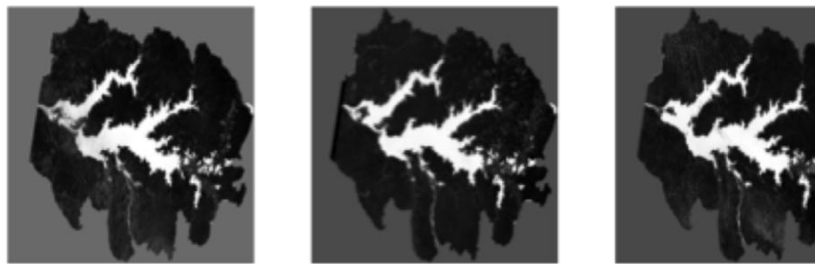
Changes in precipitation and temperature are often reflected in changes in water resources and therefore impacts on all sectors that depend directly or indirectly on the water resources (Estrela *et al.* 2012). Furthermore, variations in these vital climatic variables across the selected basin in Uganda are often a proxy for climate variability in Uganda. Climate change and variability in Uganda pose very serious national challenges and risks across various sectors such as agriculture, water resources and energy, which support the economy and the wellbeing of its people. Conducting impact assessment studies, which is not easy because of natural hydrological variability, can ameliorate these challenges and risks and effects of water abstractions on flow discharges.

This variability is evident in the surface-water area changes in the images above. For instance the El-Nino rains of 1995, raised level of water in Lake Kyoga (Fig. 10.5). During the early years of 19th century when the region experienced prolonged drought (Ba and Nicholson, 1998) there was a significant fall in lake levels. Droughts significantly affect the country's water resources, hydropower production and agriculture. The 1980s were also noted by Hulme (1992), as drought years that had consequences on food security for the continent. When the above normal rainfall was received over the region during the 1960s, Lake Victoria level rose to about 2 m, with most of the basin experiencing heavy flooding (Anyamba 1983). Such variability has consequences on human activity, migration trends and the economy in general.

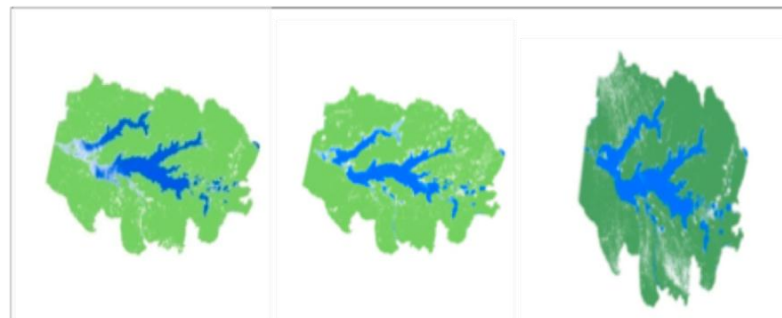
Kotido and Kangole stations are located in the driest areas of Uganda whose main activity is pastoralism. The high variability of rainfall makes these pastoralists to migrate and search for grass and water. In the process, it causes a lot of friction with the neighbouring communities like the Ateso and Pokot and often results in cattle rustling and insecurity. Currently the basin has a population of about nine million who depend largely on agro economy, variability in rainfall can greatly affect their form of livelihoods and water related natural resources. It is important therefore in future to understand the level of water stress, its rate of change in order to determine the ability of the communities' resident here to adapt to changing conditions.



(a) Lake Kyoga basin delineated from Landsat images of January (left to right), for 1986, 1995 and 2010 respectively.



(b) Enhanced images of Lake Kyoga basin after applying the MNDWI for January 1986, 1995 and 2010 (left to right) respectively.



(c)  No  Low  Moderate water  High

(c) Images for Lake Kyoga basin for January 1986, 1995, and 2010 after reclassification.

Figure 10.4 (a, b, c) showing temporal fluctuation of surface-water area in Lake Kyoga basin.

As a result of variations in the rainfall, these lakes in Kyoga basin require exceptional water management practices that would ensure that changes in climate do not cause a major effect on water availability and water stress, hence causing insecurity that may lead to the displacement of communities. Increasing water availability on the other hand may have a positive influence, which reduces water stress, but it can also have consequences of high and damaging runoff events.

10.5 Conclusions

The detection of water body change effects is not simple because the natural variability of the water cycle and the effects of water abstractions on flow discharges complicate the task of establishing clear trends. Studies focused on the use of Landsat imagery to detect changes in surface-water area have been extensively reported in numerous published works in recent years. However, majority of these studies tend to focus on exploring regional climate models, apply them on to scenarios of observed climate data to explain the effects of hydrological uncertainties on catchments. In the present work, Landsat satellite scenes over Lake Kyoga basin (1986, 1995 and 2010) have been analyzed in order to investigate the spatial-temporal variability of areal surface-water masses. Further, the derived areal surface-water changes have compared with rainfall data in order to establish a linkage between land cover changes and climatic parameters. Based on the DSI and SPI parameters reveal a close relationship between the changes observed from images and the two indices. The detected changes can be attributed to systems characteristics and its management. Unmanaged systems are likely to be the most vulnerable to climate changes. During basin management programmes, measures should take into account the different effects of climate in different water management sub-basins in Uganda. If the intense use of water resources continues, the environmental needs increase and the margin to increase available water resources is reduced, then it is most likely that current water uses will not be maintained in the future. In conclusion, it becomes essential to improve assessments of the effects and to adapt water management to the already identified impacts and to the anticipated ones by using future scenarios.

