UNIVERSITY OF NAIROBI

ASSESSMENT OF SPATIAL AND TEMPORAL CHARACTERISTICS OF THE DECEMBER-FEBRUARY SEASONAL RAINS OVER UGANDA

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DECLARATION

This dissertation is my original work and has not been presented for examination in any other University.

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DEDICATION

I dedicate this thesis to my wife Eva Nakalende Waiswa and children Daudi Pienne, Agnes Mbeiza and Jerry Denye.

ABSTRACT

Uganda's social economic activities are closely influenced by the seasonal rains since the Country is heavily rainfall dependant. Therefore, the performance of the rains is key to the Country's success or failure of the economy. Uganda experiences two main rainfall seasons namely March-April-May (MAM) and October-December (OND). The Country also experiences two dry seasons that of June-July (JJ) and December-January-February (DJF). However the dry season of DJF is the longest and driest over most parts of the Country.

The main objective of this study was to assess the spatial and temporal characteristics of the unusually extreme DJF rainfall that sometimes occur in Uganda with far reaching socio-economic implications. The study used daily and monthly datasets of rains for the main period 1961-2013 and that of the sea surface temperatures (for Pacific and Indian Ocean), cyclones and winds for the South Western Indian Ocean (SWIO). The data was used to make various analyses which included percent of normal, distribution of wet spell lengths, correlation analysis.

The results from the study revealed a positive trend in the frequency of unusually wet DJF seasons, in the recent years which may be associated with a signal of Climate Change over Uganda. The occurrences of the unusually wet DJF seasons were widespread over the Country when the El Niño and positive IOD conditions prevailed at the same time. The lengths of the wet spells were mostly frequently of 1-2 days while for those more than two days reduced following an exponential distribution. The study further revealed that for Uganda, the unusually wet DJF seasons occurred regardless whether the Cyclones in the SWIO were present or not. The anomalous wind patterns at 700-850mb over Uganda, during the unusual wet spells comprised of westerlies blowing from the neighboring country Democratic Republic of Congo. The wind anomalies at 200mb over Uganda were mainly south easterlies. The directions of the anomalies at the various heights over Uganda were the same regardless of whether the Tropical Cyclones over the SWIO are present or not.

The results from this study are useful in planning and managing the risks and disasters associated with Climate Change in order to enhance community resilience against the unusual rainfall shortages or floods, for purposes of sustaining National Development of the Country.

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LIST OF ACRONYMS

DJF	December-January-February
DMI	Dipole Mode Index
DRC	Democratic Republic of Congo
EAR	East African Rains
EASR	East African Short Rains
ECMWF	European Center for Medium -Range Weather Forecast
ERA	European Reanalysis
ENSO	El Niño Southern Oscillation
GDP	Gross Domestic Product
GHA	Greater Horn of Africa
GHACOF	Greater Horn of Africa Climate Outlook Forum
GOU	Government of Uganda
GPCC	Global Precipitation Climatology Center
IPCC	Inter Governmental Panel on Climate Change
ICPAC	IGAD Climate Prediction and Application Center
IGAD	Intergovernmental Authority for Development
IOD	Indian Ocean Dipole
IOD-E	Indian Ocean Dipole East
IOD-W	Indian Ocean Dipole West
ITCZ	Inter tropical Convergence Zone
JAMSTEC	Japan Marine-Earth Science and Technology
JAS	July-August-September
JJA	June-July-August
LTM	Long Tern Mean
MAM	March-April-May
MJO	Madden Julian Oscillation
NAPA	National Adaptation Programs for Action
NOAA	National Oceanic Atmospheric Agency
OND	October-November-December
SO	Southern Oscillation
SON	September-October-November

SOND	September-October-November-December
SPI	Standard Precipitation Index
SST	Sea Surface Temperatures
TCs	Tropical Cyclones
SWIO	South Western Indian Ocean
UBOS	Uganda Bureau of Statistics
UNMA	Uganda National Meteorological Authority
WMO	World Meteorological Organization

CHAPTER ONE

1.0 Introduction

The study investigated the spatial and temporal characteristics of the December-February rains over Uganda. This Chapter presents the background to the study, statement of problem, objectives, justification hypothesis, area of study and the climate systems influencing the rains over Uganda.

1.1 Background

The Fifth Assessment Report by Inter-Governmental Panel on Climate Change (IPCC,2013) confirms that concentrations of greenhouse gases have increased and warming of the climate system is unequivocal with the atmosphere and ocean warming, snow and ice have diminished, sea level has risen, and the extreme weather events becoming more extreme in terms of magnitudes and frequencies. Over the region including Uganda, evidences of climate change have been presented by McSweeney *et al.,* 2012; Funk, *et al,* 2012; and King'uyu, *et al.,* 2000, among many other studies.

In Uganda, the impacts of Climate Change have been highlighted by Jassogne, *et al.,* 2013; Caffrey, *et al.,* 2013; and Ruettinger, *et al.,* 2011. Furthermore Hepworth, 2010; Mubiru *et al.,* 2012 Mubiru *et al.,* 2012 observed that through increased frequency of floods and droughts, the rainfall seasons are more erratic in terms of onset and cessation, causing crop failure and hunger in many households. The increased variability of the rains over Uganda have (Magunda *et al.,* 2010) increased the importance and demand for accurate and timely climate prediction and early warning services for protecting human life, infrastructure, ensure food security and household incomes.

In the Inter Governmental Authority for Develop (IGAD) region, the IGAD Climate Prediction an Applications Center (ICPAC) has spear headed the production and provision of climate predictions for the IGAD member countries. ICPAC has also invested on research to enhance knowledge on regional climate variability and change.

Although the agriculture sector in Uganda contributes 22% to the national Gross Domestic Product (GDP), it supports a livelihood to 66% of the population of the country (Uganda Bureau of Statistics, 2013). Therefore, any disruption in any of the rainfall seasons, to which the agriculture sector heavily depends on, affects the country's economy. As an example in 2010, when the country faced rainfall deficit, the damages and losses the economy incurred, was valued at an estimate of US $ 1.2 billion (Department of Disaster Management, 2012). Reports on 1997/98 El Niño rains caused damages and loses to the country at an equivalent value of US$ 20m (Kaggwa *et al.,* 2009). These experiences emphasize the need for timely and accurate climate prediction as well as early warning services for Uganda to avert any likely disasters that are climate related. It is important to have good understanding of the space-time characteristics of rainfall over Uganda.

Uganda has three main types of rainfall patterns (Philips and Beverly, 2000). These include March-May (MAM), September-November (SON). These seasons are clearly separated from the dry seasons of December-January (DJF) and June-August (JJA). These seasons are distinct over the regions of Southern, and near the equator regions. However, as you move far northwards the two wet seasons MAM and SON tend to merge forming one long wet season from April-September. Therefore, the country has both bimodal and unimodal rainfall patterns. Most of the past studies on East African rains Uganda inclusive, the studies like those by Nandozi, *et al.,* (2012); Bowden and Semazzi, (2007); Conway, *et al.,* (2007); Indeje, *et al*., (2000); Mutai and Ward, (2000); have concentrated on MAM and OND seasonal rains and rarely on DJF.

Historically, the December-January period is known to be the driest season in Uganda. However, observations indicate more rainfall is received in this season, during certain years. Such unseasonal rains often have far reaching impacts since they occur when least expected. This study examined the temporal and spatial variability of rainfall during DJF season.

1.2 Statement of the Problem

Recent IPCC Assessment indicate that climate change is real in the world (IPCC, 2013) including Uganda. The scarcity of community-based resources like water and pasture in the dry season often triggers a number of conflicts (Stark, 2011) and (Ruettinger *et al.* 2011). The increasing impacts of variability and climate change and the increasing population exacerbate these conflicts by exerting unbearable competition for the resources. The challenges above coupled with poverty, can lead to wide spread destruction of natural resource systems like cutting down forests to produce charcoal as alternative source of livelihoods, loss of livestock. These can lead to failures of climate change mitigation and adaptation strategies like expanding tree coverage for carbon sinks. Climate Change would therefore have far reaching implications on the socio-economic development of Uganda.

Most of the socio-economic activities in Uganda are rain dependent, and occurrences of droughts and floods have been associated with many socio-economic miseries including loss of life, property, animals, crops and house hold incomes. It is therefore critical that the space-time characteristics of natural resources like rains and winds over nations are understood (Oludhe C. , 2008). In Uganda most of the past studies have concentrated over the two main rainfall seasons of March-April-May (MAM) and October-November-December (OND). Very few studies have investigated rainfall characteristics for the dry season of December-January-February (DJF), yet observations show that some of the wettest rainfall events have been observed during this season in the recent years.

Therefore, this study investigated the spatial and temporal characteristics of the December-February rains over Uganda to increase knowledge on the key ocean atmospheric systems, linked to the anomalous rains in the period.

1.3 Objective of the Study

The general objective of this study was to assess the spatial and temporal characteristics of the unusually wet December-January-February (DJF) seasons that sometimes occur in Uganda with far reaching socio-economic implications. The specific objectives were to:

i. Examine the space-time characteristics of rainfall during December-February season over Uganda.
ii. Determine the distribution of wet spells of the unusual wet December-February seasons in Uganda.
iii. Investigate the systems that may be associated with extremely wet rainfall events that are sometimes observed during the dry season of December to February over Uganda.

1.4 Justification of the Study

Although the country normally experiences dry conditions in the period of December-February, there are cases when in this period it experiences extremely wet conditions like in the year 1997/98 and 2009/2010. Advance climate information to farmers (GOU, 2007; Oludhe, *et al.,* 2013) is a priority intervention in facilitating farmers to adapt to Climate Change. Therefore knowledge on expected extreme rain events during the DJF season is useful in helping farmers and other users to positively use the rains in DJF, to grow short term crops like vegetables and harvest water for irrigation. Proactive use of these waters can lead to, food security enhancement and reduction of society conflicts.

This study therefore, investigated the space –time patterns of the rains in December-February season, and the specific ocean-atmospheric systems that are driving such characteristics.

1.5 Hypothesis of the Study

The null hypothesis chosen as in this study included

i. There is no unusual wets spell during December-February season in Uganda.
ii. The statistical distribution of the unusual DJF season wet spells is not well defined.
iii. There were no significant relationship between the unusually DJF wet spells and the major regional climate systems including ENSO/IOD, Tropical Cyclones and Monsoon Winds.

1.6 Area of Study

Uganda is the area of study. It is located within the East Africa and lies within the coordinates 29E, 1.25S to 35.5E, 1.25S and 29E4.5N to 35.5E, 4.5N. South Sudan in the North, DRC Congo in the West, Kenya in the East, Tanzania and Rwanda in the South neighbor the Country. The equator passes through approximately in the middle of the country.

Figure 1: Physical features MAP for Uganda (World, 2014)

1.6.1 Geographical Features of the Study Region

A variety of physical features are found in Uganda. These features include the water bodies, the plateau, mountains, rift valley, forests, and semi-arid lands as shown in Figure 1. The Lakes found in Uganda include Albert, Edward, and George along the Western border, Lake Kyoga in the Centre of the Country and Lake Victoria which is shared by Tanzania and Kenya. Lake Victoria is the biggest lake and forms a wide basin with its own microclimate.

The mountains in Uganda include Elgon that is shared with Kenya, Ruwenzori that is shared with DRC Congo. These two mountains influence the mountainous climate in Uganda. In the North East of the Country there is Karamoja Region which experiences semi-arid conditions. Along the Western border is the western Rift Valley, which stretches southwards into Tanzania.

The complexity of these physical features modulates the type of rainfall patterns experienced from one part of the country to another. Karamoja region in the north eastern part of the country receives the lowest amount of rainfall as low as 300mm, while in the Lake Victoria rainfall as much as 2200mm has been recorded. The northern region experiences higher temperatures than the southern region, but hottest area is Butiaba. The mountainous regions experience the coldest temperatures.

Uganda has 14 climate zones across the country (Basalirwa, 1995). The rainfall patterns in Uganda vary from bimodal patterns in the south to unimodal in extreme northern region. Midway the country north of the equator there is a transition zone where the rainfall pattern changes from bimodal to unimodal patterns. Otherwise, a larger part of the country experiences bimodal rainfall having the following distinct climatic seasons of March-May (MAM), June-August (JJA), September-November (SON), and December-February (DJF) (East Africa Meteorological Department, 1963) as sited by Basalirwa (1995).

1.7 Climate Systems Influencing Rainfall over Uganda

Atmospheric phenomena that influence rainfall over regions occur over a wide range of space and time scales. There is a tendency for phenomena with smaller (larger) spatial scales to have shorter (longer) time scales. Uganda being part of the global climate system, its rainfall is heavily influenced by the global, regional and local systems. Basalirwa (1995) reported that the major systems controlling the rainfall of Uganda included the Inter-Tropical Convergence Zone (ITCZ), the subtropical anticyclones, monsoonal winds, and the moist westerlies from Zaire, locally termed 'Congo air mass', among several other regional and local factors. Other studies by Ogallo (1989), (Conway *et al*, 2007) have shown how ENSO and IOD influence the rains in the country.

1.7.1 Inter-Tropical Convergence Zone (ITCZ)

Inter-Tropical Convergence Zone (ITCZ) is a narrow band of low pressure in which air masses moving equator wards from the south and northern hemispheres converge. This zone is characterized by humidity and precipitation, maximum cloudiness, slow winds, and low pressure. The ITCZ over Uganda is somehow complex, as it comprise of both Zonal and meridional arms. The westerly and easterly winds from Indian Ocean and Atlantic Ocean converge to form the meridional (North-South) arm. The zonal (East-West) arm of the ITCZ moves North-south and brings rainfall in the areas it passes. The general passage of ITCZ over Uganda has been known as the main factor causing rains during the MAM and OND seasons. ITCZ is, therefore, the main synoptic system known to control the East African seasonal rainfall.

1.7.2 Monsoon Winds (MW)

Monsoon winds are one of the intra-seasonal examples of ocean atmospheric oscillations that affect rainfall in East African countries Uganda inclusive. These are low-latitude winds, which have an east-west direction flow traversing Oceans and lands. This flow of winds is facilitated by patterns of differential heating between a continent and adjacent ocean that change with the seasons. Additional features that influence the monsoon winds are the anticyclones (highs) namely Mascarene in the southeastern Indian Ocean, St Helena centered off South West Africa and the Azores located over Arabian Peninsula. As the winds flow over the oceans and lands in whatever direction they cause variable changes in temperature and precipitation patterns over the areas they pass.

Uganda experiences two clear events of monsoon winds. Basalirwa (1995) reported that in March-May season Uganda experiences southeasterly monsoon winds while in September-November season, it is mainly the northeasterly winds. The passage of these monsoon winds is closely associated with the movement of the ITCZ. As the ITCZ is moving, it influences the direction of the winds. The movement of the ITCZ, southwards Africa, leads to dominant northeasterly winds. On the other hand, its movement northwards leads to dominance of southeasterly winds over Uganda. In either direction, the winds are associated with precipitation dependant on the amount of moisture brought by advection from the Indian Ocean.

