ASSESSING THE SPATIAL AND TEMPORAL CHARACTERISTICS OF RAINFALL OVER THE SOUTHERN REGION OF MALAWI

BY

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Declaration

This research project is my original work and has not been presented for the award of a degree in this or any University.

Signature ……………………………… Date 12/08/14………

This project has been submitted with our approval as University Supervisors

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Dedication

I would like to dedicate this work to my lovely and dear wife, Lillian, and my children for their encouraging words and prayers. I love you and God bless you all.

Acknowledgement

I am thankful to the Almighty God for His love, guidance and protection upon me.

My sincere gratitude goes to my supervisors Dr. Christopher Oludhe and Mr Cromwell Bosolo Lukorito for their guidance and encouragement and suggestions throughout this work. This gratitude also extends to all lectures and the entire staff of Meteorological Department, University of Nairobi, for their support and encouragement during my studies. Indeed you have been of great help to me during my whole period of study here.

I am also grateful to the Malawi government through the Department of Climate Change and Meteorological Services in Malawi for the sponsorship and data for the project.

Abstract

An understanding of temporal and spatial characteristics of rainfall is central to resources planning and management especially with evidences of climate change and variability. There are strong indications that rainfall changes are already taking place on the local, regional and global scales associated with global warming.

The main objective of the project was to assess rainfall characteristics over the Southern Region of Malawi. In order to achieve the objectives, the rainfall data was subjected to various analyses including quality control. Forty-two years of daily rainfall data (1971-2012) from 9 stations within the region was analysed inorder to observe the characteristics of rainfall such as the onset and cessation, rain days, seasonal, annual, spatial and temporal rainfall distribution. The core methodology used in analysis of rainfall trends and variability was the time series analysis, single mass curve and spatial analysis for rainfall distribution. Other tools used were surfer application for spatial rainfall analysis and Instat climatic statistical application for determination of onset, cessation and length of growing season.

In Malawi, agricultural and electricity generation productions largely depends on rain. The rainfall pattern in the area is highly variable and is associated with extreme events which cause flooding in certain areas of the region. Flooding has led to loss of property and infrastructure and to a higher extent has led to food insecurity over the region. These occurrences have negative effects on the country's economy.

The results of this study have shown that there are decreasing trends in rainfall data but they are not though insignificant. The results have also shown that the rainfall in the area is variable and has varying onset and cessation dates. The growing season has also been reduced due to the decreased number of rain days that are being experienced over the region hence the need for effective planning and proper resource management inoder to realize positive productivity with the available rain.

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List of Abbreviations

CWR	Crop Water Requirement
FAO	Food and Agricultural Organisation
GDP	Gross Domestic Product
IFPRI	International Food Policy Research Institute
IPCC	Inter Governmental Panel on Climate Change
ITCZ	Inter Tropical Convergence Zone
JFM	January February March Rainy Season
OND	October November December Rainy Season
SADC	Southern African Development Community
US$	United States Dollar
WMO	World Meteorological Organisation
ZAB	Zaire Air Boundary

CHAPTER ONE

1.0 Introduction

The economies and livelihoods of Sub Saharan Africa depends mainly on rain fed agriculture. In Malawi, more than 90% of the staple food crop maize is produced by small scale farmers under rain fed conditions. Agriculture is by far the most important sector of Malawi's economy. In 2003, it contributed 37.6 percent to the country's GDP of 1,700 million US$. Agriculture accounts for about 90 percent of the country's export earnings, with tobacco alone accounting for 60 percent, and provides employment for 81 percent of the economically active population.

Food demand in Malawi is increasing steadily because of the absolute increase in population. In addition, droughts like the one of 1991/92, partially of 1996/97 and 2001/02 caused low yields and countrywide crop failures. These scenarios confirm that Malawi is vulnerable to climate change and extreme weather events which include intense rainfall, floods, seasonal droughts, dry spells and strong winds.

There have been both increasing and decreasing trends in the rainfall amounts and shifts in the other characteristics of rainfall including delays of start of rainfall, number of rain days and cessation of rainfall, length of growing season and distribution of extreme rainfall events over different parts of Malawi. The annual and seasonal rainfall variability are key factors in the success of agricultural production.

Knowledge of the temporal changes in rainfall and the associated extreme events is essential for successful crop production and other socio – economic activities. Extreme rainfall event such as flooding is a major natural hazard in Malawi and leads to significant damage to infrastructure and property which negatively impacts the country's Gross Domestic Product (GDP).

However, fluctuations in the rainfall patterns are not easy to forecast. Afore-knowledge would assist in making decisions to plan strategically. This is central to resources planning and management especially with evidence of climate change and variability in recent years. Such information is important in agricultural planning, flood frequency analysis, flood hazard mapping, hydrological modeling, water resource assessments, climate change impacts and other environmental assessments (Michaelides, *et al.*, 2009). There have been evidences of reduction in food production especially cereals and low power generation due to low rainfall that has been experienced over the country in 1992 and 2001 (FAO, 2006).

In an economy that is heavily dependent on the agricultural sector, it is crucial to understand the implications of extreme climate events. Not only are rural livelihoods affected due to the severe impacts on the agricultural sector, but nonfarm and urban households are also vulnerable given the strong production and price linkages between agriculture and the rest of the economy. Extreme rainfall event such as flooding is a major natural hazard which impacts Malawi and lead to significant damage to infrastructure and property with an estimated 1.7 percent every year, on average, of the country's Gross Domestic Product (GDP) (Karl P., *et al.,* 2010).

1.1 Statement of the Problem

The Southern Region of Malawi is prone to drought and frequent flooding coupled with a rapidly increasing human population. Rainfall variability characterized by extreme climatic events has direct adverse effects on agricultural production, power generation, tourism and the overall economy of the country. With climate change, the region is increasingly experiencing land degradation which not only impacts adversely on the livelihoods of communities therein but also on the overall social and economic growth and development of the country.

In this regard, this study aimed at assessing the characteristics of rainfall across temporal and spatial scales with a view to guiding national socio-economic development plans that would guarantee increased agricultural production, poverty eradication, uninterrupted power supply and food security.

1.2 Objective

The main objective of the project was to assess the temporal and spatial rainfall characteristics over the Southern Region of Malawi.

.The specific objectives were:

i. To determine the monthly, seasonal and annual rainfall characteristics.
ii. To determine the trends in the rainfall characteristics over the Southern Region of Malawi
iii. To determine the patterns of extreme rainfall events over the Southern Region of

Malawi.

1.3 Significance of the study

The knowledge of the temporal and spatial characteristics of the rainfall onset, cessation and length of season is important for the prediction and mitigation of extreme weather events (flooding and drought), food security, population control, and water supply for domestic and industrial use, hydropower production and irrigation. More than 90% of the people in the region are engaged in subsistence rain-fed agriculture which is affected by rainfall variability. The recurrent floods and droughts are affecting key development investments intended to address the challenges Malawi is facing in terms of food security and poverty reduction. During the drought of 1992, maize production decreased by 50% (Malawi Ministry of Agriculture, 1993) food had to be imported. The failure of rains for more than a month in any rainy season adversely affects agriculture and the economy of Malawi. The farming community and all stakeholders require information on rainfall characteristics.

The study therefore attempted to assess the characteristics of rainfall between 1971 and 2012 in the region and thereby identifying and devising ways of sustaining the economic and agricultural activities that are taking place within the area.

1.4 Hypothesis of the Study

Understanding rainfall characterisation in the Southern Region of Malawi will help enhance agricultural planning and overall economic growth in Malawi for sustained crop production and economic activities.

1.5 Study Area

The study was conducted in the Southern Region of Malawi. Figure 1 below is the map of Malawi showing Southern Region of the country and physical features in the region.

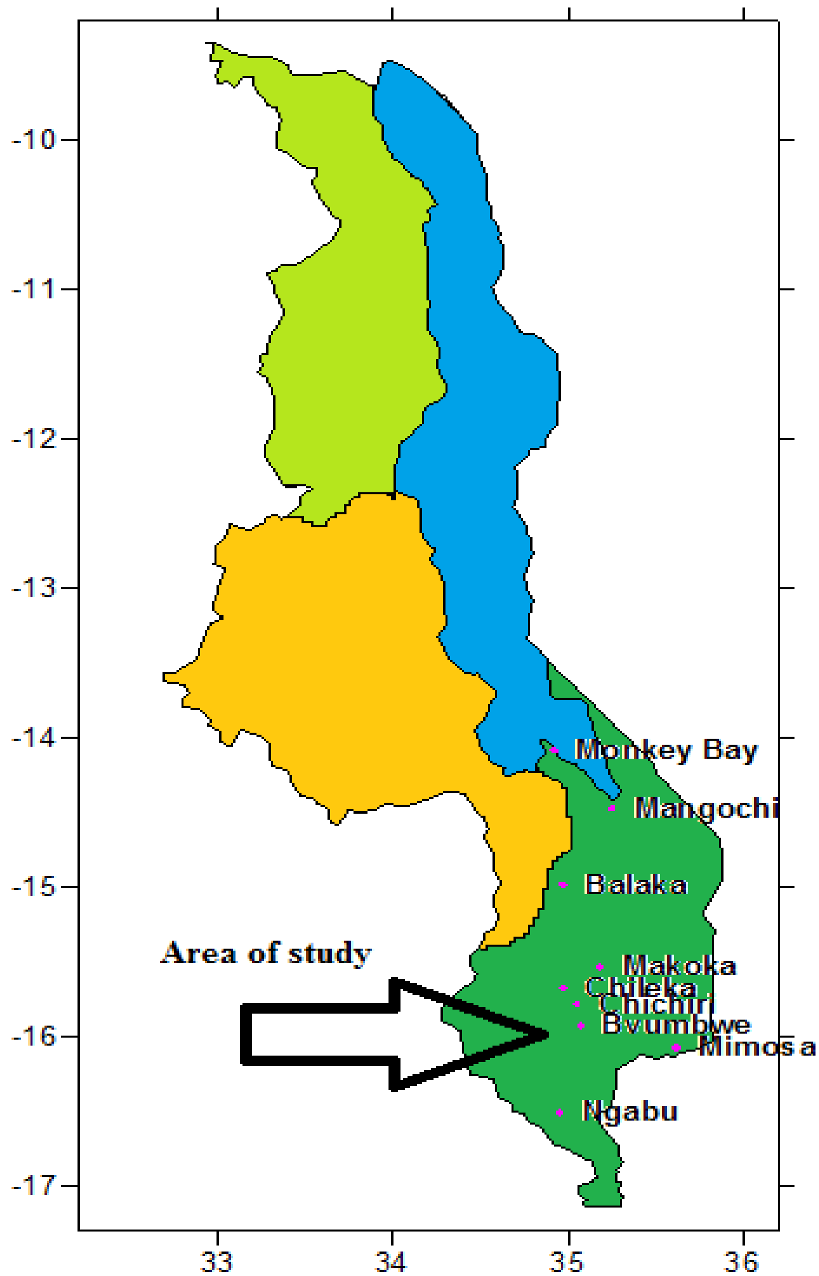

Figure 1: Map of Malawi Showing Area of study

Southern Region of Malawi is in the Southern part of Malawi and is within latitudes 14°S - 17°S and between longitudes 34°E - 36°E. It is bordered by Mozambique on the Eastern, Southern and Western sides. The area is warm and hot and is characterised with low lying areas to the Northern zone and highlands in the middle zone and with a low lying valley to the southern zone which has an altitude of 37m above mean sea level. These topographic features contribute to the spatial and temporal variations in rainfall characteristics over the region. The population in the region is approximately 7 million and the people there practice crop and livestock production.