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SECTION 5 SUMMARY AND CONCLUSIONS

Summary and Conclusion

In this study three aspects have been dealt with, Climate variability, water resources and livelihoods using both qualitative and quantitative approaches.

The study begins by carrying out a field survey in three sub counties of Katabi, Maddu, and Busukuma which lie in the Lake Victoria basin area. The interview technique was used to get information from households and key informants to get a deeper insight of the interplay between different agents dealing with natural resources. The research focused on general livelihoods in the lake basin area. Respondents for households were selected randomly. Key informants were selected using a convenience and judgements approach. The main issues interrogated through the questionnaire were respondents' awareness of climate change, understanding of household livelihoods, livelihood assets, governance, recollection of past environmental shocks and stresses among others as well as social economic challenges in livelihood formation.

During this stage, data was compared with emerging categories and leads from respondents which were then followed as defined in data. For example analysis showed that 96% of the respondents had heard about climate change, and a good number of them had noticed considerable changes in climate variables. Ninety percent of the interviewees agreed that changes in climate were impacting on their livelihoods and as a result, they have diversified into a bundle of household activities.

From this vantage point the study analysed climatic data, recorded from observations measured at specific sites (stations) and later archived at the department of Meteorology in Kampala Uganda (CLICOM). Data composed of temperature and rainfall recorded for a period of 30 to 70 years. Daily records were transformed into monthly, seasonal and annual time series for each meteorological station. Landsat images were also utilised to inform on water resources coverage and how changes in climate have impacted on them. Information was later analysed using statistical methods to arrive at conclusions presented in the various chapters, four of which have been published in peer reviewed international journals.

The fourth chapter in section 2, analysed trends and temporal variations of rainfall recorded at 36 rain gauge stations located in the main drainage sub-basins of Uganda. Characteristics and nature of rainfall in Uganda from 1940 to 2009 is described in accordance with the main drainage sub-basins that form part of water resources management.

Analysis shows decades of normal and beyond normal rainfall, with a marked contrast in seasonal cycles with in sub-basins. Mean annual rainfall is seasonal with much of the rainfall measured during March to May, and although no significant change in annual rainfall can be discerned in Uganda an increase in the variability in the distribution of monthly rainfall has been detected. Variations in annual rainfall are relatively low which imply a dependable rainfall distribution. Plots also indicate that, no single month in Uganda goes without rainfall in the sub-basins. Sub-basins in the north have a unimodal type of rainfall distribution while those in the south have a bimodal distribution with maximums in July to August and March to May respectively. The DSI has identified the drought years during the analysis period, which was consistent with previous literature.

From the monthly rainfall variables, October, November, December and January were found to have significant increasing trends. The result of trend analysis of monthly total rainfall especially in October and November is reflected in the SON season, but not in the annual series. There were downward trends in the annual rainfall series, predominantly in north western and south western of Uganda, while the rest of the sub-basins had upward trends.

Chapter 5 under the same section characterizes near surface temperature and its variability in Uganda in recent decades (1960 – 2008). Trends and other properties of temperature at selected stations from the central, eastern, southern and western parts of the Uganda have been unveiled. Data was tested for normality as required to test for linear regression trend analysis, and showed normal distribution. The series were also tested for homogeneity, in which we established that there were not homogeneous, but this inhomogeneity could not be explained because of the absence of historical metadata. Missing gaps in the data set were filled using long term means which altered the data set slightly, but means did not change. The study has revealed that maximum temperatures of the region are more variable compared to minimum temperatures. The mean trend in intra-annual variance is decreasing but not statistically significant. There is also evidence in data that warm spells vary per decade which require further understanding. Further analysis to identify abrupt changes can be done using other tests like isotonic regressions, Csorgo and Horvath change point detection and moving cut data detrended fluctuation analysis. Since trends in long-term near surface temperature do exist, then government has to take proper actions to deal with the impacts of such trends on industry, fisheries, and agriculture. It also serves to fill the gap in the distribution of temperature trend analyses across the world as well as providing useful information to the government of Uganda.

Chapter 6 focuses on the use of different methodologies to analyse climatic parameters at a regional level in order to investigate the temporal and spatial rainfall characteristics, in the Albert-Victoria water management area using old data records. This study fills in the gap for baseline data concerning trend analysis in Uganda, hence the period 1940-1977. Information on whether trends exist in Uganda's rainfall is useful for the Ugandan government to carry out effective water resource planning and management in the future. Lack of information on the characteristics of these natural water resources may result in poor decisions on Uganda's economy and human health which are vulnerable to climatic anomalies. Uganda is a small country with a wealth of water resources that originate from the western region, also transboundary. The main objectives of this chapter are (1) to describe the spatial patterns of rainfall and concentration, and the inter-annual variability of annual and monthly rainfall concentration for the period 1943 – 1977 using 58 station locations in the Albert-Victoria water management area of Uganda and (2) to analyze the rainfall trends based on both monthly and annual series using parametric and non-parametric tests.

Results show that stations close to Lake Victoria record high amounts of rainfall. The rainfall distribution is bi-modal, with maximums experienced in the MAM (39%) and SON (37%) seasons of the year. Spectral analysis of the time component reveals year periods around 6 and 10 years which is a characteristic of the annual, MAM and SON series. Average CV is 19%, which signifies low variability in analysis domain. The coefficient of variation is low

for high rainfall stations and vice versa. Interannual variability of rainfall distribution is low to moderate. Analysis also reveals that PCI values lie between 9 and 11 which denote moderate to seasonal rainfall distribution. It has also been demonstrated through mean monthly rainfall that, there was no single month without rainfall.