1.7.3 El Niño Southern Oscillation (ENSO)

Among the various ocean-atmospheric oscillations at an annual scale that affect Uganda rainfall are the El Niño and Southern Oscillation (ENSO), based in the Pacific Ocean. South Oscillation (SO) is associated with the seesaw pattern of the atmospheric pressure changes that occur in both the Eastern and Western parts of Pacific Ocean. An increase in pressure in the Eastern part is associated with a decrease in pressure in the western part of the Ocean and the vice versa forming an east-west pressure gradient. This pressure gradient modulates the strength of the trade winds over the equatorial Pacific waters. In a normal year, the atmospheric pressure is higher on the eastern side than on the western side of the Ocean resulting in enhanced trade winds on the equatorial Pacific. This maintains a surface current that moves from East to West.

1.7.4 Indian Ocean Dipole (IOD)

By definition, the Indian Ocean Dipole (IOD) is the difference in sea surface temperature between two areas of western part of Indian Ocean and the eastern Indian Ocean south of Indonesia. The IOD affects the climate of many countries that surround the Indian Ocean Basin, and is a significant contributor to rainfall variability in this region. The changes in temperature gradients across the Indian Ocean influence which regions experience most rising and descending of moisture and air in the atmosphere. In scientific terms, the IOD is a coupled ocean and atmosphere phenomenon, specific to the equatorial Indian Ocean. Several studies on the relationship between IOD and East African rains confirm a significant association especially with the SON rains.

1.7.5 Madden Julian Oscillation (MJO)

The tropical atmosphere-ocean system varies on many time scales, including diurnal, synoptic, intra-seasonal variability like Madden-Julian, seasonal and annual variability like El Niño. Among the intra-seasonal oscillations, the MJO is the dominant Wheeler and Hendon, (2004). The Madden-Julian Oscillation (MJO) oscillates at an average scale of 30-60 days. The MJO is characterized by an *eastward* propagation of rainfall over the 'warm pool' region from the Indian Ocean to the western Pacific Ocean. This propagation has consequences on the East African region, Uganda inclusive. A study by Berhane and Zaitchik (2014) confirmed significant impact of MJO influence on the wet and dry spells during the long and short rains over East Africa. Results of the study showed that the MJO are of different types and affecting East Africa rains differently in the short and long rains. Additional studies by Omeny *et al (*2008) diagnosed the relationship of MJO and rainfall over East Africa using correlation and composite analyses. The results from this study indicated significant association between MJO and East African rains especially the western part where Uganda lies. These findings make MJO a useful system to predict rains over Uganda.

1.7.6 Tropical cyclones (TC)

Tropical cyclones are warm-core low pressure systems that act as significant heat engines of the Earth by transporting energy from tropical regions to the Polar Regions. In the center of the cyclone is a calm area called an eye, surrounded with by an eye wall of very strong winds and storms. In the northern hemisphere cyclones rotate counter clockwise, while in the southern hemisphere it rotates clockwise. This direction of rotation dictates their side of impacts on landfall. The clockwise direction for the cyclones in the southern hemisphere, the impacts on land will be on the left side. While for the anti-clockwise cyclones, in the northern hemisphere the impact will be on the right hand. These cyclones occur at particular periods of the year. In the northern hemisphere, they usually occur in May-November while in the southern hemisphere they are common in November-May. In the Indian Ocean, the most active basin for cyclones is the Southwestern part in the southern hemisphere.

1.7.7 Mesoscale Systems (MS)

According to American Meteorological Glossary (2012), Mesoscale pertains to atmospheric phenomena having horizontal scales ranging from a few to several hundred kilometers, including thunderstorms, squall lines, fronts, precipitation bands in tropical and extra-tropical cyclones, and topographically generated weather systems such as mountain waves and sea and land breezes. The horizontal scales can range from 2-2000km and time scales of 1-30days (Lin, 2007). However based on time, spatial and atmospheric processes (Thunis and Bornstein, 1996) mesoscales have three sub classes which include δ-Mesoscale (200m-2km), γ-Mesoscale (2-20km) and β-Mesoscale (20-200km), Considering the above classification the Mesoscale systems in Uganda, that can influence the rainfall systems in some parts of Uganda, are associated with the Lake Victoria basin (sea and land breezes), Mountain Ruwenzori and Elgon (mountainous waves) and the forests (convective). Uganda has a number of forested areas across the Country. Mabira forest of 300 square kilometers is an example of the forests in the country. In Central Uganda, the Mabira catchment area usually receives rainfall throughout the year more than the neighboring areas. It is believed the Mesoscale system of the place is conducive to rainfall formation. The likely reason for these anomalous rains is that winds traveling through forests typically produce more than twice as much rain as those that blow over open land (Sheil and Murdiyarso, 2009). In relation to this argument, it is reported elsewhere that large-scale forest cover is associated with heavy rainfall while a large-scale loss of forest cover is associated with decreasing rains. (Webb *et al*, 2005) significant positive relationships between tree cover and the number of rain days consistently emerge. The explanation for this phenomenon by Butler (2012) links the ability of rainforests, using its dense vegetation cover, to influence the reflectivity of a surface making it absorb more heat than bare soil. The result of this ability is the warmness carrying more moisture from forest trees into to atmosphere, where it later condenses into rain. In addition to local forests, Uganda enjoys Congo air mass from the neighboring forests in the neighboring DRC Congo. The westerly winds from the Atlantic help in the advection of the moist air mass to Uganda. This air mass contributes rainfall during the periods June-August mainly in Northern Uganda.

CHAPTER TWO

2.0 Literature Review

This Chapter reviews past studies on the spatial and temporal characteristics of rains over Uganda and other relevant literature.

2.1 Rainfall Variability and Climate Change in Uganda

The changes in the rainfall patterns can be manifested in terms of time of onsets, cessations, length, seasonal characteristics, trends, patterns of floods and droughts. In Karamoja, a study by Mubiru (2010) on climate change options, assessed impacts of Climate Change in this region. The findings showed that the annual rainfall was decreasing. In addition, the average monthly rainfall in the month of June has been steadily increasing, while average monthly rainfall in the month of September and October was on a declining trend. The declining trends of September-October rains suggest that the seasonal length of Karamoja rains is shortening.

In another part of Uganda, a research study on trends and variability in localized precipitation (Stampone *et al.*, 2011) was conducted in areas around Kibale National Park, in Western Uganda. The research focused on the period 1941-1975. It investigated on the magnitude, direction and significance of trends of the annual and seasonal rains in the region. Results showed no direction and magnitude of a trend in the annual trends. However there was a significant negative trend in March-May and June-August rains in a number of stations while others had no significant trends. Positive trends in September-November rains occurred at a number of stations. The season December-February had no significant trends. The absence of annual trends may be explained as a result of the combination of the negative trend in May-June and positive trend of September-November. However the data used was of a short periods of 24 years and of long base period of 1941.

Nsubuga *et al.*, (2011) made a specific study on the trend of rains for Namulonge Station located in Central Uganda. The study used rainfall data from the years 1947 to 2009. The findings from the study revealed increasing trend in monthly rainfall amounts for the months of September, December and January especially in the recent years of 1978-2009. Among the seasons, the DJF season registered positive trend.

At a National level a study was conducted by Mubiru *et al.,* (2012) in characterizing agrometeorological climate risks and uncertainties in Uganda. The study aimed to generate intra annual and seasonal rainfall characteristics based on monthly and annual timescales and temperature trends using daily records from 1950 to 2008. The results revealed decreasing number of rain days and amounts in the March-May seasons. These results indirectly showed decreasing rainfall trend in March-May rains.

Another study (Funk *et al.,* 2012) on the climate trend analysis of Uganda focused on the periods of March-June and June September rains. It was observed that both the March-June and June-September rains have decreased in Uganda during the recent past 25 years. It further stated that Uganda was getting hotter and drier which was consistent with an increase in atmospheric circulation, bringing dry subsiding air during those periods.

An assessment was done in Uganda (Caffrey *et al.,* 2013) with a purpose to analyze the recent variability of climate in Uganda under the different agro ecological zones. The assessment focused on the districts of Gulu, Lira, Luweero, Mbale, Isingiro, and Kasese. The rainfall analyzed was for a 60year period for 1950-2010 and using seasons of December-February, March-May, June-August and September-November. In their findings the stations which had significant decreases in average annual rainfall were Gulu, Kitgum, Kotido, and Kasese. On Seasonal basis, a decrease in September-November rains was noted for northern regions and June-August for Kasese. In general the results showed no significant change in average annual rainfall detected in the 60-year historical period. However on the basis of onset of rainfall seasons this could shift by 15-30 days (earlier or later) while the length of the rain season can change by 20 to 40 days from year to year.

A study specifically in Eastern Uganda by Kansiime *et al.,* (2013) investigated the perceived and actual rainfall trends and variability in that region. It focused on the rainfall periods of March-June and August-November. The study hypothesized that there was no significant variation in the pattern of seasonal and inter-annual rainfall pattern in the three agro-ecologies of Region. The results revealed significant ($P \leq 0.05$) increasing trends in annual and seasonal rainfall for Mt Elgon region. The South Eastern Lake Kyoga had negative but not significant annual rains. On a seasonal basis, March-June rains showed a decreasing trend, while August-November rains showed an increasing trend for L. Victoria Crescent and Lake Kyoga. However Mt Elgon showed increasing trends for March-June and August-November rains. The study concluded that there were statistically significant increasing trends (P ≤0.05) in annual and seasonal rainfall for highland areas, and negative, but non-significant trends for low lying areas.

In another study by Nsubuga *et al.,* (2014) rainfall trend analysis was done for South Western Uganda for the period 1943-1977. Among other stations used in the study included Kabale, Masindi, and Mbarara. Results from the study revealed that that some stations like 6.8% of the 58 stations under experienced positive significant trends in DJF rain. However based on a regional rainfall index, there is a positive increase in the rainfall amounts for the DJF period.

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One of the systems that have been associated with climate extremes in Uganda are ENSO, IOD and tropical cyclones. Details of the past studies associated with these systems are reviewed in the following sections

2.2 Wet Spell length and their distributions

A number of researchers including Romeu (2003) and Li *et al*., (2013) have expressed the importance in knowing the most suitable probability distribution for the various rainfall characteristics of a locality. Knowing the probability distributions for the rainfall characteristic is critical in a number of applications (Deni *et al*, 2010) like in hydrology and agriculture. The different characteristics of rainfall that has attracted distribution fitting include length of wet spells, dry spells, rainfall amounts and rainfall depth. It is noted by Husak *et al*., (2006) that it is important to identify the most suitable distribution for the each rainfall characteristic to enable better prediction of the uncertainties association with each of them.

In a study by Li *et a.,l* (2013) various probability distributions of which included exponential, gamma, weibull, skewed normal, mixed exponential and hybrid exponential/generalized Pareto were compared on how they could perfectly simulate the precipitation for the Loess Plateau of China. The number of parameters for each distribution varied depending on their types but they ranged from 1 to 3 parameters.

The results from the above study showed that accurate simulations of the precipitation were best achieved through use of combined distributions as no one single distribution could simulate the accurate observed characteristics of the precipitation. It was further discovered that distributions that had three parameters were superior over those with one parameter. In the end the hybrid exponential/generalized Pareto distribution was found best in simulating frequency distributions. Never the less the skewed normal distribution performed best in simulating extreme events of precipitation.

The preceding findings were in line with a study by Deni *et al.,* (2010) conducted in Malaysia in which they wanted to identity the most suitable probability models that could describe the distribution of dry and wet spells over Peninsular Malaysia. The study compared 13 types of probability models which varied in their number of parameters.

Findings from the results suggested that the Modified Log Series (MLD) as well as the Compound Geometric Distributions (CGD) were best in describing the dry and wet spells respectively when the monsoon seasons prevailed. On the other hand the combination of the Mixed Log Series with that of the Truncated Poisson Distribution (MLTPD) was found superior at representing both the observed annual dry and wet spells distribution in most parts of the Peninsula.

A study by Sharma and Singh (2010) in India was conducted to identify best distribution for maximum rainfall events at different time scales of day, week, month, season and annual. The findings in their study showed that the lognormal and gamma distribution were best fit for annual and seasonal (4 months) rains respectively while the generalized extreme value distribution was best for weekly rains. In contrast the best fit for each month changed from month to month. The findings suggest that we cannot generalize a single distribution for monthly values of precipitation values.

In Malaysia a study by Dan'azumi *et al.,* (2010) compared the performance of three probability distributions (Generalized Pareto, Exponential and Gamma distributions), to fit the distribution of hourly rainfall depth. Their findings indicated that although all the three models could represent the rainfall data however the Generalized Pareto distribution fitted best compared to the exponential and gamma.

In Africa, Oseni and Ayoola (2012) conducted a study in Nigeria to compare the fitting of four distributions (exponential, gamma, normal and Poisson) with the daily rainfall amounts in Nigeria. The results from their study showed that the exponential distribution fitted best and next to its performance were the Normal and Poisson models.

Another study in Africa, by Husak *et al*., (2006) proposed that the gamma distribution represent monthly rainfall very well because it is popular to African Scientists and it can be presented with different shapes. Findings from a study by Amburn and Frederick (2007) concurred with the above findings and justified the use of gamma distribution because it can have different shapes. Although the preceding researchers suggest the use of the gamma distribution, as the best model to describe African rains, however the gamma type is known to have only two parameters and is not a mixture yet according to the studies of Li *et al.*, 2013 and Dani *et al.*, 2010 they seconded a distribution that has three parameters and is a complex since they performed best to those of only 1-2 parameters and is single.

Within the equatorial sub region in East Africa various studies have also been conducted to identify the most suitable probability distributions for the rainfall characteristics in the sub regions. Earlier study by Ogallo and Chillambo (1982) which studied the characteristics of wet spells in Tanzania revealed how the frequencies of the wet spells followed an exponential distribution. Related to the rainfall characteristics in Tanzania a later study by Tilya (2007) revealed that daily rainfall amounts exhibited a Gamma distribution.

In Kenya a study by Mungai (1984) and that of Gitau *et al.,* (2008) on the frequencies of occurrence of different length of wet spells exhibited an exponential distribution, whereby a wet spell of one day length were the most frequent to occur and this was followed by decreased chances of occurrence for longer length of wet spells. The exponential distribution of the wet spells in Kenya was further confirmed in a later study by (Koech, 2014).

Related studies on characteristics of wet spells were conducted in Uganda by Komutunga (2005) for the seasons March-May and September. The findings from the study revealed that just like those in Kenya, the wet spell of one-day are the most frequent to occur. There after the wet spells longer than one-day occurred at decreasing rate that is exponentially negative.

