CHARACTERISTICS OF EXTREME RAINFALL EVENTS OVER RWANDA

By

NDABARASA JEAN FELIX

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A Research project submitted in partial fulfillment of the requirements for the award of the degree of postgraduate diploma in Meteorology

AUGUST 2015

DECLARATION

I hereby declare that this project work is mine and has not been presented for examination in this University or any other institution for an academic award:

Signature…………………………………………………………Date..................................

NDABARASA JEAN FELIX

SUPERVISORS:

Signature………………………………………………………….Date……………………….

Prof. Mwalichi J. ININDA

Signature………………………………………………………….Date……………………….

Dr. R.E OKOOLA

ABSTRACT

The objective of this study was to analyze the characteristics of extreme rainfall events over Rwanda. The monthly rainfall data from 1971 to 2014 was obtained from Rwanda Meteorology Agency, Kigali. The wind, sea level pressure (SLP) and sea surface temperature (SST) data used was the NCEP/NCAR Reanalysis. In order to achieve the main and specific objectives, the following analyses were current out; temporal and spatial analysis, determination of extreme years, coefficient of variability, probability of extreme events and composite analysis of the weather systems associated with the extreme rainfall events over Rwanda.

Analysis of temporal rainfall indicated two rainfall seasons namely MAM and OND. The peak rainfall month during MAM is April while during OND is November. The results indicated that more rainfall received during MAM compared to OND. It was further noted that rainfall is concentrated over highlands hence the influence of orography is very strong over Rwanda.

The extreme wet and dry years were identified from the standardized rainfall anomalies. It was observed that the frequency of dry events was higher than that of the wet events. The results from monthly rainfall variability showed that the dry months of June to August have high coefficient of variability more than 110% while wet months MAM and OND had low coefficient of variability less than 50%. Over most region, the OND season has lower coefficient of variability compared to MAM indicating that the OND is more reliable than MAM.

The results showing the probability of occurrence of extreme rainfall events indicates that the below normal events have the highest probability compared to the normal and above normal events. Composited wind patterns for wet events indicated the presence of strong low level convergence accompanied with enhanced upper level divergence. The opposite was noted for composite dry events. SST composites for showed that wet events over Rwanda are marked by cooler Atlantic Ocean and warmer Indian ocean. However, during the dry events, the Atlantic was warm while the Indian ocean was cooler. The SLP composites for wet events show strong Mascarine and St Helena highs while the opposite observed during the dry events.

This study therefore identified that Rwanda is highly vulnerable to droughts since below normal events have the highest frequency. While the extreme wet event are fewer usually catastrophic effects such as flooding which disrupt the normal social economy activities.

DEDICATION

To my beloved family:

My wife, Ms Saidath UWAMAHORO and our daughters Ms NDABARASA SIMBI SALWA and Ms NDABARASA KARABO FAIHA, for their understanding, patience and words of encouragement.

ACKNOWLEDGEMENT

Thanks to the Almighty Lord for giving me opportunity, strength, protection, and good health in my entire study period. May His Holy Name be glorified forever. Also I would like to acknowledge Rwanda Meteorological Agency (Meteo-Rwanda) and IGAD Climate Prediction and Applications Centre (ICPAC) for sponsorship of my studies.

I would like to take this earliest opportunity to thank the supervisors, Prof. J.M Ininda and Raphael E. Okoola of Department of Meteorology at University of Nairobi (UoN) in Nairobi, Kenya for their continuous guidance, encouragement and timely completion of this project work.

Special thanks go to the University of Nairobi especially the staff in the Department of Meteorology. Thanks to the Chairman, Dr. Alfred O. Opere and his academic staff for the valuable contributions to my postgraduate diploma in Meteorology.

I am sincerely and greatly indebted to my beloved wife, Ms UWAMAHORO Saidath for her patience, moral support and understanding during the long periods of absence. I do hereby acknowledge my parents, brothers and sister for the support both in words and deeds that they provided to my family during my long periods of absence.

Finally, our thanks go to my classmates and all my friends your material and moral support was extremely valuable to us during the research.

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LIST OF ACRONYMS

CV: Coefficient of Variability

DRC: Democratic Republic of Congo

ENSO: El-Niño Southern Oscillation

ICPAC: IGAD Climate Prediction and Application Centre

IOD: India Ocean Dipole

ITCZ: Inter-Tropical Convergence Zone

MAM: March-April-May

MJO: Madden Julian Oscillation

NCEP: national Centre for Environmental Prediction

NOAA: National Oceanic and Atmospheric Administration

OND: October-November-December

QBO: Quasi-Biennial Oscillation

SD: Standard Deviation

SLP: Sea Level Pressure

SOI: Southern Oscillation Index

SST: Sea Surface Temperature

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

Rainfall is very important weather and climate parameter that affects social and economic activities of a country. This is particularly true in countries like Rwanda whose agriculture is rain- fed. Recent studies have shown that climate change manifest itself in shift of the mean and/ or change in the variance. Increased variance lead to high frequency of occurrence of extreme events. Some of the extreme events that have been observed in the recent past include floods, landslides and drought episodes constitute the major repetitive natural disasters for Rwanda and are often linked with El Niño Southern Oscillation (ENSO) episodes. Rwanda suffered serious floods linked to the El-Niño episode of 1997/98 which destroyed a large number of agricultural plantations and ecosystems occupying the swamps of Nyabarongo and Akanyaru river basins. Prolonged drought of 1999 to 2000 seriously affected Bugesera. Landslides are common in the North (Gakenke, Cyeru, Rulindo, Butaro, and Kinihira) and the West (Nyamasheke, Karongi and Ngororero) of the country, including those that occurred in the period 2001/2002.

One of the factors that contribute to vulnerability of communities to extreme climate events is lack of sufficient information on the characteristics of these extreme climate events. In addition to the climate change impacts, population and infrastructure continue to develop in areas that are vulnerable to extreme events such as flooding and storm damage. Furthermore, land use changes can often further increase vulnerability, hence increasing the potential for catastrophic impacts from climate extremes, such as flooding due to extreme precipitation events. Therefore the study of the characteristics of extreme rainfall events will help the country in the decision making as well as an early warning system.

1.2 PROBLEM STATEMENT

Extreme rainfall events often have negative impacts both the society and economy of a country. The early warning system require adequate understanding of the characteristics of extreme rainfall events. However, few studies on this subject have been carried out over Rwanda.

Therefore, lack of insufficient knowledge on the systems associated with the extreme rainfall makes it difficult to predict the occurrence of such devastating events.

1.3 HYPOTHESIS OF THE STUDY

Improved understanding of the characteristics of extreme rainfall event will lead to improved skill of forecasting rainfall over Rwanda. This information will enhance the efficiency of policy planning and implementation of early warning systems as well as development and management of agricultural, water resources and other rainfall-dependent sectors of the economy.

1.4 OBJECTIVES OF STUDY

The main objective of this study is to investigate the extreme rainfall events over Rwanda during both March to May (MAM) and October to December (OND) seasons.

In order to achieve main objective, the following specific objectives will conducted:

1. Determination of spatial variability and temporal pattern of rainfall over Rwanda
2. Identify the extreme rainfall events.
3. Examine the weather systems associated with the extreme rainfall over Rwanda

1.5 JUSTIFICATION OF STUDY

Rainfall is an essential input into Rwanda’s economy. It influences the performance of agriculture sector that employs many people in the country. For that reason, studying the characteristics of extreme rainfall in Rwanda will be importance in both policy planning and implementation of early warning systems as well as development and management of agricultural, water resources and other rainfall-dependent sectors of the economy.

1.6 AREA OF STUDY

Rwanda is located in Central/Eastern Africa and south of the equator between latitudes $1^{o}00'S$ and $3^{o}00'S$ and longitudes $28^{o}50'E$ and $31^{o}00'E$. It is the world's 149^{th} largest country with a total area of $26,338 km^2$. It is comparable in size to Haiti or the state of Maryland in the United States. The population of Rwanda is about 12,000,000; the capital city is Kigali. It is bordered by Uganda to the north, Burundi to the south, Tanzania to the east and Democratic Republic of Congo (DRC) to the west. Rwanda has many lakes, the largest being Lake Kivu. This lake occupies the floor of the Albertine Rift along most of the length of Rwanda's western border and with a maximum depth of 480 metres (1,575 ft). Therefore it is one of the twenty deepest lakes in the world. Other sizeable lakes include Burera, Ruhondo, Muhazi, Rweru, and Ihema, the last being the largest of a string of lakes in the eastern plains of Akagera National Park.

Furthermore, there are numerous rivers in Rwanda. However, the main rivers are Nyabarongo, which rises in the south-west, flows north, east, and southeast before merging with the Ruvubu to form the Kagera. The Kagera then flows due north along the eastern border with Tanzania. The country is characterized by complex topography that includes mountains, valleys and hills. Mountains dominate central and western Rwanda. The highest peaks are found in the Virunga volcano chain in the northwest; this includes Mount Karisimbi, Rwanda's highest point, at 4,507m (14,787 ft).

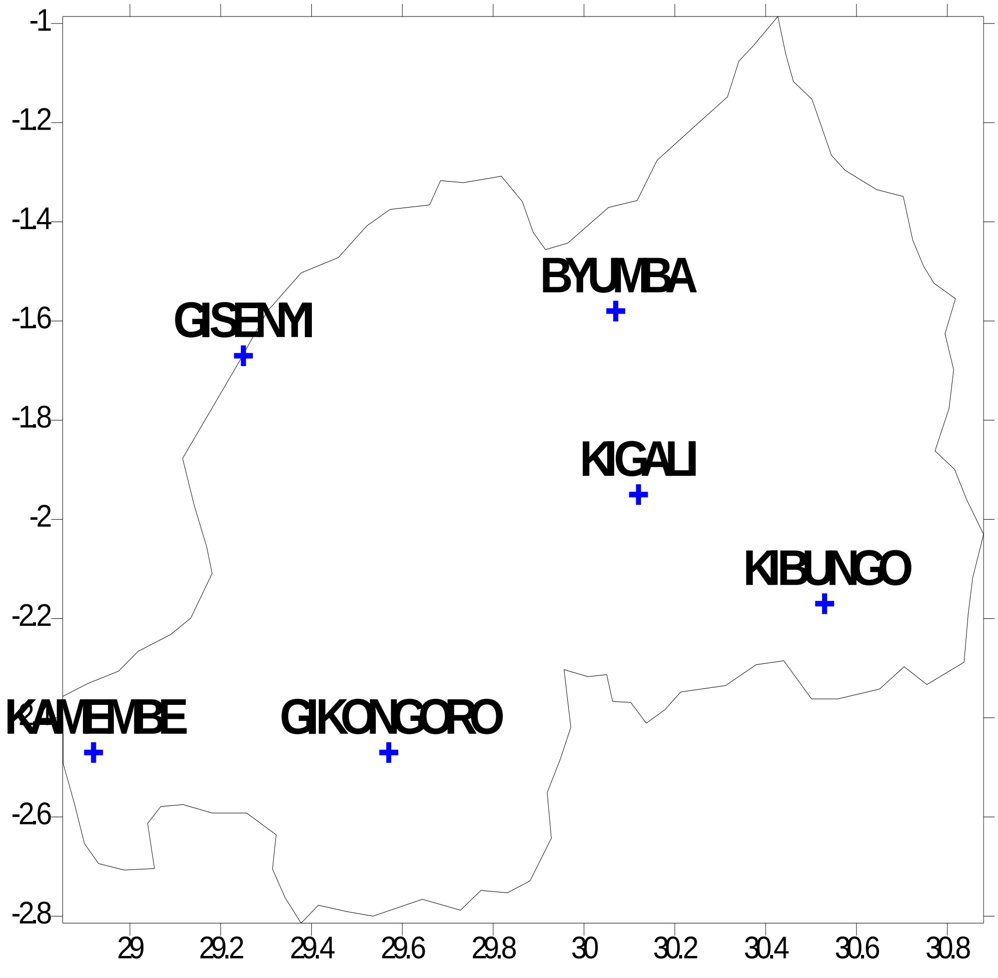


Figure 1. Area of study

1.7. CLIMATE CHARACTERISTICS OF RWANDA

Although the country is located within the equatorial belt, its climate is strictly not of the equatorial rain forest type. It has a modified humid climate including rain forest and Savannah. The central and eastern part of the country is generally of semi-arid type owing to its position in the rainy shadow of the western highlands. Rwanda has two major rain seasons in a year; the first season runs from March to May and the second one runs from mid-September to mid-December. These are separated by two dry seasons; the major dry season is from June to August and the shorter one running from mid-December to February. Rainfall varies geographically, with the western and North-Western regions of the country receiving more precipitation annually than the Central, Eastern and South-eastern regions.

Some of the main factors that influence rainfall over Rwanda include: The Inter-Tropical Convergence Zone (ITCZ), Sub-tropical Anticyclones, Tropical Cyclones, Congo air mass and Global tele-connections. These systems are detailed in the sub-sections that follow.

1.7.1 INTER-TROPICAL CONVERGENCE ZONE (ITCZ)

Over the East Africa, the ITCZ is the major synoptic-scale system that controls seasonal rainfall (Asnani, 2005). The fluctuations in the rainfall amounts and distribution have been attributed to the anomalies in the large scale factors that influence the characteristics of the ITCZ over East Africa region. The location of the ITCZ together with its overall horizontal and vertical structures largely depends on the intensity of the north-easterly and south-easterly winds which are in turn driven by the subtropical anticyclones. Comprehensive details of the ITCZ over East Africa region can be found in Ogallo (1993), Ininda (1995) and Okoola (1996) among others.

1.7.2 SUB-TROPICAL ANTICYCLONES

Sub-tropical anticyclones are synoptic scale quasi-permanent high pressure cells. They are characterized by anticyclonic circulation which gives rise to subsidence and low level horizontal velocity divergence of air masses. The four major anticyclones which influence the flow of winds over the region are; the St. Helena high pressure system to the south west of Atlantic ocean, the Mascarene high pressure system to south east Indian ocean, the Arabian high in the middle east and Azores high pressure system which control the position and the movement of ITCZ as well as the Congo Air mass regime over the central and south-east of Africa.

1.7.3 TROPICAL CYCLONES

The tropical cyclones that influence weather in eastern and southern Africa form in the West Indian Ocean equator-ward of 20^o latitude north of the equator. They usually form in the northern spring and late fall and move northwards into the Arabian Sea. The cyclones that have significant influence in eastern Africa rainfall are those that form in the south-west Indian Ocean from December to April.

1.7.4 GLOBAL SCALE AND REGIONAL SCALE SYSTEMS

El Niño Southern oscillation (ENSO), global sea surface temperatures (SSTs), Indian Ocean Dipole (IOD) and Quasi-biennial Oscillation (QBO) are the major climatic systems that affect rainfall over Rwanda through tele-connections. Other intra-seasonal waves such as the Madden Julian Oscillation (MJO) also influence rainfall patterns over Rwanda.

1.7.5 LOCAL SYSTEMS

Despite being located in the tropical belt, Rwanda experiences a temperate climate as a result of its high elevation. The north-western part is mountainous and volcanic with elevations over 2000m. Elevations reduce towards the central plateau (1500 - 2000m) of Rwanda and then again in the eastern plateau towards the border with Tanzania (less than 1500m). The highlands in the western regions enhance convective development through orographic lifting. However, eastern regions experience suppressed convection due the lack of orographic lifting.

CHAPTER TWO

2.0 LITERATURE REVIEW

Rainfall is very important weather and climate parameter that influence economic activities in east Africa as well as Rwanda. It is also climatic parameter over the tropical region with the largest space and time variability. The region of east Africa experiences two main rainfall seasons; March-May (MAM) and October-December (OND) (Omeny and Okoola, 2008). The systems that influence rainfall over East Africa include Intertropical Convergence Zone (ITCZ), monsoon wind, subtropical high-pressure systems, easterly/westerly waves, tropical cyclones, El-Niño Southern Oscillation (ENSO), jet stream, Quasi Biennial Oscillation (QBO), El Niño Southern Oscillation Index (ENSO), Congo air mass and Indian Ocean Dipole (IOD). These are sometimes linked with excess or deficits of rainfall resulting to floods or droughts (Camberlin and Okoola, 2003).

Over Rwanda rainfall is influenced by Inter Tropical Convergence Zone (ITCZ), regional and local effects, Congo air mass, tropical cyclones, El-Niño Southern Oscillation (ENSO), subtropical high-pressure systems and Lake Victoria air mass. The performance of a given rainy season does not only dependent in the overall total amount, but also requires an adequate distribution of the rains through the year. This is mainly important especially in the regions where they normally receive small amount of rains fall with a limited period of time. Rainfall information is important to reduce the impacts associated extreme rainfall events.

High frequency of rain days over western part of Rwanda usually occur between the third week of March and the second week of May. The convective activity over this region may be attributed to the strong westerly wind which bring moisture from Congo air mass. The highlands of these regions also enhance convective development through orographic lifting. Abundance of moisture for cloud formation hence rainfall is also promoted by the fact that this region is located near the Nyungwe national park (Joseph, 2014).

On the other hand, most of the active rain days over central part of Rwanda occur within the month of April to the second week of March. The convective activity over this region may be attributed to easterly wind which inject moisture from Lake Victoria and Indian Ocean and the highlands of these region also enhance convective development through orographic lifting (Joseph, 2014)

In the northern part of Rwanda, majority of the rain days occur between the third week of March and the third week of May. The convective activity over this region may be attributed to the strong westerly wind which bring moisture from Congo basin. The highlands of these regions (volcanic region) also enhance convective development through orographic lifting (Joseph, 2014).

The high frequency of rain days over eastern part of Rwanda occur within the month of April and the first two weeks of March. Low convective development to the Eastern part of the country may be attributed to Easterly wind which inject moisture from Lake Victoria and Indian Ocean and to the lack of orographic lifting (Joseph, 2014).

Over Rwanda during MAM season on day by day basis rainfall increases westward; the highest rainfall is in the south-west of the country and low rainfall in the East of the country. High rainfall over this region may be attributed to the strong westerly wind which inject moisture from Congo basin. The highlands of these regions also enhance convective rainfall development through orographic lifting. The low rainfall over the eastern part of the country may be attributed to the easterly wind which injects moisture from Lake Victoria and Indian Ocean and to the lack of orographic lifting (Joseph, 2014).