At a regional scale, positive and non-significant trends in monthly rainfall occurred in the analysis domain whereas negative trends are noted for the months presumed to be of high rains. The increases in rainfall totals for some months (February and December) are also reflected in the DJF significant trends for the area. The area generally did not reveal significant trends in the mid twentieth century at a 5% significance level. Empirical studies do not provide information on the causal factors of detected trends which is a potential area for further research. I am aware that a 30-year period is not enough to encompass fully any climatic variability signal. Therefore, the observed changes should be considered with caution.

Chapter 7 presents the first attempt to analyse climate characteristics of an area (micro) using single station data from Namulonge. Temperatures and rainfall are regarded as parameters of climate with large spatial and temporal variations and are useful to consider in climate change studies. With climate change a reality it is important to update and inform on observed climatic trends from a micro-level approach where livelihoods are greatly dependent on climate. Results show monthly maximum temperatures for the period under consideration have been increasing significantly especially during the second climate normal. This study has established that maximum temperatures have been increasing significantly at a rate of $0.17^{\circ}\text{C}/\text{decade}$. Records indicate that 2005 was the hottest of all years with a mean monthly average of 32.8°C . It is evident that variation of mean monthly temperatures throughout the year is very small ranging between 1° – 2°C .

It is also evident from the 56 year record that mean annual minimum temperatures are increasing but not statistically significant. However the minimums of the minimum temperatures reflect a statistically significant trend which is increasing. This implies that, the nights were warming, especially from the 1990's which is an indication of climate change. Warming temperatures are likely to impact on the livelihoods of the people, their health and water resources among others. Elevated temperatures may enhance evaporation losses, unless they are compensated by increased precipitation, even runoff is likely to be further reduced. The increasing temperatures may impact water resources in and around Namulonge and also alter crop water balances.

Rainfall is decreasing especially in the MAM season. Over the first 30 years higher rainfall was recorded compared to the recent 30 years. Analysis shows that the early 1960s were the wettest years on record.

The results from this study can be ably interpreted in the context of other impacts, meaning that it is likely that constraints on livelihood could be exacerbated. The majority of Ugandan farmers, like those in Namulonge, practice rain-fed agriculture which is sensitive to fluctuations in weather conditions. Declining rainfall may lead to crop failure, increasing

temperatures and reduced rainfall can even lead to scarcity of water resources for human consumption and watering of livestock. Increases in temperatures may lead to decline in milk and meat production, largely because the animals remain in shade instead of foraging. Crop water balances may be affected through changes in precipitation and other climatological elements such as the increase in evapotranspiration. The impacts of land degradation at Namulonge and the surrounding areas are already quite severe. The population growth, human settlements, transport, agriculture, utilization of trees for energy and other human activities are probably responsible for the anthropogenic forcings.

The climate systems in Namulonge are still complex and not fully understood. Climate model simulations also anticipate increase in rainfall with in Namulonge region where as this study shows that rainfall is on the decrease at the station. Further research into the underlying local factors that influence climate is therefore required. Future studies ought to investigate aspects of urbanisation among others on temperatures. A study on the possible impacts of climate change on food crops like maize, beans, potatoes, bananas and commercial activities like poultry, fish farming and flower farming that are carried out in the area is also required.

The study originally set out to answer the set objectives. At the end of it a number of questions are pondered upon. For example; Are people in Uganda conscious of climate change? Is the climate of Uganda changing? What is the impact of climate change on livelihoods in Uganda? What is the effect of climate change on water resources or their management? In this section the issues will be summarised in the following subsections;

a) Perception of climate change in Uganda.

Using a case study approach, the study found out that 96% of the respondents knew about climate change, mainly from the media and government role was barely noticed in this campaign. Changes like, increase in day temperatures, hail storms, fog, drought, warm nights and January rains were observed by respondents in the sample study area to have occurred in the last 10 to 20 years.

The study also showed that 90% of the respondents believed that climate change was going to affect majority of livelihoods and 96% suspected climate change to be affecting the economy. This perception has contributed to the current livelihood diversity in the country. The study has demonstrated how the people perceive of climate change and what they anticipate it will impact on Uganda. But also requires that future studies should be carried out to establish the impact of climate change on the economy of the country.

b) Livelihood formation in Uganda

The study has established that livelihoods in Uganda have evolved based on the availability and opportunities afforded by the natural resources base and market forces. The main sources of livelihoods are commonly supported by diversity of secondary livelihoods. The study has shown that the main sources of household livelihoods are subsistence farming, employment income and family support. Majority of the respondents in the sample study area generate livelihoods from farming. Close to 60% of households in all three sample areas indicated that friends and family also contribute to livelihoods. Remittances and other transfers did not

register in the livelihood portfolios of the sample households despite being a critical source of income for the country.

The main livelihood problems are mainly economic in nature, coupled with remote access to natural resources and infrastructure, weather related problems, poor enabling environment, technology and technological changes. Assets determine the economic activities of households in a given context. Capital assets like natural, human, financial, physical, social and political in a house hold are combined with different resources at their disposal to create activities that will enable them to achieve the best possible livelihood assets and outcomes. Different households will have different access to this range of assets. The livelihood approach has limitations, because it focuses on the household as a unit of analysis which often ignores the intra-household differences such as gender. As Goulden (2008) has identified, the approach is limited by patterns of behaviour at a scale larger than the household such as collective action which may be missed when the livelihoods approach is the only approach used in the study.