The results above were confirmed with later results from a study conducted by Bamanya (2007).

Although the preceding studies were conducted in Uganda, the period of study concentrated on the two main wet seasons of March-May and October-December. Considering that December-February season is experiencing increasing events of unusually wet spells it is important to determine how the length of the wet spells in DJF could be characterized.

2.3 El Niño South Oscillation (ENSO) and East African rains

Ever since the discovery of El Niño South Oscillation (ENSO) phenomenon scientists have endeavored to understand its relation with the Rains in East African Rains (EAR). Among the earliest studies, include one by Ogallo (1988) who investigated the teleconnections between South Oscillation and seasonal rainfall in East Africa using correlation methods. The study used SO index data and rainfall for the period 1923-1984. The results from this study indicated that significant negative correlations between SO and EAR for the period October-December at zero lag period. The strongest correlation between the two was along the coast. However, the correlation changed to negative between the two for period July-September over some western parts of the region. Unfortunately, the relation between the SO and the rains were found low for the period January-May and annul records. When it came to lag period of 2-3 months the relation was consistent with negative values for the October-November period. The results showed that not all extreme wet/dry events were associated with SO. These results suggest that SO is a useful tool for predicting the SOND rains. On the other hand, there must be other large-scale systems that are associated with January-May rains, apart from the SO.

Another study by Ogallo (1989) was conducted on the East African rains with a purpose to understand the dominant spatial and temporal modes of the season rains. The focal period of the study was 1922-1983. Results from this study showed seasonal shifts in the rains, influenced by the Inter Tropical Convergence Zone (ITCZ). The large water bodies inland like Lake Victoria and the Indian Ocean were also influencing the rains. The analysis delineated into 26 homogenous spatial zones. However, the rains were found significantly associated with the El-Niño/Southern Oscillation events.

In a later study, Beltrando and Camberlin (1993) investigated the relation between the East African rains and the temperatures of the Indian and Pacific Oceans. Findings revealed a significant negative correlation between the northern autumn rains for Somalia with the Southern Oscillation. The rains in Somalia and Kenya were found positively correlated with temperatures of the Indian Ocean. However, the summer rains over Ethiopia were found to be with positive correlations with the Southern Oscillation. The implication is that although rains in Greater Horn of Africa had significant relationship with the ENSO and IOD this varied in strength and direction from one sub region to another and from one season to another.

A study by Indeje *et al*., (2000) conducted with the objective was to identify how sub-regional rainfall in East Africa associates with ENSO. The results were consistent with those of Ogallo (1989) and Beltrando and Camberlin (1993) that the East African rains have a significant relationship with ENSO phenomena. During El Niño years, the rains were relatively wetter for the periods March-May and October-December. The results further confirmed that during ENSO years some regions experienced excess rains. Therefore, results confirmed that in East Africa, ENSO played a significant role in influencing the monthly and seasonal rains. During ENSO years, there were shift in terms of onset, cessation and amount in the rainfall. Surprisingly post ENSO years had also effects of reducing rainfall months for June-September periods.

Mutai and Ward (2000) conducted a study in East Africa with a purpose to improve prediction of East African rains. In this study, results revealed that seasonal rainfall prediction for October-December, using a variety of predictors like sea surface temperatures of Pacific, Indian and Atlantic Ocean (ENSO) was far better than using only ENSO. In addition, the large-scale SST predictors correlate well with average rainfall over smaller sub regions.

Variability of the East African Climate was assessed by Schreck III and Semazzi (2004). The study investigated the relationship between regional eastern African rainfall variability and global warming. The focal season was the short rains of October-December and included the years of 1961-2001 compared to previous studies of Indeje *et al.,* (2000) which had fewer years. The results confirmed the relationship of ENSO with OND rains. The positive ENSO was associated with above normal rainfall amounts for the OND rains. Additional results revealed that decadal variability (Trend mode) has a potential connection to the OND rains.

The trend mode was associated with positive rainfall anomalies over north of the eastern Africa and negative conditions over the southern sector.

A study to analyze the intra-seasonal variability of ENSO–IOD during the OND season in the Greater horn of Africa was conducted by Bowden and Semazzi (2007). In the results, the OND had two dominant modes of intra-seasonal variability. These included a mixed El Niño - Southern Oscillation - Indian Ocean dipole and the decadal mode. The ENSO-IOD was the main one where a positive event was associated with above normal rains. However, this was not the exact opposite when the ENSO-IOD was negative. The variability of the second mode was related with a decadal shift in the rains, having the northern (southern) GHA being wetter (drier) in the recent decades.

A research on Forecasting droughts in East Africa (Mwangi *et al.*, 2013) evaluated the use of European Centre for Medium-Range Weather Forecasts (ECMWF) products to make drought predictions in the year. The results confirmed earlier findings that October-December rains had higher skills than the March-May rains.

A new study on East African rains (Nicholson, 2014) focused on distinguishing areas based on rainfall regimes and considered the three (MAM, JAS, OND) rainy seasons in both regions. Unlike the former studies, which emphasized SSTs of oceans, this study emphasized atmospheric dynamics. The results showed that that OND season could be predicted in 5 months ahead in both regions and JAS rains in 2 months' time when using atmospheric dynamics. This suggested that atmospheric variables could provide a better forecast skill than surface variables like ENSO and IOD. It also confirmed that MAM predictability had barrier limits in enabling long lead prediction.

Considering the review above on ENSO and East African rains, it is clear the scientific community have skewed their efforts on using the ENSO as the main predictor for SOND rains. Climate Change projections indicate, the dry season of December-February is expected to get wetter than present. It is important to increase attention other seasons like December-February. This implies DJF may have more rains that facilitate crop production. Having this in mind it is high time we understand the relation of ENSO with December-February as a potential future rainfall season.

2.4 Indian Ocean Dipole (IOD)

In 1999, Nature Journal issued a report by (Saji *et al.,* 1999) for having discovered a Dipole in the Indian Ocean. The researchers discovered the dipole after analyzing surface data of the Indian Ocean for the period 1958-1998. The dipole had a characteristic of a systematic change of low (high) sea surface temperatures between the east of the Indian Ocean and high (low) seas surface temperatures in the western part. The IOD focal areas in the study are Western Indian Ocean is (10S–10N, 30E–70E) and that in the Eastern Indian Ocean is (10S–0S, 90E–110E). They observed that winds and precipitation anomalies accompanied these temperature changes. The Dipole had a unique air-sea interaction process inherent in the Indian Ocean and independent from the El Niño Southern Oscillation. The report further revealed that in the active years, of the dipole, Eastern Africa experienced severe rainfall and Indonesia experienced droughts. In conclusion, the researchers had discovered the Indian Ocean Dipole (IOD), which was an independent predictor for East African rains.

Additional researchers conducted studies to investigate the Indian Ocean Dipole phenomenon. Iizuka and Matsuura (2000) conducted a study to simulate IOD using 50 years data. Results from the simulation confirmed the independence of IOD from ENSO. The east-west dipole mode of the sea surface temperatures was confirmed. The results further confirmed that tropical air-sea interaction, which was strongly influenced by ocean dynamics was crucial in generating the dipole mode events.

The discovery of the Indian Ocean Dipole (IOD) attracted further interest to improve prediction of East African rains. In addition, Scientists got interested in understanding the individual contribution of both El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole as predictors to the East African rains. A study by Behera, *et al.,* (2003) investigated the independence of IOD from ENSO influence on East African rains. In their results, they found that correlation values of IOD alone with African rains were higher than with ENSO predictors. With a focus on the September-November (SON) rains, IOD had correlation of 0.65 while ENSO had 0.28. These results confirmed earlier results of Saji *et al,* (1999) that IOD was independent from ENSO and had a better skill in rainfall prediction.

A review paper on the Indian Ocean Dipole by Marchant *et al,* (2006) focused on its relationship with the Climatic Variability in East Africa. The review highlights these suggestions. The Indian Ocean was an independent circulation system called Indian Ocean Dipole, which partly could influence climate variability of the neighboring masses. IOD was a separate and distinct phenomenon from the ENSO. It experienced a positive and negative phases. During a positive IOD, the Indian Ocean experienced lower sea surface temperatures in its southeastern part while in the western part the sea surface temperatures rose. The term IOD referred to a zonal dipole structure of the various ocean-atmosphere parameters such as SST, surface pressure, outgoing long wave radiation and sea surface height anomalies. Considering that the East African rainfall originates from the Indian Ocean, then the IOD must be an important predictor for the rains.

A keen interest arose by researchers to project the influence of IOD on East African rains from the present to the future using Global Climate Models. Therefore, Conway *et al,* (2007) made a study to assess the ability of six state-of-the-art ocean-atmosphere coupled GCMs to simulate the spatial and temporal characteristics of East African rainfall and its characteristics with the IOD. The focal period was 1961-1990 and the seasonal rains were for SON. Findings showed that five of the models (CCCma CGCM3.1, CSIRO MK3.0, ECHAM5, HadCM3, HadGEM1) reproduced similar correlations to those observed between DMI and east African rains. However, there were no clear inter-model patterns of SON rains or DMI behavior. The simulation from the models showed no significant increases in annual rainfall. However specific to SON rains, three of the models showed an increasing trend of a positive phase of the DMI, two showed a decrease and one no change. In conclusion, the models did not give a uniform output.

Ummenhofer *et al.,* (2009) studied the contribution of Indian Ocean Sea Surface Temperatures to the enhanced east African rains. The goal of the study was to explore the contributions of local and large scale SSTs to above normal short rains of East Africa via Indian Ocean atmospheric circulations. The results revealed that enhanced ON rains were mainly driven by the local warm SST anomalies in the western part of Indian Ocean. The SST anomalies induced the atmospheric circulation to reorganize. There was a reduction in the Sea Level Pressure over western Indian Ocean and this led to more moisture convergence and increased convective activity over East Africa. This moisture convergence is facilitated by the anomalous winds. In conclusion, the higher (lower) the SST over the Equatorial Western Indian Ocean the higher (lower) moisture convergence leading to anomalous above (below) ON rains.

There are many cases when evolution of ENSO coincides with IOD. Usually under such circumstances, it is hard to pinpoint the contributions of each predictor to the East African rains. Hong *et al.,* (2008) conducted a study to examine the relation between various IODS and the precipitation over Asia, with the following four purposes (1) to examine the relation between various IODs and the precipitation over Asia, (2) to describe the characteristics of time evolution and structure of the four types of IODs to describe the characteristics of time evolution and structure of the types of IODs, (3) to examine the impact of ENSO on the IOD, and (4) to interpret the physical mechanisms of the evolution of each IOD event. The focus period was from 1948-2002. The results of this study revealed that the IOD with and without ENSO had large difference in its temporal evolutions and their triggering mechanisms. In both negative and positive IOD events without ENSO, the SST anomaly in the western Indian ocean appeared to be an oceanic dynamical response to the anomalies in the eastern Indian ocean. However, during the ENSO years, the temporal and spatial contrast of the asymmetry of the IOD evolution was smaller. The anomalies of the incoming radiation due to changes in cloudiness caused by the ENSO drove the SST anomalies.

The search for more understanding of the linkages between IOD and East African rains further attracted a number of researchers. Owiti *et al.,* (2008) conducted a study using statistical approaches to understand how the IOD related with East African rains. Composite analyses, correlation and regression were the statistical methods used in the study. The results from the study confirmed that IOD could evolve independently as well as co-occur with ENSO. Significant correlation results were strongest between IOD and OND rainfall than with ENSO. Unfortunately they were not significant with MAM rains. Significant positive correlations were wide spread during OND rains. However, the highest correlations were located on the eastern side of East Africa. The linkages seemed stronger when positive IOD co-occurred with positive ENSO. Whereas above normal rains were associated with positive IOD, it was not necessarily the opposite with negative IOD.

There are various prediction systems used to forecast seasonal rains. In the study by Bahanga *et al.,* (2013) the performance of different dynamical seasonal forecast systems were assessed for the prediction of East African rainfall anomalies. The focus period was 1982-2005 and 10 forecasts systems were assessed. The purpose of this study was to identify the best seasonal forecast systems for rains over east Africa. The results from this study indicated that nine of the models could predict the SSTs of the IOD with skills greater than 0.5 and highly significant above 99.9% level. Five coupled models (NCEP, SUT1, UHT, POAMA and CANCM3) out of ten could show statistically significant skill in predicting equatorial East Africa short rains.

A study conducted by Du *et al.*, (2013) investigated the behavior of the IOD for the past 60 years. Based on the criteria of peak season, duration of IODs, the study discovered a new type of IOD called “unseasoned”. The Unseasoned IOD always developed in May-June and matured in July-August. Therefore, its duration is about four months. This unseasoned IOD, started existing after 1970s and without an El Niño event. The change in winds along the equator was believed to be its major forcing. The other types of IOD are the normal and prolonged. Normal IOD mostly develops and matures within September-November. Prolonged IOD develops in June-August and mature in September-November. The last two IODs are referred to as canonical ones.

There is an increasing interest to understand how East African Short Rains (EASR) intensified since the 1900’s. Manatsa and Behera, (2013) investigated the epochal changes related to the IOD itself that led to observed extremes observed in the OND rainfall patterns. The focal period of investigation was 1901-2009 using rainfall data from the Global Precipitation Climatology Center (GPCC) database.

The results revealed shift of rains, which occurred in 1961 and 1997. There was no significant relation between IOD and EASR before 1961. However 1n 1961 an abrupt coupling between IOD and EASR started and sustained until 1997. There after another stronger shift after 1997 occurred and sustained. Before 1961, the IOD could only explain about 50% of the EASR variability. However, after 1961, the IOD could explain 73% of the EASR variability, which increased to 82% after 1997. Further results revealed that each shift was accompanied by both sharp increase in the frequency of rainfall extremes and spatial coherence. These findings have implication on deciding the time series range to use in statistical analysis.

The Indian Ocean Dipole is a recent discovery in 1999 though it has been around. The IOD acquires its name from the systematic changes in the sea surface temperatures between the east and west axis. In addition the IOD is an independent entity though in some cases its occurrence coincides with ENSO. There three types of IODs (Unseasoned, Normal and

Prolonged Normal). Significant relation between IOD and East African rains started in 1961. Since then there are increasing intensities of IOD. Although there exists events of positive and negative IODs, more emphasis is on positive IOD because strong significant relation it has with the East African rains.

The findings from the above reviews suggest IOD is a superior predictor for East African Rains (EAR) compared to ENSO. It has stronger significant correlations with the EAR than ENSO. However, its strength is with the rains of September-November and October-December periods over East Africa. This has attracted the majority of researchers to concentrate on the period September-December. In the end the periods like December-February are left out. Some of the impacts of climate change include shifting and changing of rainfall seasons. In that aspect of thinking, the SOND rains are reported decreasing in amounts while DJF rains are reported increasing. This suggests that at a later time DJF season will be wetter than present and will require prediction ahead of time for people to benefit from its waters.