Figure 2: Map of Southern Malawi Showing Physical features

The main rain bearing system in Malawi is the Inter Tropical Convergence Zone (ITCZ). This is a Pro- cone in the equatorial low pressure belt towards which the north-easterly and south-easterly trade winds of the two hemispheres converge. The ITCZ oscillates randomly across the country during the rainy season and produces widespread rainfall. The rains in Malawi start in the Southern Region and progress northwards. Other rain bearing systems that affect Malawi are:

Zaire Air Boundary (ZAB) - a recurred south Atlantic south-east trade winds which after picking moisture over the Atlantic and Congo (Zaire) rain forests arrives in Malawi via Zambia as a moist north-westerly wind bringing widespread rainfall.

Tropical Cyclones - are intense low-pressure cells that originate in the Indian Ocean and move from east to west and bring widespread heavy, rainfall, mainly in the south, depending on their position in the Mozambique Channel. These rains usually result in flooding.

The easterly waves system, which is mostly active towards the end of the rainy season (March/April). The existence of easterly waves in the atmosphere causes isolated but locally heavy rains in some parts of the country.

The main rain season is from October to April and the dry season is from May to September. However, from May to July it is relatively cool and some high altitude areas in the Southern region of the country experience sporadic winter rains locally called Chiperoni. These rains originate from an influx of cool moist southeast winds during the period. Annual rainfall in Malawi varies from 700 mm in the low-lying areas to 2,500 mm in the southern and parts of the northern highlands. Rainfall distribution is influenced by topography (orographic effects) and proximity to lake Malawi. Least rainfall is registered in rain shadow areas such as in the Shire Valley, West of Shire Highlands and Zomba plateau (e.g. Lake Chirwa area), north-west of both Viphya and Nyika plateaus. Highest rainfall is experienced in high altitude areas; for instance, Mulanje, Nyika and Viphya plateaus. The most common types of soils found in the Southern Region of Malawi are clay and sandy clay and the vegetation type is Savanna grassland.

The mean annual minimum and maximum temperatures for Malawi range from 12 to 32 degrees Celsius. The coldest months are June and July. Highest temperatures are recorded in the Shire Valley and along the lake shore while the lowest are recorded over the high attitude areas particularly the Shire Highlands, the Viphya and Nyika plateau, Dedza and Mulanje mountains and other high-altitude areas.

CHAPTER TWO

2.0 Literature Review

Rainfall amount, distribution and variability is one of the most important aspects that determine the day to day socio economic activities in any given region or country. High variations have been observed in the distribution of the rainfall from one month to the other. Trends in rainfall distribution and variability have been studied and researched by many authors in different aspects. The studies have shown that changes in rainfall are typically harder to detect due to the fact that rainfall varies so much from place to place and from year to year. Ogallo *et al*, (1988) investigated the persistence of the monthly rainfall over East Africa and found out that the rainfall patterns are poorly correlated for the month to month persistence. Again, Ogallo (1979), found out that rainfall over Africa is oscillatory in time. Chabala *et al*, (2013) in their study on characterisation of temporal changes in rainfall and temperature in Zambia found that the trends in seasonal rainfall were variable while temperatures generally showed an increasing trend.

The amount and seasonal distribution of rainfall are the most important factors to consider when looking at rainfall across southern Africa. Southern Africa, to which Malawi belongs, is a predominantly semi-arid region with high intra-seasonal and inter-annual rainfall variability, with extreme events such as droughts and floods occurring frequently (IPCC, 2007).

Davis (2011) confirms that existing evidence for rainfall trends suggest moderate decreases in annual rainfall over parts of Southern Africa. Faucherean *et al* (2003) show that inter-annual rainfall variability over Southern Africa has increased since the rate 1960’s and that droughts have become more intense and widespread in the region. Fowler *et al* (2005) also indicates that there have been concerns that with future climate change, rainfall events will become more intense and frequent and therefore increase the risk of flooding. High rainfall events that also lead to flooding are determined by four main factors which include intensity, duration, antecedent and soil moisture and the response of the catchment, (Hand *et al*, 2004).

Whilst studying rainfall characteristics, rainfall onset and cessation are also important as they determine the length of the growing season. Several authors and researchers have given several differing definitions regarding rainfall onset. Kerand *et al* (2008) defines rainfall onset as the first day of any week having a cumulative rainfall of at least 20 mm, one of which must be 10 mm or more, followed by two other weeks each with at least 50% of the weekly Crop Water Requirement (CWR). This definition is based on crop water requirement. Sawa *et al* (2011) refers to onset as the time a place receives an accumulated amount of rainfall sufficient for growing crops. It is not the first day the rain falls. For this study the adopted definition of rainfall onset from the University of Reading is being the first occasion with more than 20mm of rainfall totalled over 2 consecutive days on or after 1st October and no dry spell of 10 days or more within the following 30 days. This is most appropriate for crops in its early critical stages of germination.

Africa is considered highly vulnerable to climate change (FAO, 2004), largely because many socio-economic activities in Africa, particularly agriculture, depend on climate and especially rainfall. Consequently, climatic variations and change have an impact on the productivity of many socio-economic activities (Obasi, 2005). Within the agriculture sector drought is arguably the most important climatic challenge and has major impacts on rural livelihoods (Buckland *et al.*, 2000). In the 1991/92 drought alone, cereal output in the Southern African Development Community (SADC) region (excluding South Africa) fell from an average of 11.3 million to 6.2 million tonnes, necessitating extensive food imports (FAO, 2004). Furthermore, projections of future change place southern Africa's agriculture sector at the forefront of climate change vulnerability with potential negative impacts on revenue from dryland farming (Kurukulasuriya, *et al*. 2006). Therefore rainfall is a major determinant of agricultural production in any agro-ecological zone anywhere in the world and is a dominant mode of food production in the majority of rural Sub-Saharan Africa (Cooper, *et. al*., 2008). The reliance of the agricultural sector on natural rainfall places it at a serious risk of shrinkage due to the inter-annual rainfall variations. (Nnyaladzi, 2009), observed that with the declining rainfall trends in Southern Africa and most of the Sub-Saharan Africa region, agricultural production and other economic activities are most likely to decline, raising concerns about issues of food security.

CHAPTER THREE

3.0 DATA AND METHODOLOGY

3.1 Data

The data used in this study comprised of daily, monthly and annual rainfall from 9 stations in the Southern Region for 42 years (1971 to 2012) with the exception of Balaka and Monkey Bay which had their data from 1976 and 1979 respectively. This data was collected from the Department of Climate Change and Meteorological Services in Malawi. The table below lists the stations used.

Table 1: list of stations

Station Name	Longitude (deg)	Latitude (deg)	Altitude (m)
Ngabu	34.95	-16.5	102
Mimosa	35.62	-16.07	652
Bvumbwe	35.07	-15.92	1146
Chichiri	35.05	-15.78	1132
Chileka	34.97	-15.67	767
Makoka	35.18	-15.53	1029
Mangochi	35.25	-14.47	482
Monkey Bay	34.92	-14.08	482
Balaka	34.97	-14.98	625

3.1.1 Data Quality Control

Data quality control was done in order to clean the dataset and put them in standard format that is appropriate for analysis. Poor quality dataset is normally due to different causes and arises from the way they were acquired, transmitted from the stations to the collection centre as well as archiving.

3.1.1.1 Estimation of Missing data

Different methods exist for the estimation of missing data. Arithmetic mean method was used for estimating missing data for Mangochi and Mimosa. Mangochi had daily missing data in three days and Mimosa had four days of missing data. The rest of the stations had no missing data values.

The arithmetic mean is given by.

$$P_x = \frac{1}{n}\left(\sum_{i=1}^{n} P_i \ \frac{N_x}{N_i}\right) \tag{1}$$

Where; Px = estimation of ppt at station x, Pi = ppt at Nx = normal ppt at station X and Ni is ppt at the *ith* surrounding station.

The estimated data was less than 10% of the record in any given location otherwise the records would have been disregarded.

3.1.1.2 Data Consistency

The accumulated rainfall data was plotted against time to test for data homogeneity. Single mass curves give quick information about the consistency in the data. A straight line in a single mass curve indicates the homogeneity of data. In case the data is not homogeneous, the ratio of the two straight lines obtained is used. Rainfall records prior to the break are multiplied by the ratio of the slopes after and before the break.

3.2 Methodology

The following methods were used to analyse rainfall data in order to achieve the objectives of the study.

3.2.1 Rainfall Onset and Cessation and length of growing season

Rainfall onset refers to the time a place receives an accumulated amount of rainfall sufficient for growing of crops. For this study, an amount of more than 20mm would mean onset of rain in the region. On the other hand, cessation refers to the termination of the effective rainy season. It does not imply the last day rain fell but when rainfall can no more be assured or be effective. This is done through the water balance approach when it drops to zero. Length of the season is the duration between onset and cessation dates. To meet the objectives, determination of onset was based on 1st October being start of season with more than 20mm recorded in a single day or 2 days consecutive and no dry spell exceeding 10 days during the following 30 days.

3.2.2 Raindays

According to the Department of Climate Change and Meteorological Services in Malawi, the threshold of a rain day is 0.3mm. Any amount of rain below 0.3mm is considered as trace.

The rainy season of Malawi starts in October and ends in April of the other year. All days that had received more than 0.3mm of rainfall were counted to determine the number of rain days.

3.2.3 Trend and Time Series Analysis

Trend is the long term behavior of a time series. The method was used in order to determine the rainfall trends over the various stations within the area with respect to time so as to depict the changes in rainfall characteristics. The equation for determining trend is:

$$\mathbf{Y_{(t)}} = \alpha x + \beta \quad \text{...} \mathbf{(2)}$$

Where; $Y_{(t)}$ is the time index. The parameters alpha and beta (the "slope" and "intercept" of the trend line) are estimated through a simple regression in which Y is the dependent variable and the time index t_i is the independent variable

In time series analysis, graphs of rainfall dataset (monthly, seasonal and annual) were plotted against time in order to analyse the seasonal and annual rainfall trends over the region. The equation for determining time series is:

$$Y_{(t)} = F_{(t)} \quad \text{...(3)}$$

Where; $Y_{(t)}$ are rainfall values for time (t_i) from 1971 – 2012.

3.2.3.1 Trend Significance

The significance of the observed trends for seasonal, OND, JFM and annual rainfall were tested using the student t-test method. The equation for student t- test is:

$$t = \frac{\bar{X_1} - \bar{X_2}}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} \quad \text{...(4)}$$

Where,

$x1^{-}$ = Mean of first set of values

$x2^{-}$ = Mean of second set of values

S_1 = Standard deviation of first set of values

S_2 = Standard deviation of second set of values

n_1 = Total number of values in first set

n_2 = Total number of values in second set.