In the sample study area, the study has established that access to adequate livelihood assets is affected by climate and non- climatic factors which household's members have little control.

c) *Impact of climate change/variability on livelihoods formation*

Climatic factors influence the choices, households make about using assets to form livelihoods. They can destroy assets directly, can force people to abandon their home areas and dispose of assets, prematurely as part of coping strategies. Between 1940 – 2009, Uganda experienced decades of normal and beyond normal rainfall with marked contrast in seasonal cycles. Mean annual rainfall is seasonal, with much of it being received during March to May. There is no significant change in annual rainfall and PCI is relatively low which imply a dependable rainfall distribution. No single month goes without rainfall in Uganda. The reduction of rainfall revealed by this study is in contradiction with what climate model simulations anticipate.

The study has also revealed that maximum temperatures of the region are more variable compared to minimum temperatures. The mean temperature trend in intra-annual variance is decreasing but not statistically significant. Analysis indicates that Uganda has experienced positive trends in minimum temperature series for the last 41 years, hence supporting the 94% respondents who observed that night temperatures are also warming. It can be concluded that the nights are warming faster compared to day temperature. This research is not able to explain the cause of such warming which could be a result of high humidity levels that can contract the daily temperature range. Tests revealed that annual temperature range and daily temperature range are experiencing statistically significant decreasing trends at a rate of 1% per annum. The findings reveal an observed mean trend towards warmer temperatures in Uganda. The increase in hot nights at most stations will impact on people who have to divert their financial capital towards the purchase of cooling facilities. Failure to buy a fan, may force household members to keep windows open at night to allow cool air into the house consequently exposing them to mosquito bites.

Increase in temperatures also leads to a decline in milk and meat production largely because animals remain in shades instead of foraging. Furthermore, most of the crops in Uganda have already reached their highest temperature tolerance levels, so any increase in temperatures will affect crop yields and affect food security. Additional evidence points to increase in pest incidence like the coffee berry borer due to rise in temperatures which might affect Uganda's important cash crop.

d) *Water resources potential in Uganda*

Almost 15% of the country is covered by fresh water. Much of Uganda's water resources are transboundary to the extent that Uganda is both a downstream and upstream riparian state. Domestically lakes and rivers are also transboundary across administrative boundaries which results in several challenges. These issues are further aggravated by climate change, climate variability and population growth among others. The current water management practices in Uganda are not as robust to cope with these impacts and increasing water requirements. If water demand increases and pessimistic predictions about climate change come true then adverse effects have to be faced.

Open water resources are mainly in the form of rivers, swamps and lakes which fall into eight drainage sub-basins. Wetlands are part of the resources potential in Uganda. They cover about 13% of the total area of the country. By 2008, wetlands found in the major drainage basins had declined considerably. The decline is largely attributed to encroachment for expansion of urban centres, settlement, industry and agriculture.

Ground water is the major source of water supply to 61% of consumers in the rural, semi arid and arid areas in the country. A study by DWRM however, has reported a decline in ground water resources in some parts of the country due to climate change, land use change, poor catchment management and reduced rainfall. In spite of this threat, government of Uganda through strategic investment plans intends to provide safe water supply coverage to 77% of rural populace and 100% to urban residents by 2015.

e) *Water resource potential and climate change*

One of the consequences of a changing climate is the alteration of rainfall patterns. The seasonality, amount, distribution and timing of rainfall are important to people who depend on rain fed agriculture for their subsistence. Most important is the fact that rainfall is the main input to the global hydrological cycle, thus any variation in climate can have profound effects on the variability of water resources especially those in Uganda which derive significant recharge from rainfall like Lake Victoria. Understanding the spatial and temporal variability of rainfall is important when estimating water availability. For example, when rains are late and early rains are poor, it creates a situation of food insecurity in the region resulting into hyper-inflation among other factors.

The study discovered down ward trends in the annual rainfall series, predominant in north western and south western basins of Uganda, while the rest of the sub-basins had upward trends. Decrease in inland precipitation will affect storage dams which,

supply water to the pastoralists in time of drought. Variation in rainfall can result in major economic losses, social and political conflicts.

Extreme events of rainfall like those of 1960's have been experienced recently especially in the eastern part of the country and in urban areas. Such events can result into storm water discharges from combined sewer and surface water flows e.g. in urban areas, erosion and weakening of dams.

The warming trend is exacerbating the constraints of life and livelihood activities, water resources for human consumption and watering of livestock as well as affecting crop water balance. Increasing temperatures have an impact on water demand and feed resources of livestock, though this study was not able to establish an empirical relationship.

There is also a significant correlation between lake rainfall series and lake levels. This has been demonstrated in results where landsat imagery has been used to detect changes in surface water area in relation to climate changes. Based on the SPI and DSI assessment indices there was a close relationship between the observed surface water area changes and the two indices. In conclusion, it becomes essential to improve assessments of the effects and to adapt water management to the already identified impacts and to the anticipated ones by using future scenarios.

Appendix

CLIMATE CHANGE/VARIABILITY AND ITS IMPLICATIONS FOR WATER RESOURCES AND LIVELIHOODS IN UGANDA.

This is a survey around the parish involving households, asking about climate change and the livelihoods that you formulate. The results will be used to write a thesis for a doctoral award, and also to sensitize people on above aspects that are key in creating livelihoods. The survey takes about 50 minutes. Your participation is anonymous and voluntary, and all your answers will be kept completely confidential. If there are any questions that you don't feel you can answer, please let me know and we move to the next one. So if I have your permission I will continue.