2.5 Tropical Cyclones in the SWIO

The South Western Indian Ocean (SWIO) is a host to ocean related atmospheric systems which include changes in sea surface temperatures (SSTs), Tropical Cyclones (low pressure zones), anti cyclone (Mascarene High) which a high pressure zone and the associated winds among others. Whereas the Mascarene High (MH) is taken as a single system, the Tropical Cyclones (TCs) are individual systems which form and die off over the year in the SWIO.

The formation of TCs in the SWIO over the year is mainly concentrated in the period December-March and in the region 5-20S, 35-90E. The presence of the TCs and MH exert considerable influence on the East African Rains (EARs) of the same period December-March. In a study by Shanko and Camberlin (1998) findings revealed that presence (absence) of cyclones in the SWIO were associated with rainfall deficts (excess) in Ethiopia. These finds are in line with a later study by Mapande and Reason (2005) whose results showed that rainfall anomalies wet(dry) over western Tanzania arose from anticyclonic(cyclonic) anomalies over the SWIO during the October-April period.

The attributes of the TCs appear to play a role in how they influence the EARs. These attributes highlighted by Ii, *et al.,* (2002) include their tracks, strength, speed, size and geographical positions. In their study results showed that while the rainfall amounts over large scales are related with the size of the TCs, rainfall amounts over smaller scales are highly linked TCs movement speed. In a related study by Chang-Seng and Jury (2010) findings suggest that while westward tracks of TCs maintains their intensity compared to the southward tracks, however when TCs move southwards, equatorial rainfall re-establish itself. Their findings further revealed that TCs moving westwards were not associated with monsoon inflow as compared to those which underwent a re-curve. These findings confirm earlier findings by Shanko and Camberlin (1998) that the presence of cyclonic activity near the equator may limit rainfall activity in the equatorial zone.

The formation of TCs is not individually but collectively influenced by various atmospheric systems like the ENSO, IOD, MJO (Iizuka and Matsuura, 2012; Bessafi and Mathew, 2006; Manhique *et al.,* 2011). In the times of El Niño years, there is more than normal TCs genesis in the western basin from 75-85E and less than normal in the eastern part 75-85E (Chang-Hoi, *et al.,* 2006; Kuleshov, 2012) resulting into westward location of convection zones. However in terms of TC passages during EL Niño the TCs move far eastwards than during La Niña events. The combination of ENSO and IOD are linked to different movements of the TCs over the SWIO. Ash and Matya (2012) showed that during a combination of El Niño and negative IOD phases the tracks of the TCs tended to follow southward or southeastward directions. In addition, when the normal or La Niña events are in combination with negative IOD events, the tracks of the cyclones are moslty westwards.

An assesment of geographical locations of TCs formation by Matyas (2015) revealed that TCs formed mostly in northern(southern) portion of the Mozambique channel of SWIO when the SIOD was negative(postive). These results suggest that if the IOD is strongly negative (postive), the TCs may form near(away) the Equator.

In a study by Okoola (1989) the origin and characteristics of the westward moving disturbances in the Western Indian Ocean were examined. The findings of the study revealed that a change in the pressure levels of the Mascarene High creates a pressure gradient that takes a meridional gradient between the equator and latitude 25S. These changes stimulate a zonal wind gradient as a result of the changes in pressure near the Mascarene. These changes eventually lead to easterly winds which affect the East African Coast regions.

Further study on the influence of Mascarene by Xue *et a.,l* (2003) revealed that when the Mascarene High intensifies the nearby wind systems like the Somali jet gets enhanced. The study therefore suggested that Mascarene changes are closely tied with the general atmospheric circulation to both the south and northern hemispheres as evidenced by the resulting rains.

The influence of the Mascarene High (MH) on the East African Short rains was investigated by Manatsa *et al.,* (2014) using observation and reanalyzed data. Results in this study revealed that the East African rains are strongly linked to the zonal movement of the Mascarene High zone. With the displacement of the MH eastern ridge to the west(east) from its normal position, the South Easterly trade winds over the SIWO strengthen(weaken) anomalously. These changes are associated with a suppressed (enhanced) convective activity over the western equatorial SWIO which leads to deficits (excess) of rainfall over East Africa. Below normal rains are linked to eastward movements of the MH. These findings suggest that the geographical positioning of the anticyclone zones in the South Western Indian Ocean determines the rainfall amounts experienced over East Africa.

CHAPTER THREE

3.0 Data and Methodology

This Chapter describes the data set and methodologies, which the study used to achieve the objectives outlined in section 1.3

3.1 Data

The study used a dataset that included daily rainfall for Uganda, Tropical Cyclones in the SWIO, Sea Surface Temperatures in the Indian and Pacific Ocean as well as wind data. The descriptions of the datasets are as follows.

3.1.1 Rainfall Data

The study used historical daily rainfall data for the 13 rainfall stations over Uganda. The monthly rainfall data span 30 years, stretching from 1961 to 2013.

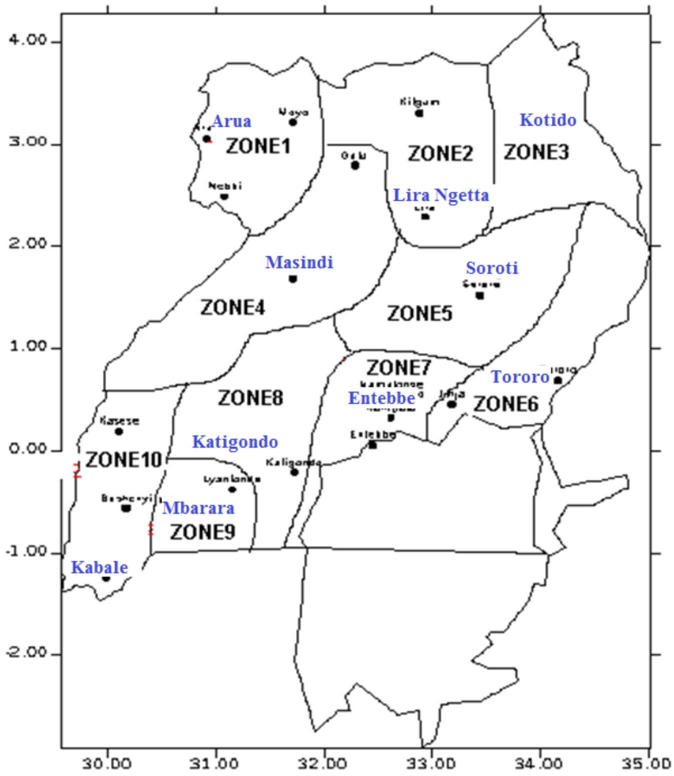


Figure 2 : Map of Uganda showing the locations of the Weather Stations and homogenous rainfall zones in Uganda

Figure 2 above shows the distribution of the weather stations across the country while Table 1 below shows the names and particulars of the coordinates of the weather stations, used in the study. The 13 stations are the main ones in Uganda with long historical data. The study acquired the data from the Uganda National Meteorological Authority (UNMA) and ICPAC.

Table 1 : Table of Weather stations used in the study

SNo	Stations	Latitude (°) N/S	Longitude (°) E	Elevation (m)	Period (years)
1	Arua	3.05	30.92	1280	1961-2013
2	Gulu	2.78	32.28	1105	1961-2013
3	Kitgum	3.30	32.88	940	1961-2013
4	Lira	2.28	32.93	1300	1961-2013
5	Soroti	1.72	33.62	1132	1961-2013
6	Tororo	0.68	34.17	1170	1961-2013
7	Jinja	0.45	33.18	1175	1961-2013
8	Entebbe	0.05	32.62	1130	1961-2013
9	Namulonge	0.53	32.62	1130	1961-2013
10	Masindi	1.68	31.72	1147	1961-2013
11	Kabale	-1.25	29.98	1869	1961-2013
12	Mbarara	-0.60	30.68	1420	1961-2013
13	Kasese	0.18	30.10	691	1961-2013

3.1.2 Sea Surface Temperatures (SSTs)

The study used high-resolution data for surface temperature (SST) for the period of study. The data was downloaded from the National Oceanic and Atmospheric Administration (NOAA) website. The spatial resolution of the data is 0.25° x 0.25°. This ENSO data is for the Pacific Ocean region located at 5N-5S, 170-120W popularly known as Niño3.4 and a number of researchers including Philippon *et a.,l* (2014) and Omondi *et al.,* (2013) among others have used for studying East African rains. NOAA maintains a website (http://www.cpc.ncep.noaa.gov) where monthly data on ENSO and IOD is updated. The specific areas for the Niño3.4 and IOD are shown in Table 2 below

Table 2: Showing definition areas for Niño3.4, IOD W, IOD E, and SWIO

	Definition Areas	Geographical Coordinates
1	Niño3.4	5N-5S, 150-120W
2	Indian Ocean Dipole West	10N-10S, 50-70E
3	Indian Ocean Dipole East	0-10N, 90-110E
3	South Western Indian Ocean	5N-45S, 30E-90E

Adapted from (Yosuke, et al., 2012)

3.1.3 El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) Data

ENSO data was downloaded from the NOAA (Climate prediction Center) website (http://www.cpc.ncep.noaa.gov). The ENSO data was grouped into El Niño, Neutral and La Niña years for the period of study. Any SST value with more than normal temperature by 0.5°C is taken as El Niño and if it is below normal by -0.5°C is taken as La Niña phase. The values in between are considered neutral conditions.

The source for the monthly IOD data was from ICPAC and Japan Agency for Marine-Earth Science and Technology (JAMSTEC) website (http://www.jamstec.go.jp. The IOD data was categorized into positive, neutral and negative phases. Significant positive phase has value of ≥ +0.5 while significant positive IOD has values of ≤-0.5 where negative. Meanwhile the values in between those positive and negative are taken as neutral.

3.1.4 Wind Data

This study used wind data from ECMWF Re-Analysis (ERA)-Interim wind data (1200hrs) from European Centre for Medium range Weather Forecast (ECMWF). This data has spatial resolution of 0.25° x 0.25° for the different levels including those at 850mb and 200mb of the atmosphere where most of the weather processes occur. At the level 850 mb the surface has no much influence on the wind speed and direction. The study has already obtained permission to get the data from the ECMWF data server through its website (http://apps.ecmwf.int).

Uganda's climate is heavily influenced by winds speeds and direction since this is the vehicle for moisture advection. Since Uganda has no historical database for winds, the study used the specific re-analyzed database of ERA-Interim from the ECMWF) since it has a better resolution and skill at reproducing, Monsoons winds. Compared to other reanalyzed database, the ERA-Interim wind datasets have been used successfully by Mukabana and Pielke (1996) and Okoola (1999) for studies over East Africa.

3.1.5 Historical Tropical Cyclones (TC) Data

The source of the data on Tropical cyclones that occur over the South West Indian Ocean came from the Australia Severe Weather Office (2015) website (http://www.australiasevereweather.com) The organization tracks the cyclones on a daily basis. They document the name, and dates of occurrence of tropical cyclones occurring from December to February and maintain the data South West Indian Ocean cyclone portal. This cyclone data also give the intensity of each of the cyclone. The study downloaded the data from the website.

3.2 Methodology

As Uganda rainfall data usually have gaps, the study first endeavored to fill the gaps and conducted a homogeneity tests to ensure quality of the data. Thereafter, the analysis of the data followed as detailed in next subsections.

3.2.1 Estimation of Missing Rainfall Data and Homogeneity test

It is very common that historical records of rainfall for some stations have gaps due to various reasons like those that no records were taken or records got misplaced. This problem always frustrates research endeavors in the climate sector. As a way of solving this challenge the study, filled the missing data with the highest, precision and test for quality for availing reliable and near homogeneous series. The methods used for filling missing data included regression, correlation and arithmetic mean. The study used the correlation and arithmetic mean method to fill the data, that were standardized as shown in equation 1.

$$X_i = \bar{X}_i \frac{X_o}{\bar{X}_o} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where

X_i is the estimated data

$\bar{X}_i$ the mean value for the station with missing data

X_o is the data of the station with the highest correlation with station whose data is missing

$\bar{X}_o$ the mean of the station with highest correlation with station whose data is missing

The study used a single mass curve method to assess the quality of all data. As a confirmation that the records of the data were homogeneous, it was possible to plot a straight line through the data against time. In case the data has heterogeneity, it will reflect a different pattern. In that case a double mass curve must be used to adjust the records (Omondi, 2010).

3.2.2 Determination of Anomalous Wet Seasons

It was first important to identify the wet and dry spells in the DJF season. The study used the approach of Koech (2014) for reasons that the DJF season in Kenya is almost similar to Uganda. Based on the above approach that has been used by many others a rain day at a station was considered a wet day if it was at least 1mm of rainfall in a day A wet spell was considered as a sequence of running wet days (Gitau *et al.*, 2008; Mwangala, 2003; Pena and Douglas, 2002). The characteristics of the wet spells were analyzed for each of the climatological zones in the country. The unusually wet years were delineated as highlighted below

The amount of rainfall received in each DJF season X_t was first determined. The seasonal amounts for each DJF season X_t were then normalized to allow comparisons to be made between locations and years as shown in equation 2

$$X_t = \frac{100X_{tj}}{\bar{X}_j} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where

X_t is specific season normalized total rainfall

X_{tj} is the observed seasonal rainfall total

$\bar{X}$ is the long term seasonal mean for 30 years

The X_t values attained are used to classify the above normal, normal and below normal categories as shown in Table 3.

Table 3: Classification of rainfall anomalies

No.	Classification	Anomaly range (%)	Category Symbol
1	Above Normal	$X_t > 125$	AN
2	Normal	$75 < X_t < 125$	N
3	Below Normal	$X_t < 75$	BN

All years falling in AN category were delineated and formed the focus of this study as unusual wet years.

3.2.3 Determination of Wet Days, Wet Spells and the associated Statistical Distribution

In order to determine the distribution of the wet spell length for each climatological zone, a wet and dry spells were first determined. Whereas there are various definitions of a wet day, in this study, the definition used as wet day is any day that received at least 1mm of rain (Gitau, 2008; Ogallo and Chillambo, 1982) while a wet spell of *k* days represents a situation when 1mm of rain was received in *k* continuous days. The frequency of occurrence of different length of wet spells was then examined, and the best statistical distribution fitting the spells assessed. Past studies have fitted the wets spells to Exponential, Weibull among many other distributions.
The probability density function of a Weibull distribution may be expressed as;

$$f(x;\lambda,k) = \begin{cases} \frac{k}{\lambda}\left(\frac{k}{\lambda}\right)^{k-1} e^{-(x/\lambda)^k} & x\geq 0, \\ 0 & x<0, \end{cases} \quad \text{...............} \; (3)$$

where $k > 0$ is the shape parameter and $\lambda > 0$ is the scale parameter of the distribution.

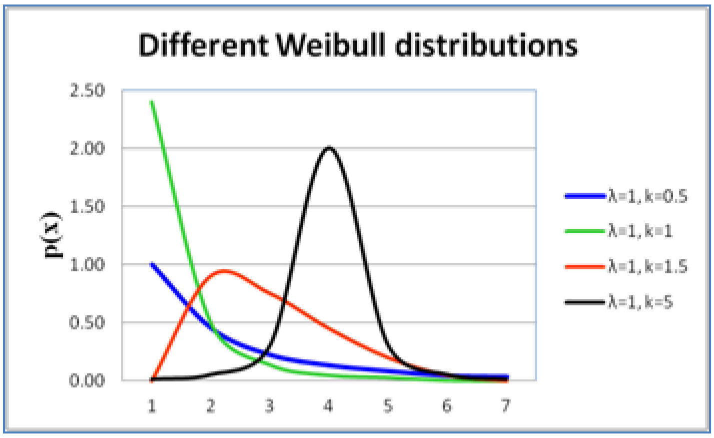


Figure 3: Illustrations of Weibull distributions of various parameters
Adapted from Martz (2013)

Figure 3 shows a Weibull distribution of two parameters that of scale and shape. The Weibull distribution is related to a number of other probability distributions depending on the values of the shape and parameters. As an example when parameter *k*=0.5 Weibull distribution takes a shape that resembles an exponential distribution as shown in Figure 3.

On the other hand Figure 4 below shows some examples of Exponential distributions with parameters of different values. The probability density function of an exponential distribution may therefore be expressed as

$$f(x;\lambda) = \begin{cases} \lambda e^{-\lambda x} & x \geq 0, \\ 0 & x < 0, \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

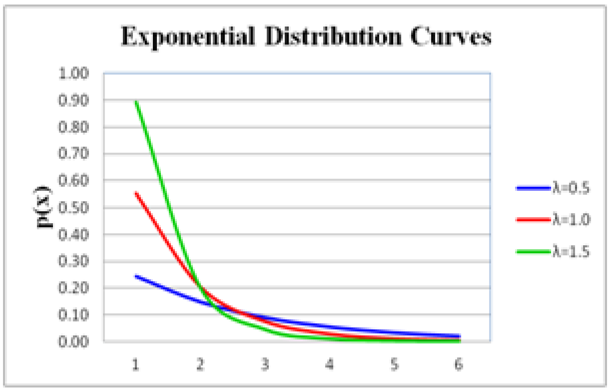


Figure 4: Illustrations of Exponential distribution of various parameters
Adapted from (Johnson and Wichern (2007)

Past studies that have fitted climate data to statistical distribution include Mutua (1986), Bamanya (2007), Komutunga (2005), Ogallo and Chillambo (1982) with success.

In this study after the frequency distribution of the wet spells were fitted to Exponential distribution, statistical significance of the fitted models were tested. Considering the few sample space for wet spells, the study used the Anderson and Darling (AD) test as recommended by Engmann and Cousineau(2011); Jamaludin and Jemain (2007); Rahman *et al.,* (2006) and Romeu (2003). The AD test was used to calculate the p-values of the goodness-of-fit test which was the basis to statistically determine if the data was exponential. Therefore the AD test equation (5) is shown below

$$A^2 = -n - \frac{1}{n}\sum_{i=l}^{n}(2i-1) \,.\, [lnF(X_i) + ln(1 - F\,(X_{n-i+1}))] \ldots\ldots\ldots\ldots\ldots..(5)$$

Where n is sample size

$F(X_i)$ is underlying theoretical cumulative distribution

The adjusted test statistic A* was computed using the equation (6) below to account for effect of sample size n of an exponential distribution

$$A^* = A^2\left(1.0 + \frac{0.6}{\sqrt{n}}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where

A^* is adjusted Anderson-Darling statistic

A^2 is Anderson-darling statistic

n is size of sample

At significance level of 0.05, when the A* p-value was more (less) than 0.05 the distribution was considered similar (different) to exponential.

2.2.4 Contingency Table and Correlation Analysis

This section examined linkages between the unusual DJF wet spells and un usual anomalies on a few known regional and global systems that drive climate circulation over Uganda especially ENSO and IOD. The first methodology for examining such associations was based on simple contingency table as shown in Table 4.

Table 4: Contingency table for analyzing Rainfall with ENSO and IOD

	ENSO			**IOD**		
RAINFALL	AN	N	BN	AN	N	BN
AN						
N						
BN						

Where

AN is Above Normal

N is Normal

BN is Below Normal

Probability of occurrence of unusual rainfall for each ENSO/IOD category can then be computed from the contingency frequency tables. The DJF rainfall spatial maps for some of these cases will also be presented.

The study also examined potential teleconections between un usual rainfall and ENSO/IOD was based on the computation of simple correlation coefficient (r) between amount of total rainfall received during the unusual wet days and IOD / ENSO indies independently. A simple correlation coefficient was used as shown in equation 7

$$r = \frac{\sum_{i-1}^{N}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i-1}^{N}(X_i - \bar{X})^2 \sum_{i-1}^{N}(Y_i - \bar{Y})^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(7)}$$

Where

X is independent variable

$\bar{X}$ is mean value for independent variable

y is dependent variable (DJF)

$\bar{Y}$ is mean value dependent variable (DJF)

r is correlation coefficient

The significance of the value of the calculated correlation *r* was tested using t-test on assumption of confidence level at 95% and significance level of P (0.05).

$$t = r\sqrt{\frac{n-2}{1-r^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(8)}$$

The study tested the significance of the computed correlation values at 95% level of Significance.

3.2.5 Regional Circulation Systems and unusual DJF Rainfall Season

Chapter two presented the various systems that drive the climate of the region. It is essential to determine the characteristics of some of these systems during the unusual wet periods. One key parameter that can integrate the regional characteristics of these systems is the regional circulation patterns. It is on this basis that the space-time patterns of the winds at 850mb and 200mb levels were examined for the anomalous wet periods. Attempts were also made to examine the characteristics of the tropical cyclones that occurred during the individual unusual DJF rainfall cases.

CHAPTER FOUR

4.0 Results and Discussions

This Chapter presents the results obtained using the various methods highlighted in the Section 3.2. The results first presented are on quality control of data used in the study.

4.1 Results on Data Quality Control

Quality and quantity of data used in any study is critical for any study. In this one all the climate data that were used were subjected to data quality tests based on heterogeneity tests using mass curve, among many other tests that were discussed in section 3.2.1. Some of the examples obtained are shown in Figures 5(a-b).

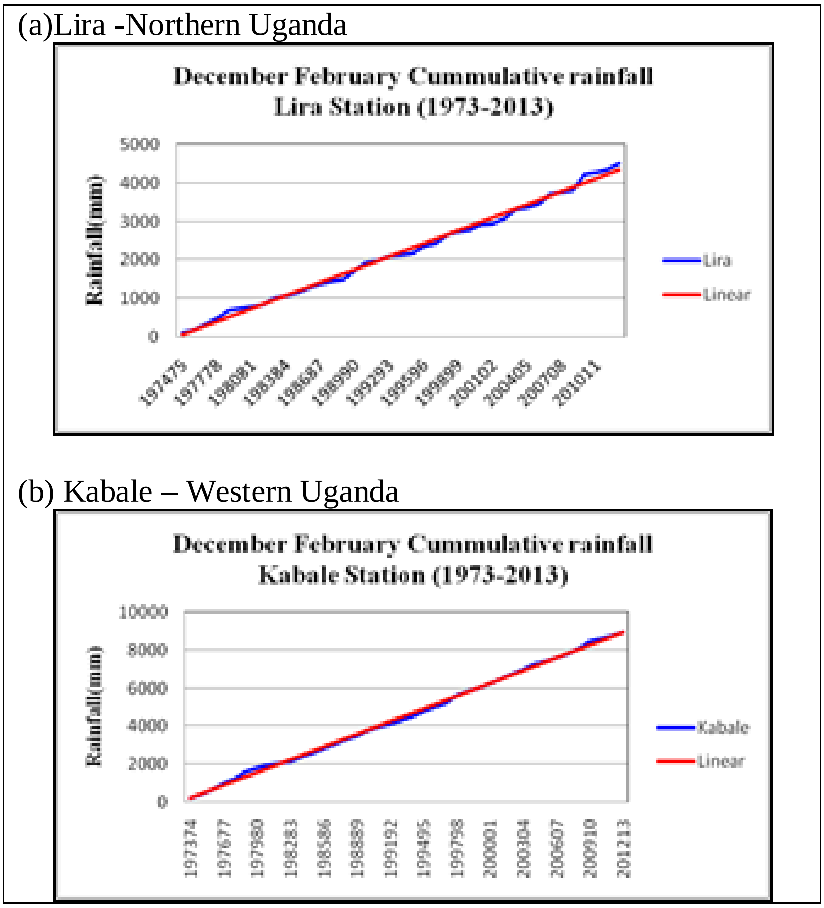


Figure 5: Cumulative December-February (DJF) Seasonal rainfall totals over (a) Lira in Northern Uganda, (b) Kabale in Western Uganda

Results from the graphs shows that a straight line could be fitted on most of the cumulative rainfall amounts graphs signifying the homogeneity and good quality of the data used in the study. The high quality of the climate data have been observed by past studies including those by Bamanya (2007), Komutunga (2005), Bazira (1997), Basalirwa (1995), Nsubuga *et al.*, (2014).

4.2 Results for Space Time Characteristics of Wet December-February Seasons

The first step attempted to delineate the anomalous wet years through classifications of the observed OND rains into Above Normal, Normal and Below Normal categories.

4.2.1 Identified unusually Wet DJF Years

The results reveal within the analysis period that there were 10 unusually wet DJF years of which seven occurred between the late 1990's and 2000's. The Table 5 below shows the years when most of Uganda experienced unusually wet DJF seasons. The years included 1961-62, 1989-90, 1990-91, 1995-96, 1997-98, 2002-03, 2003-04, 2006-07, 2009-10 and 2012-13.

Table 5 : Showing Years of unusually wet DJF Seasons

Sno	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Period of unusual wet Rains	1961 /62	1989 /90	1990 /91	1995 /96	1997 /98	2002 /03	2003 /04	2006 /07	2009 /10	2012/ 13

The high number of events of unusually wet DJF seasons recorded in the recent years suggests that the DJF season over Uganda is experiencing a positive trend of increased rainfall amounts. The trend may be associated with signals of climate change impacts as projected by earlier studies by Shongwe, *et al.*, (2011); CIAT (2011) and Vizy and Cook (2012)

Examples of the spatial patterns of the unusually wet DJF years are shown in Figure 6 below. Although DJF season is usually a dry season but from the figure it reveals the extent to which the wet spells covered most of the country in the periods of 1961/62 and 1997/98. Most of the country experienced above normal rains in those years.

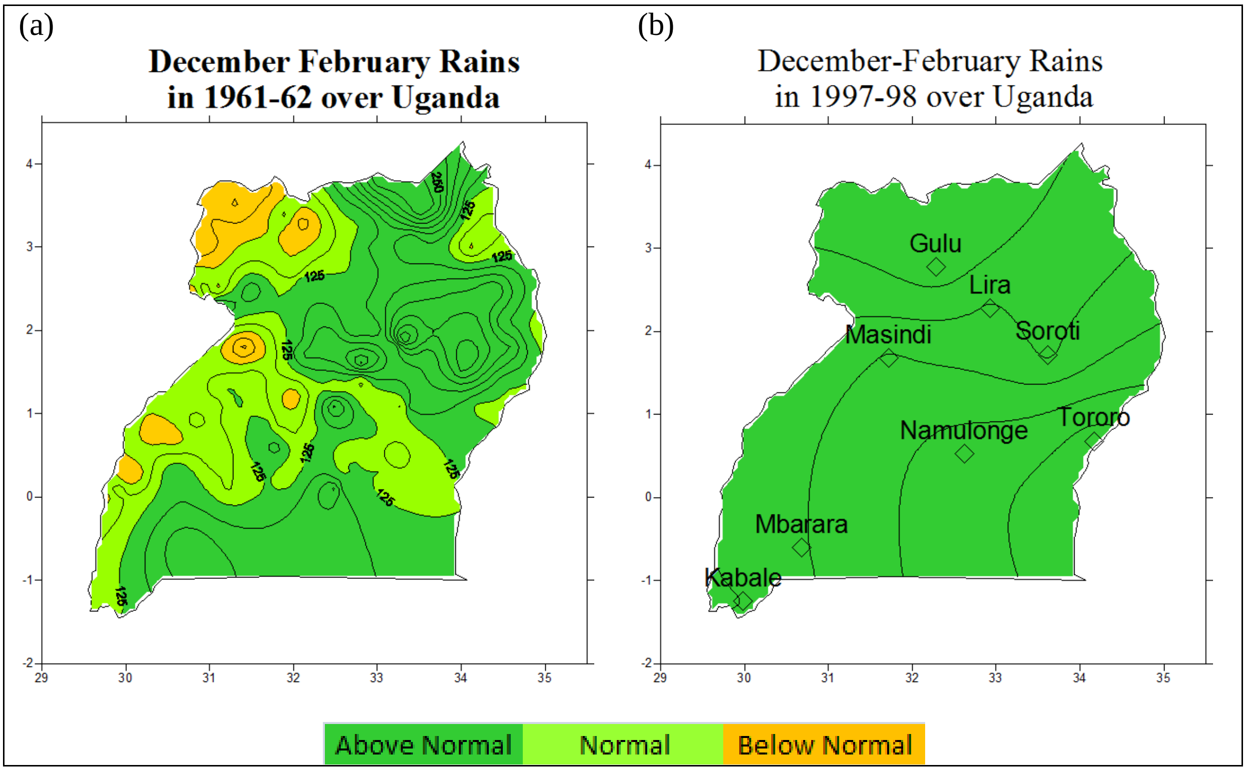
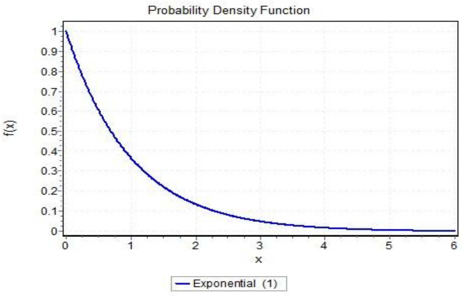


Figure 6: Examples of unusually wet years of the DJF Period.

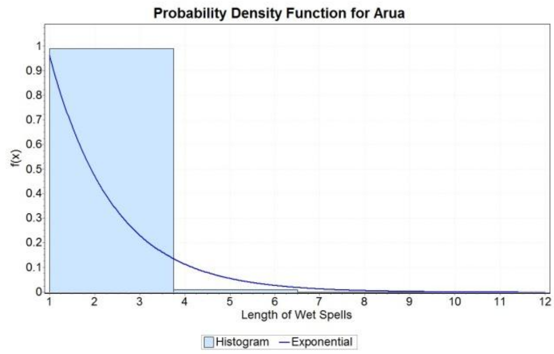
4.2.2 Statistical Distribution of length of Wet Spells Frequencies

The results from the study showed that the wet spells of one day had the highest frequency followed by those of 2-days and thereafter 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 days. The frequency of the wet spells extending beyond two days reduced exponentially. Therefore the best statistical distribution that fitted the frequency of the wet spells at most locations was the exponential distribution. Examples of the fitted distributions are given in Figure 7 below.

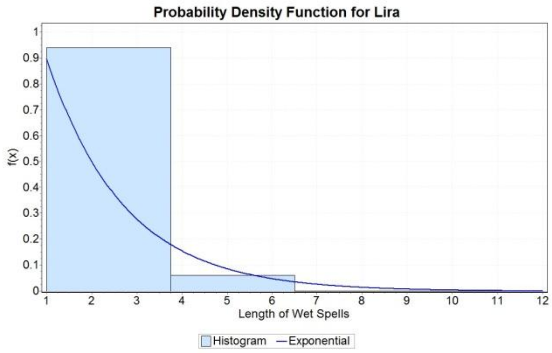
These results are in line with those of earlier researchers which includes Koech, (2014), Engmann and Cousineau (2011), Gitau *et al*., (2008), Jamaludin and Jemain(2007), Tilya (2007), Rahman *et al*., (2006), Romeu(2003), Mungai (1984) and Ogallo and Chillambo (1982).



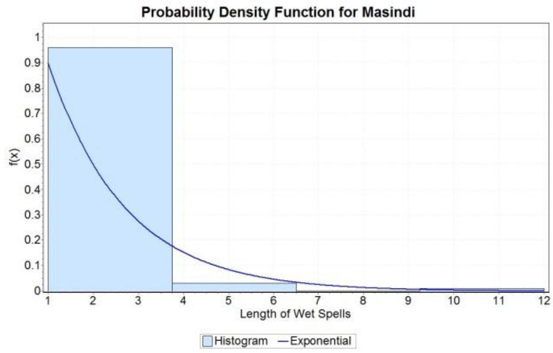
Exponential distribution



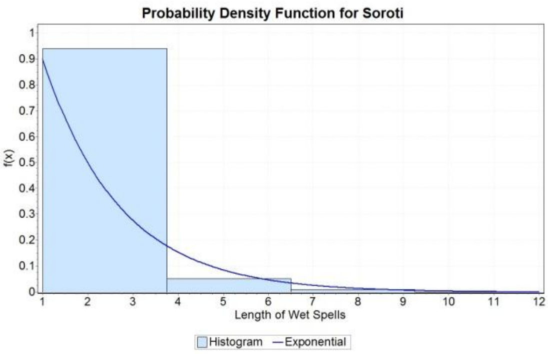
Zone 1: Arua



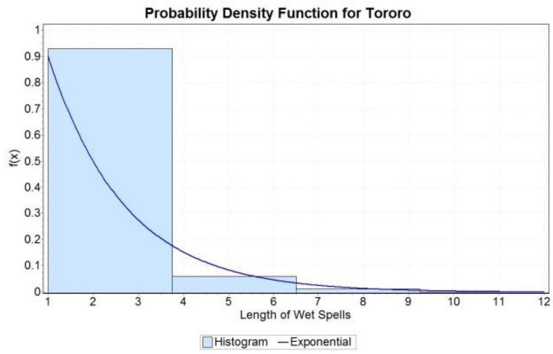
Zone 2: Lira



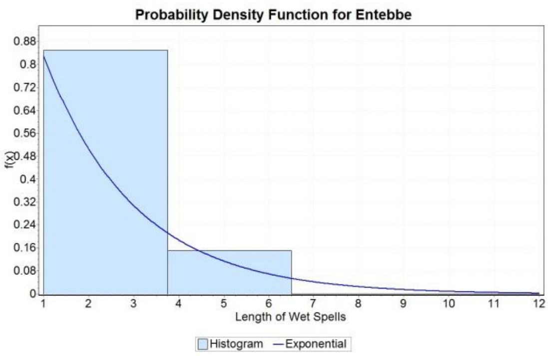
Zone 3: Masindi



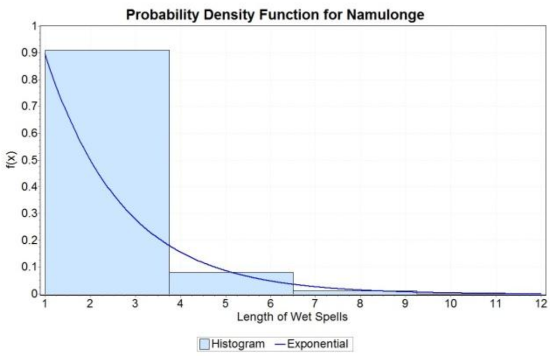
Zone 5: Soroti



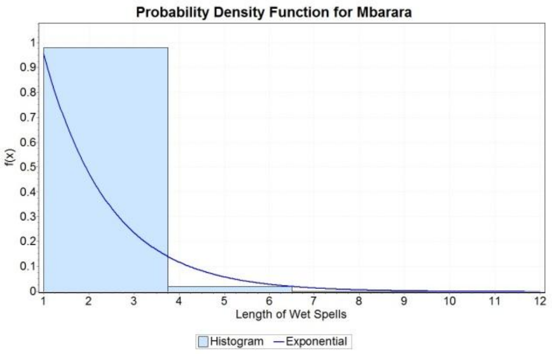
Zone 6: Tororo



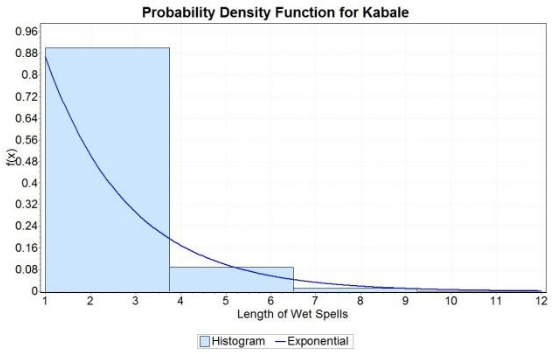
Zone 7: Entebbe



Zone 8: Namulonge



Zone 9: Mbarara



Zone 10: Kabale

Figure 7: Graphs showing Probability Density Functions for the different length of wet spells in unusually wet DJF seasons for the different zones in Uganda

Table 6 below shows how the length of the wet spells for each station was statistically tested if it fitted an exponential distribution. The results show that most of the p-values of the AD* test were above the significance level of 0.05 which confirmed that empirical distribution of the wet spells were similar to the theoretical exponential distribution. Entebbe station, which had a p-value of 0.03 was tested based on a significance level of 0.01 which proved that it had an exponential distribution.

Table 6: Anderson-Darling Test for Exponential Distribution of Fitted (Theoretical) Wet Spell Lengths for December-February rains over Uganda

	Zone	AD Test Value	AD test p-value	Decision
1	Arua	1.34	0.22	Accept Null Hypothesis at α 0.05
2	Masindi	1.66	0.14	Accept Null Hypothesis at α 0.05
3	Lira	2.06	0.09	Accept Null Hypothesis at α 0.05
4	Soroti	1.72	0.13	Accept Null Hypothesis at α 0.05
5	Tororo	2.27	0.07	Accept Null Hypothesis at α 0.05
6	Entebbe	2.89	0.03	Accept Null Hypothesis at α 0.01
7	Namulonge	2.21	0.07	Accept Null Hypothesis at α 0.05
8	Mbarara	1.17	0.28	Accept Null Hypothesis at α 0.05
9	Kabale	2.23	0.07	Accept Null Hypothesis at α 0.05

4.2.3 Spatial characteristics of the wet DJF rains during ENSO and IOD

The events of the unusually wet years during the DJF period were tallied with the ENSO and IOD events. The results in Table 7 show how the unusual rains performed under the influence of ENSO and IOD conditions. It is clear from the contingency table that there were four El Niño and one La Niña event occurred during the unusually wet years. On the other hand six positive IOD events occurred during the unusually wet years.

Table 7: Showing some of the Years of unusual wet DJF Seasons

Year	Kabale	Mbarara	Masindi	Arua	Lira	Soroti	Tororo	Entebbe	Namulonge	ENSO	IOD
1961/62	**129**	**189**	81	41	**145**	**170**	**144**	121	106	No	Positive
1989/90	122	121	90	120	**196**	**338**	**172**	**141**	114	No	No
1990/91	92	108	**219**	**135**	**184**	**178**	77	87	78	No	Positive
1995/96	98	**151**	117	98	**148**	**195**	111	**188**	**151**	La Niña	Positive
1997/98	**185**	**219**	**213**	**221**	**202**	**192**	**283**	**238**	**265**	El Niño	Positive
2002/03	102	72	88	**147**	114	**188**	**237**	**134**	**160**	El Niño	No
2003/04	98	111	121	115	**221**	**136**	76	120	**149**	No	Positive
2006/07	92	72	**132**	53	**217**	**171**	123	114	**144**	El Niño	No
2009/10	**165**	**168**	**167**	**303**	**357**	**284**	**241**	**132**	119	El Niño	Positive
2012/13	89	111	**261**	121	**151**	**186**	86	**152**	**219**	No	No

In some years, El Niño occurred concurrently with positive IOD like in 1997/98 and 2009/10, but in a number of cases Positive IOD events occurred with no EL Niño conditions like for years 1961/62, 1990/91 and 2002/03. The contingency table revealed that the IOD system is commonly associated with unusual rains, but its effect is more widespread when it couples with El Niño conditions.

Examples of the spatial patterns of the unusually wet DJF years are shown in Figures 8 and 9 below. In Figure 8 the unusually wet years that corresponded with years of significant IOD anomalies included 1961/62 and 2003/4.

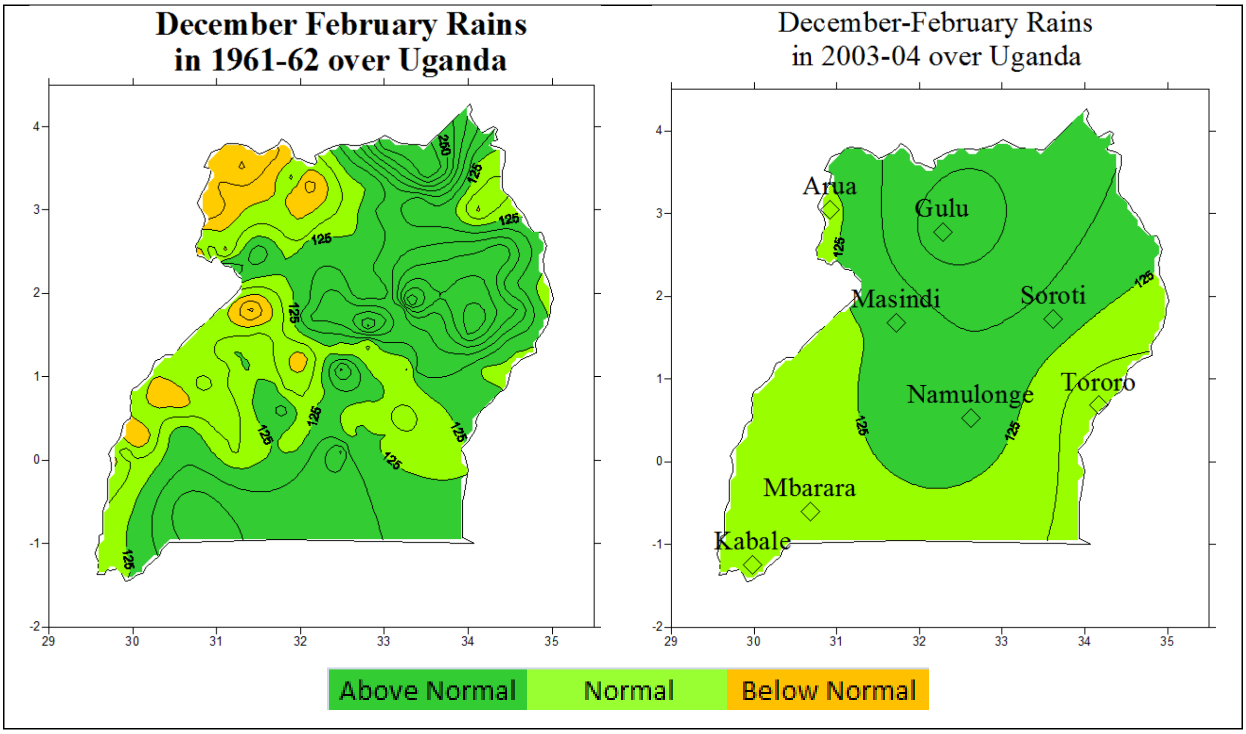


Figure 8: Maps of Uganda showing the rainfall received during DJF expressed as percentage of the LTM during (a) 1960/61 (b) 2003/04 for IOD Significant

Figure 8, reveals that, the Positive IOD conditions can produce widespread unusual rains across the country in the DJF period.

In Figure 9, below the results show how the unusually wet DJF rains generally spread over most of Uganda during a strong combination of El Niño and Positive IOD years for periods 1997/98 and 2009/10. The results in the Figure further indicated that some exceptional anomalies occurred over northeastern and northern regions during some moderate La Niña conditions like were observed in 1995/96.

In general the study revealed that the IOD system is commonly associated with unusual rains, but its effect is more widespread when it couples with El Niño conditions.