3.2.4 Extreme Rainfall Events

Extreme rainfall events are occurrences of extreme rainfall that is above a defined threshold of a particular locality. For this study, the threshold for extreme rainfall is 40mm or more. The Countif function was used to isolate daily extreme rainfall events. This type of rain can cause flooding which is the major natural hazard that damages infrastructure and property. Generally extreme rainfall causes soil erosion and leaching of soils as such crop production is affected thereby creating food insecurity in a nation. The mostly affected areas with flooding every year are low lying areas especially in the lower Shire plains of the region. Flooding is dependent on intensity and duration of rainfall as well as soil moisture content.

3.2.5 Statistical Applications

Data was also analysed using packages such as Excel and INSTAT. Instat is a simple general statistics package that includes a range of special facilities that simplify the processing of climatic data. It is a valuable tool in carrying out statistical calculations. Instat was used in the determination of onset, cessation and seasonal length. Excel was used in drawing graphs and charts. **Surfer** was used in drawing maps for spatial rainfall distribution over the region.

CHAPTER FOUR

4.0 Results and Discussions

4.1 Homogeneity tests

Figures 3 to 8 show homogeneity tests that were carried out using single mass curve method. All the data from all stations was homogeneous. Below are some representative stations:

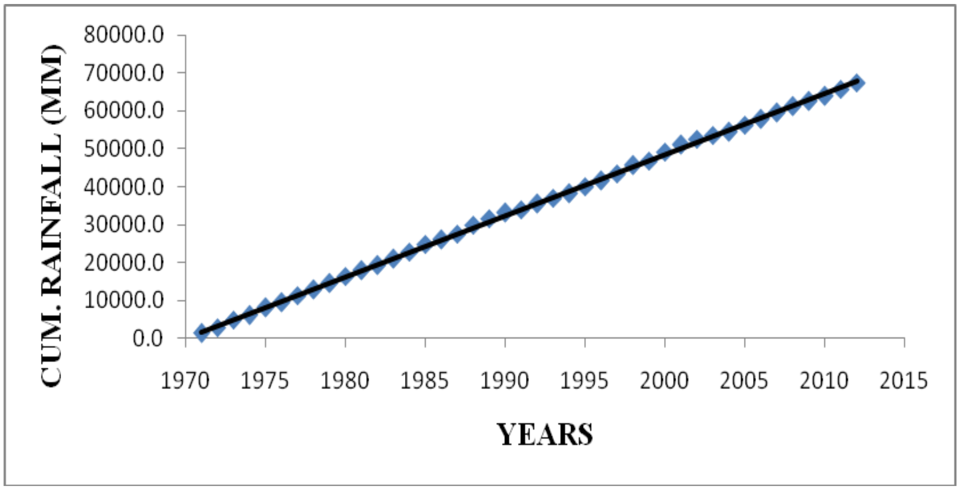

Figure 3: Single Mass Curve for Mangochi

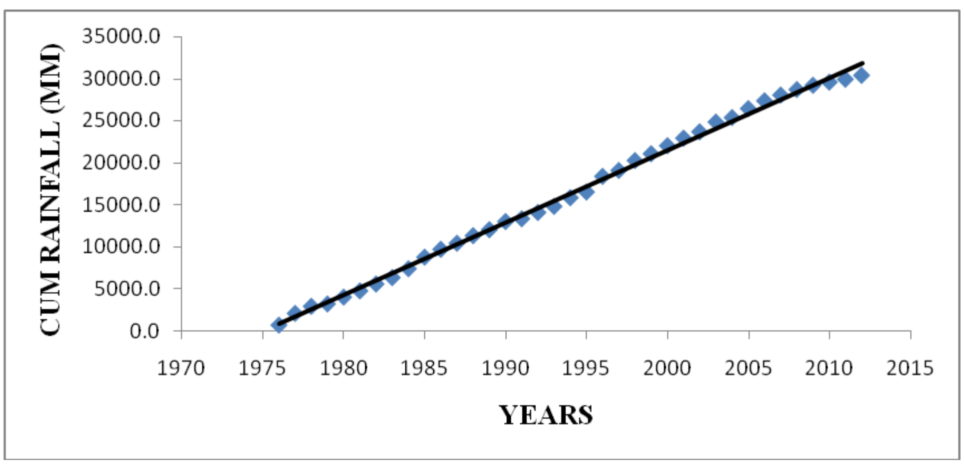

Figure 4: Single Mass Curve for Balaka

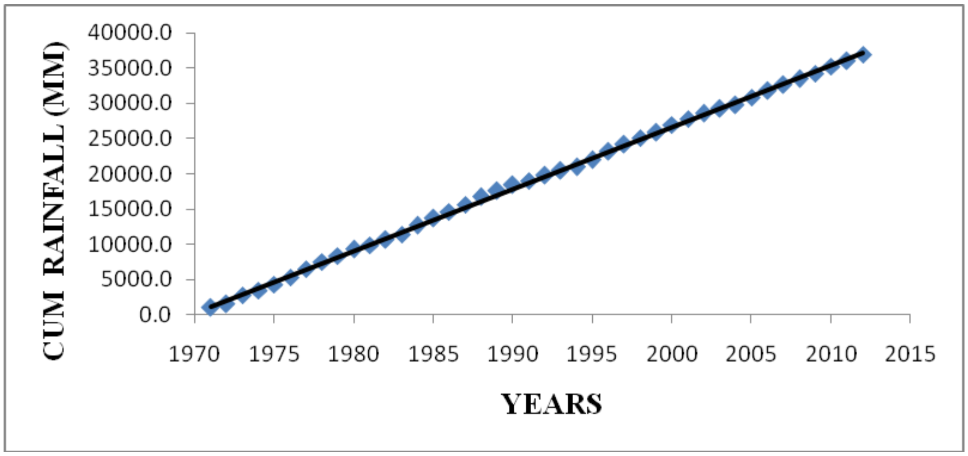

Figure 5: Single Mass Curve for Chileka

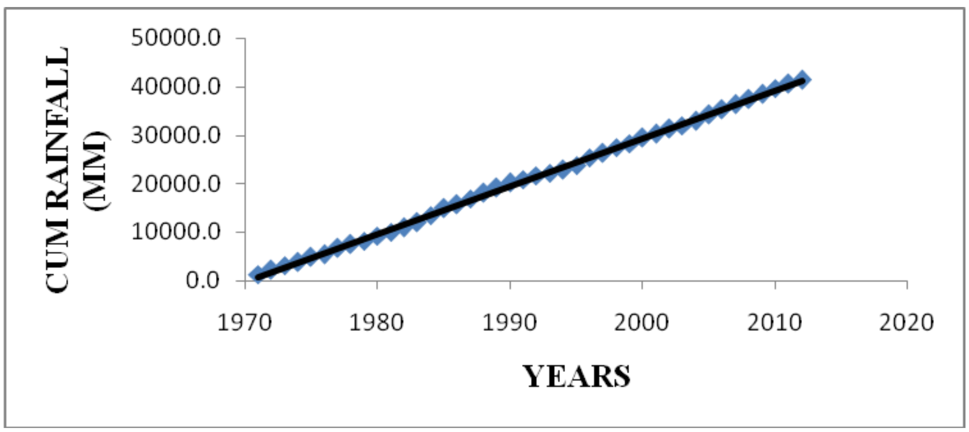

Figure 6: Single Mass Curve for Makoka

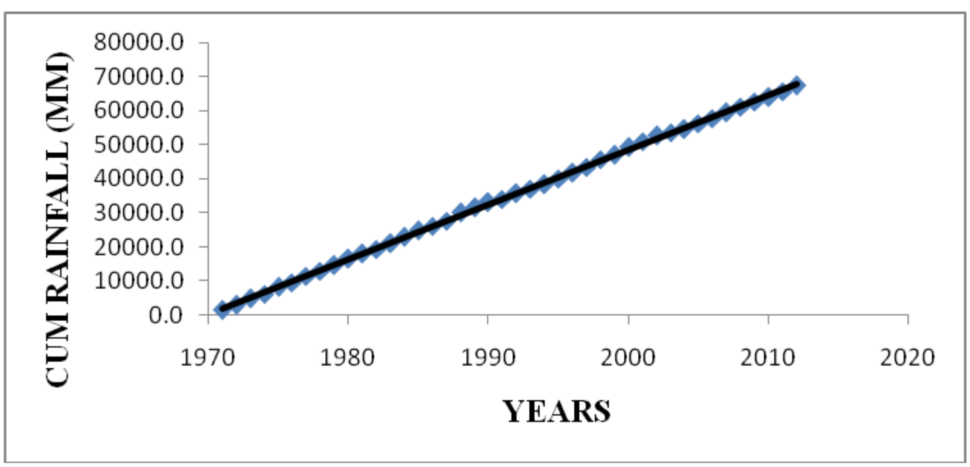

Figure 7: Single Mass Curve for Mimosa

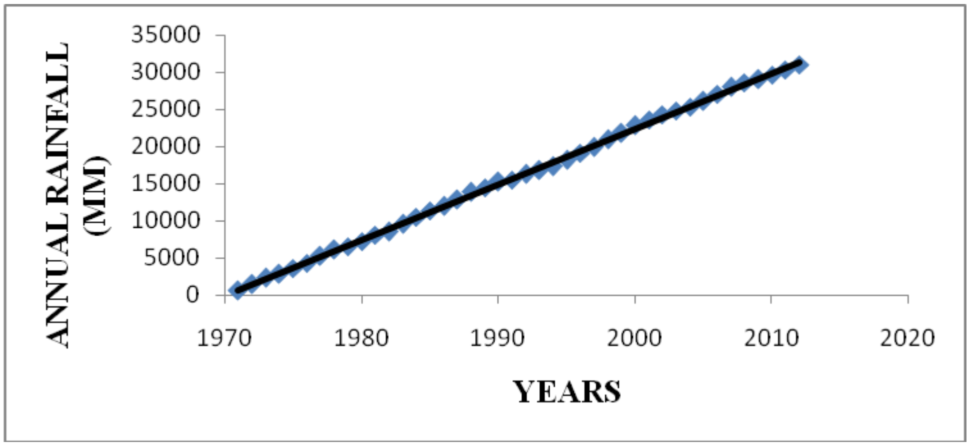

Figure 8: Single Mass Curve for Ngabu

All the mass curves gave linear plots indicating that the data obtained from all the stations used in this study were homogeneous.

4.2 Trend and Time Series analysis

4.2.1 Monthly Rainfall Analysis

Figures 9 to 14 show the monthly rainfall variation over some stations in the region for the period 1971 – 2012 except for Balaka.