Target: **Adult House hold member**

Section A

1. Have you heard about climate changing? Provide a tick.

Yes		No	
-----	--	----	--

- i. How did you know about Climate change? (tick the appropriate box)

2.1 The Internet		2.2 Media		2.3 From scientists		2.4 Friend	
2.5 Movie/Documentary		2.6 Word of mouth		2.7 Government official.		2.8 Other(	

1. Please indicate on a scale of 1 to 4, of how much you personally agree or disagree with the following statements. Where 1 means strongly disagree, 2 disagree, 3 agree, 4 strongly agree.

3.1 The world's climate is changing.	1	2	3	4
3.2 The climate of Uganda is changing	1	2	3	4
3.3 The change in climate has nothing to do with the way i secure a livelihood.	1	2	3	4
3.4 Climate change is not going to affect livelihoods.	1	2	3	4
3.5 There are other factors other than climate change that are affecting livelihoods.	1	2	3	4
3.6 There are no climate change evidences in Uganda	1	2	3	4
3.7 Climate change will impact on the majority of livelihoods in Uganda.	1	2	3	4
3.8 Climate change is impacting on the economy of this country.	1	2	3	4

4. Indicate on a scale of 1 to 4, on how much you personally agree or disagree with the following statements. Where 1 means strongly disagree, 2 disagree, 3 agree, 4 strongly agree. (Evidence that climate has changed)

4.1The weather seasons in this country have changed	1	2	3	4
---	---	---	---	---

4.1 The weather seasons in this country have changed	1	2	3	4
4.2 Experience longer droughts than used to be	1	2	3	4
4.3 Experience more frequent floods	1	2	3	4
4.4 Experience high temperatures than before	1	2	3	4
4.5 Experience more days of rain in the year.	1	2	3	4
4.6 There are warmer days in the year than it used to be.	1	2	3	4
4.7 Morning temperatures are warmer than they used to be.	1	2	3	4
4.8 Morning temperatures are colder than they used to be.	1	2	3	4
4.9 Night temperatures are higher than they used to be.	1	2	3	4
4.10 Night temperatures are colder than they used to be	1	2	3	4
4.11 There is change in biodiversity.	1	2	3	4
4.12 Species behavior and life has changed.	1	2	3	4

5. What other climatic change(s) have you noticed recently (10-20 yrs)?

.....
.....
.....

6. Indicate on a scale of 1 to 4, on how much you personally agree or disagree with the following statements. Where 1 means strongly disagree, 2 disagree, 3 agree, 4 strongly agree. (Perceived Risk) .If in the future, climate continues to change?

6.1 Living standards will decrease.	1	2	3	4
6.2 There will be food shortage	1	2	3	4
6.3 There will be an increase in infectious disease.	1	2	3	4
6.4 Few problems will arise because people can adapt to change.	1	2	3	4
6.5 There will be better weather.	1	2	3	4
6.6 A hydro-political situation will emerge	1	2	3	4
6.7 There will be less hydro electricity generated.	1	2	3	4
6.8 Few people will be involved in activities that are controlled by climate.	1	2	3	4

j) Explain how you are coping or adapting to changes that are brought about by change in climate?

.....
.....
.....

7. Understanding House hold livelihoods.

h) State the number of people in the household.

i) What is the main activity that supports your livelihood in this house hold?

.....

j) What other activity do you do to supplement your livelihood?
.....

k) Who else contributes to your livelihood?
.....

l) Who else in this Household is involved in livelihood activities?

	Age	Livelihood activities	Role in the Activity	Duration of involvement in activity.(in yrs)
1.Mother				
2.Father				
3.Brother				
4.Son				
5.Daughter				
6.Sister				
7.Employee				

m) When do these activities take place (time of day/month/seasons) and where?

Activity	Location/distance	Time of day	Month/season

n) What are the different activities that house holds in this area/parish use to support their livelihood?
.....

8. What natural resources are available to the community?
Who uses them? How are they used in the formation of livelihood?

(Such as land, water, animals, forest, clay, Rock, swamps, ponds, grazing land)

Natural resources.	Men	Women	All	Form of livelihood

a) What are the main (3) challenges in forming livelihoods?
.....

b) How has the change in Climate impacted on the way you secure your livelihood?

.....

c) What is the role of government in managing the resource from which you form a livelihood?

.....

9. a) What is the highest level of education that you have attained? Tick the most appropriate.

- | | | |
|--------------------|---|---|
| 1. O-level | [|] |
| 2. A-level | [|] |
| 3. Diploma | [|] |
| 4. Undergraduate | [|] |
| 5. Graduate | [|] |
| 6. Primary leaving | [|] |

b) What type of skill/training/ experience do you have?

.....

c) Do you use this skill/experience to make a living/ to carve out a livelihood?

Yes []

How?

No []

Why?

10. a) Do household members have access to and use of the following infrastructure.....?

Infrastructure	Open access	Payment	Individual	pooled	Closed access	Other
a. Transport						
b. Marketing facilities						
c. Health facilities						
d. Water supply						
e. Electricity						
f. Waste disposal						
g. Storage facilities						
h. Telecommunication						
i. Housing facility						

b) In which way has the change in climate impacted on the infrastructure you use in livelihood formation?

.....

c) Study the list below and choose the tools/equipment you use in formulating a livelihood.

d) How do you access these tools? Tick in the space provided.

Tool(s)/ Equipment	Ownership	Hiring	Sharing	Loan	Free
1.Boats					
2.Fish Nets					
3.Fishing Hooks					
4.Hoes					
5.Panga					
6.Tractor					
7.Spray pump					
8.Bicycle					
9.Sewing					
11.Cooking utensils					
12.Furniture					
13.Oxen					

e) How has climate variability affected the way you access the tools you use to form a livelihood.