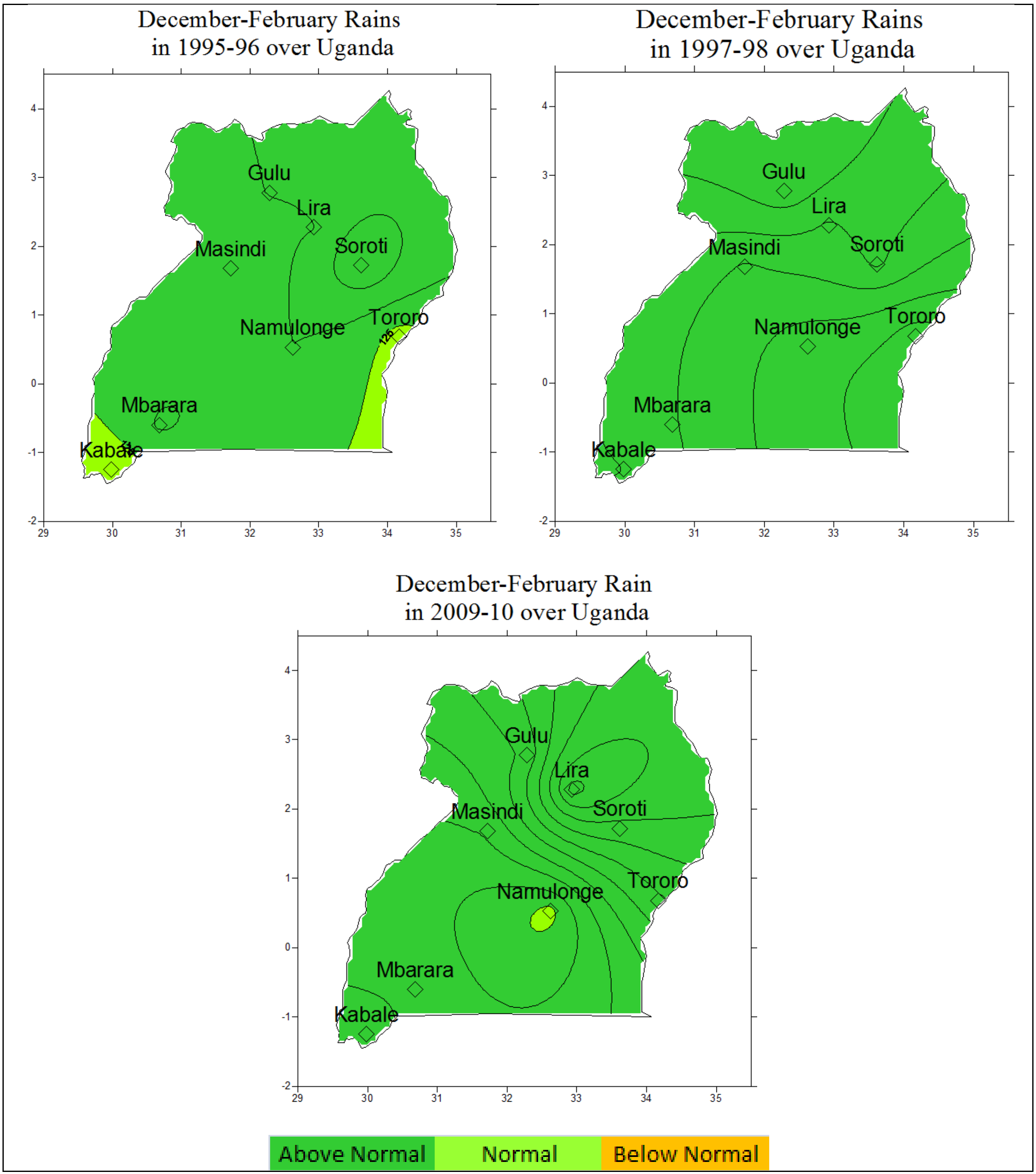


Figure 9: Maps of Uganda showing the rainfall received during DJF expressed as percentage of the LTM during (a) 1995/96 (b) 1997/98 (c) 2009/10 when El Niño and positive IOD. Orange shows Below Normal, Yellow for Normal, and Green shows above Normal.

4.2.4 Correlation Analysis between DJF Rains and ENSO, IOD

This section presents the results when DJF seasonal rains were correlated with Niño3.4 and the IOD independently.

The results in Table 8 below show how at lag period of zero months the DJF rains over Uganda are correlated with the Niño3.4 indices and the IOD coefficients. In general the correlation coefficients were significant at 95% confidence level, but the percentage of the variance explained (r^2) were relatively low. With a maximum correlation of 0.6, the maximum wet spells rainfall variance accounted by ENSO or IOD was about 36% only, giving a challenge to any efforts of using ENSO and IOD in the prediction of the wet spells.

Table 8: Correlation coefficient values between ENSO, IOD and DJF rainfall The bold figures show significant values at 95% significance level.

Zone	Stations	Size n	Niño3.4 r	IOD r
1	Arua	30	**0.447**	**0.445**
2	Lira	30	**0.462**	**0.458**
3	Masindi	30	0.271	**0.423**
5	Soroti	30	**0.408**	**0.376**
6	Tororo	30	**0.532**	**0.405**
7	Entebbe	30	0.245	**0.430**
8	Namulonge	30	0.279	**0.608**
9	Mbarara	30	**0.416**	**0.456**
10	Kabale	30	**0.574**	**0.520**

The above results are in line with earlier findings by Omondi *et al.,* (2013); Bowden and Semazzi (2007); SchreckIII and Semazzi (2004); Indeje *et al,* (2000); Mutai and Ward (2000); Beltrando and Camberlin (1993); Ogallo (1988) which showed that seasonal rains over East Africa are associated with ENSO phenomenon. Although their studies were mainly focused on the rainfall seasons of MAM, JAS and OND, this study confirms that Niño3.4 has significant positive relation with the DJF rains at zero month lag period.

4.2.5 Tropical Cyclones, and the monsoons Wind Vector Patterns associated with un usual wet spells

This section presents the wind patterns and the tropical cyclones that were observed during the unusually wet periods. The number of cyclones that occurred each unusually wet year where complied and the associated wind pattern analyzed.

4.2.5.1 Tropical Cyclones

This section attempts to give some insight regarding the major circulation systems that are dominant over the region in DJF during the unusually wet periods. Table 9 below reveals that occurrence of cyclones in DJF period is a common feature every year. The number of Cyclones that occurred in the SWIO can range from 3 to 8 over the DJF period. However the number of cyclones occurring appears to have no trend with whether it is an ENSO or IOD year.

Table 9: Number of Tropical cyclones which occurred during the unusual WET DJF years over the SWIO

Period	1961/62	1989/90	1990/91	1995/96	1997/98	2002/03	2003/04	2006/07	2009/10	2012/13
Number of Cyclones	6	3	6	4	5	8	4	8	6	6

Table 10 and 11 provide a summary of the occurrence of Cyclones in SWIO and Wet spells over Uganda in the DJF periods for 1995/96 and 2009/10 which were analyzed as shown below.

Table 10: Cyclone Occurrences in SWIO and Wet Spells over Uganda in DJF 1995-96.

(a) December 1995

Days of Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
No Cyclone																															
Rain Spells														■	■	■	■							■	■	■	■	■	■		

(b) January 1996

Days of Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Cyclone Bonita	15	20	25	25	30	35	60	115	135	125	75	55	75	55																	
Rain Spells																															

(c) February 1996

Days of Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	1	2
Cyclone Doloresse												20	25	30	40	55	75	75	30												
Cyclone Edwige																		15	20	25	45	45	45	30	35	85	85	45	30		
Cyclone Flossy																										25	40	100	105	95	65
Rain Spells																			■	■	■	■	■	■	■	■	■	■			

Key: 115 Cyclone day and speed in kts; ■ Rain Spell

(Light blue represents position of Cyclone when it was east of Madagascar while Blue color represents position of Cyclone when it was west of Madagascar)

Table 10(a) reveals that Uganda experienced two wet spells in December 1995 between 14-17 and 24-29. These unusually wet spells occurred in the absence of Cyclones in the SWIO sub-region. In contrast in the following month of January 1996, Table 10(b) shows that Uganda experienced no significant wet spells although there was occurrence of Cyclone Bonita in the SWIO region. Bonita occurred between the period 1-14 January which was a length of 14 days. Bonita spent ten days and four east and west respectively of Madagascar.

In Table 10(c), the results show that in the month of February 1996 the SWIO region experienced three Cyclones. These included Doloresse during 12-19 February, Edwige during 18-29 February, and Frank during 26 Feb to 2 March. Doloresse spent six of its last days west of Madagascar while Edwige and Flossy spent all their lifetime east of Madagascar. During the existence of these Cyclones, Uganda experienced a wet spell from 19-28 of the month. One common features during the DJF 1995/96 period was the significant anomalies of the IOD patterns.

Table 11: Cyclone Occurrences in SWIO and Wet Spells over Uganda in DJF 2009-10

(a) December 2009

Days of Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Cyclone Cleo				15	15	30	45	115	90	50	30	25	30	25																	
Cyclone David												20	30	30	30	30	25	25	25	35	35	45	50	50	50	30					
Rain Spells																															

(b) January 2010

Days of Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Cyclone Edzani	15	30	25	30	30	45	105	140	115	90	50	45	40	35																	
Cyclone 201011																											30	30	30	25	
Rain Spells																															

(c) February 2010

Days of Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29		
Cyclone Fami	25	40																													
Cyclone Gelane															30	45	80	95	125	80	35	20									
Rain Spells																															

Key 115 Cyclone day and speed in kts Rain Spell

(Light blue represents position of Cyclone when it was east of Madagascar while Blue color represents position of Cyclone when it was west of Madagascar)

On the other hand in Table 11a above, it shows that during the month of December 2009, the SWIO region experienced two Cyclones which were Cleo and David. Both of these Cyclones existed east of Madagascar. Cyclone Cleo's lifetime stretched from 4th to 14th while David was from 12th to 26th of December. During the existence of these Cyclones Uganda experienced three rain spells from 9-11, 14-17 and 24-29 of December. This would give an impression that the occurrence of the two cyclones may have caused the wet spells over the Country. However in Table 11(b) during the month of January 2010, although the SWIO experienced two Cyclones (Edzani and 201011) which occurred from 1-14 and 27-30 respectively, Uganda did not experienced significant wet spells. Never the less, in the following month of February as shown in Table 11(c), two Cyclones occurred in the names of Fami and Gelani in the periods of 1-3 and 15-22 respectively. Cyclone Fami's lifetime was spent west of Madagascar while that Gelani was in the east. During this period, Uganda experienced a wet spell towards the last four days of Gelani Cyclone. Strong anomalies were also evident in the DJF patterns of IOD. The study made attempts to assess any linkage of the unusually wet DJF season with the location of the TCs either west or east of Madagascar. The results shown in Tables 10-11 revealed that at most times the TCs were usually on the Eastern side of Madagascar when there were unusually wet spells over Uganda. So it was not possible to draw any conclusion as there were times the TCs though prevailed in the SWIO, there was no rains over Uganda.

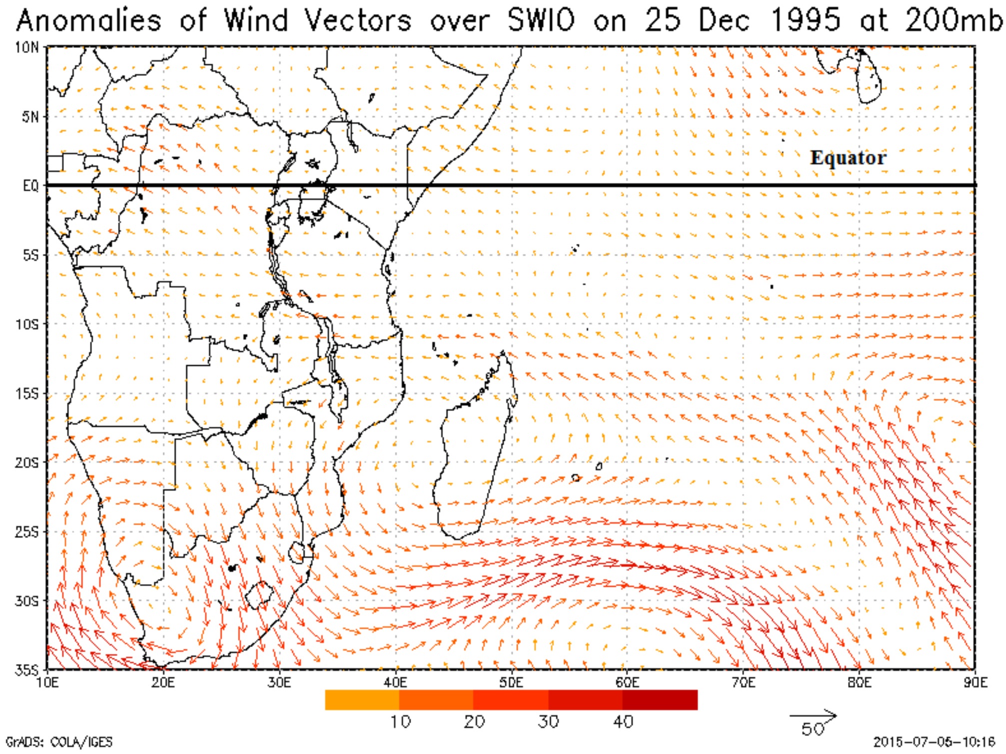
It may be concluded from the study that although some of the unusually wets rains occurred when tropical cyclones were located over SWIO sub region, several unusual DJF rains occurred during years when there was no tropical cyclones over the region.

4.2.5.2: Monsoon Winds Vectors during the Wet Spells

In this section attempts were made to identify the patterns of monsoon wind over the SWIO region during the wet spells in Uganda. Special consideration was given to the days of wet spells during the absence or presence of cyclones in the region.

In Figure 10 the wind pattern over the SWIO on 25th December, which was part of the wet spell of 24-29 December 1995 over Uganda, is shown at the different levels of 200mb and 700mb. At level 200mb as shown in Figure 10(a) the winds blowing south of Madagascar were mainly westerlies which were associated with a low pressure zone. North of Madagascar, south easterlies were blowing from the Indian Ocean into the hinterland of East Africa. Over Uganda the winds were predominantly south easterlies. These winds appear to originate from an anti clockwise movement of winds over the zone of Madagascar.

(a)



(b)

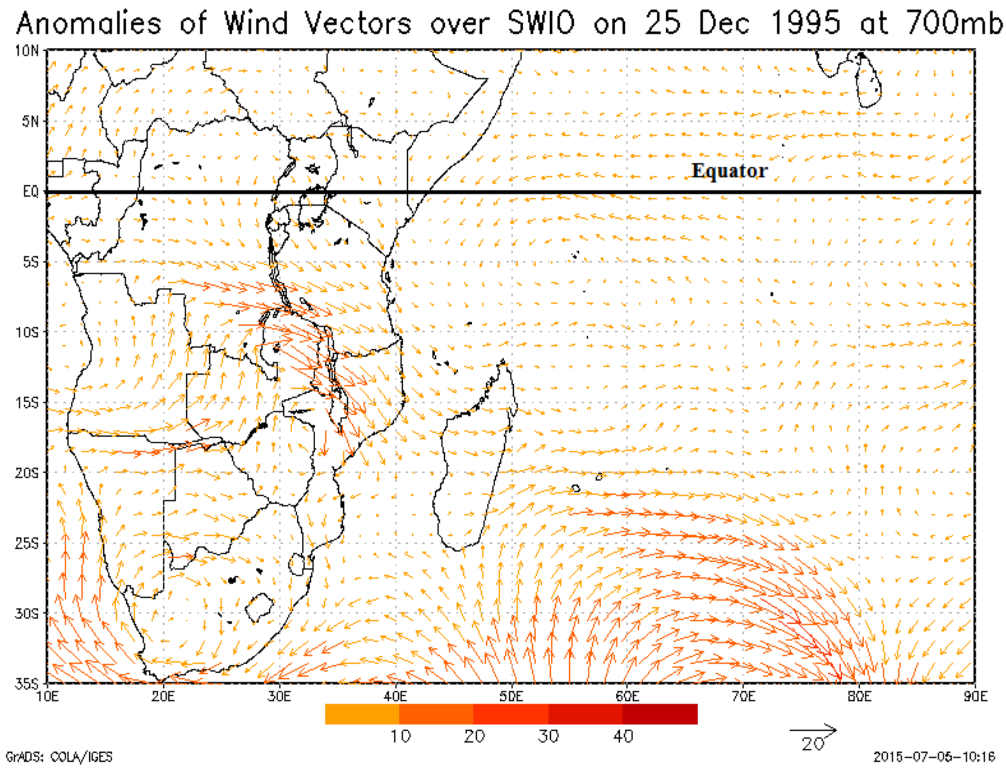


Figure 10: Wind Anomalies at 200mb and 700mb over SWIO region during the wet spell 24-29 December 1995 over Uganda

In contrast the winds over Uganda at level 700mb in Figure 11 (b) above, and that in Figure 12 below comprised mostly of westerlies blowing from the neighboring country Democratic Republic of Congo. The westerlies from DR Congo were very strong over Tanzania as well. Over the SWIO region, there was no Cyclone and clear direction of the winds blowing from the Indian Ocean to the hinterland of East Africa. However there was a high pressure zone at the East African Coast, and a low pressure zone south east of Madagascar.