Since 1902, a series of severe famines, following prolonged droughts episodes has been recorded in Rwanda. In 1999/2000, the east and south-eastern regions of the country were seriously affected by a low agricultural production associated with the La Nina episode of 1999/2000. A similar event occurred again in 2005/2006. Also, an increase of frequent prolonged droughts has been experienced since the 1980's. Table 1 gives the historical perspectives of the drought impacts in Rwanda since 1902. (Rwanda Climate Report, 2009)

Table 1. Historical perspectives of the drought impacts in Rwanda since 1902 (Source, NAPA Report, 2006)

El Nino/La Nina Episodes and Famines in Rwanda Period	El Nino /La Nina Episodes	Catastrophe	Consequence	Affected Region
1902/03	El-Nino Episode		"Kimwaramwara" Famine	Butare
1916/1918	La Nina	-	"Rumanura" Famine	Generalized
1924/25	La Nina	-	Famine	Various regions
1943/44	La Nina	Drought	"Ruzagayura" Famine	Generalized
1963	El-Nino Episode	Diluvian rain	"Rwagakoco" famine	Generalized
1982/83	El-Nino Episode	Drought, high temperatures	Low agricultural production	Generalized
1986/87	Episode El-Nino	high temperatures	-	-
1990	La Nina	-	Famine	Various regions
1991/92	El-Nino Episode	Drought	-	East
1997/98	El-Nino Episode	Drought, high temperatures	-	-
1999/2000	La Nina	Drought, high temperatures	Famine	East of country especially Bugesera
2005/2006	La Nina	High temperatures and prolonged drought	Famine; water sources drying; tendency of desertification	Generalized; East and South mostly affected

CHAPTER THREE

3.0 DATA AND METHODOLOGY

This chapter is comprised of the data used during the research and various methods which were applied in order to achieve the objectives.

3.1 DATA

The data to be used in the study include monthly rainfall totals from six representative rainfall stations and reanalysis atmospheric circulation data.

3.1.1 RAINFALL DATA

The rainfall data used in this work are monthly rainfall totals that were representative of various climatic rainfall homogeneous zones over Rwanda. Rainfall data cover the period of 44 years, i.e. from 1971 to 2014 for 6 meteorological stations. The monthly rainfall data were obtained from Rwanda Meteorological Agency (Meteo-Rwanda) headquarters located at Kigali.

Table 2. List of rainfall stations and their location

N^o	**stations**	**latitude**	**longitude**
1	KIGALI	1.95^{o}S	30.12^{o}E
2	KIBUNGO	2.17^{o}S	30.53^{o}E
3	GIKONGORO	2.47^{o}S	29.57^{o}E
4	BYUMBA	1.58^{o}S	30.07^{o}E
5	KAMEMBE	2.47^{o}S	28.92^{o}E
6	GISENYI	1.67^{o}S	29.25^{o}E

3.1.2 ATMOSPHERIC CIRCULATION DATA

The wind data at 850hpa and 200hpa atmospheric levels were analyzed. The analysis was done using the NCEP/NOAA Plotting Page. The plots were analyzed to depict the atmospheric patterns the low and middle level circulation patterns as well as moisture advection.

Sea level pressure (SLP) data from the NCEP/NOAA Reanalysis website were also plotted. This data is useful in showing the pressure patterns than influence both wind flow and moisture transport.

Sea surface temperature (SST) data from the NCEP/NOAA reanalysis website were plotted. this data is useful in investigation of Ocean temperature pattern.

3.2 METHODOLOGY

To achieve the objective of the study, various methods were used; these methods are discussed in the subsection below.

3.2.1 DATA QUALITY CONTROL

Data quality control consists of tests designed to ensure that meteorological data meet certain standards. It involves looking for errors in the acquired data sets. Data quality control involves estimation of missing data and homogeneity test. These methods are briefly discussed next.

3.2.1.1 ESTIMATION OF MISSING DATA

In this study, missing data were estimated using the correlation and regression techniques. The station that was highly correlated with the one with missing data was initially identified. Regression equations were then derived for the two stations for the period during which both stations have the data. The regression equation was later used to estimate the missing data. Upon filling in the missing data gaps, the quality of the data was assessed before any analysis was undertaken. It is worthy to mention that less than seven percent of the rainfall was estimated. Continuous missing data were not estimated and such stations were excluded from this study.

Correlation coefficient $$r_{xy} = \frac{\frac{1}{n}\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\left[\frac{1}{n}\sum_{i=1}^{n}(X_i - \bar{X})^2 \frac{1}{n}(Y_i - \bar{Y})^2\right]^{\frac{1}{2}}}$$

Where X_i are data values at station of missing records, Y_i are the corresponding data values from nearby station with complete records and whereby the missing value is calculated as $X_i = r_{xy} Y_i$

3.2.1.2 HOMOGENEITY TEST

The homogeneity test is important to data quality control. The most popular methods are double and single mass curves. In this study the single mass curve will be used to test data homogeneity for the stations. The method involves plotting the accumulated seasonal rainfall record at a station against time.

3.2.2 SPATIAL AND TEMPORAL VARIABILITY PATERNS OF RAINFALL

3.2.2.1 SPATIAL VARIABILITY OF RAINFALL OVER RWANDA

Spatial variability of seasonal and annual rainfall was analyzed using Suffer software that will provide spatial map showing the rainfall distribution over the whole country. Therefore, this method will facilitate understanding how rainfall varies from one place to another.

3.2.2.2 DETERMINITION OF TEMPORAL PATTERN OF RAINFALL OVER RWANDA

In this study temporal variability was investigated using graphical and statistical methods. Graphical method will include plotting of time series of seasonal rainfall and frequency distribution. The statistical method will include;

(a) The computation of coefficient of variability (CV) which is given by the formula

$$\text{CV} = \frac{\sigma}{\overline{X}} 100\%$$

Where $\overline{X}$ represent mean and σ is a standard deviation. Higher CV values indicate highest variability while low values indicate least variability. Therefore, high CV values indicate that the station studied has tendency to experience extreme events. The skewness and kurtosis measures deviations of the rainfall pattern from the normal distributions.

(b) Skewness = $\dfrac{\sum_{i=i}^{n}\left(X_i - \overline{X}\right)^3}{N}$

(c) Kurtosis = $\dfrac{\sum_{i=i}^{n}\left(X_i - \overline{X}\right)^4}{N}$

(d) Probability of occurrence of extreme rainfall events. This was determined by the ratio of the number of the given events to the total number of events in the series.

3.2.3 DETERMINATION OF EXTREME EVENTS

The identification of dry and wet years was done using the following formulae:

Dry years events $X < \overline{X} - \sigma$

Wet years events $X > \overline{X} + \sigma$

Where $\overline{X}$ represent mean and σ is a standard deviation

3.2.4 WEATHER SYSTEMS ASSOCIATED WITH EXTREME RAINFALL OVER RWANDA

Case studies of selected dry and wet years were selected. The events were studied in regard to the wind circulation, sea surface temperatures (SSTs) and sea level pressure (SLP) composite patterns during the extreme events. The same analysis as composite is repeated for individual of extreme years (2 or 3 cases)

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

This chapter presents the results and discussion from the analysis.

4.1 RESULT FROM DATA QUALITY CONTROL

The objective of data quality control is to detect and remove errors in the data sets. however data quality control involves estimation of missing gaps and homogeneity test.

In practice it is common to obtain missing rainfall data from the set of records. there are numerous reason for getting missing data from database; some of them are absence of the observers because of different reason; one example is in 1994 during genocide, therefore the correlation and regression techniques was used for estimation of missing record. Given that the stations in the study had no more than 10% of their data missing, the analysis was therefore pursued using the same data.

4.1.1 TEST FOR DATA HOMOGENEITY

The single mass curves was used in this study to tests for the homogeneity of the data. Single mass curve is a plot of annual cumulative rainfall against time; the mass curve of the stations were almost straight lines indicating that data from the stations are almost homogeneous. Figure 2 show the homogeneity test for six stations. It is therefore evident that the rainfall data for these stations is useful for research purposes.

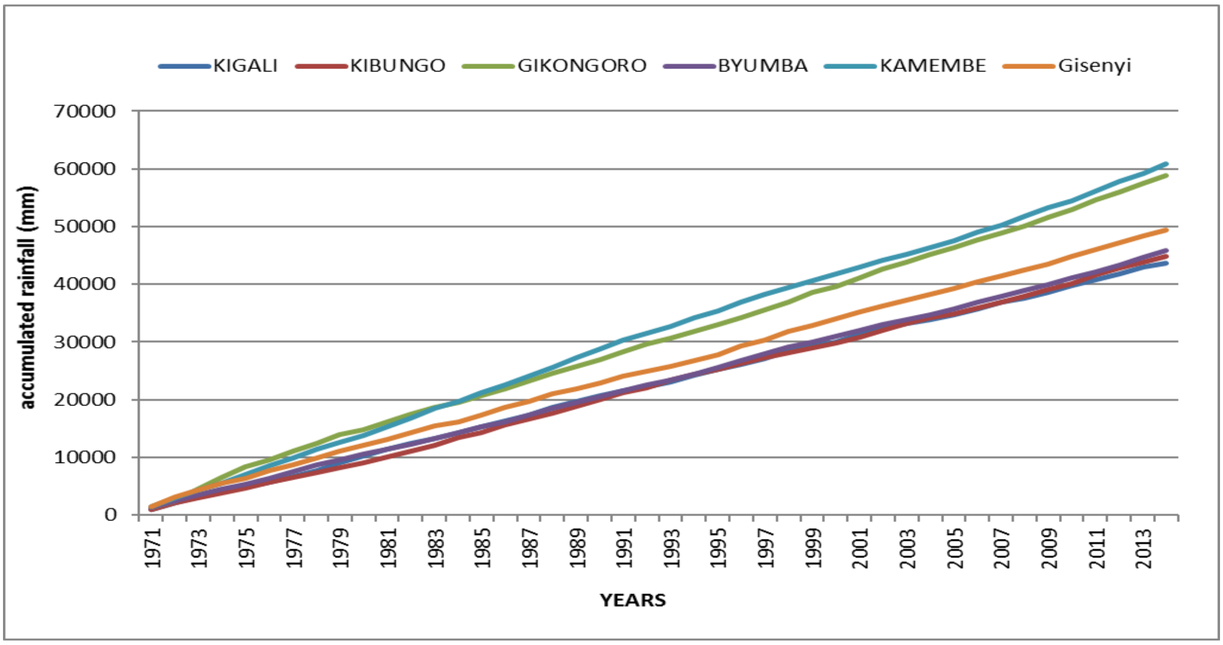


Figure 2. single mass curve for Kigali, Kibungo, Gikongoro, Byumba, Kamembe and Gisenyi (1971/2014)

4.2 RESULT FROM SPATIAL RAINFALL DISTRIBUTION OVER RWANDA

Figures 3 and 4 shows the spatial distribution of the seasonal and annual rainfall in Rwanda. In general the rainfall increases from east to west of the country.

For March – May, (Figure 3a) the rainfall amount ranges from 350mm to 430mm. The minimum is in the northeast regions of Gabiro and Kagitumba, while the maximum is located in the southwest. There is a relative minimum over Bugesera area (Karama). Moreover, high rainfall amounts are observed at Kibungo (Gahororo), the Nyungwe natural forest region, Gishwati natural forest region and Byumba province (Byumba). The region of enhanced rainfall extendes from the southwest sector (Mibirizi, Wisumo, Kibeho) all along Congo Nil Crest to northern highland (Rwankeri, Kinigi, Ruhengeri, Byumba), excluding the Lake Kivu coast. During the OND season (Figure 3b), the rainfall amount range from 315 - 470mm. This shows a slight decrease in rainfall compared to MAM rainfall. The minimum is located in the east (Umutara, National park and eastern Kibungo) while the maximum is in the southwest (Mibirizi). The relative minimum arise over Bugesera area and the relative maximum was observed over northwestern highland (Kinigi). The wide area of much rainfall amount was observed in the west and the north (Mibirizi, Wisumo, Mubuga, Kinigi, Byumba).

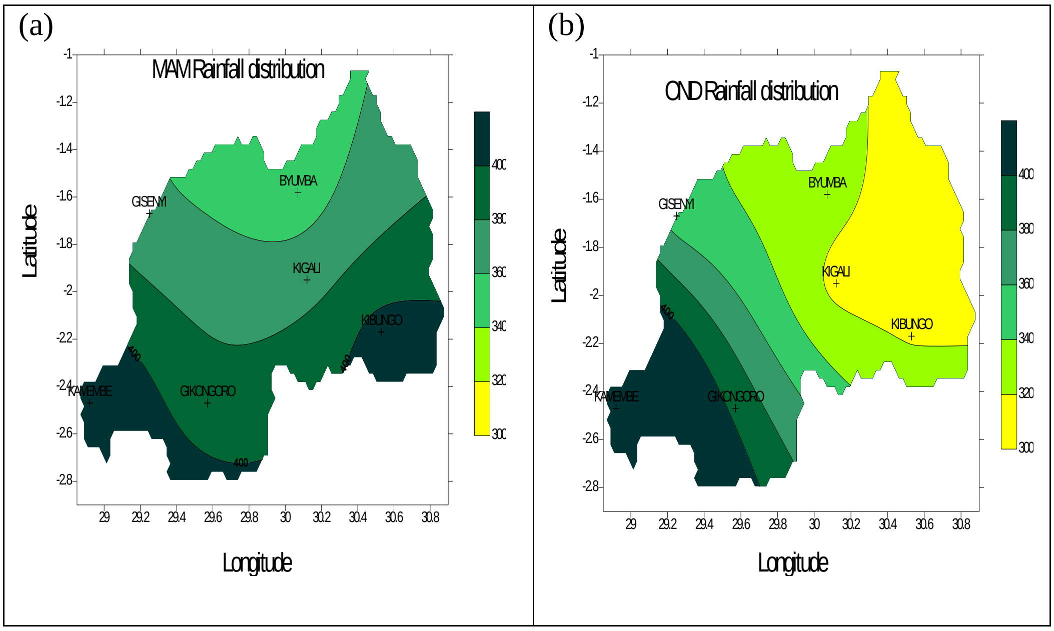


Figure 3. Spatial distribution of mean total rainfall over Rwanda during MAM and OND in left and right panels respectively over the period 1971-2014

The annual rainfall distribution (Figure 4) is very similar to the OND distribution. The rainfall amount varies from 900mm over northeast (eastern Umutara) to 1500mm over Nyungwe natural forest and northwestern highland (kinigi). Lowest amounts are observed over Bugesera area (Karama, 900mm) while the regions of Kibungo (Gahororo) southwest (Mibirizi) and Gishwati natural forest (Muramba) experience the highest amounts. A similar pattern is also observed in the western half of the country extending from Byumba to Kibeho and from Kinigi to Mibirizi including the Lake Kivu coast.

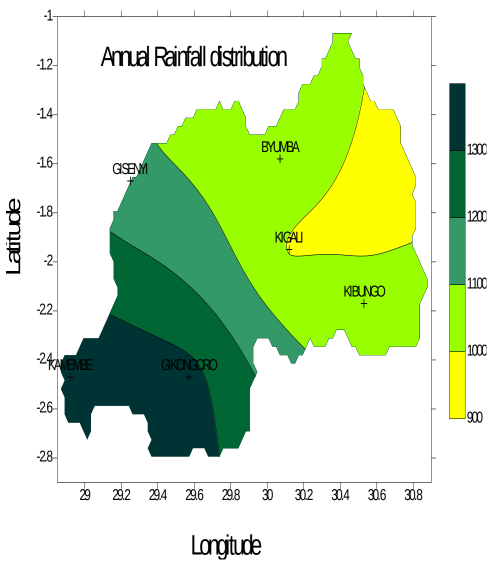


Figure 4. Spatial distribution of mean total annual rainfall over Rwanda for the period 1971-2014

4.3 RESULT FROM TEMPORAL RAINFALL OVER RWANDA

4.3.1 TEMPORAL DISTRIBUTION OF MEAN MONTHLY RAINFALL

The temporal distribution of rainfall over Rwanda was investigated. The rainfall regime over Rwanda was found to be bimodal as indicated in Figures 5 to 10. The long rains occur in March to May (MAM) season while the short rains last from October to December (OND). It is also noted that the June to August period forms the driest season in Rwanda.