.....

11. Financial capital:

a) Please indicate the range that best describes your monthly household income: (take into consideration all income from different sources activities? Estimated to 1\$= u.shs1800)

0-1800	[]
1800-18000	[]
18000-90000	[]
90000-180000	[]
180000-900000	[]
900000-1800000	[]
1800000-over	[]

b) Remittances;

0-1800	[]
1800-18000	[]
18000-90000	[]
90000-180000	[]
180000-900000	[]
900000-1800000	[]

1800000-over []

- c) What other sources of finances are available to you in formulating the type of livelihood? Indicate by ticking in the box

(Rank)

Bank credit,	[]	[]
NGO support	[]	[]
Micro-finance	[]	[]
Rotating Credit& saving scheme	[]	[]
Bonna Baggaggawale ⁴	[]	[]
Insurance	[]	[]
Government funding	[]	[]
Money lenders	[]	[]

- d) How important are the above finance schemes in supporting livelihoods?

Rank accordingly using (1) Very important (2) important (3) less important (4) not important, in the spaces provided under (Rank) above.

- e) What influence has the change in climate had on the way you access finances that you use in forming the livelihood.

.....

- e) How much of the income per month do you spend on basic things like these mentioned in the table below? (Provide a tick in the appropriate space of the average range) 1\$=U.shs 1800.

Ug. Shs/ item	0-1800	1800-18000	18000-90000	90000-180000	180000-900000	900000-1800000	1800000-over
1.Clothing							
2.Education							
3.Transport							
4.Electricity							
5.Petrol							
6.Paraffin							
7.Feeding							
8.Medical							
9.Rent							
10.Loan service							
11.Security							

⁴ A common term for government funding programme to fight poverty(prosperity for all)

Ug. Shs/ item	0-1800	1800-18000	18000-90000	90000-180000	180000-900000	900000-1800000	1800000-over
12.Taxes							
13.Cooling facility							
14. Heating							
15. Water removal							

12. Social capital

a) What links does this household have with other households or individuals in the community? (*tick on one or more of these choices*)

1. Kinship (*related by blood*), []
2. Social group, []
3. Membership of organizations, []
4. Political contacts, []
5. Patronage (*support, encouragement, sponsorship*) given by another H/h []
6. Other (s) (.....)

b) In what situations do these links become important?

1. Mutual assistance []
2. Pooling labour []
3. Climatic Disaster management []
4. Raising capital []
5. Avoiding the Law []
6. When making decisions []
7. During traditional ceremonies []

13. Vulnerability context:

a) When do you experience serious changes in?

	Jan-Mar	Apr-Jun	Jul-Sept	Oct-Dec
Food supply				
Income				
Expenditure				
Weather				
Production				

b) What crises has the household faced in the past? Choose any three from the list.

Extreme temperatures	[]	Floods	[]
Crop failures,	[]	Civil unrest,	[]
Legal problems,	[]	Death ,	[]
Disease	[]	Earthquakes	[]
Pest invasion	[]	Epidemics	[]
Drought	[]	Theft	[]
Fire	[]	Destructive storm	[]
Conflict over natural resource	[]	Other	[]

c) How did you deal with the crisis?

.....

d) What longer-term changes (10- 20 yrs) have taken place in the household's natural, economic and social environment and how has it dealt with these changes?

<i>changes in the household</i>	<i>nature of change</i>	<i>dealing with change</i>
<i>economic changes</i>		
<i>social changes</i>		
<i>environmental changes</i>		

14. What brought about the change? Select only three from the list below.

- | | |
|----------------------------------|-----------------------------|
| 1. Changes in weather | 9. Disease |
| 2. Political affiliation | 10. Natural disaster |
| 3. Retrenchment | 11. Conflict |
| 4. Government policy/legislation | 12. Privatization |
| 5. Globalisation | 13. Changes in Technology |
| 6. Financial inability | 14. Price fluctuation |
| 7. Insolvency | 15. Global financial crisis |
| 8. Increased competition | 16. My own making |

15. Which of the above has had a big influence on your decision to form a livelihood strategy?

.....

16. Policies, institutions and processes:

a) As a member of this household, do you participate in any of the following; organization, society, cooperatives, political party?

	<i>Name of Association</i>	<i>Role of Household member</i>
Organization		
Society		
Cooperative (s)		
Political Party		
Pressure groups		

b) How do the above assist you in forming a livelihood?

.....

d) Have you ever attended any meeting at any one time where climate change was discussed?

Yes () When was that? Month () Year () No ()

e) What were the issues discussed in that meeting?

.....

f) Who else was in attendance during that meeting? (Choose from the list below)

Government official []

Local council officials []

Natural resource specialists []

Member(s) of the Civic Society. []

Users of the resources []

Investor(s)/Business community []

Donors []

g) Have you interacted with, the following on issues that relate to resource use?

	Issue of interaction	Impact
Scientists		
Government Officials		
Civil society		
Business community		
Resource Users		
Donors		

h) Can you tell of any incidence when you were involved in the taking of decision on the formation of livelihoods in this area

.....

CLIMATE CHANGE/VARIABILITY AND ITS IMPLICATIONS FOR WATER RESOURCES AND LIVELIHOODS IN UGANDA.

Target: **Key informants** [Coordinator of a NGO, CBO, FBO, Local council leaders (Lc1, Lc2, Lc3), institutional representative, water officer, community officers.....]