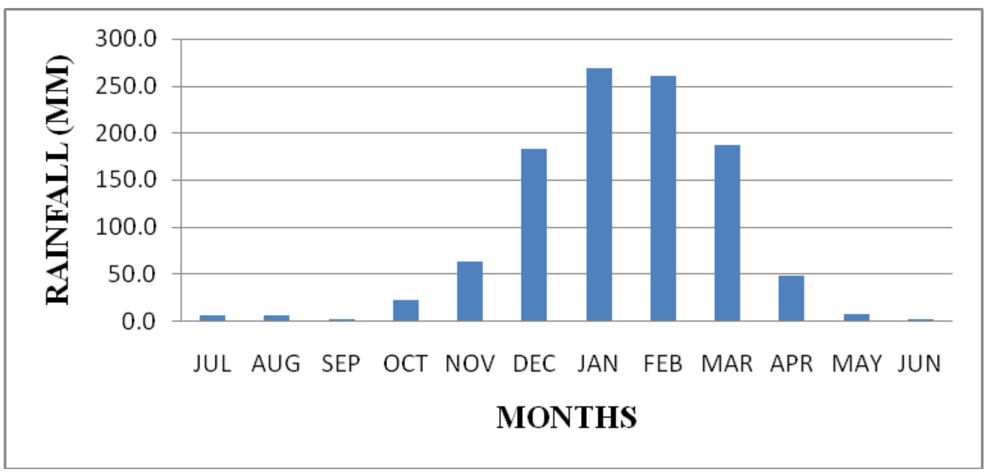

Figure 9: Monthly Mean rainfall for Mangochi

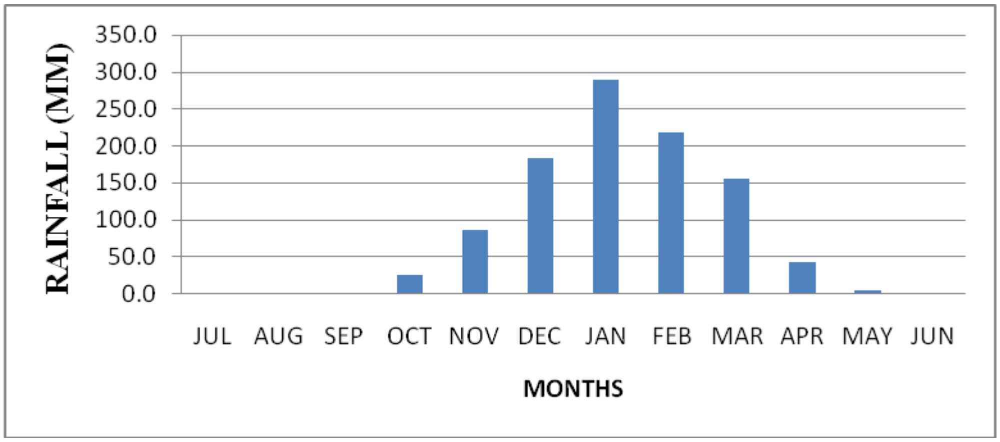

Figure 10: Monthly Mean Rainfall for Balaka for 1976 – 2012

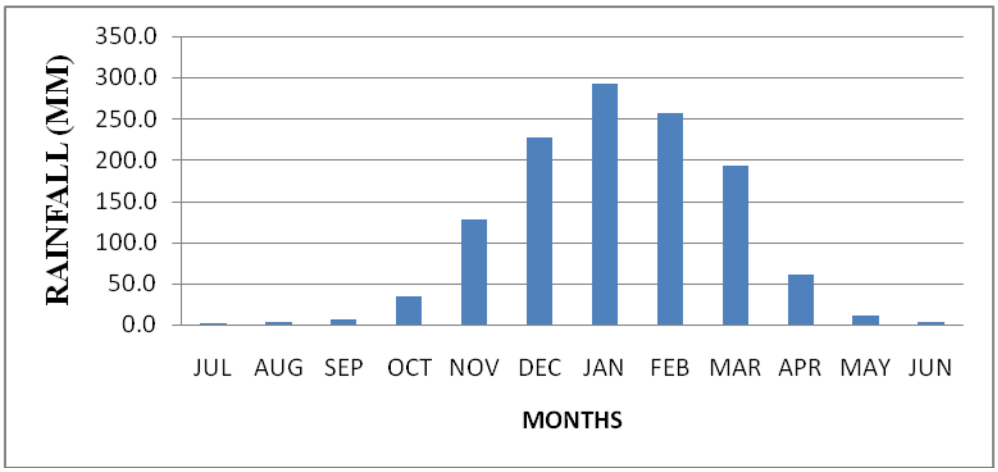

Figure 11*: Monthly Mean Rainfall for Chileka*

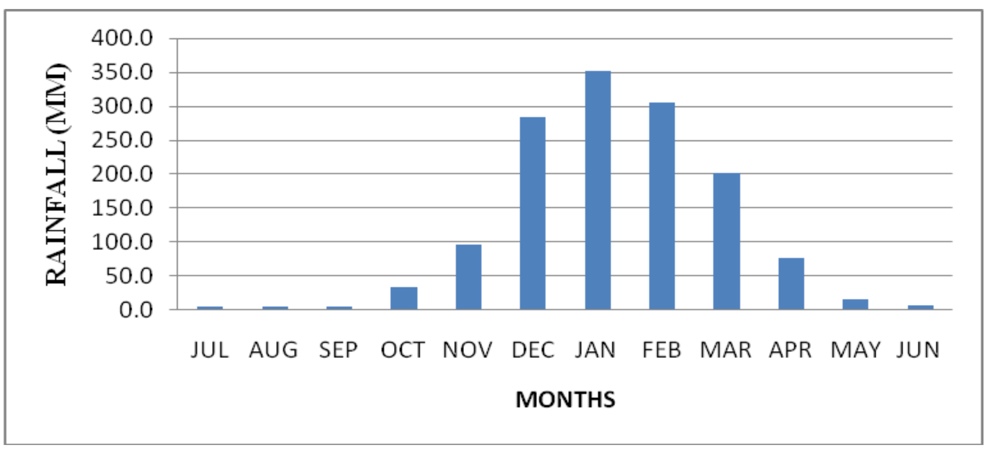

Figure 12*: Monthly Mean Rainfall for Makoka*

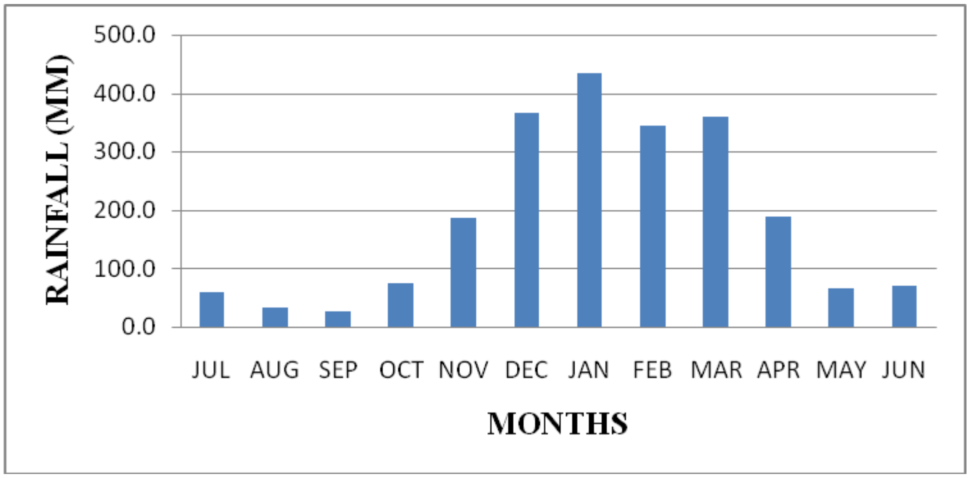

Figure 13: Monthly Rainfall for Mimosa

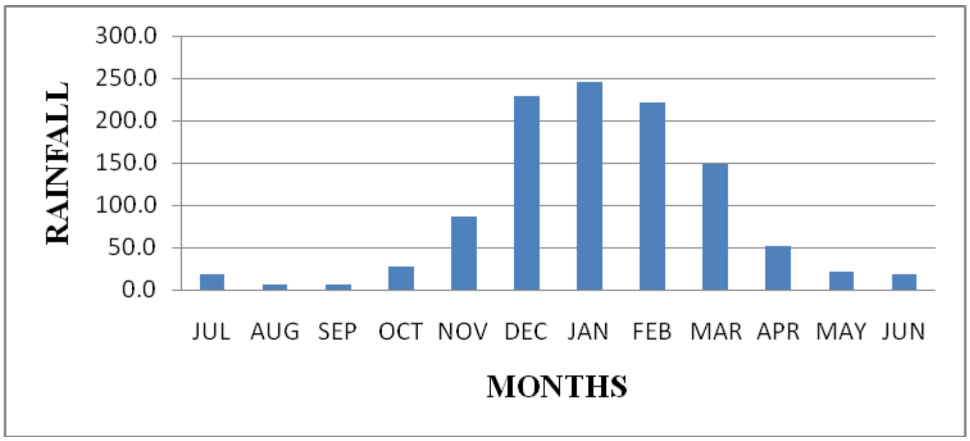

***Figure 14**: Monthly Mean Rainfall for Ngabu*

High rainfall has been registered in the month of January in all the stations and the highest rainfall has been recorded at Mimosa. The monthly distributions show a unimodal rainfall regime that occurs from October to April.

4.2.2 Seasonal and Annual Rainfall analysis

It was observed that the rainfall trends were generally variable for all the stations. Results indicated that annual rainfall for Mangochi, Bvumbwe, Chichiri, Makoka and Monkey-Bay had an increasing trend which is not statistically significant throughout the data period. It was noted, that the increasing trend for Mangochi, Bvumbwe, Chichiri, Makoka and Monkey-Bay were particularly noticeable around the years 1975, 1996, 2001, 1996, and 2002 when rainfall amounts of 1299mm, 1823mm,1666mm, 1594mm and 1278mm, respectively, were recorded.

The results further showed that annual rainfall for Chileka, Ngabu, Mimosa, and Balaka had a decreasing trend that was not statistically significant. The results showed that even though there were decreasing trends significant amounts of rainfall for Chileka, Ngabu, Mimosa, and Balaka were recorded in 1984, 1983, 1988 and 1996 with annual rainfall amounts of 1289mm, 1140mm, 2357mm and 1871mm. This suggests that the area could be prone to floods considering that the average annual rainfall was above 700mm. The high variability in rainfall could mean rain-fed agricultural production remains unpredictable and that crop moisture stress is a definite challenge if cropping operations are not properly timed. Figures 15 - 26 shows the inter-seasonal and inter-annual trends of rainfall for some selected stations.