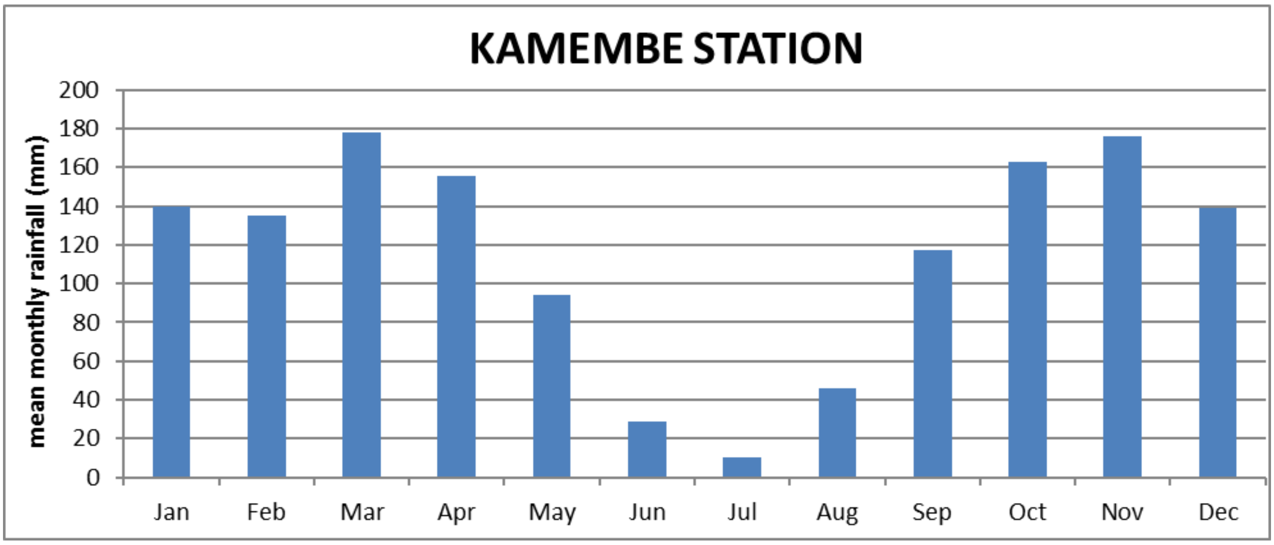


Figure 5. Mean monthly rainfall for Kamembe station for the period 1971 to 2014

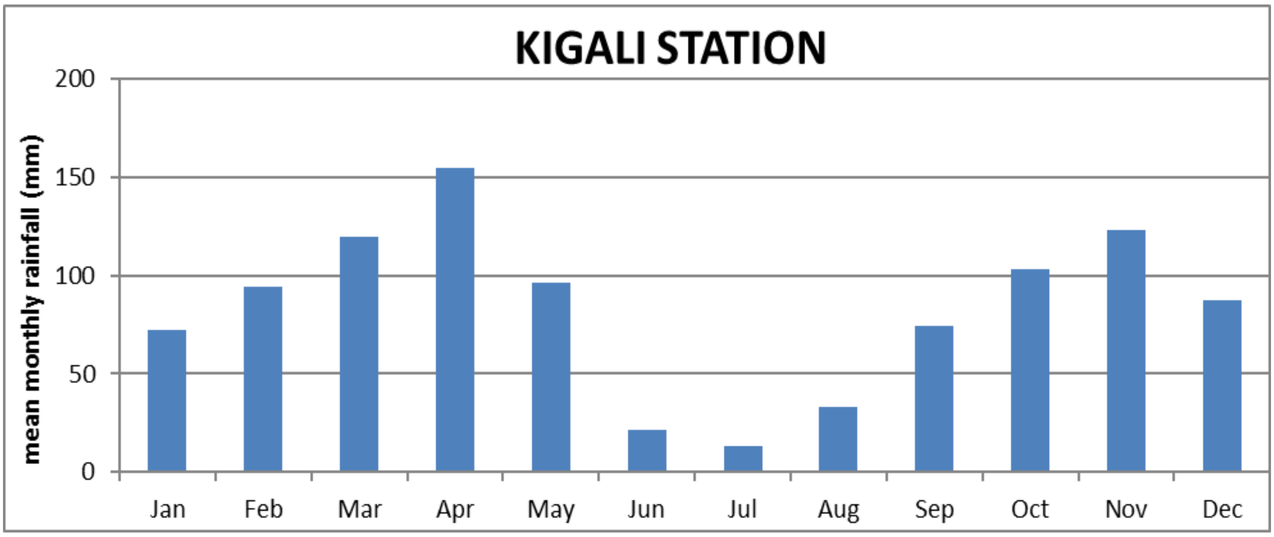


Figure 6. Mean monthly rainfall for Kigali station for the period 1971 to 2014

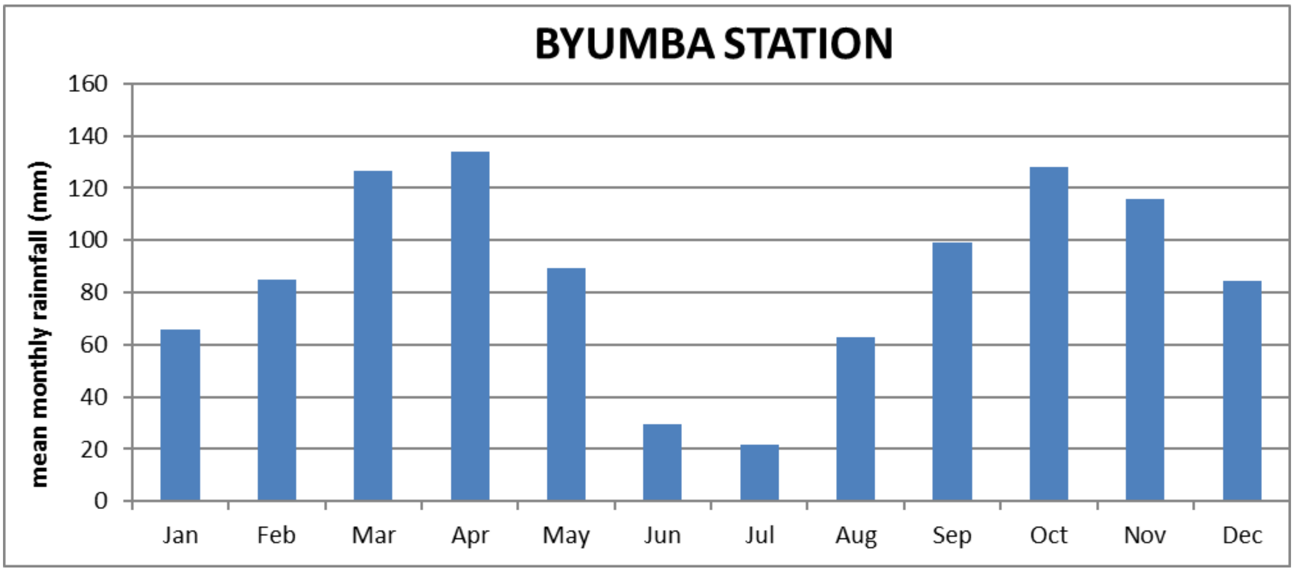


Figure 7. Mean monthly rainfall for Byumba station for the period 1971 to 2014

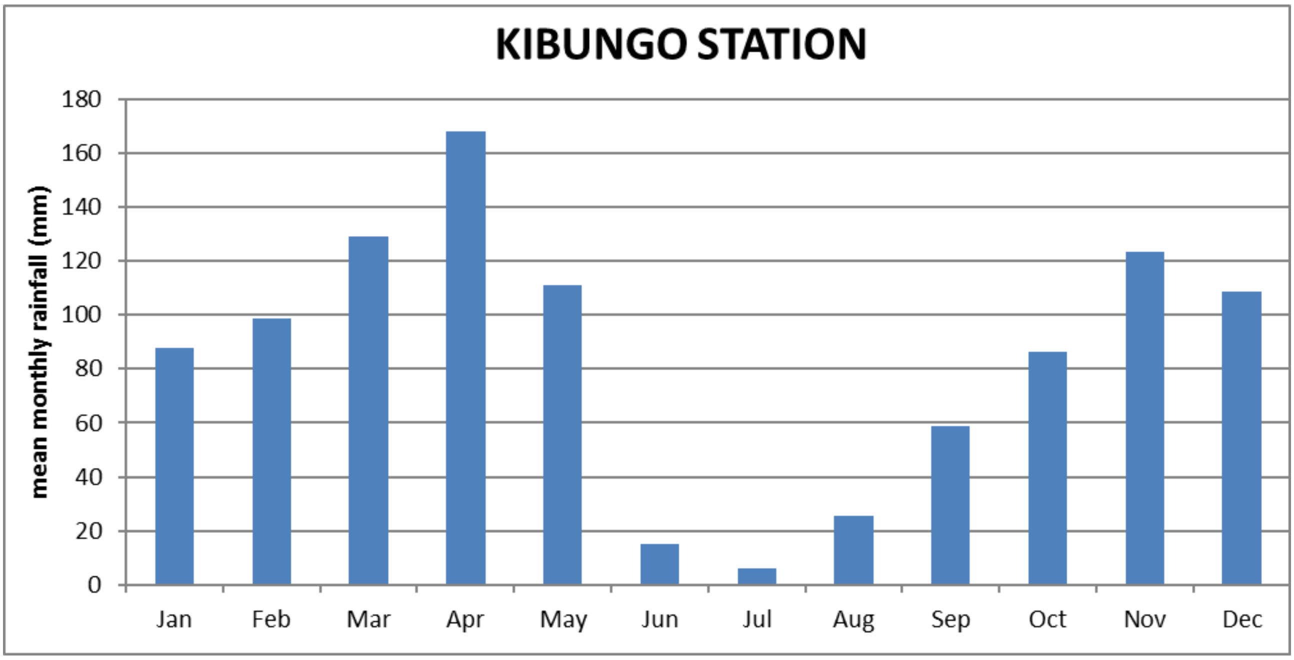


Figure 8. Mean monthly rainfall for Kibungo station for the period 1971 to 2014

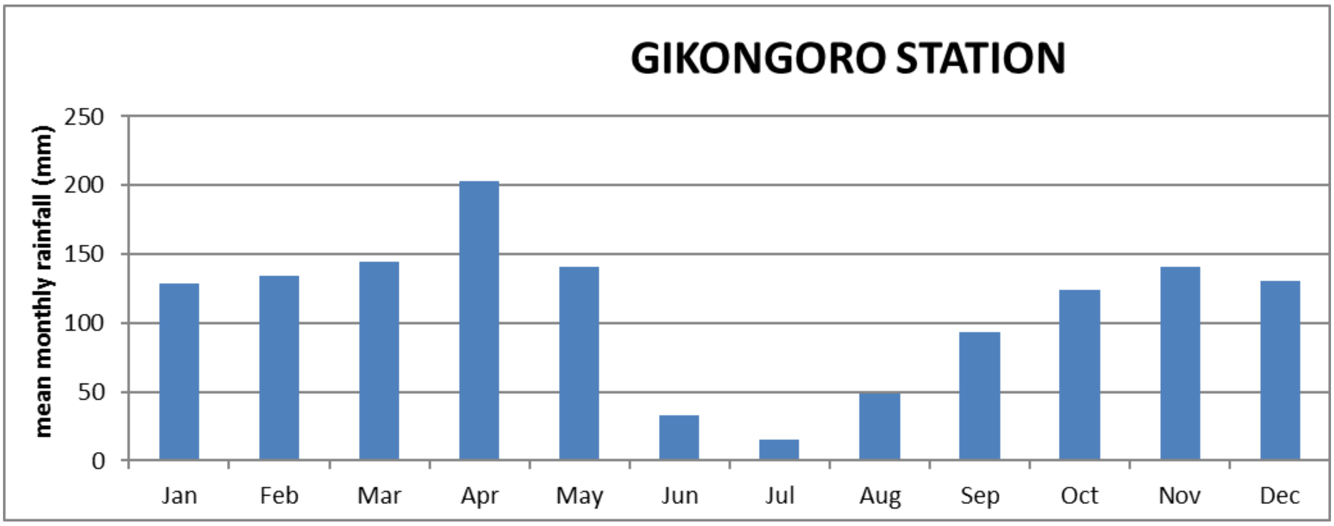


Figure 9. Mean monthly rainfall for Gikongoro station for the period 1971 to 2014

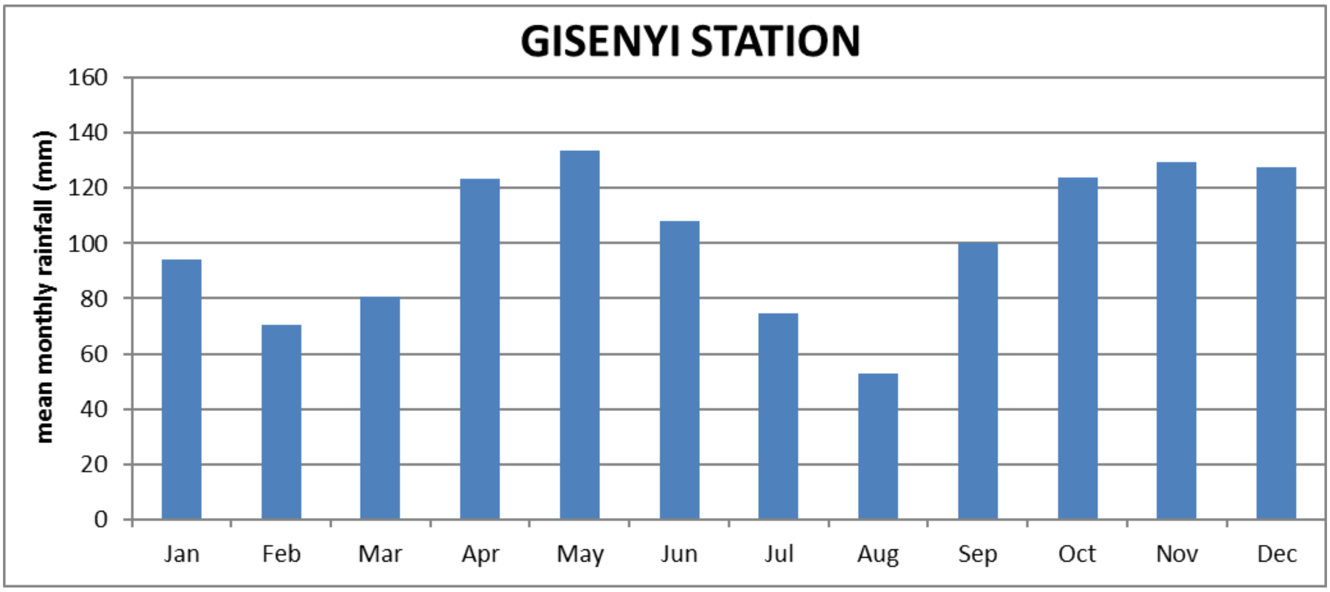


Figure 10. Mean monthly rainfall for Gisenyi station for the period 1971 to 2014

4.3.2 SEASONAL AND ANNUAL RAINFALL ANOMALIES

Figures 11 to 13 shows the anomalies for both seasonal and annual time series for the representative stations. During MAM, the representative stations show that depressed rainfall was observed in 1980, 1984, 1986, 1992, 1996, 2007 and 2014 among others. On the other hand, the events of enhanced MAM rainfall include 2013, 2012, 2006 and 1998. Moreover, other extreme events include 1973, 1979 and 1988 were record enhanced rainfall was reported in Gikongoro, Kigali and Gisenyi respectively. This observation shows that MAM rainfall also has high spatial variability in Rwanda.

During OND, enhanced rainfall events include 1972, 1975, 1983, 1997, 2009, 2001, 2011 and 2012. On the other hand, the depressed rainfall anomalies were recorded in 1974, 1979, 1981, 1993, 1996, 1999, 2000, 2003, 2004, 2005, 2008 and 2010 . Extremely enhanced or depressed rainfall events are usually related to the occurrence of floods or droughts that have negative impacts on both the society and the economy of Rwanda.

The annual rainfall anomalies in Figure 13 shows that rainfall over Rwanda has high inter-annual variability. However, the period 2002 to 2009 has a marked reduction in the inter-annual variability.