Introduction

I am From university of Pretoria, carrying out a survey research on the implications of climate change livelihoods that are water resource oriented. This study has been sponsored by.... And the results will be used to write a thesis for a Doctoral award. The interview will take approximately 30 minutes. Your participation is voluntary. If there are any questions that you don't feel you can answer, please let me know and we will move to the next one. So if I have your permission I will continue.

1.

Principal Natural Resource	Livelihoods Formation Activity

2. Livelihoods (the diverse ways in which people make a living and build their worlds)

b) What are the different activities that house holds in this area use to support their livelihood?
.....

c) Who else contributes to their livelihood?
.....

3. For the following questions please fill in the table below.

- d) What are the key livelihood activities in this area?
- e) How many house holds depend on these key livelihoods?
- f) Who is involved in these key livelihood activities?
- g) When do these activities take place?

Livelihoods	Number of Hh involved(est.)%	Age-category (young, adult, old, all)	Gender Men, women, all	Season/ time of day/ month

4. House hold information: (mini-census data/national census data 2002 and projections) (sub-county chief, statistics dept, district population officer)

b. What is the ratio of men to women in this parish community?
.....

c. What is the dominant ethnic group?
.....

d. What is the dependence status (ratio) in the study area?
.....

e. What is the average number of people in the household?
.....

f. What is the general education status of the community?
1. Primary leaving ()

2. Secondary ()
3. High school ()
4. Diploma holders ()
5. Vocational ()
7. Graduates ()

5. Human capital:

- a) What skills capacity, knowledge and experience do different household members have?

.....

- b) How have the members in the community used the skills in formulating different kinds of livelihood?

.....

6. Physical capital:

- a) What infrastructure do members in the community have access to?

Rank according to majority access. Use a scale of 1-4, (1) indicates high access, (2) accessible (3) low access (4) not accessible.

- | | |
|--------------------------|--------------------------|
| Transport () | Marketing facilities () |
| Health facilities () | Water supply () |
| Education facilities () | Electricity Grid () |
| Tel-Communication () | Waste disposal () |
| Storage facilities () | |

- b) What are terms of access to different types of infrastructure? Indicate by choosing the appropriate means of access. (1) Payment (2) Open access (3) Individual (4) Pooled

- | | |
|--------------------------|--------------------------|
| Transport () | Marketing facilities () |
| Health facilities () | Water supply () |
| Education facilities () | Electricity Grid () |
| Tel-Communication () | Waste disposal () |
| Storage facilities () | |

- c) What tools or equipment do household members use during different livelihood activities? Rank according to majority use, using (1) most used (2) used (3) Not used (4) sometimes used.

- | | |
|----------------------|--------------------|
| Boats [] | Nets [] |
| Hooks [] | Hoes [] |
| Panga [] | Tractor [] |
| Spray pumps [] | Bicycle [] |
| Furniture [] | Sewing machine [] |
| Cooking utensils [] | |

- d) What are the terms of accessing the tools or equipment? Indicate by choosing the appropriate means of access. (1) Ownership (2) Hiring (3) Sharing/borrowing (4) loan (5) free.

Boats	[]	Nets	[]
Hooks	[]	Hoes	[]
Panga	[]	Tractor	[]
Spray pump	[]	Bicycle	[]
Furniture	[]	Sewing machine	[]
Cooking utensils	[]		

7. Financial capital:

a) Please indicate the range that best describes the monthly earnings of the majority household from different Income-generating activities? (est.1USD: U.shs 1800)

i)	0-1650	[]
ii)	1650-16500	[]
iii)	16500-82500	[]
iv)	82500-165000	[]
v)	165000-825000	[]
vi)	825000-1650000	[]
vii)	1650000-over	[]

b) Remittances;

i)	0-1650	[]
ii)	1650-16500	[]
iii)	16500-82500	[]
iv)	82500-165000	[]
v)	165000-825000	[]
vi)	825000-1650000	[]
vii)	1650000-over	[]

c) How important are the following sources of finance to the house holds in this area? Rank using; (1) Very important (2) important (3) less important (4) not important

i)	Bank credit	[]
ii)	NGO support	[]
iii)	Microfinance	[]
iv)	Rotating credit & saving scheme	[]
v)	Women social groups (Nigiina)	[]
vi)	Bonna Baggaggawale(scheme)	[]
vii)	Insurance	[]

- viii) Government funding []
- ix) Money lenders []
- x) Other []

8. Social capital

a) How important are the following in linking up household with other households or individuals in the community? Rank according to the most influential (1), influential (2), less influential (3), non- influential (4)

- Kinship, () Family ()
- Social group, () Membership of organizations ()
- Political contacts, () Political affiliation ()
- Patronage () Religious groups ()
- Religion () Proximity ()
- Level of education () Faith-Based Organizations ()
- Non-Governmental Organizations ()
- Community Based organizations ()
- Social norms and values ()

b) In what situations do those links become important and how?

(1) Very important (2) important (3) less important (4) not important

- Mutual assistance. ()
- Pooling labour. ()
- Community work. ()
- Social functions. ()
- Mobilizing for funds. ()
- Harvest, planting, weeding. ()
- Starting up a business (livelihood). ()
- Traditional functions ()

Policies, institutions and processes:

9. What organizations, institutions and associations (societies, cooperatives, political parties, etc) do members of the community participate in?