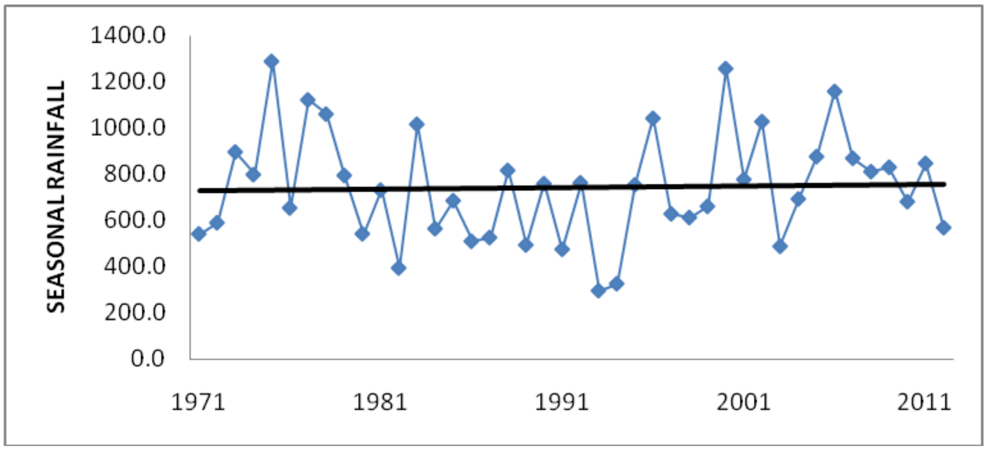

***Figure 15**: Seasonal Rainfall for Mangochi*

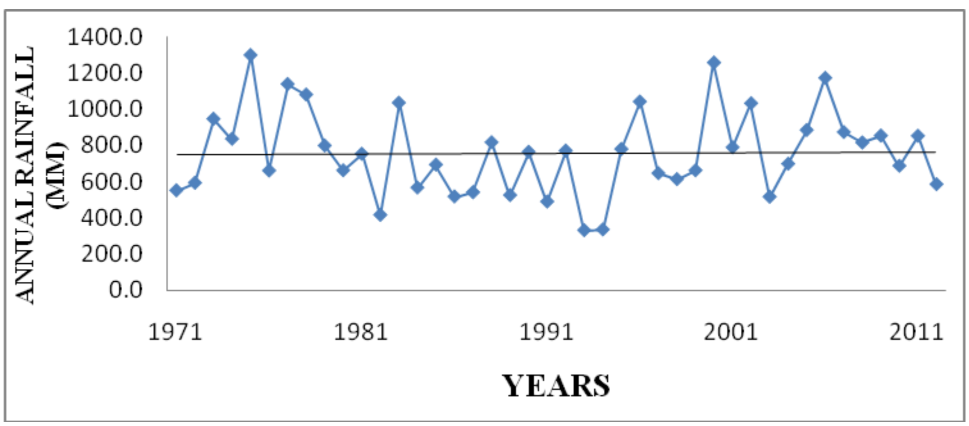

Figure 16: Annual Rainfall for Mangochi

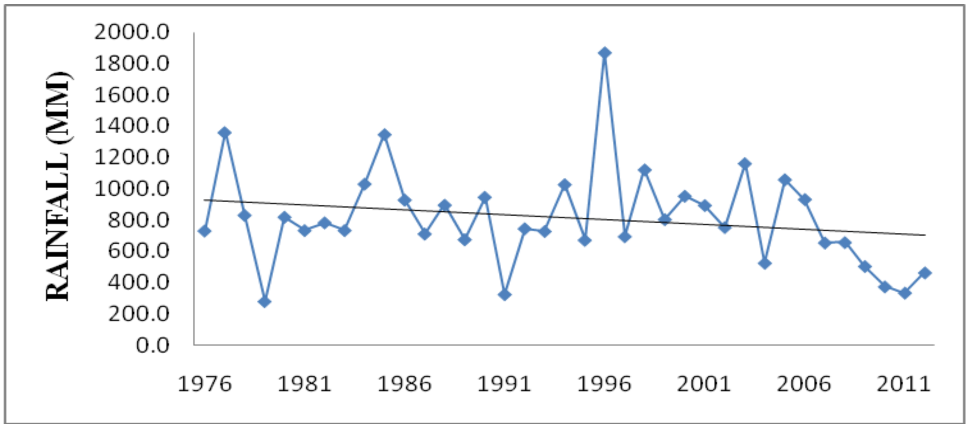

Figure 17: Seasonal rainfall for Balaka

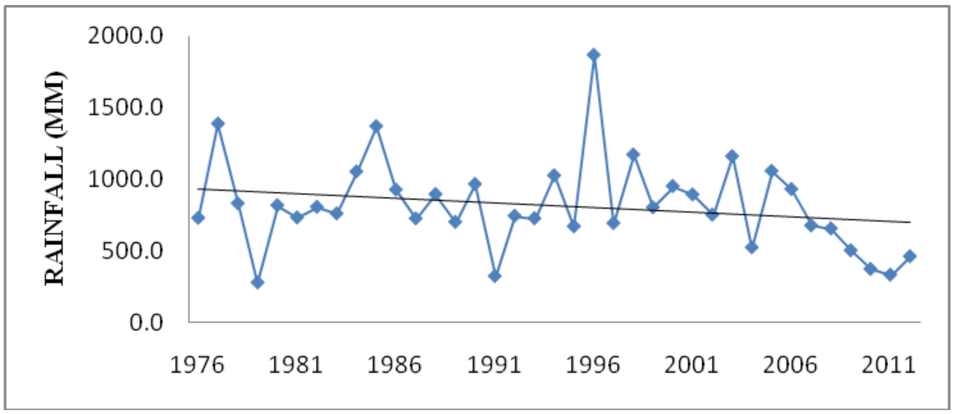

Figure 18: Annual rainfall over Balaka

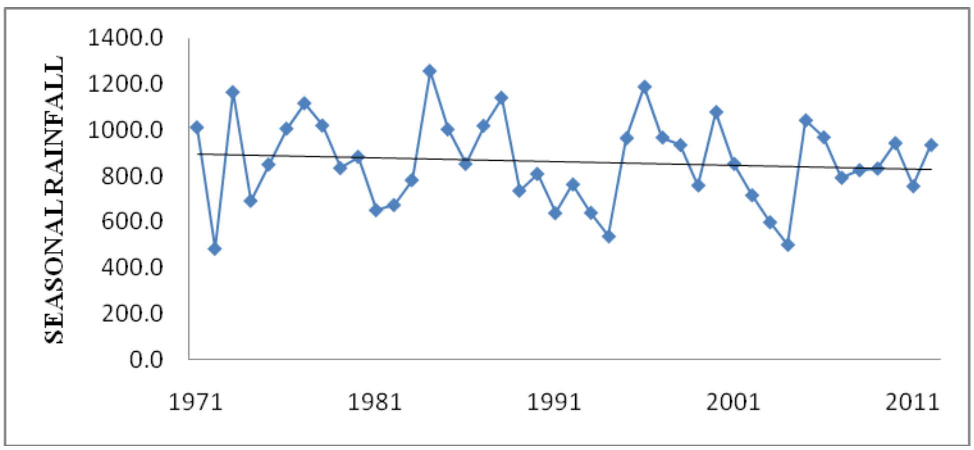

Figure 19: Seasonal Rainfall over Chileka

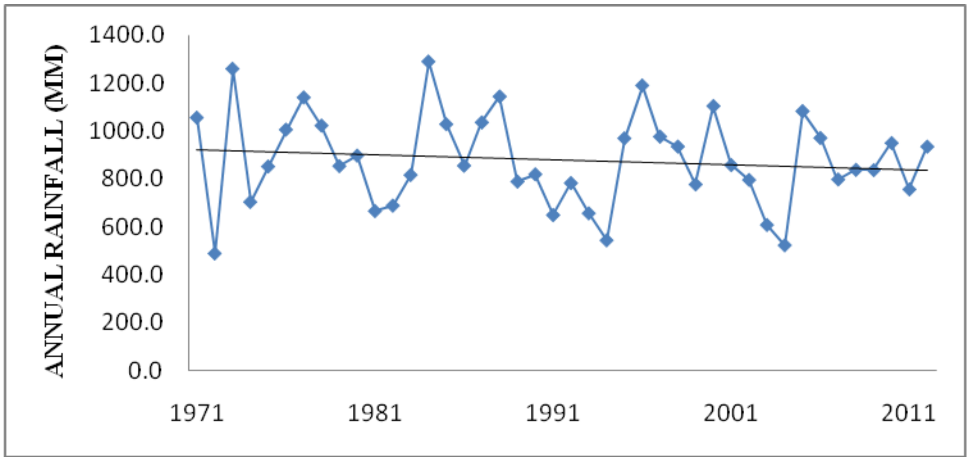

Figure 20: Annual rainfall over Chileka

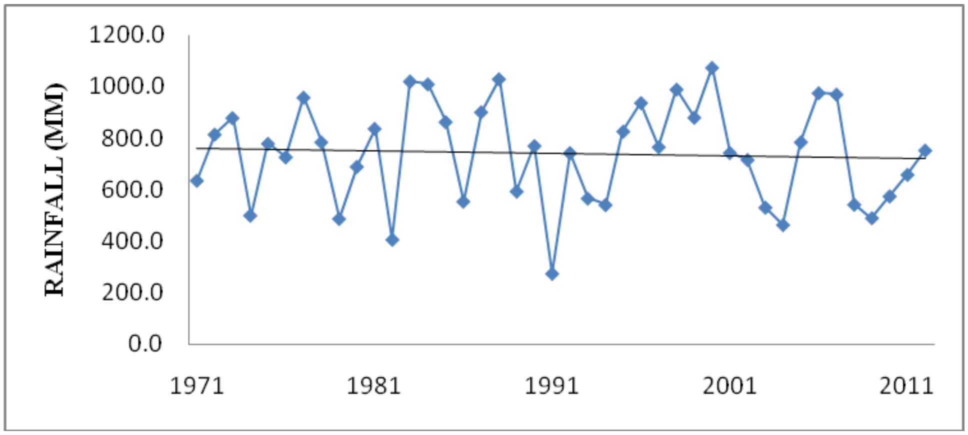

Figure 21: Seasonal rainfall for Ngabu

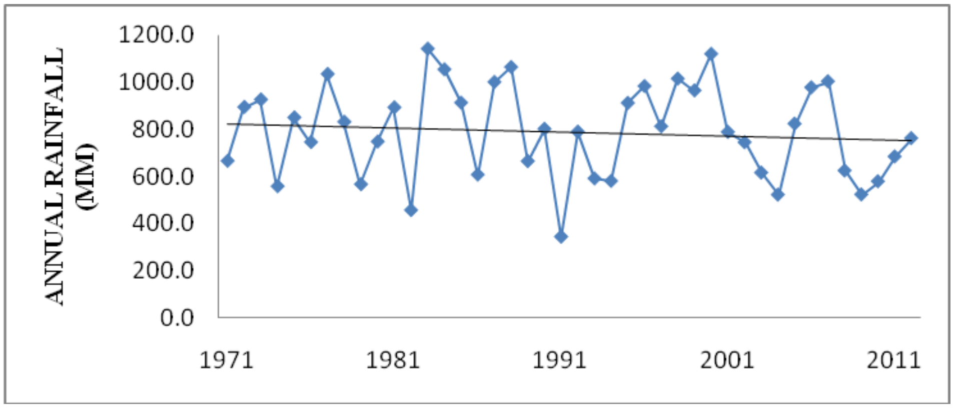

Figure 22: Annual rainfall for Ngabu

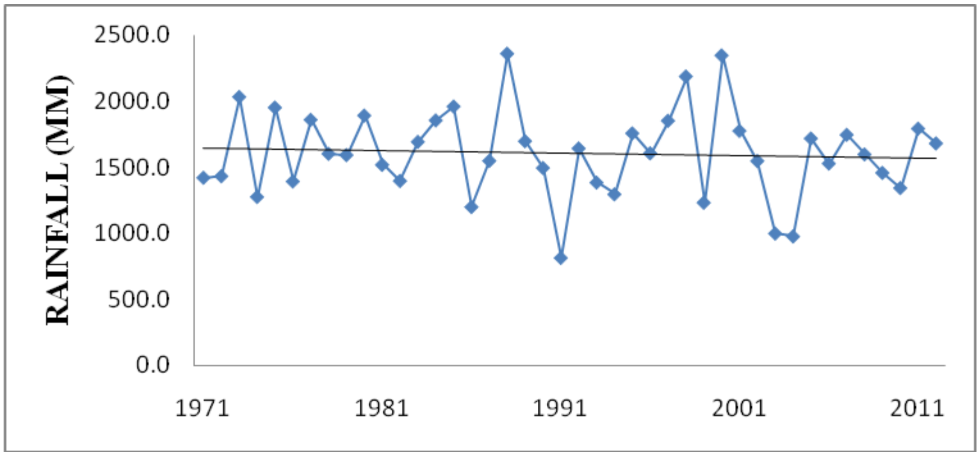

Figure 23: Annual rainfall for Mimosa

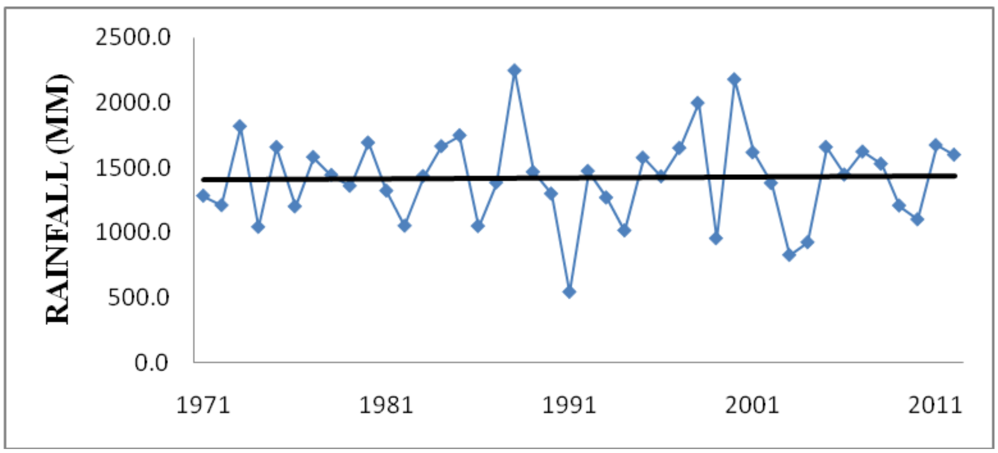

Figure 24: Seasonal rainfall over Mimosa

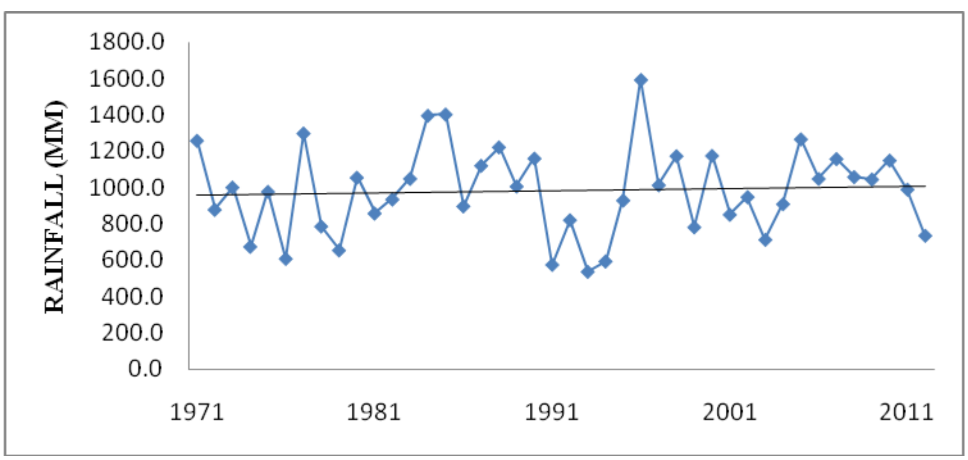

Figure 25: Annual rainfall over Makoka.

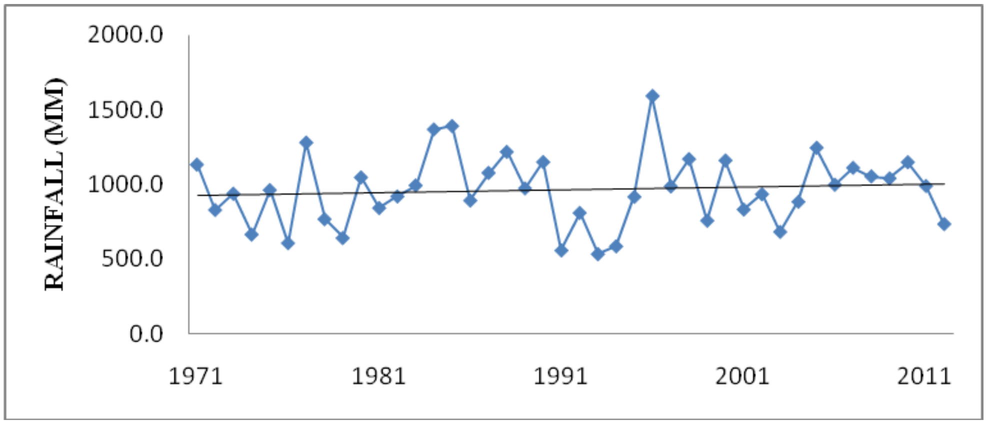

Figure 26: Seasonal rainfall for Makoka

4.2.3 Significance Tables

Tables 2 - 5 depict the t-test results for seasonal and annual rainfall for all the stations.

Table 2: Significant table for Seasonal rainfall

Station	Trend Equation	T - Stat	T - Critical	Remark
Mangochi	y = 0.743x + 726.8	-0.49	2.09	Not Significant
Ngabu	y = -0.942x + 759.6	-0.23	2.09	Not Significant
Chileka	y = -1.632x + 896.9	0.92	2.09	Not Significant
Mimosa	y = 0.677x + 1404	-0.26	2.09	Not Significant
Makoka	y = 1.868x + 923.4	0.06	2.09	Not Significant
Balaka	y = -6.173x + 930.2	0.27	2.11	Not Significant
Bvumbwe	y = 2.249x + 1040	-1.02	2.09	Not Significant
Chichiri	y = 1.648x + 1051	-0.89	2.09	Not Significant
Monkey-Bay	y = 2.222x + 806.6	0.06	2.09	Not Significant

Table 3: Significance table for Annual rainfall

Station	Trend Equation	T - Stat	T - Critical	Remark
Mangochi	y = 0.307x + 751.3	-0.35	2.09	Not Significant
Ngabu	y = -1.663x + 824.4	-0.01	2.09	Not Significant
Chileka	y = -1.995x + 921.7	1.00	2.09	Not Significant
Mimosa	y = -1.868x + 1645	0.23	2.09	Not Significant
Makoka	y = 1.24x + 958.4	0.24	2.09	Not Significant
Balaka	y = -6.507x + 944.0	0.33	2.11	Not Significant
Bvumbwe	y = 0.981x + 1109	-1.04	2.09	Not Significant
Chichiri	y = 2.514x + 1108	-0.66	2.09	Not Significant
Monkey-Bay	y = 1.932x + 815.2	-1.44	2.12	Not Significant

By using the student's t-test, the values of **t** were calculated and compared with their respective **t** values from the table. The t- test shows that only Mangochi has a significant value.

4.2.4 Onset, Cessation and Length of growing Season

Figures 27 to 29 show the onset, cessation dates and length of growing season of some stations in the region.

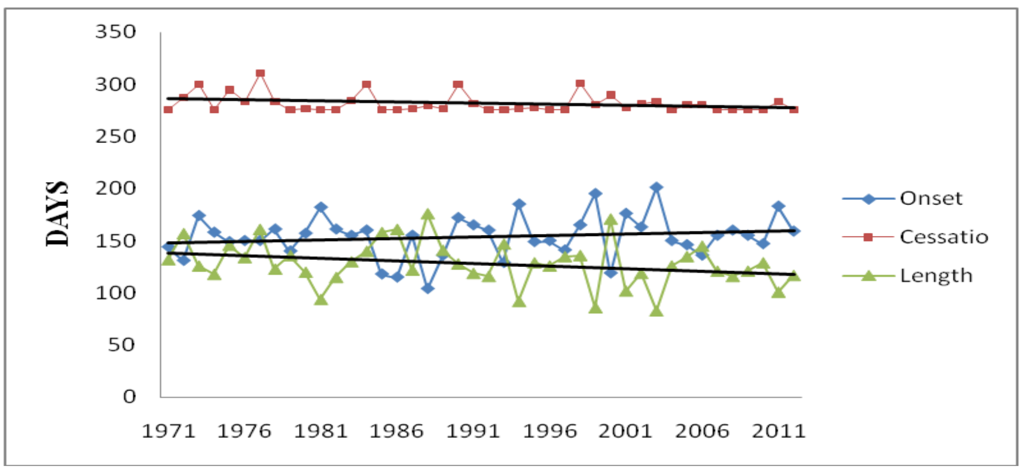

Figure 27: Seasonal Rainfall onset and cessation for Ngabu

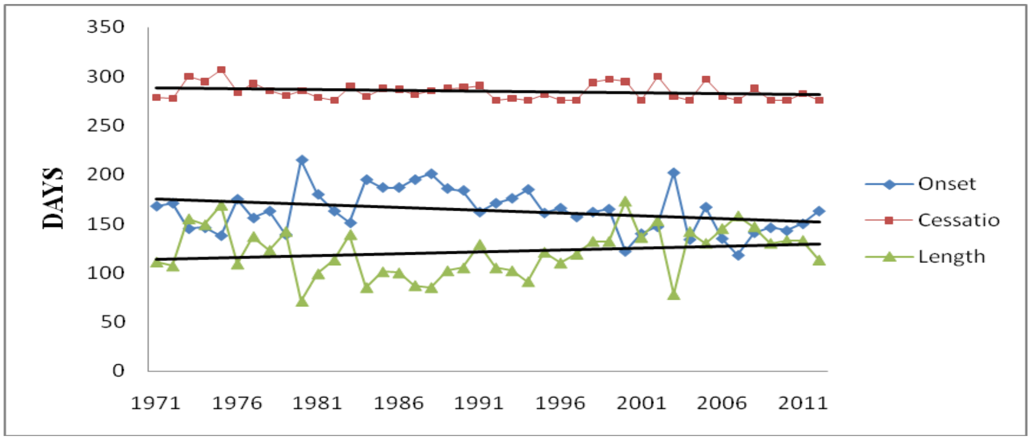

Figure 28: Seasonal Rainfall Onset and Cessation for Mangochi

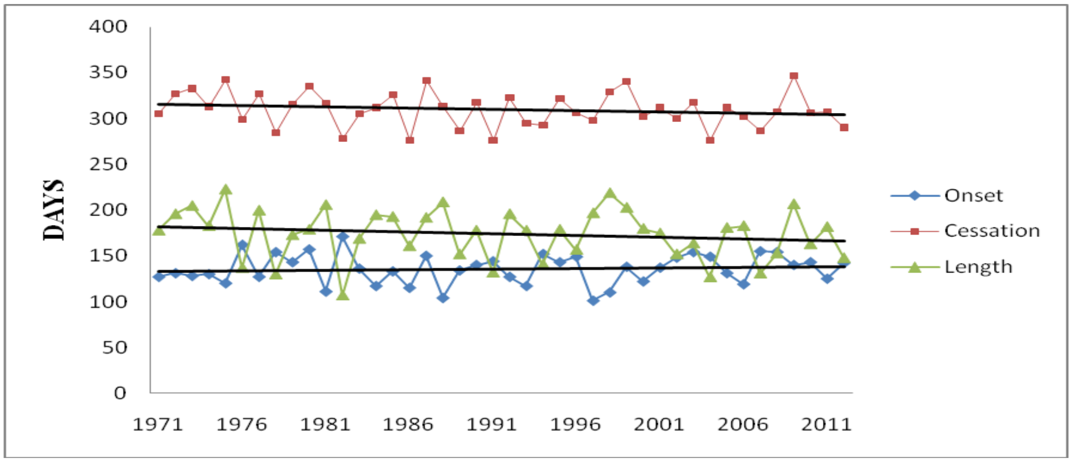

Figure 29: Seasonal Rainfall Onset,Cessation and length of season for Mimosa

Table 4: Summary of Onset, Cessation and Length of Season

Table 4 summarises the onset, Cessation and length of season for all the stations.