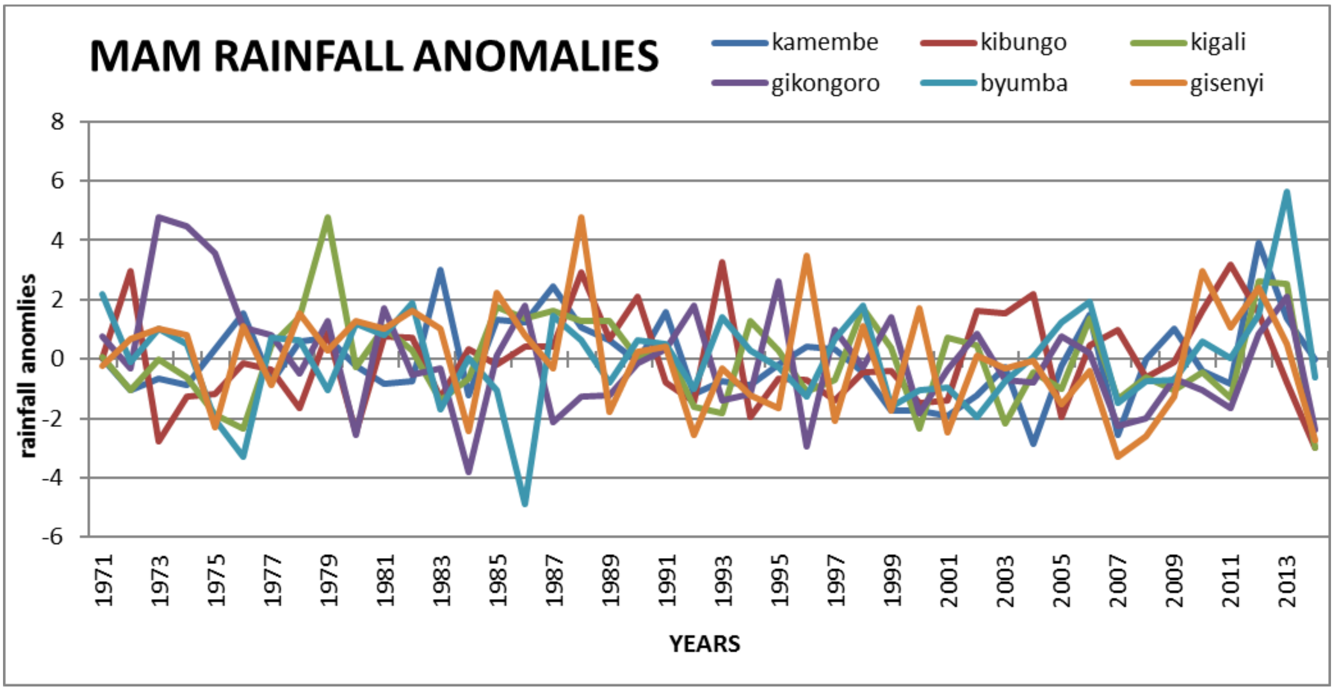


Figure 11. MAM rainfall anomalies for the period 1971 to 2014

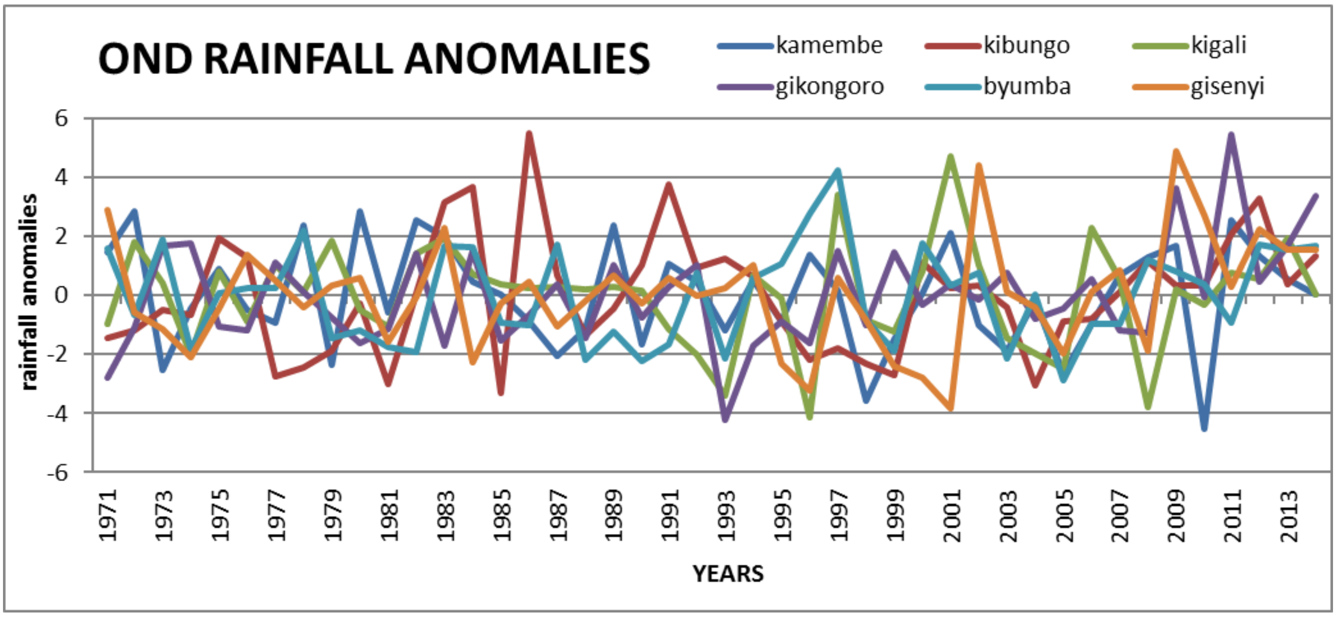


Figure 12. OND rainfall anomalies for the period 1971 to 2014

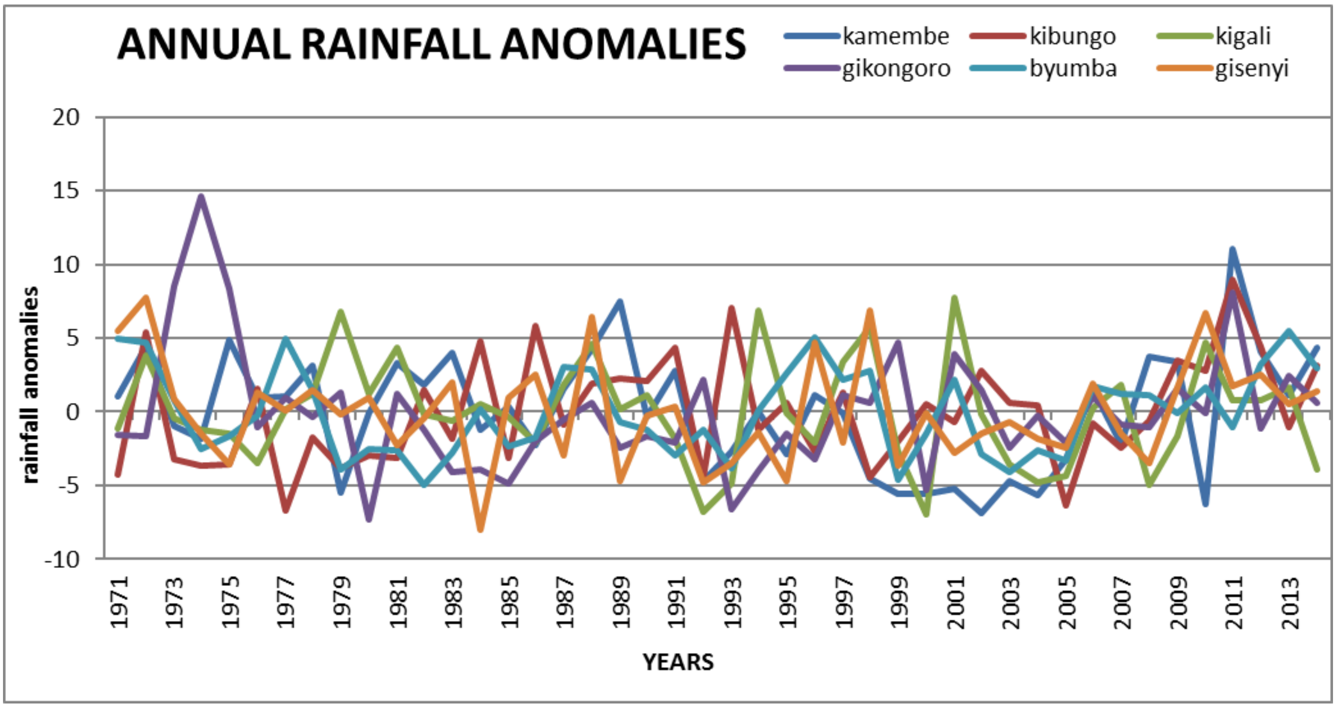


Figure 13. Annual rainfall anomalies for the period 1971 to 2014

4.3.3 COEFFICIENT OF VARIABILITY (CV)

In this study an attempt has been made to examine monthly, MAM, OND and annual rainfall variability over Rwanda using the method of the coefficient of variability. The results from monthly rainfall variability showed that during dry months has high coefficient of variability more than 110% of coefficient of variability while wet months showed the low coefficient of variability less than 50%. Over most region, the OND season has lower coefficient of variability compared to MAM indicating that the OND is more reliable than MAM

Results from MAM seasonal coefficient of variation found that the largest value of variability was observed at Kigali and Gikongoro, 46.10% and 45.29% respectively. The lowest value of variability was found at Kamembe 36.20%.

During OND, the highest value of variability was observed at Kibungo and Gikongoro, 42.62% and 44.37% respectively while the lowest of 27.29% was reported in Kamembe.

Annual coefficient of variability showed that the least value of variability in Kamembe (27.29%) while high values of variability of 50.88%, 52.54% and 51.96% were observed in Kigali, Gisenyi and Gikongoro respectively. Table 3 shows the results of monthly, wet seasonal and annual coefficient of variability over Rwanda. Table 3 Result of monthly, seasonal and annual rainfall variability.

Table 4 Result of monthly, seasonal and annual rainfall variability

STATIONS	MONTHLY	MONTHLY VARIABILITY	SEASONAL	SEASONAL VARIABILITY	ANNUAL VARIABILITY
GISENYI AERO	DECEMBER	45.67	MAM	44.10	52.54
	JANUARY	52.57			
	FEBRUARY	51.05			
	MARCH	40.71			
	APRIL	46.05			
	MAY	45.54			
	JUNE	81.08	OND	38.44	
	JULY	125.30			
	AUGUST	83.60			
	SEPTEMBER	44.82			
	OCTOBER	31.04			
	NOVEMBER	40.61			
KIGALI AERO	DECEMBER	40.69	MAM	46.10	50.88
	JANUARY	48.87			
	FEBRUARY	57.94			
	MARCH	45.39			
	APRIL	35.89			
	MAY	63.36			
	JUNE	114.07	OND	38.72	
	JULY	216.14			
	AUGUST	91.17			
	SEPTEMBER	53.06			
	OCTOBER	38.81			
	NOVEMBER	37.24			
KAMEMBE AERO	DECEMBER	28.21	MAM	36.20	36.11
	JANUARY	37.35			
	FEBRUARY	31.58			
	MARCH	32.71			
	APRIL	36.07			
	MAY	42.97			
	JUNE	79.09	OND	27.29	
	JULY	165.40			
	AUGUST	80.31			
	SEPTEMBER	36.13			
	OCTOBER	29.57			
	NOVEMBER	24.45			

Table 5 Result of monthly, seasonal and annual rainfall variability (continued)

STATIONS	MONTHLY	MONTHLY VARIABILITY	SEASONAL	SEASONAL VARIABILITY	ANNUAL VARIABILITY
BYUMBA	DECEMBER	41.48	MAM	44.69	50.20
	JANUARY	61.80			
	FEBRUARY	54.48			
	MARCH	41.90			
	APRIL	38.75			
	MAY	57.57			
	JUNE	101.22	OND	38.99	
	JULY	124.90			
	AUGUST	75.10			
	SEPTEMBER	47.96			
	OCTOBER	36.99			
	NOVEMBER	39.37			
KIBUNGO	DECEMBER	38.98	MAM	40.30	46.14
	JANUARY	49.61			
	FEBRUARY	40.30			
	MARCH	41.86			
	APRIL	33.71			
	MAY	48.45			
	JUNE	112.34	OND	42.62	
	JULY	214.27			
	AUGUST	109.96			
	SEPTEMBER	48.32			
	OCTOBER	57.02			
	NOVEMBER	35.76			
GIKONGORO	DECEMBER	47.01	MAM	45.29	51.96
	JANUARY	51.21			
	FEBRUARY	51.60			
	MARCH	39.14			
	APRIL	38.42			
	MAY	61.48			
	JUNE	116.76	OND	44.37	
	JULY	156.73			
	AUGUST	96.30			
	SEPTEMBER	58.90			
	OCTOBER	40.45			
	NOVEMBER	45.42			

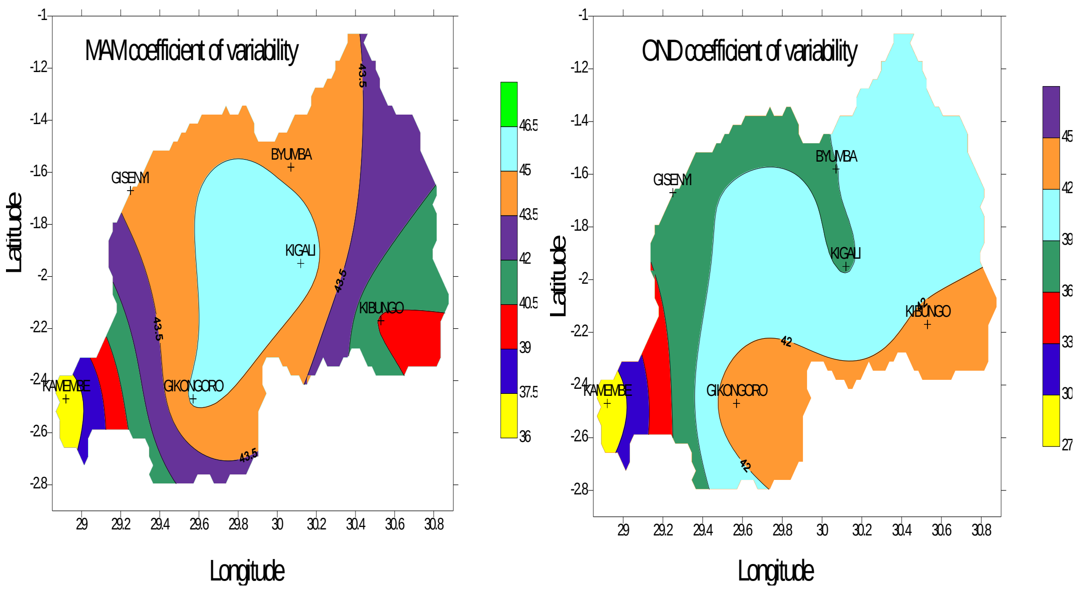


Figure 14. The spatial pattern of coefficient of variation (%) for the MAM and OND rainfall

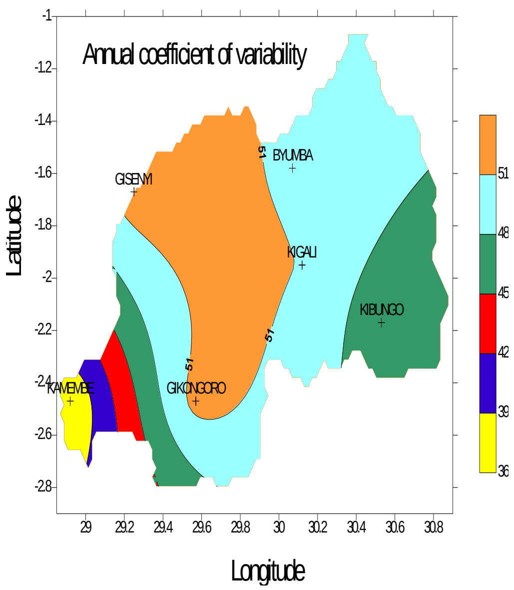


Figure 15. The spatial pattern of coefficient of variation (%) for the annual rainfall

4.3.4 SKEWNESS AND KURTOSIS

Table 6. Results of monthly, seasonal and annual skewness and kurtosis

Stations	months	Monthly skewness	Seasons	Seasonal skewness	Annual skewness	Monthly kurtosis	Seasonal kurtosis	Annual kurtosis
KAMEMBE	JAN	0.75	MAM	0.75	0.05	1.30	0.74	-0.78
	FEB	0.15				-0.60		
	MAR	0.76				0.19		
	APR	0.61				0.11		
	MAY	0.26				-0.16		
	JUN	0.65				-0.25		
	JULY	2.43	OND	-0.34		6.47	-0.31	
	AUG	0.67				-0.60		
	SEP	0.51				1.42		
	OCT	0.23				-1.20		
	NOV	0.09				-0.73		
	DEC	0.51				0.87		
KIBUNGO	JAN	0.54	MAM	0.31	0.44	-0.29	-0.50	-0.39
	FEB	0.76				0.24		
	MAR	0.44				-0.54		
	APR	0.39				-0.69		
	MAY	0.36				0.45		
	JUN	1.11				0.39		
	JULY	2.88	OND	0.54		8.88	0.17	
	AUG	1.95				4.85		
	SEP	0.26				-0.71		
	OCT	0.90				-0.15		
	NOV	0.14				0.11		
	DEC	-0.04				-0.70		
KIGALI	JAN	0.60	MAM	0.62	0.12	-0.26	1.09	-0.48
	FEB	1.90				5.21		
	MAR	1.80				4.30		
	APR	0.93				0.59		
	MAY	1.49				2.81		
	JUN	1.33				1.58		
	JULY	2.92	OND	-0.04		8.53	0.79	
	AUG	1.26				1.86		
	SEP	0.83				1.08		
	OCT	0.41				0.71		
	NOV	0.47				-0.40		
	DEC	0.05				-0.97		

Table 7 Results of monthly, seasonal and annual skewness and kurtosis (continued)

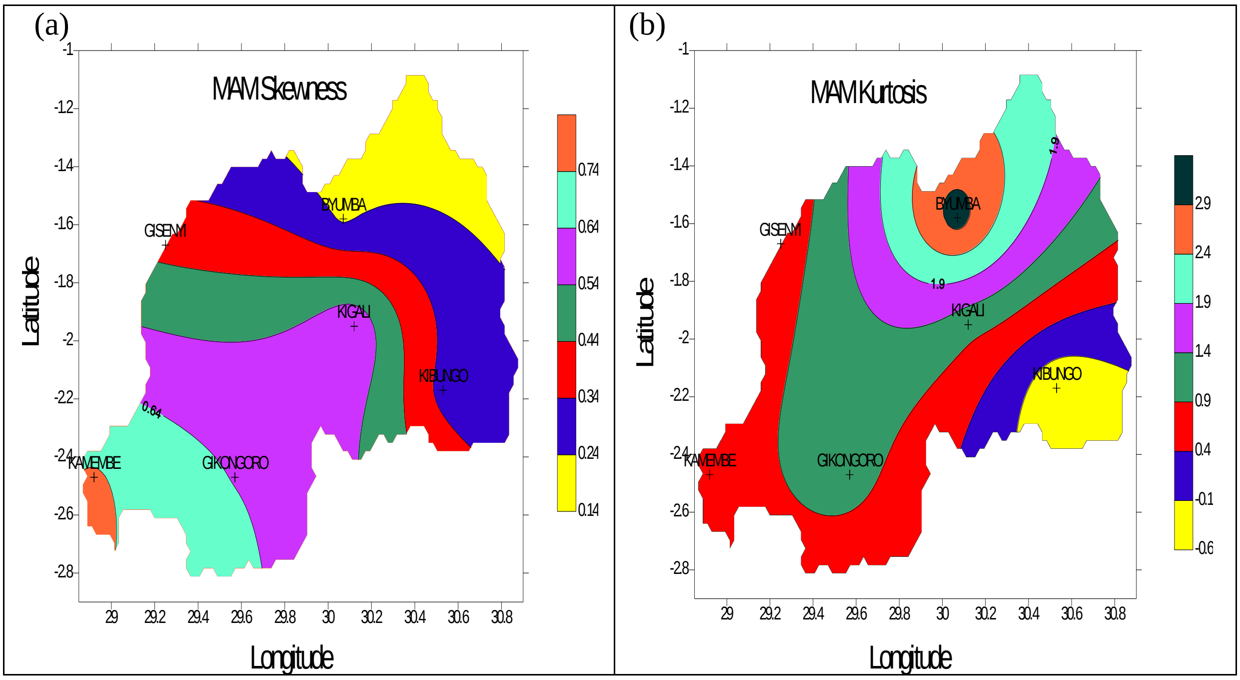
Stations	months	Monthly skewness	Seasons	Seasonal skewness	Annual skewness	Monthly kurtosis	Seasonal kurtosis	Annual kurtosis
GIKONGORO	JAN	1.93	MAM	0.64	1.00	7.11	1.06	1.82
	FEB	0.52				-0.13		
	MAR	0.56				0.95		
	APR	1.16				2.62		
	MAY	1.59				4.78		
	JUN	2.09				5.32		
	JULY	1.97	OND	0.70		3.68	1.29	
	AUG	1.61				2.86		
	SEP	0.49				-0.37		
	OCT	0.43				-0.42		
	NOV	0.97				1.07		
	DEC	0.72				0.14		
BYUMBA	JAN	1.32	MAM	0.22	0.33	2.98	3.14	-0.95
	FEB	0.52				-0.05		
	MAR	1.79				6.86		
	APR	1.08				2.39		
	MAY	0.38				-0.56		
	JUN	1.66				3.48		
	JULY	1.77	OND	0.24		3.25	-0.67	
	AUG	0.84				-0.06		
	SEP	0.77				0.74		
	OCT	0.56				-0.44		
	NOV	0.75				1.37		
	DEC	0.82				0.43		
GISENYI	JAN	0.03	MAM	0.30	0.68	-0.80	0.00	0.56
	FEB	0.40				0.23		
	MAR	0.27				0.43		
	APR	0.76				0.48		
	MAY	0.25				0.23		
	JUN	0.74				-0.37		
	JULY	1.70	OND	0.35		2.00	0.43	
	AUG	1.45				2.24		
	SEP	0.74				0.84		
	OCT	0.31				0.78		
	NOV	-0.33				-0.19		
	DEC	0.51				0.20		

The spatial distribution both skewness and kurtosis for MAM, OND and annual rainfall over Rwanda are given in Figures 16 and 17. In MAM, Figure 16 (a), the skewness values are positive showing that Rwanda long rains have their high frequency of wet events. This may imply the occurrence of depressed seasonal rainfall.

Figure 16(b) shows that the majority of the regions in Rwanda experience positive kurtosis. Negative kurtosis is recorded only in the region of Kibungo, located in the southeastern region of Rwanda. In general the MAM rainfall in Rwanda is usually within the mean (and median) of the distribution. The MAM rainfall therefore has a low variability showing that the season is reliable.

The skewness pattern in Figure 16(c) gives negative values to the southwest and positive values in the larger eastern region. This implies that rainfall over Rwanda is not normally distributed. There is high frequency of seasonal amounts greater (less) than the long term mean in the western (eastern) regions. During OND given in Figure 16(d) kurtosis is positive in the whole country except for the northeastern and southwestern regions. Therefore, these regions experience high variability of rainfall from the mean. The rest of the country experiences rainfall which is relatively close to the mean.

The skewness pattern in Figure 17(a) shows that positive values dominate the whole country. Therefore, it annual rainfall recorded within the period of study has high frequency of events less than the long term mean. On annual timescale, Figure 17(b), the spatial distribution of kurtosis is similar to that of the OND season. This implies that on the annual rainfall pattern is least variable in the central regions while high variability is recorded in the south western and eastern regions.



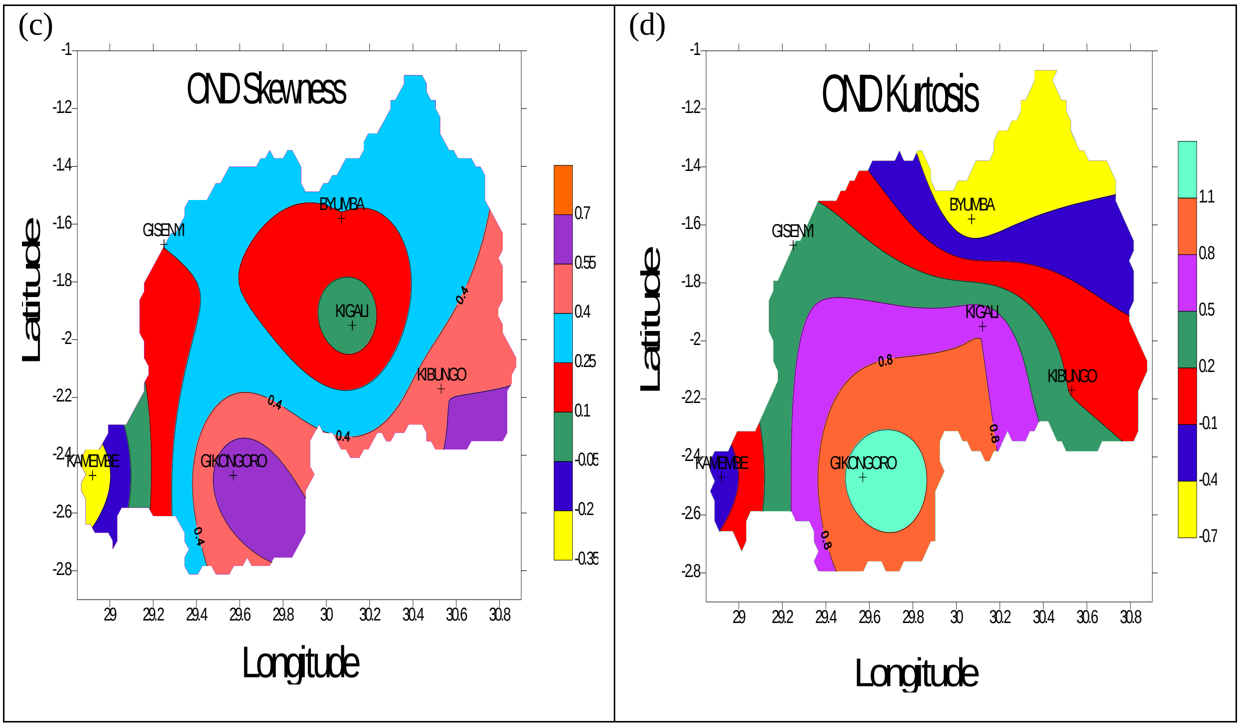


Figure 16. Spatial distribution of skewness and kurtosis for MAM (a and b) and OND (c and d) respectively

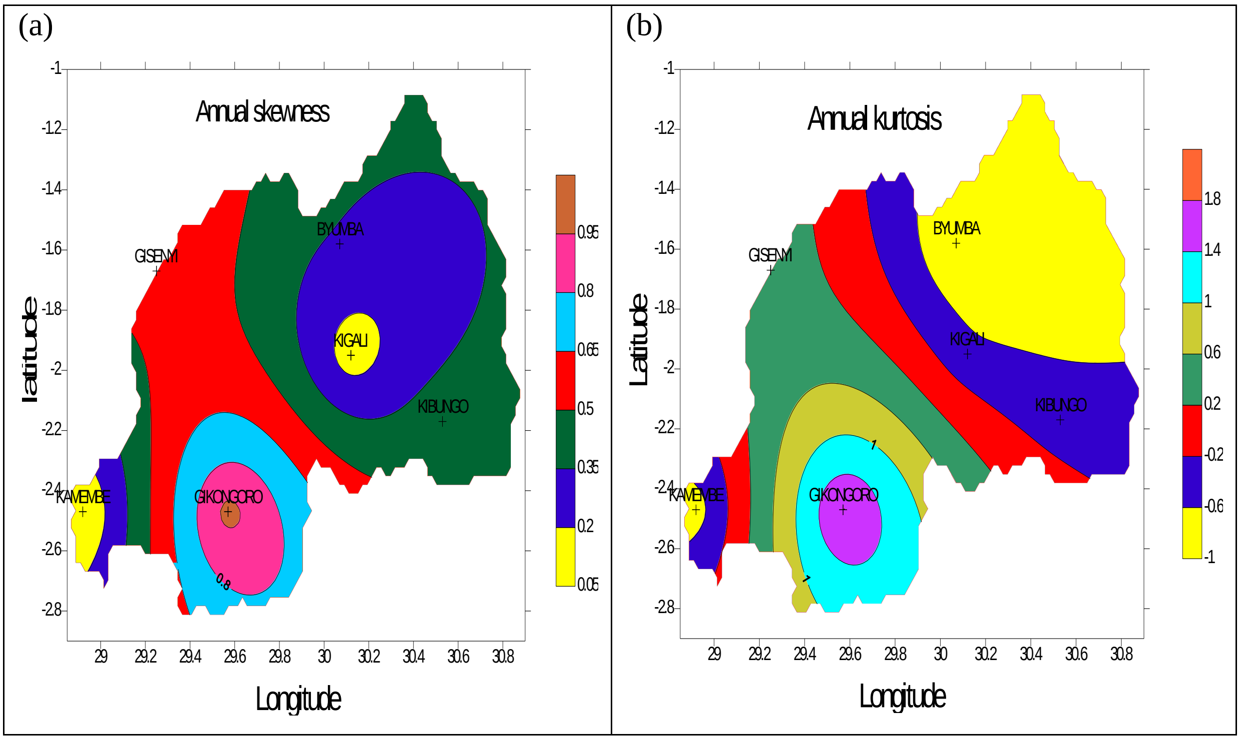


Figure 17. Spatial distribution of annual rainfall skewness and kurtosis (a) and (b) respectively

4.3.6 PROBABILITY OF OCCURRENCE OF EXTREME RAINFALL EVENTS

Table 5 Percentage Probability of occurrence of extreme rainfall events

		BN	**N**	**AN**
Overall	MAM	47.7	40.9	9.1
	OND	45.5	38.6	15.9
	ANNUAL	43.2	36.4	15.9
Kamembe	MAM	59.1	15.9	25.0
	OND	45.5	22.7	31.8
	ANNUAL	50.0	4.5	45.5
Kibungo	MAM	54.5	22.7	22.7
	OND	47.7	22.7	29.5
	ANNUAL	52.3	9.1	38.6
Kigali	MAM	45.5	25.0	29.5
	OND	38.6	38.6	22.7
	ANNUAL	52.3	13.6	34.1
Gikongoro	MAM	54.5	20.5	25.0
	OND	54.5	15.9	29.5
	ANNUAL	59.1	9.1	31.8
Byumba	MAM	29.5	29.5	25.0
	OND	45.5	22.7	31.8
	ANNUAL	52.3	6.8	40.9
Gisenyi	MAM	47.7	18.2	34.1
	OND	50.0	27.3	22.7
	ANNUAL	52.3	13.6	34.1

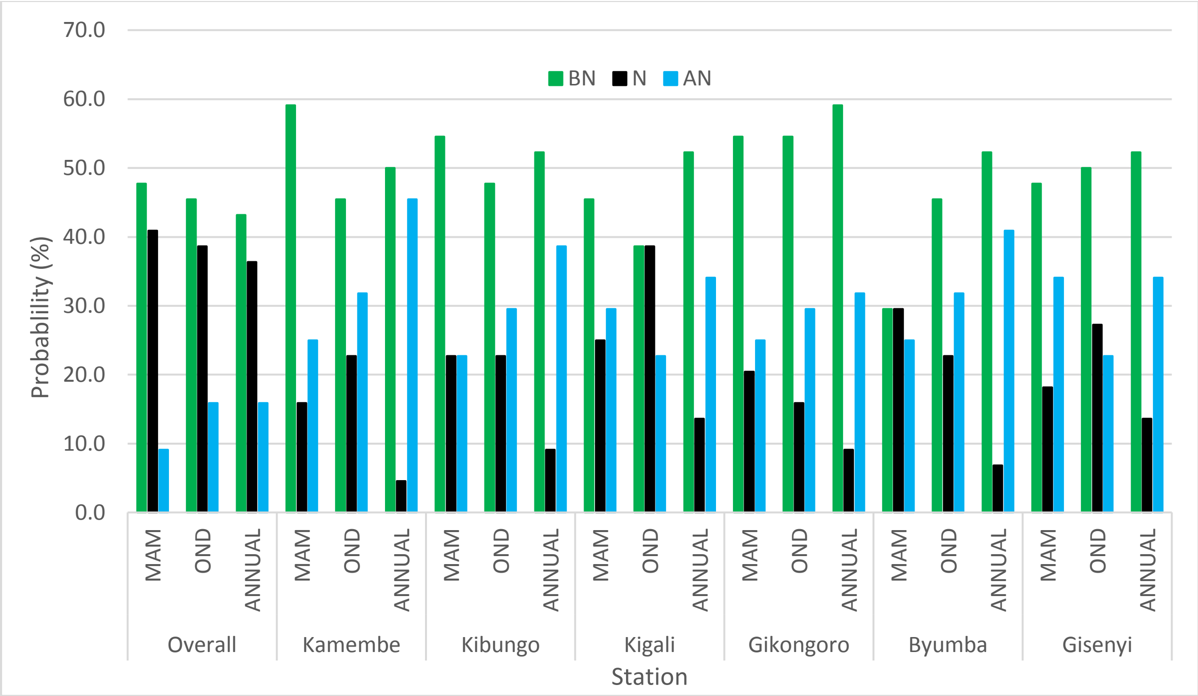


Figure 18 Probability of seasonal and annual rainfall events for representative stations in Rwanda

From Figure 18, The results showing that the probability of occurrence of extreme rainfall events indicates that the below normal events have the highest probability compared to the normal and above normal events.. Therefore, there is a greater chance of occurrence of droughts unlike flooding. It is therefore important for drought early warning systems to be operationalized in the country.

4.4 DETERMINATION OF EXTREME EVENTS

Table 6 Result of wet and dry years during MAM over Gikongoro

Years	**MAM Rainfall values**	**x<mean-sd**	**x>mean+sd**	**Years**	**MAM Rainfall values**	**x<mean-sd**	**x>mean+sd**
1971	559.6	wet season	dry season	1995	689.1	wet season	wet season
1972	460.8	wet season	dry season	1996	259.7	dry season	dry season
1973	909.8	wet season	wet season	1997	562.6	wet season	dry season
1974	797	wet season	wet season	1998	462.1	wet season	dry season
1975	769.3	wet season	wet season	1999	538.5	wet season	dry season
1976	582	wet season	dry season	2000	335.1	dry season	dry season
1977	545.5	wet season	dry season	2001	447.1	wet season	dry season
1978	504.6	wet season	dry season	2002	538.6	wet season	dry season
1979	588.3	wet season	dry season	2003	454.2	wet season	dry season
1980	278.9	dry season	dry season	2004	419.6	wet season	dry season
1981	603.6	wet season	dry season	2005	500	wet season	dry season
1982	464.9	wet season	dry season	2006	501.1	wet season	dry season
1983	484.3	wet season	dry season	2007	340.7	dry season	dry season
1984	202	dry season	dry season	2008	322.9	dry season	dry season
1985	485	wet season	dry season	2009	448.6	wet season	dry season
1986	604.2	wet season	dry season	2010	426.1	wet season	dry season
1987	348.7	wet season	dry season	2011	366	wet season	dry season
1988	386.2	wet season	dry season	2012	574.6	wet season	dry season
1989	381.4	wet season	dry season	2013	610.9	wet season	dry season
1990	470.3	wet season	dry season	2014	299.9	dry season	dry season
1991	518.3	wet season	dry season	average	487.975		
1992	613.8	wet season	dry season	SD	142.02		
1993	407.7	wet season	dry season	**mean-sd**	**345.10**		
1994	407.3	wet season	dry season	**mean+sd**	**629.10**		

Table 7 Result of wet and dry years during MAM over Kigali

Years	**MAM Rainfall values**	**x<mean-sd**	**x>mean+sd**	**Years**	**MAM Rainfall values**	**x<mean-sd**	**x>mean+sd**
1971	379.3	wet season	dry season	1995	389	wet season	dry season
1972	315	wet season	dry season	1996	303.7	wet season	dry season
1973	372.9	wet season	dry season	1997	329.7	wet season	dry season
1974	335.6	wet season	dry season	1998	477.3	wet season	wet season
1975	266.6	dry season	dry season	1999	383.9	wet season	dry season
1976	237	dry season	dry season	2000	236.1	dry season	dry season
1977	396.6	wet season	dry season	2001	403	wet season	dry season
1978	447.5	wet season	dry season	2002	400.5	wet season	dry season
1979	657.2	wet season	wet season	2003	246.2	dry season	dry season
1980	360.3	wet season	dry season	2004	338.8	wet season	dry season
1981	426.2	wet season	dry season	2005	313.9	wet season	dry season
1982	392.3	wet season	dry season	2006	448	wet season	dry season
1983	287.8	wet season	dry season	2007	299.8	wet season	dry season
1984	327.2	wet season	dry season	2008	332.8	wet season	dry season
1985	463.7	wet season	wet season	2009	313.7	wet season	dry season
1986	445	wet season	dry season	2010	344.3	wet season	dry season
1987	471.5	wet season	wet season	2011	294.9	wet season	dry season
1988	444.5	wet season	dry season	2012	528.6	wet season	wet season
1989	442	wet season	dry season	2013	501.4	wet season	wet season
1990	366.3	wet season	dry season	2014	200.6	dry season	dry season
1991	402.4	wet season	dry season	average	370.81		
1992	277.9	dry season	dry season	SD	89.43		
1993	274	dry season	dry season	**mean-sd**	**281.39**		
1994	440.8	wet season	dry season	**mean+sd**	**460.24**		

Table 8 Result of wet and dry years during MAM over Kibungo

Years	**MAM Rainfall values**	**x<mean-sd**	**x>mean+sd**	**Years**	**MAM Rainfall values**	**x<mean-sd**	**x>mean+sd**
1971	413	wet season	dry season	1995	371.7	wet season	dry season
1972	574.2	wet season	wet season	1996	368.1	wet season	dry season
1973	253	dry season	dry season	1997	329.8	wet season	dry season
1974	336.4	wet season	dry season	1998	382.8	wet season	dry season
1975	340.6	wet season	dry season	1999	386.4	wet season	dry season
1976	403.1	wet season	dry season	2000	327	wet season	dry season
1977	386.7	wet season	dry season	2001	334	wet season	dry season
1978	320.5	wet season	dry season	2002	498.7	wet season	wet season
1979	453	wet season	dry season	2003	493.5	wet season	dry season
1980	273.2	dry season	dry season	2004	527.8	wet season	wet season
1981	452	wet season	dry season	2005	297.9	dry season	dry season
1982	443.2	wet season	dry season	2006	434.8	wet season	dry season
1983	337	wet season	dry season	2007	460.2	wet season	dry season
1984	427.9	wet season	dry season	2008	372.6	wet season	dry season
1985	403.2	wet season	dry season	2009	401.2	wet season	dry season
1986	429.4	wet season	dry season	2010	498.7	wet season	wet season
1987	429.1	wet season	dry season	2011	583.7	wet season	wet season
1988	563.2	wet season	wet season	2012	493.7	wet season	dry season
1989	448.7	wet season	dry season	2013	364	wet season	dry season
1990	522.7	wet season	wet season	2014	245.9	dry season	dry season
1991	362.5	wet season	dry season	average	408.16		
1992	328.8	wet season	dry season	SD	88.06		
1993	585.8	wet season	wet season	**mean-sd**	**320.10**		
1994	299.4	dry season	dry season	**mean+sd**	**496.22**		

Table 9 Result of wet and dry years during MAM over Byumba

Years	**MAM Rainfall values**	**x<mean-sd**	**x>mean+sd**	**Years**	**MAM Rainfall values**	**x<mean-sd**	**x>mean+sd**
1971	463.2	wet season	wet season	1995	335.2	wet season	dry season
1972	344.8	wet season	dry season	1996	284.4	wet season	dry season
1973	401.2	wet season	dry season	1997	384.3	wet season	dry season
1974	378	wet season	dry season	1998	442.1	wet season	wet season
1975	244.7	dry season	dry season	1999	267.5	wet season	dry season
1976	179.7	dry season	dry season	2000	295.3	wet season	dry season
1977	388	wet season	dry season	2001	298.3	wet season	dry season
1978	383.8	wet season	dry season	2002	247.2	dry season	dry season
1979	294.1	wet season	dry season	2003	309.8	wet season	dry season
1980	408.9	wet season	dry season	2004	351.8	wet season	dry season
1981	391.8	wet season	dry season	2005	415.6	wet season	dry season
1982	443.8	wet season	wet season	2006	448.2	wet season	wet season
1983	260.4	dry season	dry season	2007	271.8	wet season	dry season
1984	353.1	wet season	dry season	2008	313.8	wet season	dry season
1985	294.6	wet season	dry season	2009	312.9	wet season	dry season
1986	96.1	dry season	dry season	2010	379.7	wet season	dry season
1987	423	wet season	dry season	2011	353.2	wet season	dry season
1988	383	wet season	dry season	2012	428.2	wet season	dry season
1989	306.5	wet season	dry season	2013	647.6	wet season	wet season
1990	383.6	wet season	dry season	2014	317.9	wet season	dry season
1991	376.3	wet season	dry season	average	349.76		
1992	298.7	wet season	dry season	SD	87.35		
1993	422.5	wet season	dry season	**mean-sd**	**262.43**		
1994	365.5	wet season	dry season	**mean+sd**	**437.12**		

Table 10 Result of wet and dry years during MAM over Kamembe

Years	**MAM Rainfall values**	**x<mean-sd**	**x>mean+sd**	**Years**	**MAM Rainfall values**	**x<mean-sd**	**x>mean+sd**
1971	415.3	wet season	dry season	1995	403.8	wet season	dry season
1972	363.7	wet season	dry season	1996	453.1	wet season	dry season
1973	380.2	wet season	dry season	1997	446.8	wet season	dry season
1974	368.9	wet season	dry season	1998	412.7	wet season	dry season
1975	451.2	wet season	dry season	1999	353.4	wet season	dry season
1976	519.5	wet season	wet season	2000	353.4	wet season	dry season
1977	383.8	wet season	dry season	2001	331.7	dry season	dry season
1978	465.7	wet season	dry season	2002	363.9	wet season	dry season
1979	446.5	wet season	dry season	2003	381.8	wet season	dry season
1980	380.8	wet season	dry season	2004	290.7	dry season	dry season
1981	373.5	wet season	dry season	2005	393.9	wet season	dry season
1982	381.8	wet season	dry season	2006	481.2	wet season	dry season
1983	605.4	wet season	wet season	2007	298.1	dry season	dry season
1984	388.6	wet season	dry season	2008	426.6	wet season	dry season
1985	521.8	wet season	wet season	2009	466.7	wet season	dry season
1986	509.7	wet season	wet season	2010	400.3	wet season	dry season
1987	534.5	wet season	wet season	2011	387.1	wet season	dry season
1988	489.2	wet season	dry season	2012	636.9	wet season	wet season
1989	468.1	wet season	dry season	2013	504.7	wet season	wet season
1990	427.3	wet season	dry season	2014	457.6	wet season	dry season
1991	508.1	wet season	wet season	average	426.51		
1992	371	wet season	dry season	SD	73.34		
1993	391	wet season	dry season	**mean-sd**	**353.17**		
1994	376.6	wet season	dry season	**mean+sd**	**499.86**		

Table 11 Result of wet and dry years during MAM over Gisenyi

Years	**MAM Rainfall values**	**x<mean-sd**	**x>mean+sd**	**Years**	**MAM Rainfall values**	**x<mean-sd**	**x>mean+sd**
1971	359.3	wet season	dry season	1995	275.9	wet season	dry season
1972	380.4	wet season	dry season	1996	542.3	wet season	wet season
1973	433.3	wet season	dry season	1997	240.5	dry season	dry season
1974	398.8	wet season	dry season	1998	405.2	wet season	dry season
1975	247.4	dry season	dry season	1999	270.5	wet season	dry season
1976	421.3	wet season	dry season	2000	443.8	wet season	dry season
1977	321.3	wet season	dry season	2001	227.4	dry season	dry season
1978	447.2	wet season	dry season	2002	368.1	wet season	dry season
1979	388.7	wet season	dry season	2003	363.3	wet season	dry season
1980	436.6	wet season	dry season	2004	369.1	wet season	dry season
1981	417.7	wet season	dry season	2005	280.4	wet season	dry season
1982	458.7	wet season	dry season	2006	345.7	wet season	dry season
1983	426.5	wet season	dry season	2007	193	dry season	dry season
1984	239.7	dry season	dry season	2008	221.6	dry season	dry season
1985	501.2	wet season	wet season	2009	293.9	wet season	dry season
1986	416.7	wet season	dry season	2010	513.7	wet season	wet season
1987	344.2	wet season	dry season	2011	413.7	wet season	dry season
1988	637	wet season	wet season	2012	502.6	wet season	wet season
1989	260.5	dry season	dry season	2013	391.6	wet season	dry season
1990	387	wet season	dry season	2014	223.2	dry season	dry season
1991	378.1	wet season	dry season	average	364.79		
1992	224.3	dry season	dry season	SD	98.66		
1993	345.3	wet season	dry season	**mean-sd**	**266.12**		
1994	293.6	wet season	dry season	**mean+sd**	**463.43**		

Table 12 Overall dry and wet years during MAM

Years	MAM Average rainfall	x<mean-sd	x>mean+sd	Years	MAM Average rainfall	x<mean-sd	x>mean+sd
1971	431.62	wet season	dry season	1995	410.78	wet season	dry season
1972	406.48	wet season	dry season	1996	368.55	wet season	dry season
1973	458.40	wet season	Wet season	1997	382.28	wet season	dry season
1974	435.78	wet season	dry season	1998	430.37	wet season	dry season
1975	386.63	wet season	dry season	1999	366.70	wet season	dry season
1976	390.43	wet season	dry season	2000	331.78	dry season	dry season
1977	403.65	wet season	dry season	2001	340.25	dry season	dry season
1978	428.21	wet season	dry season	2002	402.83	wet season	dry season
1979	471.30	wet season	wet season	2003	374.80	wet season	dry season
1980	356.45	wet season	dry season	2004	382.97	wet season	dry season
1981	444.13	wet season	dry season	2005	366.95	wet season	dry season
1982	430.78	wet season	dry season	2006	443.17	wet season	dry season
1983	400.23	wet season	dry season	2007	310.60	dry season	dry season
1984	323.08	dry season	dry season	2008	331.72	dry season	dry season
1985	444.92	wet season	dry season	2009	372.83	wet season	dry season
1986	416.85	wet season	dry season	2010	427.13	wet season	dry season
1987	425.17	wet season	dry season	2011	399.77	wet season	dry season
1988	483.85	wet season	wet season	2012	527.43	wet season	wet season
1989	384.53	wet season	dry season	2013	503.37	wet season	wet season
1990	426.20	wet season	dry season	2014	290.85	dry season	dry season
1991	424.29	wet season	dry season	average	401.34		
1992	352.42	wet season	dry season	SD	49.68		
1993	404.38	wet season	dry season	**mean-sd**	**351.66**		
1994	363.87	wet season	dry season	**mean+sd**	**451.02**		

Table 13 Result of wet and dry years during OND over Kamembe

Year	OND rainfall values	x<mean-sd	x>mean+sd	Year	OND rainfall values	x<mean-sd	x>mean+sd
1971	536.2	wet season	dry season	1995	433.5	wet season	dry season
1972	597.5	wet season	wet season	1996	538.3	wet season	dry season
1973	367.3	dry season	dry season	1997	480	wet season	dry season
1974	461.4	wet season	dry season	1998	320.9	dry season	dry season
1975	523.5	wet season	dry season	1999	421	wet season	dry season
1976	454.2	wet season	dry season	2000	481.4	wet season	dry season
1977	439.4	wet season	dry season	2001	572.6	wet season	wet season
1978	578.8	wet season	wet season	2002	427.5	wet season	dry season
1979	374.4	dry season	dry season	2003	392.5	dry season	dry season
1980	596.8	wet season	wet season	2004	462.3	wet season	dry season
1981	455.3	wet season	dry season	2005	362.5	dry season	dry season
1982	598.9	wet season	wet season	2006	431.6	wet season	dry season
1983	561.8	wet season	wet season	2007	509	wet season	dry season
1984	493.7	wet season	dry season	2008	537.3	wet season	dry season
1985	477.4	wet season	dry season	2009	557.1	wet season	wet season
1986	447.1	wet season	dry season	2010	281.1	dry season	dry season
1987	396.9	dry season	dry season	2011	580.6	wet season	wet season
1988	433.5	wet season	dry season	2012	538.5	wet season	dry season
1989	592.2	wet season	wet season	2013	496.3	wet season	dry season
1990	408.9	wet season	dry season	2014	487.7	wet season	dry season
1991	535	wet season	dry season	Average	478.48		
1992	509	wet season	dry season	SD	77.70		
1993	414.6	wet season	dry season	**mean-sd**	**400.78**		
1994	487.5	wet season	dry season	**mean+sd**	**556.18**		

Table 14 Result of wet and dry years during OND over Kibungo

Year	**OND rainfall values**	**x<mean-sd**	**x>mean+sd**	**Year**	**OND Rainfall values**	**x<mean-sd**	**x>mean+sd**
1971	250.4	wet season	dry season	1995	276.8	wet season	dry season
1972	266.6	wet season	dry season	1996	222.4	dry season	dry season
1973	299	wet season	dry season	1997	231.6	wet season	dry season
1974	282.9	wet season	dry season	1998	216.1	dry season	dry season
1975	399.6	wet season	dry season	1999	196.6	dry season	dry season
1976	373.8	wet season	dry season	2000	379.6	wet season	dry season
1977	200	dry season	dry season	2001	323.5	wet season	dry season
1978	212.6	dry season	dry season	2002	325.6	wet season	dry season
1979	231.5	wet season	dry season	2003	301.4	wet season	dry season
1980	299.1	wet season	dry season	2004	180.6	dry season	dry season
1981	183.2	dry season	dry season	2005	274.9	wet season	dry season
1982	314.3	wet season	dry season	2006	280.6	wet season	dry season
1983	460.8	wet season	wet season	2007	335.8	wet season	dry season
1984	484.8	wet season	wet season	2008	374.6	wet season	dry season
1985	171.7	dry season	dry season	2009	325.6	wet season	dry season
1986	565.9	wet season	wet season	2010	325.6	wet season	dry season
1987	355.1	wet season	dry season	2011	412.4	wet season	wet season
1988	251.5	wet season	dry season	2012	469	wet season	wet season
1989	299.9	wet season	dry season	2013	336.8	wet season	dry season
1990	362	wet season	dry season	2014	378.4	wet season	dry season
1991	489.1	wet season	wet season	average	318.30		
1992	367.5	wet season	dry season	SD	90.61		
1993	370.2	wet season	dry season	**mean-sd**	**227.69**		
1994	345.6	wet season	dry season	**mean+sd**	**408.91**		

Table 15 Result of wet and dry years during OND over Kigali

Year	OND rainfall values	x<mean-sd	x>mean+sd	Year	OND rainfall values	x<mean-sd	x>mean+sd
1971	274.7	wet season	dry season	1995	316.8	wet season	dry season
1972	400.1	wet season	wet season	1996	147.9	dry season	dry season
1973	329.8	wet season	dry season	1997	447.9	wet season	wet season
1974	230.9	dry season	dry season	1998	283.8	wet season	dry season
1975	333.7	wet season	dry season	1999	259.2	wet season	dry season
1976	263.5	wet season	dry season	2000	349.7	wet season	dry season
1977	352	wet season	dry season	2001	509.8	wet season	wet season
1978	306.4	wet season	dry season	2002	347.9	wet season	dry season
1979	389.7	wet season	wet season	2003	257.3	wet season	dry season
1980	298.7	wet season	dry season	2004	229.3	dry season	dry season
1981	268.7	wet season	dry season	2005	213.5	dry season	dry season
1982	364.2	wet season	dry season	2006	409	wet season	wet season
1983	392.4	wet season	wet season	2007	340.1	wet season	dry season
1984	344.8	wet season	dry season	2008	159.3	dry season	dry season
1985	343.1	wet season	dry season	2009	323.9	wet season	dry season
1986	317.4	wet season	dry season	2010	295.4	wet season	dry season
1987	344	wet season	dry season	2011	338.9	wet season	dry season
1988	324.4	wet season	dry season	2012	342.8	wet season	dry season
1989	314.9	wet season	dry season	2013	402.8	wet season	wet season
1990	309.7	wet season	dry season	2014	316.1	wet season	dry season
1991	265.7	wet season	dry season	average	313.88		
1992	225.2	dry season	dry season	SD	71.84		
1993	184.5	dry season	dry season	**mean-sd**	**242.05**		
1994	341	wet season	dry season	**mean+sd**	**385.72**		

Table 16 Result of wet and dry years during OND over Gikongoro

Year	**OND Rainfall values**	**x<mean-sd**	**x>mean+sd**	**Year**	**OND rainfall values**	**x<mean-sd**	**x>mean+sd**
1971	239.8	dry season	dry season	1995	319.2	wet season	dry season
1972	330.1	wet season	dry season	1996	290.6	dry season	dry season
1973	497.2	wet season	dry season	1997	485.9	wet season	dry season
1974	528.8	wet season	wet season	1998	318.7	wet season	dry season
1975	328.1	wet season	dry season	1999	498.4	wet season	dry season
1976	304	wet season	dry season	2000	382	wet season	dry season
1977	477	wet season	dry season	2001	419.1	wet season	dry season
1978	403.4	wet season	dry season	2002	392.6	wet season	dry season
1979	354	wet season	dry season	2003	420.8	wet season	dry season
1980	311.3	wet season	dry season	2004	348.1	wet season	dry season
1981	323.9	wet season	dry season	2005	380.5	wet season	dry season
1982	479.9	wet season	dry season	2006	437.7	wet season	dry season
1983	302.4	wet season	dry season	2007	320.5	wet season	dry season
1984	470.7	wet season	dry season	2008	322.1	wet season	dry season
1985	307.5	wet season	dry season	2009	622.4	wet season	wet season
1986	351.3	wet season	dry season	2010	392.3	wet season	dry season
1987	419	wet season	dry season	2011	711	wet season	wet season
1988	301.6	wet season	dry season	2012	421.9	wet season	dry season
1989	459.1	wet season	dry season	2013	503.1	wet season	wet season
1990	349.3	wet season	dry season	2014	582.4	wet season	wet season
1991	395.8	wet season	dry season	average	395.37		
1992	434.2	wet season	dry season	SD	103.60		
1993	153.6	dry season	dry season	**mean-sd**	**291.78**		
1994	305	wet season	dry season	**mean+sd**	**498.96**		

Table 17 Result of wet and dry years during OND over Byumba

years	OND Rainfall values	x<mean-sd	x>mean+sd	years	OND rainfall values	x<mean-sd	x>mean+sd
1971	394.4	wet season	dry season	1995	372.8	wet season	dry season
1972	298.2	wet season	dry season	1996	448.3	wet season	wet season
1973	385.6	wet season	dry season	1997	501.7	wet season	wet season
1974	245	dry season	dry season	1998	291.6	wet season	dry season
1975	318.1	wet season	dry season	1999	251.2	dry season	dry season
1976	328.1	wet season	dry season	2000	410.4	wet season	wet season
1977	353.2	wet season	dry season	2001	352.2	wet season	dry season
1978	408.5	wet season	wet season	2002	363	wet season	dry season
1979	263.8	wet season	dry season	2003	237.8	dry season	dry season
1980	283.5	wet season	dry season	2004	315.6	wet season	dry season
1981	252.1	dry season	dry season	2005	211.2	dry season	dry season
1982	248.6	dry season	dry season	2006	289.2	wet season	dry season
1983	405.8	wet season	wet season	2007	300.2	wet season	dry season
1984	388.6	wet season	dry season	2008	379.5	wet season	dry season
1985	297.2	wet season	dry season	2009	359.5	wet season	dry season
1986	283.8	wet season	dry season	2010	352.4	wet season	dry season
1987	421.9	wet season	wet season	2011	293.3	wet season	dry season
1988	240.6	dry season	dry season	2012	400.2	wet season	wet season
1989	275.1	wet season	dry season	2013	372.2	wet season	dry season
1990	228.5	dry season	dry season	2014	407.7	wet season	wet season
1991	256.8	dry season	dry season	average	328.15		
1992	367.9	wet season	dry season	SD	68.23		
1993	230.1	dry season	dry season	**mean-sd**	**259.86**		
1994	353.1	wet season	dry season	**mean+sd**	**396.44**		

Table 18 Result of wet and dry years during OND over Gisenyi

Year	**OND rainfall values**	**x<mean-sd**	**x>mean+sd**	**Year**	**OND rainfall values**	**x<mean-sd**	**x>mean+sd**
1971	477	wet season	wet season	1996	210.1	dry season	dry season
1972	330.5	wet season	dry season	1997	365.3	wet season	dry season
1973	298.1	wet season	dry season	1998	305.1	wet season	dry season
1974	245.9	dry season	dry season	1999	230.2	dry season	dry season
1975	327.1	wet season	dry season	2000	220.8	dry season	dry season
1976	407.8	wet season	dry season	2001	190.5	dry season	dry season
1977	386.3	wet season	dry season	2002	548.6	wet season	wet season
1978	338.4	wet season	dry season	2003	348.3	wet season	dry season
1979	367.7	wet season	dry season	2004	331.2	wet season	dry season
1980	384.1	wet season	dry season	2005	253.7	dry season	dry season
1981	279.9	wet season	dry season	2006	365.5	wet season	dry season
1982	345.6	wet season	dry season	2007	402.6	wet season	dry season
1983	450.9	wet season	wet season	2008	248	dry season	dry season
1984	254.9	dry season	dry season	2009	576.2	wet season	wet season
1985	353.9	wet season	dry season	2010	466.3	wet season	wet season
1986	377.7	wet season	dry season	2011	363.2	wet season	dry season
1987	312.3	wet season	dry season	2012	438.4	wet season	wet season
1988	337	wet season	dry season	2013	434.8	wet season	dry season
1989	376.8	wet season	dry season	2014	420.7	wet season	dry season
1990	336.3	wet season	dry season	average	351.02		
1991	376.1	wet season	dry season	SD	84.54		
1992	348.4	wet season	dry season	**mean-sd**	**266.48**		
1993	372.7	wet season	dry season	**mean+sd**	**435.56**		

Table 19 Result of overall dry and wet years during OND

Years	OND overall average rainfall	x<mean-sd	x>mean+sd	Years	OND overall average rainfall	x<mean-sd	x>mean+sd
1971	362.1	wet season	dry season	1995	325.7	wet season	dry season
1972	370.5	wet season	dry season	1996	309.6	dry season	dry season
1973	362.8	wet season	dry season	1997	418.7	wet season	wet season
1974	332.5	wet season	dry season	1998	289.4	dry season	dry season
1975	371.7	wet season	dry season	1999	309.4	dry season	dry season
1976	355.2	wet season	dry season	2000	370.7	wet season	dry season
1977	368.0	wet season	dry season	2001	394.6	wet season	dry season
1978	374.7	wet season	dry season	2002	400.9	wet season	dry season
1979	330.2	wet season	dry season	2003	326.4	wet season	dry season
1980	362.3	wet season	dry season	2004	311.2	dry season	dry season
1981	293.9	dry season	dry season	2005	282.7	dry season	dry season
1982	391.9	wet season	dry season	2006	368.9	wet season	dry season
1983	429.0	wet season	wet season	2007	368.0	wet season	dry season
1984	406.3	wet season	dry season	2008	336.8	wet season	dry season
1985	325.1	wet season	dry season	2009	460.8	wet season	wet season
1986	390.5	wet season	dry season	2010	352.2	wet season	dry season
1987	374.9	wet season	dry season	2011	449.9	wet season	wet season
1988	314.8	dry season	dry season	2012	435.1	wet season	wet season
1989	386.3	wet season	dry season	2013	424.3	wet season	wet season
1990	332.5	wet season	dry season	2014	432.2	wet season	wet season
1991	386.4	wet season	dry season	average	364.2		
1992	375.4	wet season	dry season	SD	45.0		
1993	287.6	dry season	dry season	**mean-sd**	**319.2**		
1994	372.9	wet season	dry season	**mean+sd**	**409.2**		

Table 20 Result of annual overall wet and dry years

Years	**Annual overall average**	**x<mean-sd**	**x>mean+sd**	**Years**	**Annual overall average**	**x<mean-sd**	**x>mean+sd**
1971	1202.3	wet year	dry year	1995	1097.6	wet year	dry year
1972	1323.5	wet year	wet year	1996	1178.4	wet year	dry year
1973	1256.1	wet year	wet year	1997	1165.1	wet year	dry year
1974	1177.4	wet year	dry year	1998	1235.1	wet year	wet year
1975	1172.0	wet year	dry year	1999	1067.6	wet year	dry year
1976	1127.7	wet year	dry year	2000	1007.8	dry year	dry year
1977	1173.2	wet year	dry year	2001	1215.2	wet year	dry year
1978	1193.3	wet year	dry year	2002	1094.7	wet year	dry year
1979	1113.9	wet year	dry year	2003	1042.7	dry year	dry year
1980	1042.7	dry year	dry year	2004	1028.6	dry year	dry year
1981	1163.7	wet year	dry year	2005	991.9	dry year	dry year
1982	1132.6	wet year	dry year	2006	1204.2	wet year	dry year
1983	1128.3	wet year	dry year	2007	1095.6	wet year	dry year
1984	1051.4	dry year	dry year	2008	1053.9	dry year	dry year
1985	1102.4	wet year	dry year	2009	1201.2	wet year	dry year
1986	1167.6	wet year	dry year	2010	1231.7	wet year	dry year
1987	1186.8	wet year	dry year	2011	1314.2	wet year	wet year
1988	1311.6	wet year	wet year	2012	1278.1	wet year	wet year
1989	1139.0	wet year	dry year	2013	1261.2	wet year	wet year
1990	1154.2	wet year	dry year	2014	1173.6	wet year	dry year
1991	1152.9	wet year	dry year	average	1149.5		
1992	1006.8	dry year	dry year	SD	85.6		
1993	1027.8	dry year	dry year	**mean-sd**	**1063.9**		
1994	1131.6	wet year	dry year	**mean+sd**	**1235.1**		

4.5 WEATHER SYSTEMS ASSOCIATED WITH EXTREME RAINFALL OVER RWANDA

4.5.1 SELECTED OF EXTREM YEARS

Table 21 The selected extreme rainfall events for both MAM, OND and annual

Overall	MAM	Dry years	2014	2007	1984	2008	2000	2001	1992	1994	1975	1980
		Wet years	2012	2013	1988	1979	1973	1985	2006	1981		
	OND	Dry years	2005	1993	1998	1981	1999	1996	2004	1988	1985	1974
		Wet years	2009	2011	2012	2014	1983	2013	1997			
	ANNUAL	Dry years	2005	1992	2000	1993	2004	1980	2003	1984	1999	1985
		Wet years	1972	2011	1988	2012	2013	1973	1998	2010	2009	2014
Kamembe	MAM	Dry years	2004	2007	2001	2000	1999	1984	2002	1992	1972	1974
		Wet years	2012	1983	1987	1991	1976	2006	2013	1985	1986	1988
	OND	Dry years	2010	1998	2005	1973	1979	1987	2003	1990	1999	1993
		Wet years	1980	1972	1982	2011	1989	1978	2001	1983	2009	1971
	ANNUAL	Dry years	2002	2010	2004	1999	2000	1979	2001	2003	1992	1998
		Wet years	2011	1989	1975	1972	2014	1988	2012	1983	2008	2009
Kibungo	MAM	Dry years	2014	1973	1980	1994	2005	1978	2000	1992	1997	2001
		Wet years	1993	2011	1972	1988	2004	1990	2010	2002	2003	2012
	OND	Dry years	1985	2004	1981	1977	1999	1978	1998	1996	1979	1997
		Wet years	1986	1991	1984	2012	1983	2011	1975	2014	1976	1993
	ANNUAL	Dry years	1977	2005	1992	1998	1971	1979	1975	1973	1981	1985
		Wet years	2011	1993	1986	1972	1984	2012	1991	2009	2014	2010
Kigali	MAM	Dry years	2014	1976	2000	2003	1975	1993	1992	1983	2007	2011
		Wet years	1979	2012	2013	1985	1998	1987	1978	2006	1986	1994
	OND	Dry years	1996	2008	1993	2005	1974	1992	2004	2003	1999	1991
		Wet years	2001	1997	2006	1983	2013	1979	1972	1982	1977	2002
	ANNUAL	Dry years	2000	1992	2008	1993	2004	2005	2014	2003	1976	1999
		Wet years	2001	1994	1979	1998	2010	1988	1981	1972	1997	2007
Gikongoro	MAM	Dry years	1984	1996	1980	2014	2007	1987	2008	2000	2011	1993
		Wet years	1973	1974	1975	1995	2013	1986	1992	1981	1999	1979
	OND	Dry years	1993	1971	1983	1994	1980	1996	1985	1988	2008	1976
		Wet years	2011	2009	2014	1974	1973	2013	1984	1997	1999	1982
	ANNUAL	Dry years	1990	1993	2000	1985	1983	1994	1984	1996	2003	1986
		Wet years	1974	1973	1975	2011	1999	2001	2013	1992	2009	2002
Byumba	MAM	Dry years	1986	1976	1975	2002	1983	1999	2007	1996	1985	2000
		Wet years	2013	1971	2006	1982	1998	2012	1987	1993	2005	1980
	OND	Dry years	2005	1990	1988	1993	2003	1982	1999	1974	1981	1991
		Wet years	1997	1996	1978	1973	2000	1987	2012	2014	1983	1984
	ANNUAL	Dry years	1982	1999	2003	1993	2005	1991	2002	1983	2004	1981
		Wet years	2013	1996	1971	1977	1972	2012	1987	2014	1988	1998
Gisenyi	MAM	Dry years	2007	2014	2008	1992	2001	1984	1975	1997	1989	1999
		Wet years	1988	1996	2010	2012	1985	2000	1982	1978	1980	1976
	OND	Dry years	2001	1996	2000	1999	1995	1984	1974	2005	2008	1981
		Wet years	2009	2002	1971	2010	1983	2012	2013	2014	1976	1994
	ANNUAL	Dry years	1984	1992	1989	1995	1999	1975	2008	1993	1987	2001
		Wet years	1972	1998	2010	1988	1971	1996	2012	1986	1983	2006

The extreme rainfall events over Rwanda are given in Table 23. In the larger country, there were 10 (8) dry (wet) events during MAM, 10(7) dry (wet) events during OND and 10 both dry and wet events in the annual category. The seasonal categories support the results from probability analysis, that the chance of dry events is higher as compared to the chance for the occurrence of wet events.

Representative events of those in Table 23 were composited for wind, SSTs and SLP so as to understand the ocean-atmospheric patterns that yielded the observed rainfall events. These results are discussed in the sections that follow.

4.5.2 WIND COMPOSITES AT 850hpa AND AT 200hpa FOR MAM AND OND

During the wet events, the composited wind patterns in Figure 23 shows southeasterly winds reaching Rwanda from the Indian Ocean at 850hpa. This low level flow is speed of this flow is from the Indian Ocean is seen to decay upon reaching the vicinity of Rwanda. Therefore, it may be hypothesized that this reduction of speed is a signal of level convergence, promoted to orographic lifting that yields enhanced rainfall in the region. At 200hpa, easterly flow is seen to dominate the equatorial region.

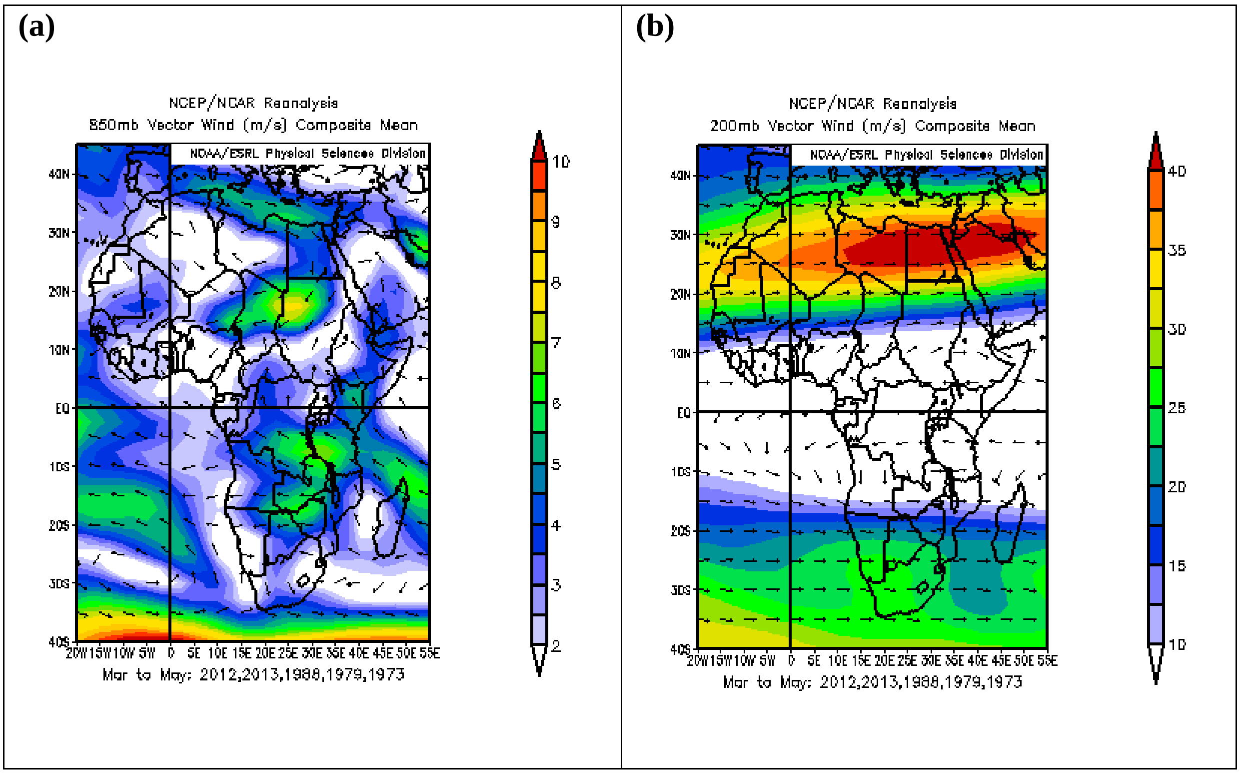


Figure 19. Wet MAM composited wind pattern anomaly over Africa at 850hpa (a) and 200hpa (b)

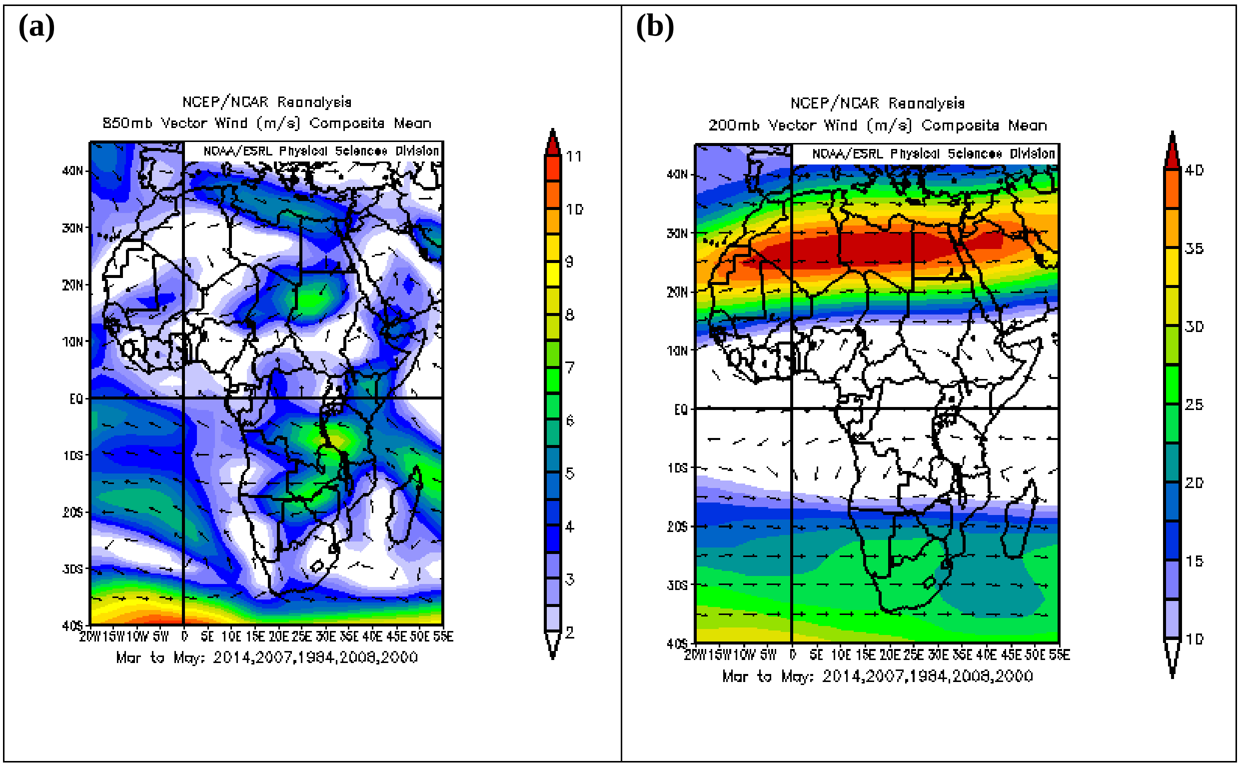


Figure 20. Dry MAM composited wind pattern anomaly over Africa at 850hpa (a) and 200hpa (b)

During the MAM events, Figure 19 shows the composited wind patterns at 850 and 200hpa in (a) and (b) respectively. At 850hpa, it evident that moisture flow is along the south-easterlies from the Indian Ocean. The 200hpa shows an easterly flow over the equatorial region.

During the OND wet events in Figure 20, easterly winds are observed to flow from both the south and north hemispheres at the 850hpa level. Areas of convergence include the Congo and Rwanda, as depicted by low wind speeds while the higher speeds are record in much of the neighborhood countries to the east, namely Kenya, Tanzania and Somalia. In the vicinity of Madagascar, an area of remarked wind speed represented the Mascarine anticyclone is evident. During this season, the Mascarine weakens hence the ITCZ moves southwards. At 200hpa, the wind is westerly over the equatorial region. This is a remarkable difference compared to the MAM 200hpa patterns.

In Figure 21, the composited wind patterns for dry OND events are shown. At 850hpa, the moisture influx is evidently from the Indian Ocean while the 200hpa does not have a signal for the causal mechanism of moisture into the region. In general composited wind patterns for wet events indicated the presence of strong low level convergence accompanied with enhanced upper level divergence. The opposite was noted for composite dry events

From the results in this section, it is also evident that due to low resolution of the NCEP/NCAR Reanalysis data (2.5 x 2.5 degrees, which is even larger than the area of study), the detailed wind flow patterns have been masked out.

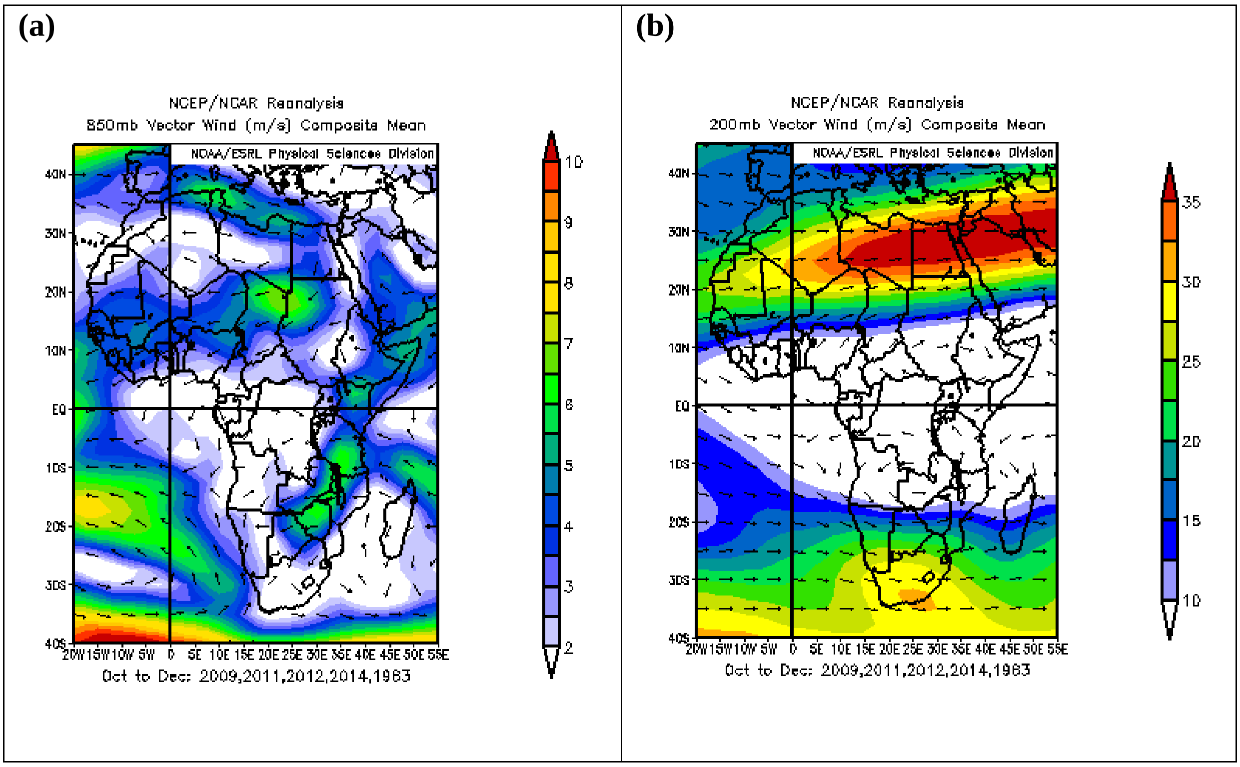


Figure 21. Wet OND composited wind pattern anomaly over Africa at 850hpa (a) and 200hpa (b)

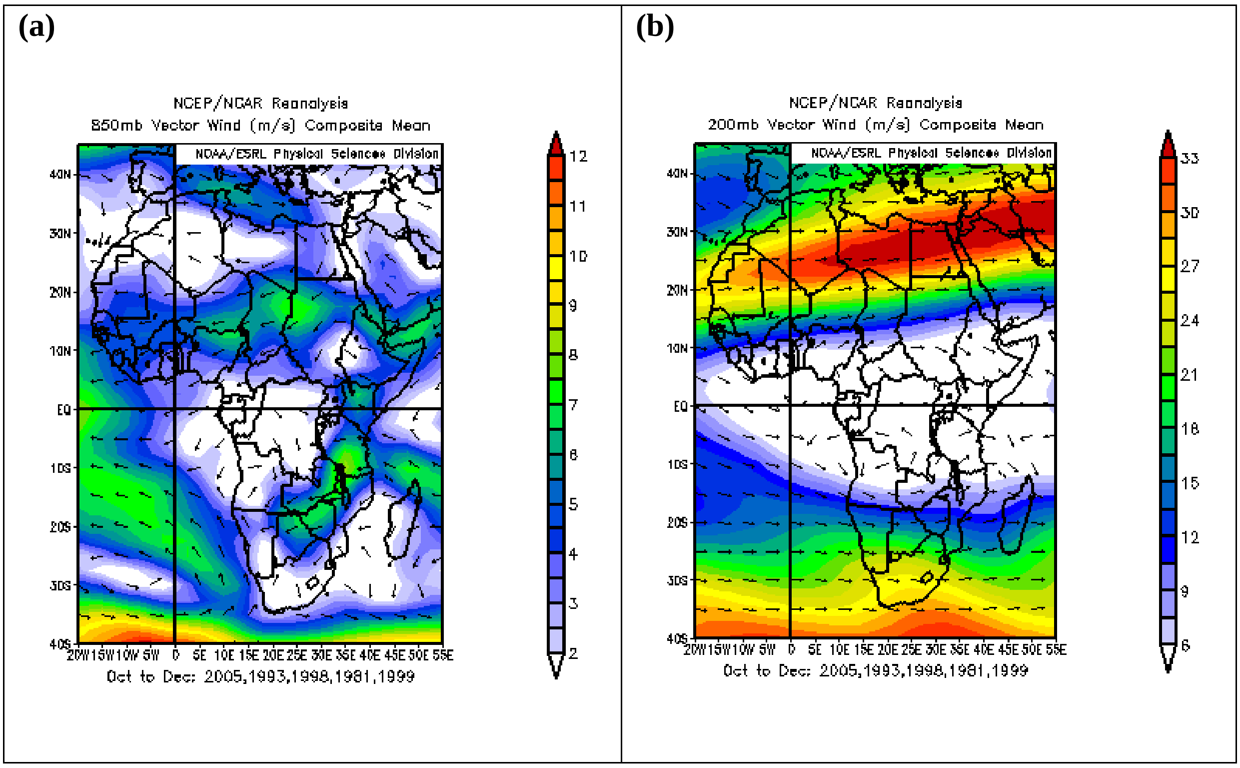


Figure 22. Dry OND composited wind pattern anomaly over Africa at 850hpa (a) and 200hpa (b)

4.5.3 SST COMPOSITED EVENTS

In Figures 23 and 24, the composited MAM and OND SST patterns around Africa extending from 20°W to 55°E are shown. During both wet and dry MAM events in Figure 23, maximum SSTs are located in the equatorial region of both the Atlantic and Indian Ocean regions in the vicinity of Africa. However, SSTs have not strong impact to the MAM rainfall as compared to the OND.

During the wet OND events, maximum SSTs are observed over the coast of Kenya and Somalia as well as in West African coast. Warm SSTs over the western Indian Ocean have been related to enhanced seasonal rainfall over East Africa during the OND season (Owiti *et al.*, 2008). This is because warm SSTs in this basin enhances convection hence moisture transport mainland through the south easterly winds. During the dry OND events, the SSTs.

In general SST composites showed that wet events over Rwanda are marked by cooler Atlantic Ocean and warmer Indian ocean. However, during the dry events, the Atlantic was warm while the Indian ocean was cooler.

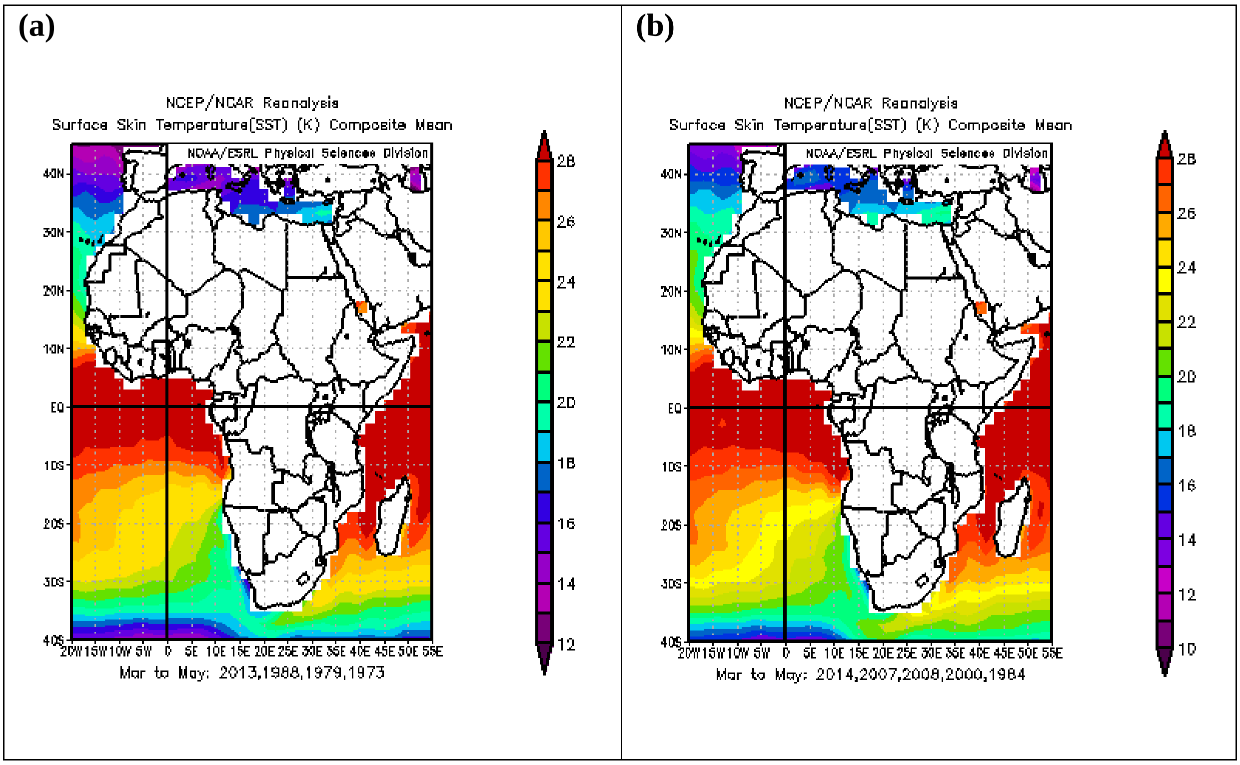


Figure 23. Wet MAM (a) and dry MAM (b) composited SST

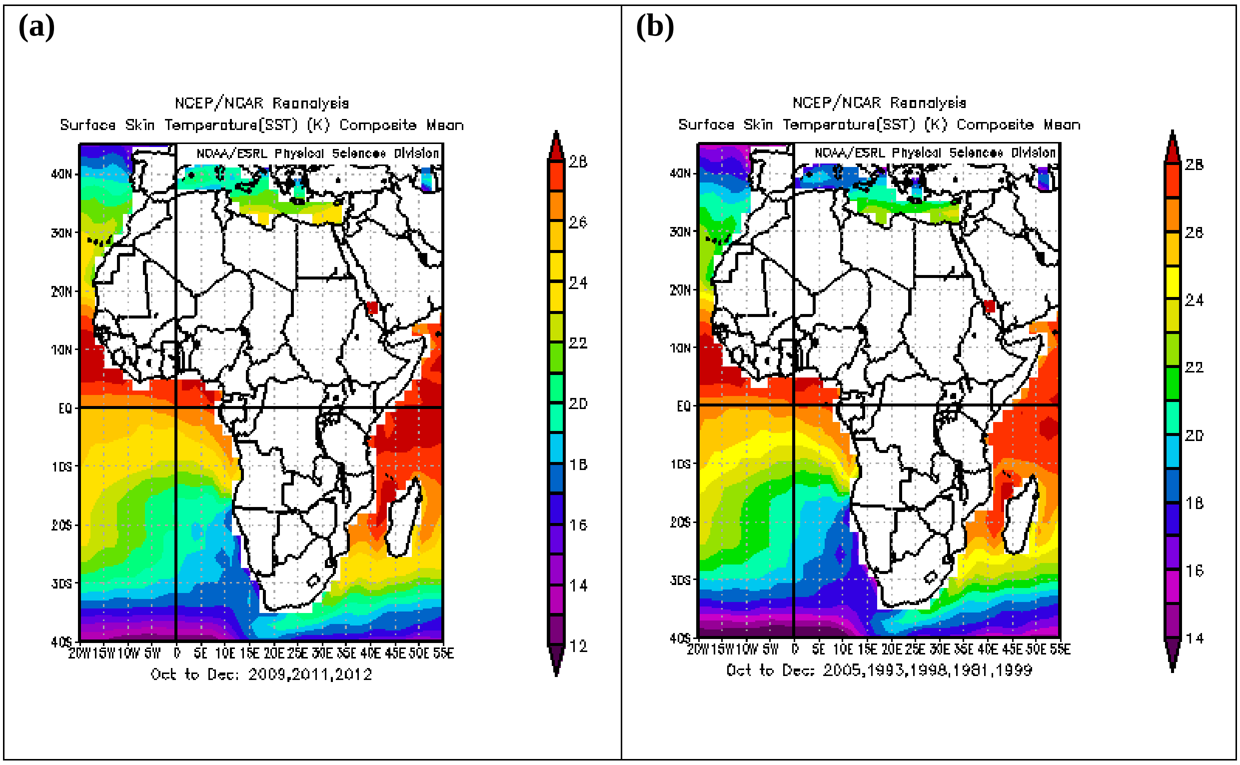


Figure 24. Wet OND (a) and dry OND (b) composited SST

4.5.4 SLP COMPOSITED EVENTS

The Sea Level Pressure (SLP) composited events are given in Figures 25 and 26. Figure 25 shows the composited SLP patterns during the MAM wet and dry events. During the wet events, highest pressure is observed in the St Helena anticyclone. Lower pressures are observed in the region of Rwanda thereby creating a pressure gradient that supports westerly influx of moisture from both the Congo Basin and the Atlantic Ocean. However, during the dry events, the Mascarine high is displaced eastwards hence hindering intense moisture flow along the south easterlies.

Figure 26, the composited SLP events in (a) show a weaker Mascarine high as compared to the St. Helena. This pattern therefore promotes moisture influx from the Congo Basin as well as the southward progression of the ITCZ. This pattern therefore favor enhanced rainfall over Rwanda. During the dry OND event in (b), the St Helena anticyclone is as well stronger than the Mascarine. Moreover, most of the equatorial and southern Africa is dominated by a minimum of pressure pattern. This implies that there is weak pressure gradients in the region thereby hindering moisture transport and consequently resulting to the observed depressed rainfall over Rwanda.

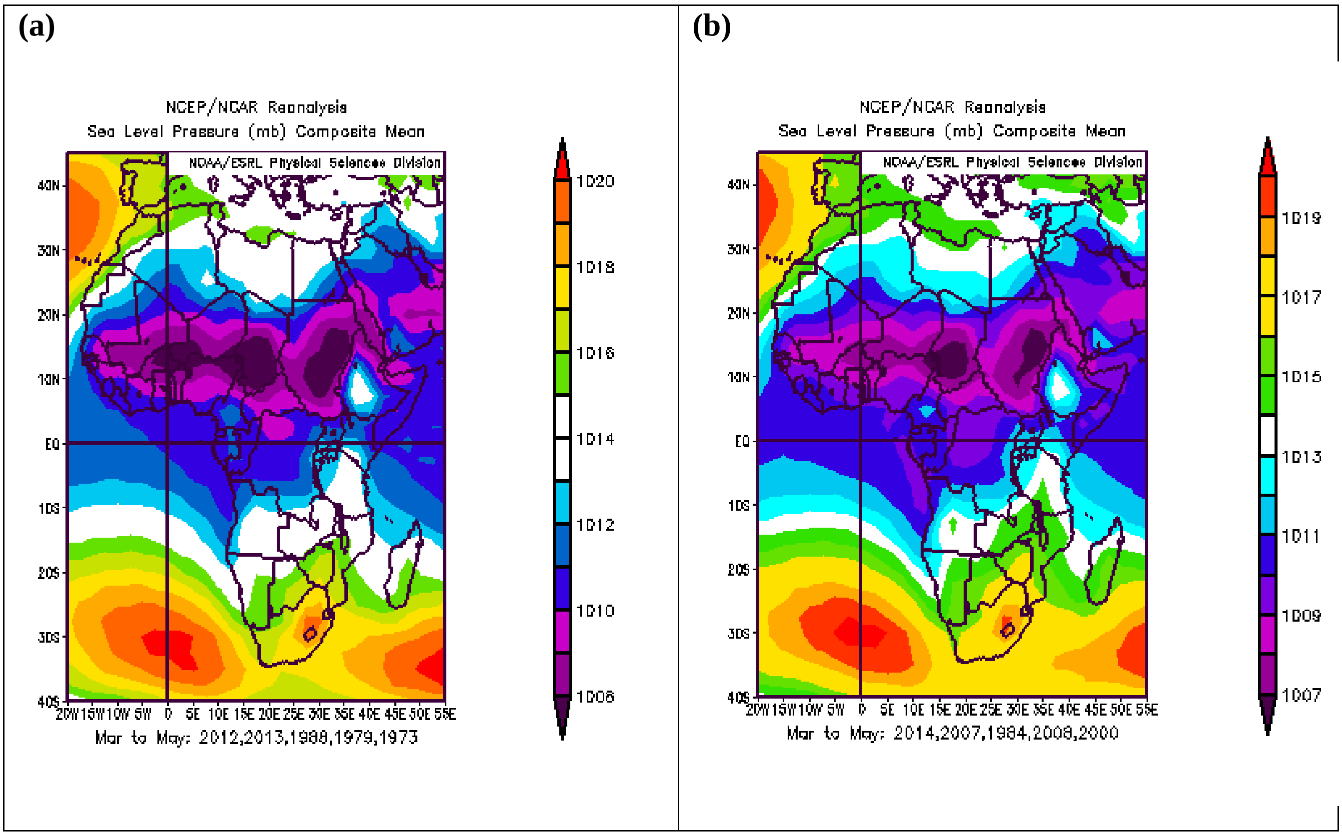


Figure 25. Wet (a) and dry (b) MAM composited SLP pattern over Africa

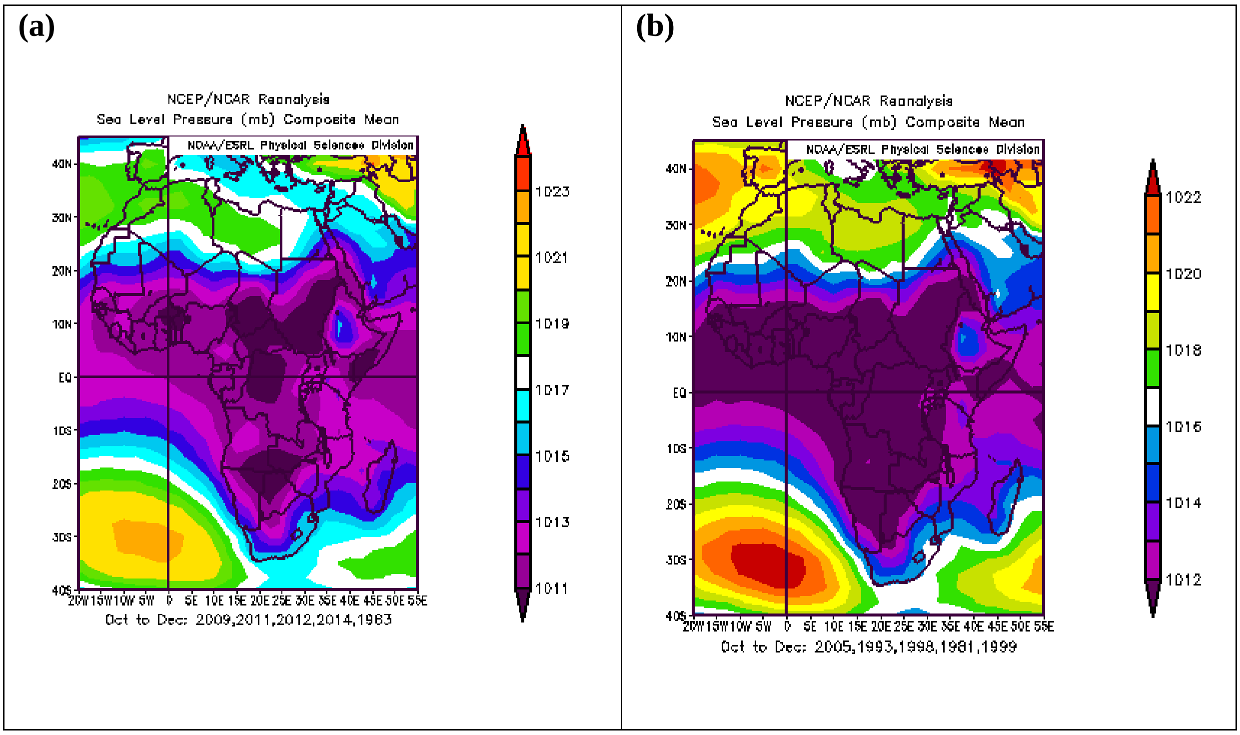


Figure 26. Wet (a) and dry (b) OND composited SLP pattern over Africa

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMANDATION

This chapter presents the conclusions drawn from the results of this study as well as the recommendations for applications and future studies in over Rwanda.

5.1 CONCLUSION

The results from this study show that both MAM and OND rainfall over Rwanda is not normally distributed. During MAM, the western region has the least inter-annual variability as compared to the central and eastern regions. The western region is wet as compared eastern region. This pattern is also observed during the OND season as well as the annual timescale.

In Rwanda, it is noted that both seasonal and annual rainfall has the highest probability of depressed anomalies. The area of study therefore has high frequency of droughts than normal and above normal rainfall. SST-rainfall relationships are best evident in OND season than MAM. During MAM, warm SSTs over the western Indian Ocean basin promote enhanced rainfall. The wind patterns also reveal that the moist easterlies are responsible for the moisture transport during both the MAM and OND seasons. It is therefore evident that rainfall over Rwanda is controlled by synoptic scale ocean-atmospheric interactions. Orographic lifting is also evidently a contributing factor of spatial rainfall distribution over Rwanda. This is especially true over the western region.

5.2 RECOMMENDATION

The results from this study several recommendations are suggested. It is first recommended that effective drought monitoring and early warning systems should be put in place. This is because there is high probability of depressed rainfall in Rwanda.

It is also recommended that studies on more SST-rainfall relationships over Rwanda should be pursued. This can help develop better forecasting tools for seasonal rainfall especially during the OND season.

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