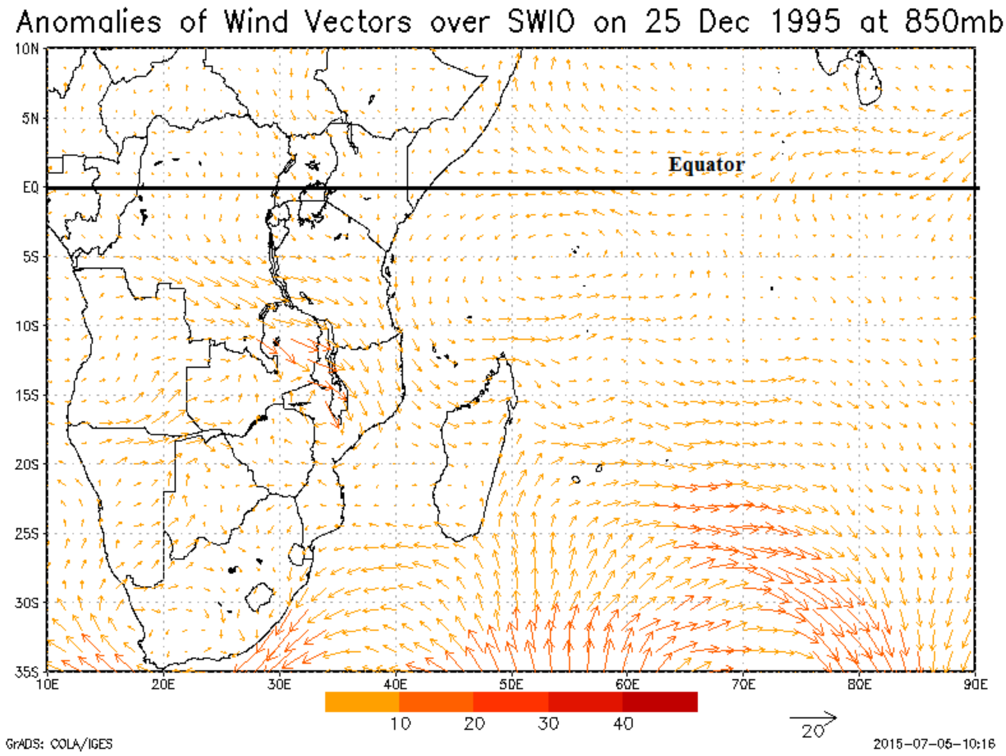


Figure 11: Wind Anomalies at 850mb in SWIO region during the wet spell 24-29 December 1995 over Uganda

The results suggest that the likely source of moisture during the wet spell over Uganda were from the winds blowing from the DR Congo at both 700mb and 850mb.

In Figure 12 below when the SWIO experienced a Cyclone, the wind pattern at 200mb comprised of South easterlies covering the East African Region of which Uganda is included. There was a strong band of easterlies blowing from the Equatorial Indian Ocean to the East Africa hinterland and on reaching the coast the direction changed to south easterlies. South of Madagascar, the wind pattern was mainly comprised of easterlies blowing to the South African coast.

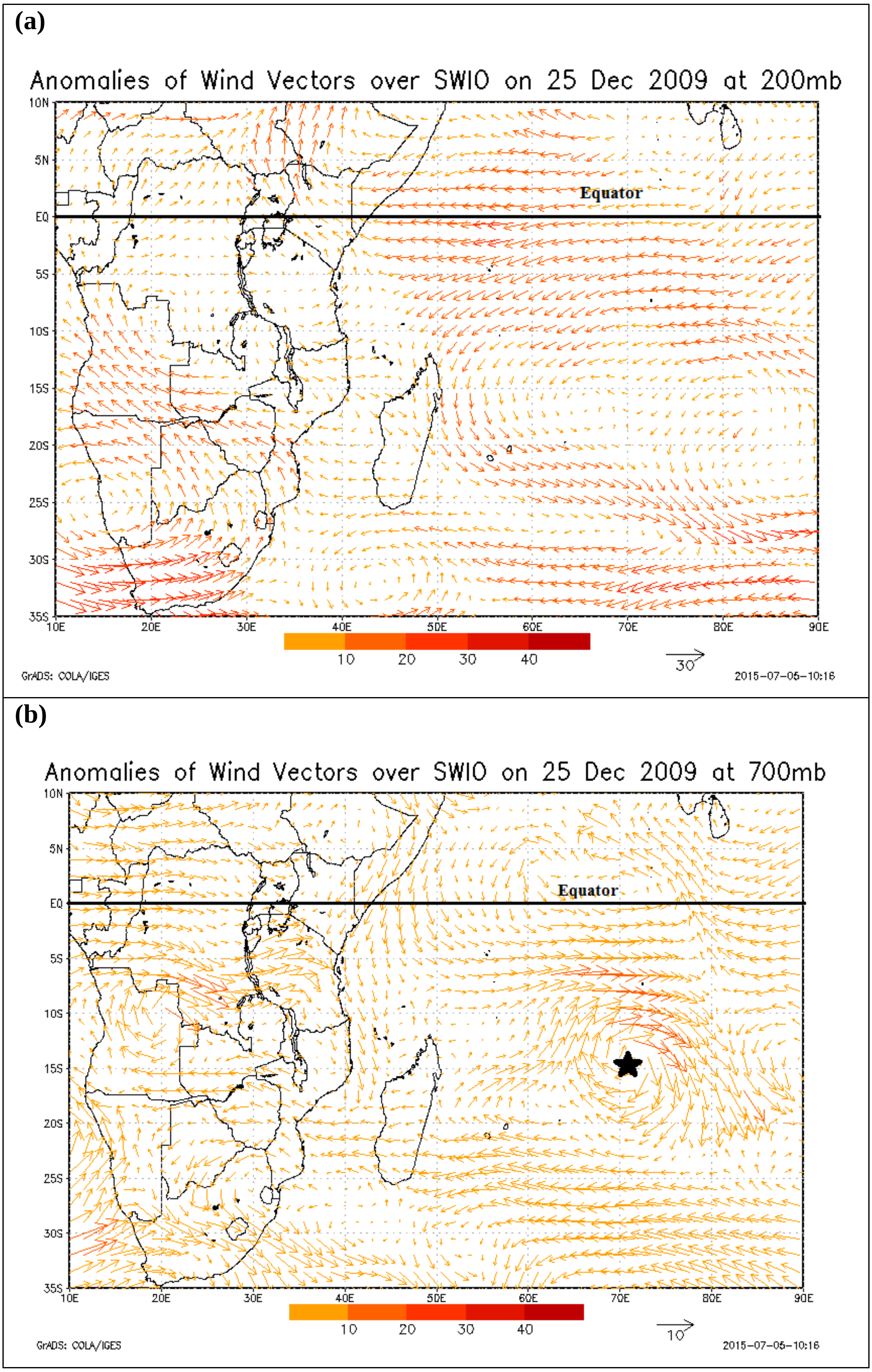


Figure 12: Winds Anomalies at 200mb and 700mb in SWIO region during the wet spell 24-29 December 2009 over Uganda

At the level of 700mb the wind pattern over Uganda, comprised of westerlies blowing from DR Congo. Over the SWIO a cyclonic activity was very predominant with its center shown by the black star. Southwards to the pole the winds were predominantly easterlies.

The winds at level 850mb as shown in Figure 13 below, indicates the location of the Cyclonic activity with a black star. During the period 12-26 December 2009, the SWIO experienced Cyclone David. During that period the predominant wind pattern over Uganda, comprised of westerlies blowing from the neighboring country where we find Congo forest.

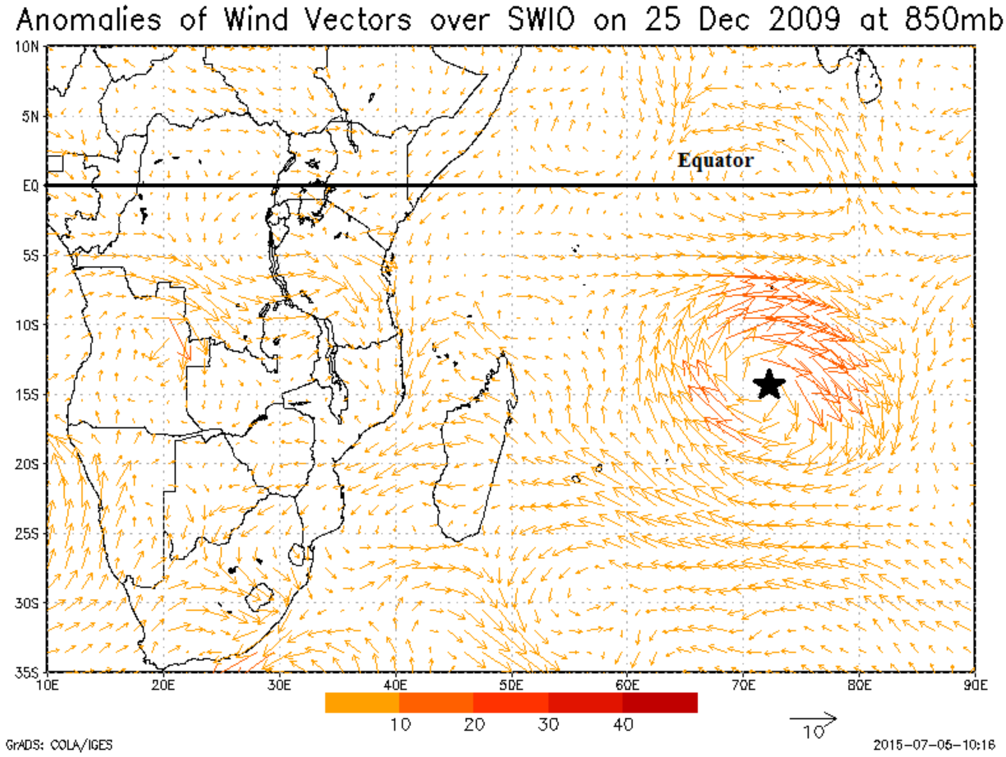


Figure 13: Wind Anomalies at 850mb in SWIO region during the wet spell 24-29 December 2009 over Uganda

The comparison of the wind patterns in Figure 10(b) and Figure12 (b) reveals that the winds blowing over Uganda at 700mb were predominantly westerlies from the DR Congo. However the anomalous westerlies over DR Congo which reach up to Uganda appear to originate as far as the Atlantic Ocean. This suggests that the atmospheric pressure conditions in the Atlantic Ocean may have a role enabling the flow of anomalous moist westerlies from the Ocean pass over DR Congo where they may pick additional moisture from the Congo Forests then blown over to Uganda during the unusually wet DJF Seasons.

CHAPTER FIVE

5:0 Conclusions and Recommendations

This Chapter contains the main conclusion made from the results of this study. In addition it also provides some recommendations to facilitate research studies in the future.

5.1 Conclusions

The results obtained confirm an increased frequency of unusually wet DJF seasons over Uganda. Considering that the majority of these DJF events where identified in the period 1995-2013, this suggests a positive trend in the increase of rainfall amounts in the season over the years. The positive trend may be signal impacts of Climate Change over the Country.

The unusually wet DJF seasons were found to occur mainly during a coupling of El Niño and positive IOD events. This implies that as the impacts of Climate Change increased the frequency of El Nino and positive IOD events this is likely to increase the frequency of unusually wet DJF seasons.

The most frequent wet spells found during the DJF period were of 1-day followed by that of 2-days. There after the frequency of Wet spells were less following an exponentially. Therefore the wet spells over Uganda during the unusually wet DJF over Uganda followed an exponential distribution. This suggests that risk analysis Climate Change related floods resulting from unusually wet DJF events must consider an exponential occurrence of events.

The IOD and ENSO predictors are positively correlated with the unusually wet DJF seasons over Uganda. However the relation of IOD with the DJF rains is more widely spread across the Country than that of the ENSO.

Uganda can experience unusually wet DJF seasons regardless of the absence of Tropical Cyclones in the SWIO. Therefore the occurrence of Tropical Cyclones in the South Western Indian Ocean can either contribute to a wet DJF or a dry DJF. What causes the difference requires detailed study.

According to the Monsoon Wind analysis, the unusually wet DJF Seasons are associated with anomalies of westerlies at 700-850mb from the Democratic Republic of Congo(DRC). It is not clear whether the intensity of the westerlies from DRC has increased due to the impacts of Climate Change, however this requires further study. Never the less the westerlies from DRC appear to be important in advection of moisture from the Congo Forest.

5.2 Recommendations

Considering the findings of the study and the interest to use these findings to ensure sustained development activities in Uganda, the study recommends the following.

Government should mainstream these events in the planning and budgeting process to cater for the management of funds needed to mitigate disasters related to above normal rains in the DJF period. The mainstreaming should involve the different sectors that are directly or indirectly affected by these rains. The sectors include finance, local government, health, water, roads, agriculture, tourism and environment

ICPAC as the regional body in charge of producing regional forecast can facilitate production of the DJF seasonal rainfall forecasts ahead of time for the Country. This involves providing training in use of atmospheric predictors of anomalous westerlies over Atlantic Ocean and DRCongo to produce DJF rainfall forecast for Uganda.

The Uganda National Meteorological Authority must produce tailored DJF forecasts ahead of time to meet the user's demands in the Country. In addition UNMA should increase its research activities in producing forecasting models for these rains. UNMA should sensitize development partners in the values of the DJF rains.

Universities should increase their research and training in the dynamics of DJF rains to be able to produce forecasting and monitoring tools attached to the rains.

The Development partners like NGOs must play a role in sensitizing farmers on how to benefit from the changed dynamics of the DJF rains to ensure food security

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