	Onset	Cessation	Length of Season
Mangochi	27th Nov - 12th Dec	1st April - 9th April	90 - 120 days
Balaka	27th Nov - 5th Dec	25th Mar - 2nd apr	90 - 120 days
Monkey-Bay	1st Dec -15th Dec	6th Apr - 15th apr	90 - 120 days
Chileka	23rd Nov - 3rd Dec	1st Apr - 15th Apr	100 - 130 days
Chichiri	6th Nov - 20th Nov	16th Apr - 30th Apr	100 - 150 days
Bvumbwe	9th Nov- 20th Nov	16th Apr - 30th Apr	100 - 150 days
Makoka	12th Nov - 2oth Nov	13th Apr - 30th April	100 - 140 days
Mimosa	30th Oct - 13th Nov	20th apr - 30th Apr	120 - 160 days
Ngabu	15th Nov - 10th Dec	1st April - 17th April	90 - 120 days

4.2.5 Rain Days

Figure 30 shows the number of rainy days experienced in some parts of the Southern Region of Malawi.

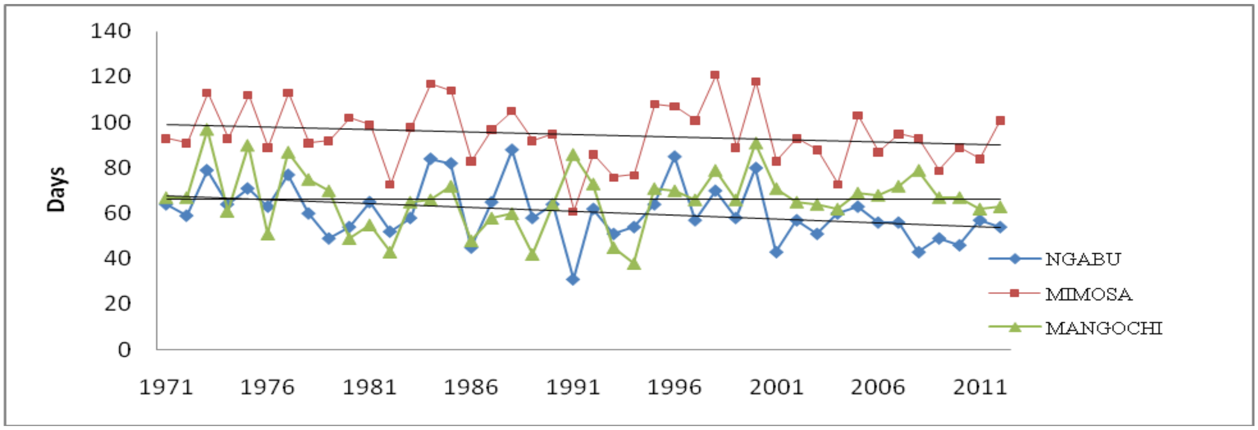

Figure 30: Rain Days for Ngabu, Mimosa and Mangochi

These are the actual number of days when rain of 0.3mm or more was recorded at each station. The rain days are also varying with a decreaing trend over time. This gives a problem to farmers to choose the right type of crop to plant to suit the rain amount that will be available.

4.2.6 Spatial Distribution of Rainfall

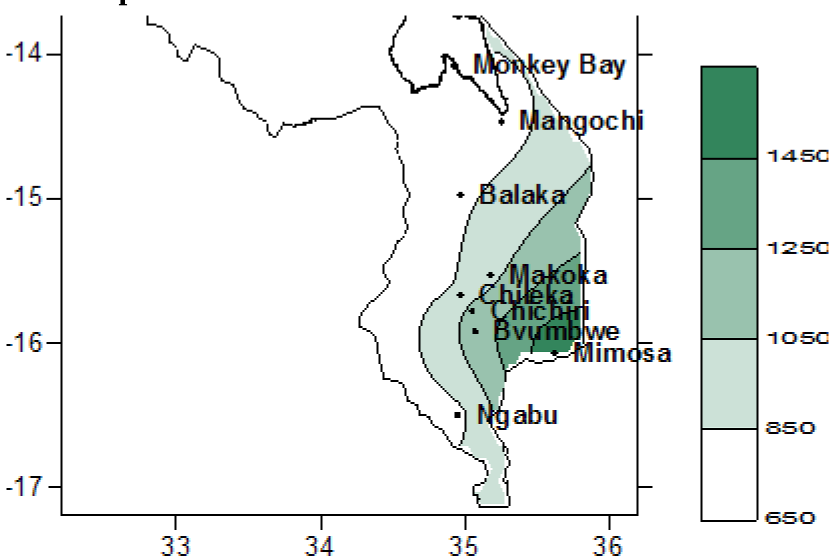

Figure 31: Annual rainfall distribution over Southern Malawi.

Figure 31 shows that the Western part of the Southern region receives relatively low rainfall compared to the Eastern part. This might be attributed to topography and the moist South Easterly winds from the Indian Ocean which normally affects the eastern side.

4.2.7 Extreme Rainfall Events

The frequency of receiving rainfall greater than 40mm from the results is concentrated between January and March in all the stations.

Figures 32 to 37 show some of the distributions of extreme rainfall event occurrences in some stations. Seasonal extreme rainfall was summed over 5 day period from October to April.

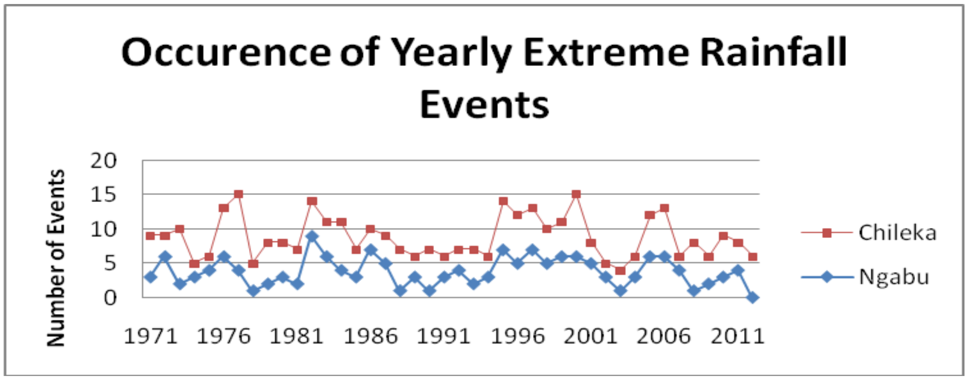

Figure 32: Extreme rainfall events for Chileka and Ngabu.

Chileka has recorded more occurences of extreme events than Ngabu. In 1977 and 2001 Chileka recorded 14 occurences while Ngabu recorded only 9 extreme events in 1982.

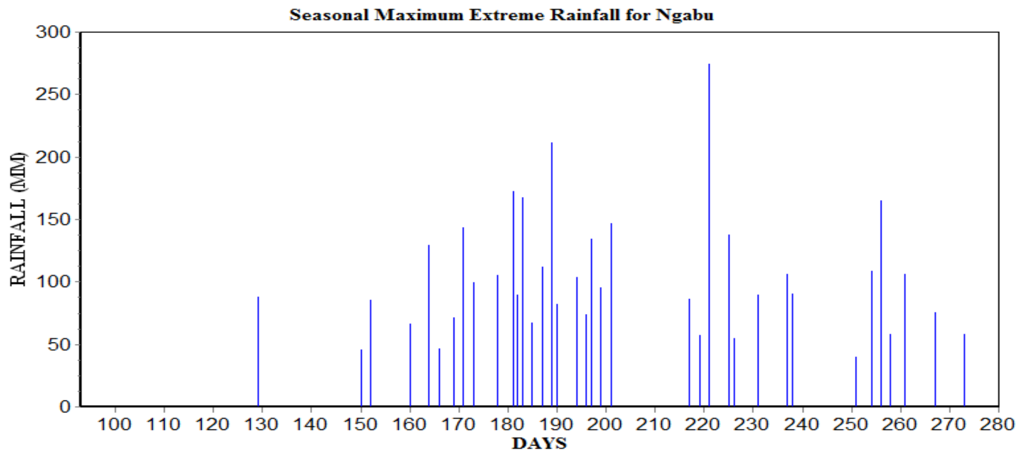

Figure 33: Seasonal Extreme rainfall over Ngabu.

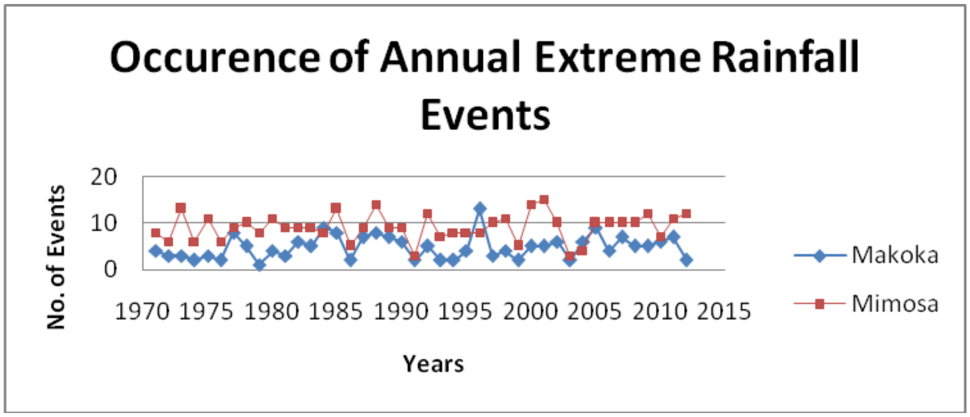

Figure 34: Extreme rainfall event

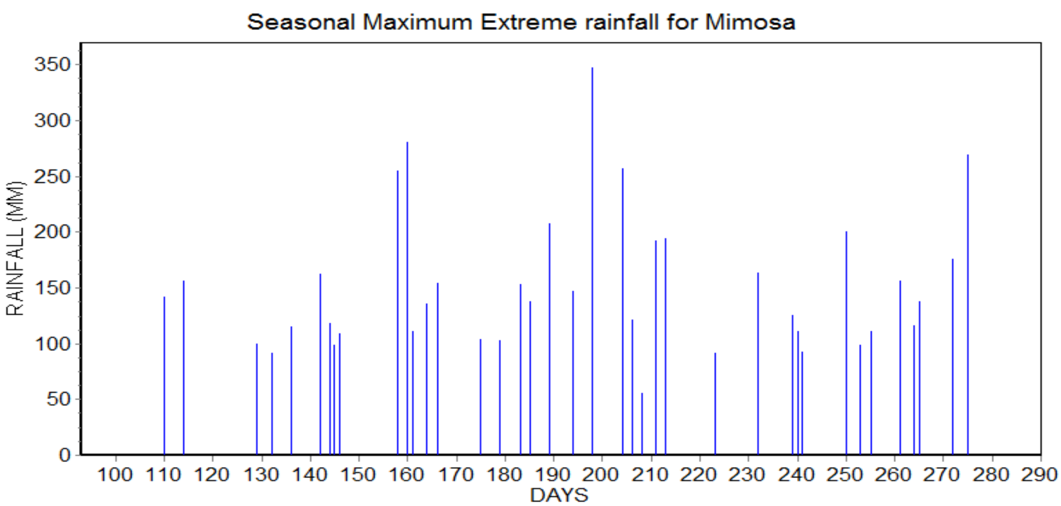

Figure 35: Seasonal Extreme rainfall over Mimosa.

There is much occurrence of rain over Mimosa as it extends into winter period. There are longer rainy periods over Mimosa than any other station in the Southern Region. The rains in this area are the ones that cause flooding over the Shire valley. Mimosa also recorded over 10 events of extreme events every year tha Makoka.

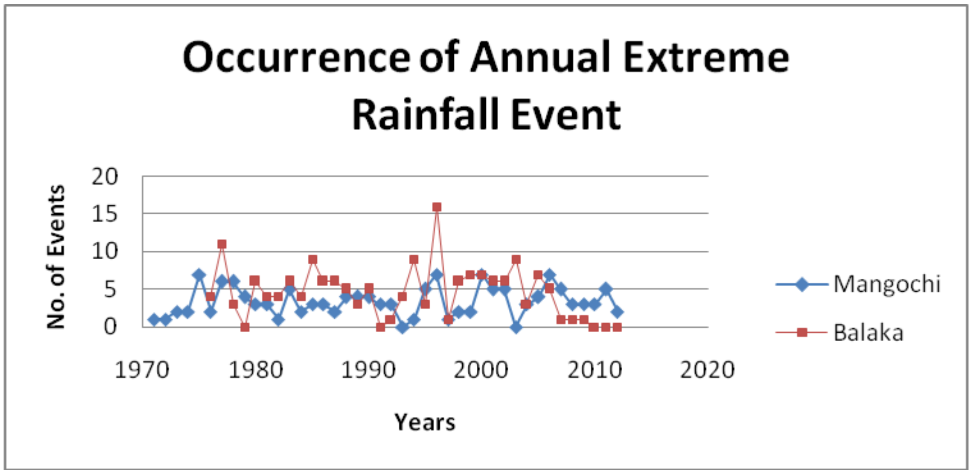

Figure 36: Extreme rainfall over Mangochi and Balaka.

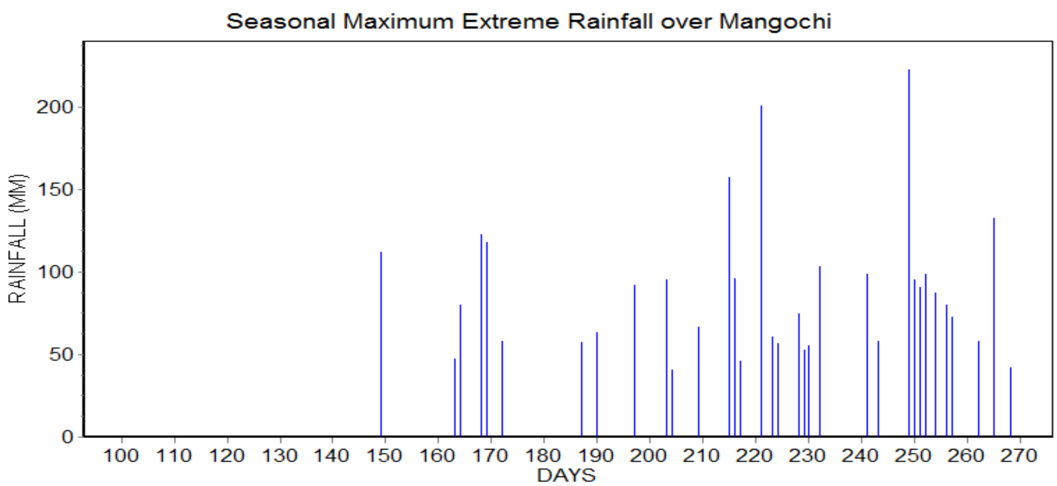

Figure 37: Seasonal Extreme rainfall over Mangochi

Table 5 below shows the daily extreme rainfall amounts recorded in the region. These extremes are hazardous to crops and infrastructure.

Table 5: Summary of extreme rainfall per day (1971 and 2012)

STATION	DATE	AMOUNT OF RAINFALL
CHILEKA	07th February 1987	169 mm
MIMOSA	06th December 1988	185 mm
MAKOKA	26th December 1990	147 mm
BALAKA	29th January 1994	144 mm
CHICHIRI	06th March 1998	126 mm
MONKEY-BAY	01st February 1999	210 mm
NGABU	12th March 1999	165 mm
BVUMBWE	20th January 2001	127 mm
MANGOCHI	05th March 2005	153 mm

Results of analysis of extreme rainfall events suggest that field management practices such as weeding and fertilizer application if done from January to February period could have negative implications. Fertilizers may be leached or washed away and could further enhance weed growth. Moreover, established crops could be washed away by flash floods. Relatively large duration of extreme rainfall events could also explain the widespread shallow debris flows that may damage crops and infrastructure such as roads and buildings.

4.3 Impact of spatial and temporal rainfall characteristics on Agriculture

The rainfall characteristic over the Southern region of Malawi has an impact on Agricultural production. Rainfall variability alters the cropping season and choice of the crop to plant. With extreme rainfall occurrences, there is flooding which destroys crops which lead to food insecurity over the region. Heavy rainfall causes soil erosion and leaching of the soil thereby also affecting crop yields.

CHAPTER FIVE

5.0 Summary, Conclusion and Recommendation

5.1 Summary

The objective of the study was to assess the spatial and temporal rainfall characteristics over the Southern Region of Malawi with specific emphasis on determination of seasonal and annual rainfall onset, cessation, length of the growing season, trend analysis and extreme rainfall events.

The dataset used in this research was confirmed to have been in the required standard through the homogeneity test carried out in this study. The rainfall in the Southern Region of Malawi shows variations in Seasonal, Monthly and Annual amounts, rain days, onsets, cessation and length of the growing season.

The variability in onset, cessation, raindays, length of growing season and extreme events show trends that are either increasing or decreasing in almost all the stations. However, these trends are not significant.

It has been observed that most of the rains in the region start in November and not in October and high rainfall is mostly experienced in the month of January. Mimosa is the station that receives the highest rainfall amongst other stations.

According to zonal representation rain onset over Ngabu (Shire Valley) on average is on 12th November and ends on 10th April. The length of the season shows a decreasing trend and is 140 days. The Lakeshore zone (Mangochi) rainfall onset on average is on 01st December with marked variability which was observed between 1986 and 1989 where onset was in January. Cessation is observed on 14th April. Length of the season on average is about 142 days. In the Shire highlands (Mimosa) rainfall onset is on 29th October and cessation being observed on 26th April. This zone has the longest season which is on average over 150 days.

On the occurrence of extreme rainfall events, Mimosa recorded 10 events per year whilst other areas are showing decreasing trend in events. Balaka recorded the highest number of events (16) in 1996 and Chileka recorded 15 events in 1976 and 2000. The events that occur in Mimosa affect the Shire valley with a lot of flooding.

The frequency of rainfall greater than 40 mm is concentrated between January and March. Relatively large duration of extreme rainfall events could also explain the widespread shallow debris flows that may damage crops and infrastructure such as roads, power turbines and buildings.

With regard to the spatial distribution of rainfall, Shire highlands receives the highest rainfall as compared to other areas due to topographical factors and incursion of cool moist South Easterly winds from the Mozambican channel. On temporal distribution, there is decreasing rainfall which gives rise to dry days than wet days.

5.2 Conclusion

The results have shown that trends in seasonal and annual rainfall series are variable without significant trend. The positive or negative trends were declared insignificant by a statistical test that was carried out. This variability has also affected the onset, cessation and length of growing season where shifts in days have been observed. Extreme rainfall occurences are concentrated in January to March. The findings presented in this paper highlight the need for consistent and sustained adaptations strategies if rain-fed agriculture production is to be successful.

5.3 Recommendation

From the results, it is recommended that:

i. Information on rainfall pattern should be made available to all users in time so that they take necessary adaptation measures.

ii. Further research should be conducted on what causes rainfall variability and shortening of the growing season over the region.

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Appendix 1: Interpretation of Instat Days

This appendix displays annual seasonal days as used in Instat. The annual rainy season runs from July to June of the other year.

DAY	MONTHS										
	JUL	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**
1	1	32	63	93	124	154	185	216	245	276	306	337
2	2	33	64	94	125	155	186	217	246	277	307	338
3	3	34	65	95	126	156	187	218	247	278	308	339
4	4	35	66	96	127	157	188	219	248	279	309	340
5	5	36	67	97	128	158	189	220	249	280	310	341
6	6	37	68	98	129	159	190	221	250	281	311	342
7	7	38	69	99	130	160	191	222	251	282	312	343
8	8	39	70	100	131	161	192	223	252	283	313	344
9	9	40	71	101	132	162	193	224	253	284	314	345
10	10	41	72	102	133	163	194	225	254	285	315	346
11	11	42	73	103	134	164	195	226	255	286	316	347
12	12	43	74	104	135	165	196	227	256	287	317	348
13	13	44	75	105	136	166	197	228	257	288	318	349
14	14	45	76	106	137	167	198	229	258	289	319	350
15	15	46	77	107	138	168	199	230	259	290	320	351
16	16	47	78	108	139	169	200	231	260	291	321	352
17	17	48	79	109	140	170	201	232	261	292	322	353
18	18	49	80	110	141	171	202	233	262	293	323	354
19	19	50	81	111	142	172	203	234	263	294	324	355
20	20	51	82	112	143	173	204	235	264	295	325	356
21	21	52	83	113	144	174	205	236	265	296	326	357
22	22	53	84	114	145	175	206	237	266	297	327	358
23	23	54	85	115	146	176	207	238	267	298	328	359
24	24	55	86	116	147	177	208	239	268	299	329	360
25	25	56	87	117	148	178	209	240	269	300	330	361
26	26	57	88	118	149	179	210	241	270	301	331	362
27	27	58	89	119	150	180	211	242	271	302	332	363
28	28	59	90	120	151	181	212	243	272	303	333	364
29	29	60	91	121	152	182	213	244	273	304	334	365
30	30	61	92	122	153	183	214		274	305	335	366
31	31	62		123		184	215		275		336	