<i>nstitution/organization/ association</i>	<i>Membership</i>	<i>legal status</i>	<i>Period of operation</i>	<i>Extent of coverage/operat ion</i>

10. How are decisions reached within these organizations, institutions and associations? [Tick the three (3) common ways]

	Organization	Institution	Association
Debate among Committees and trustees			
Consultation and thorough research			
By involving the stake holders			
Voting (winner takes it all) majority			
Government/ policy makers			
Consensus			

11. What are the centers of decision-making?

- i) Senior members of the community (elders). []
- ii) The local council committees []
- iii) General local council meetings []
- iv) Natural resources specialists []
- v) Government intervention []
- vi) Individuals []
- vii) Land owners []

12. Who makes decisions about the use of natural resources in this area?

- i) The District Natural Resources Officer []
- ii) People who are affected (stakeholders) []
- iii) National Environment Management Authority []
- iv) Minister and his team []
- v) The local leaders and the committee []
- vi) Pressure groups []
- vii) Lobbying []
- viii) Scientists []
- ix) Natural resources Policy committee []
- x) Land owners []

Structures and processes

13. What rules, regulations and customs that relate to natural resource access are in place?

.....

14. Who of the following have you interacted with on issues that relate to the management of Natural Resource? (Tick the appropriate box)

Scientists []

Government Officials []

Civil society []

Business community []

Donors []

Resource users []

15. How often have the stakeholders been involved in Natural resource management?

Very often () often () not often () not at all ()

16. On which issues have you involved stakeholders?

.....

g) How have people in this parish adapted to changes in climate, which have impacted on their livelihood?

.....

Vulnerability context:

17. What crises has the community faced in the past ten years (10-20)? Choose only three (3).

Extreme temperatures	[]	Drought	[]
Earthquakes	[]	Floods	[]
Pest invasion	[]	Epidemics	[]
Crop failures,	[]	Civil unrest,	[]
Legal problems,	[]	Indebtedness,	[]
Disease	[]	Theft	[]
Conflict over natural resources []			

18. How did the community deal with the crises?

.....

19. What longer-term changes have taken place in the community?

i) Natural.....

ii) Economic.....

iii) Social environment

20. How has the community dealt with these changes?

.....

21. What is the impact of these long term changes on the community livelihoods?

.....

Climate change awareness.

22. Have you heard about climate change?

Yes		No	
-----	--	----	--

If (yes) continue to the next question.

If (No) terminate the process (thank you for your time).

23. How did you know about Climate change?

23.1 The Internet		23.2 Media		23.3 scientists		23.4 Friend	
23.5 Movie/documentary		23.6 Word of mouth		23.7 Government official.		23.8 Other(	

24. Please indicate on a scale of 1 to 4, of how much you personally agree or disagree with the following statements. Where 1 means strongly disagree, 2 disagree, 3 agree, 4 strongly agree.

24.1 The world's climate is changing.	1	2	3	4
24.2 The climate of Uganda is changing	1	2	3	4
24.3 The change in climate has nothing to do with the way people secure a livelihood.	1	2	3	4
24.4 Climate change is not going to affect livelihoods	1	2	3	4
24.5 There are other factors other than climate change that are affecting livelihoods.	1	2	3	4
24.6 There are no climate change evidences in Uganda	1	2	3	4

25. Please indicate on a scale of 1 to 4, on how much you personally agree or disagree with the following statements. Where 1 means strongly disagree, 2 disagree, 3 agree, 4 strongly agree. (Perception)

25.1 There will be no serious consequences if the climate changes.	1	2	3	4
25.2 Climate change is responsible for the increased frequency in the Occurrence of natural disasters.	1	2	3	4
25.3 Climate change will impact on the majority of livelihoods in Uganda.	1	2	3	4
25.4 Climate change is impacting on the economic sector of this country.	1	2	3	4

26. Indicate on a scale of 1 to 4, on how much you personally agree or disagree with the following statements. Where 1 means strongly disagree, 2 disagree, 3 agree, 4 strongly agree. (Evidence that climate has changed)

26.1 The weather seasons in this country have changed	1	2	3	4
26.2 Experience longer droughts than used to be	1	2	3	4
26.3 Experience more frequent floods	1	2	3	4
26.4 Experience high temperatures than before	1	2	3	4
26.5 Experience more days of rain in the year.	1	2	3	4
26.6 Livelihoods have been greatly affected by climate change.	1	2	3	4
26.7 There are warmer days in the year than it used to be.	1	2	3	4
26.8 There is change in biodiversity.	1	2	3	4
26.9 Species behavior and life has changed	1	2	3	4

27. Indicate on a scale of 1 to 4, on how much you personally agree or disagree with the following statements. Where 1 means strongly disagree, 2 disagree, 3 agree, 4 strongly agree. (Perceived Risk) .If the next fifty (20-50) years, temperatures increase (1.30-1.60 degree Celsius),...

27.1 Living standards will decrease.	1	2	3	4
27.2 There will be food shortage	1	2	3	4
27.3 There will be an increase in infectious disease.	1	2	3	4
27.4 Few problems will arise because people can adapt to change.	1	2	3	4
27.5 There will be better weather.	1	2	3	4
27.6 A hydro-political situation will emerge	1	2	3	4
27.7 There will be less hydro electricity generated.	1	2	3	4
27.8 Few people will be involved in activities that are controlled by climate.	1	2	3	4
27.9 Industries that rely on key resources will close down	1	2	3	4

28. How have people in this parish adapted to changes in climate which have impacted on their livelihood?

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29. Do you take climate data and information into consideration when planning and making policies in the area?

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30. In this area, what evidence is there to show that the climate has changed?

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Signed by

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Date: