INVESTIGATING DRY SPELLS IN MALAWI DURING THE RAINFALL SEASON

BY

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DECLARATION

I declare that this project is my original work and has not been submitted for a degree in this or any other university

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This project has been submitted for examination with our approval as University Supervisors.

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I am grateful to the department of climate change and meteorological services for providing me with the daily rainfall data. Thanks to the Government of Malawi for providing me with the scholarship that made the pursuance of this study successful.

DEDICATION

I dedicate this research to my parents, relatives and friends for their encouragement and support.

ABSTRACT

This study investigated the occurrence of dry spells during the main rainfall seasons over Malawi so that the farming community and other stakeholders can use this information to reduce vulnerability of the agricultural produce to the negative impacts of dry spells within the season.

The dataset used in the study was observed daily rainfall data from 10 synoptic stations for the period 1961 - 2012. A dry day was defined as a day with less than 1.0 mm of rainfall while for investigating dry spells 7 consecutive dry days, 10 consecutive dry days, and 15 consecutive dry days were used.

Quality control was done on the data set. The number of occurrence of dry spells were determined using Instat software, time series plots were done with Microsoft Excel to show the trend lines. Significance of trends were analysed using the Mann-Kendall trend test.

The time series plots for 7 consecutive dry days and for 10 consecutive dry days from Excel were showing increasing trends or decreasing trends but the Mann-Kendall trend test showed that all the trends were not significant. The time series plots for 15 consecutive dry days from Excel were showing increasing or decreasing trends but the Mann-Kendall trend test showed that one station had a significant decreasing trend while the remaining nine stations trends were not significant.

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LIST OF ACRONMYS

LDS – Length of Dry Spell

MLDS – Maximum Length of Dry Spell

AMDSL – Annual Maximum Length of Dry Spell

CDD - Consecutive Dry Days

NDVI – Normalized Difference Vegetation Index

ITCZ – Inter-Tropical Convergence Zone

NDSP – Number of Dry Spell Periods

CAB – Congo Air Boundary

SDNP - Sustainable Development Network Programme

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The economy of Malawi depends on rain-fed agricultural production. In most rural areas, people depend on agriculture for subsistence. Rainfall variability places Malawi in a vulnerable position since it leads to losses in incomes and increased vulnerability to food security (SDNP, 1996).

Malawi has been experiencing significant variations in weather patterns, ranging from severe drought conditions, extreme flood events, changes in Normalized Difference Vegetation Index (NDVI) and the occurrence of dry spells (SDNP, 1996).

The length of dry spells affects the yield of rain-fed crop, depending on the stage of the growing process (establishment, vegetative, heading, flowering, yield formation, De Groen, 2001). Regularly, a mid-season dry spell severely diminishes crop yields (De Groen, 2001). In addition to affecting the yield of a rain-fed crop, dry spell distribution can be used in deciding on suitable crop variety to be considered in a particular area (Simba et al., 2012).

In water resources and agriculture, knowledge of dry spell distribution is important in irrigation schemes in planning for supplementary irrigation during a rainy season as well as reliably forecasting irrigation demand (Simba et al., 2012).

Dry spells not only affect water resources and agriculture. They also affect fisheries, human health, generation of hydroelectricity etc. and hence their analysis is also crucial in various decision making processes related to climate **(**Mathugama and Peiris, 2011).

This study investigated occurrence of dry spells (length of dry spells) in Malawi during the rainy season using historical daily rainfall data derived from 10 main synoptic stations in Malawi.

1.2 Problem Statement

Fluctuations in total crop yields during the growing season are caused by climatic factors such as occurrence of dry spells during the growing season. The farming community seeks for information about occurrence of dry spells and other climatic factors from the Department of Climate Change and Meteorological Services but the Department lacks information pertaining to occurrence of dry spells.

1.3 Objectives of the Study

The main objective is to investigate the occurrence of dry spells in Malawi during the rainfall season.

To achieve the above main objective, the following specific objectives will be pursued:

(i) To determine the frequency of dry spell
(ii) To determine the trends of dry spells

1.4 Justification of the Study

Dry spells are considered to be the major cause of poor crop production; that is success and failure in crop production during rainfall seasons is dependent on the frequency and length of dry spells. Since crop production is affected by occurrence of dry spells, some researchers have engaged in investigating dry spells, characterizing them, correlating them with both agricultural and climatic parameters. Results, conclusions and recommendations of the researches on the topic of dry spells are readily accessible since the world is now a global village. The information on dry spells together with other climatic information has trickled down to the farming community as part of climate change sensitization projects.

The farming community sees the dry spells, they have heard about dry spells in climate change sensitization projects and as such they want reliable information about the occurrence of dry spells so that they use this information for land preparation and planting activities. The farming community seeks for information about occurrence of dry spells and other climatic factors from the Department of Climate Change and Meteorological Services since the Department was mandated by the Republic of Malawi to provide reliable meteorological and climatic information to the required users.

Despite the need for information about dry spells by the farming community, The Department of Climate Change and Meteorological Services in Malawi lacks such information since there has never been a study by the Department to investigated occurrence of dry spells during the rainfall season in Malawi. Since the department lacks such information, there is a need to investigate dry spells in Malawi so that the department has reliable information about dry spells which the farming community can readily access.

1.5 Area of Study

1.5.1 Geography

Malawi is a land-locked country covering an area of 118,484 km^2, lying between latitudes 9°S and 17°S and longitudes 32°E and 36°E. Lake Malawi lies in the Great African Rift valley and is 571.5 km long and 470 m above sea level. Lake Malawi covers two thirds of the length of the country in the east. The altitudes of different areas vary from near sea level to more than 1,500 m in some plateaus and up to about 2,500 m in mountainous areas rising to 3,000 m at Mt. Mulanje in southern Malawi. Figure 1.1 is the map of Malawi showing geographical features.

Figure 1.1: Map of Malawi Showing the Geographical Boundaries

Source: http://www.infoplease.com/atlas/country/malawi.html

1.5.2 Climate of the Study Area

Malawi experiences a tropical type of climate with two seasons, namely the rainy season and the dry season. The rainy season is experienced from November of one year to April of the next year while the dry season is experienced from May to October. Summers are generally hot and wet while winters are cool and dry. According to Torrance (1972) the climate of Malawi depends on the ITCZ, the subtropical high pressure belt in the south between 25° and 35°S, and its topography.

Malawi is affected by a broad belt of a strong convective activity during the rainy season. This ITCZ belt, which is the main rain bearing system, marks the converging point of northeasterly monsoon of the Northern Hemisphere and the southeasterly trade winds of the Southern Hemisphere. The belt is known as Inter-Tropical Convergence Zone (lTCZ), lagging behind the sun by a month or so (Hsu and Wallace, 1976; Kidson, 1977). It enters the country from the north on its southward movement to its southern limit in February and then moves back to the north.

The other main rain bearing system for Malawi weather during the rainy season is the Congo Air Boundary (CAB) which marks the confluence between the Indian Ocean southeast trades and recurved South Atlantic air that reaches Malawi as northwesterly air rnass through the Democratic Republic of Congo. This system brings well-distributed rainfall over the country and even floods may be experienced in some areas especially if it is associated with the ITCZ.

There are times when the country is affected by tropical cyclones originating from the Indian Ocean. Depending on its position over the Indian Ocean, a cyclone may result in having either a dry or a wet spell over Malawi.

The other weather features of significance are easterly and westerly waves, and temperate weather systems. The extra tropical waves are believed to be active during the start and end of the rainy season.

During winter Malawi is influenced by a divergent southeasterly air mass driven by high pressure cells southeast of Africa. A strong high pressure cell over the eastern South African coast draws a cool moist easterly air mass into the country causing overcast conditions with drizzle over highlands and east facing escarpments near Lake Malawi, locally called "Chiperoni"(Mwafulirwa, 1999).

CHAPTER TWO

2.0 LITERATURE REVIEW

A dry spell was first defined and used in British rainfall in 1919 as, a period of at least 15 consecutive days during which none of the days recorded greater than 0.1 mm of rainfall (Douguedroit, 1987). However it was suggested that the minimum number of consecutive dry days to make up a dry spell has to be identified in a meaningful manner depending on the considered practical problem (Mathugama and Peiris, 2011).

Some research work has indicated that depending on the soil depth and retention capacity, dry spells of about a minimum of 10 consecutive dry days cause water stress in many crops thereby reducing yield (Kumar et al., 2009 **,** Stoute et al., 2008). Shallow rooted crops in low water retaining soils can experience water stress in less than 7 days. Deep rooted crops in high water retaining soils can go for about 15 days before suffering significant water stress. In addition, it was found that dry spells causes most significant water stress in crops during their first 30 days of their life cycles (Simba et al., 2012).

The analysis of dry spells is normally done based on two variables namely Maximum Dry Spell Length (MDSL) and number of Dry Spell Periods (NDSP) (Samba et al., 2012). Already several researchers have done some work towards analysing trends in dry spells using these variables. In 2004, a study in China found a significant positive trend in length of dry spells in various regions (Schmidli et al., 2005**.** Studies in Catalonia, Spain (Serra et al., 2006**)** found decreasing trend for number of annual dry spells but increasing trend for annual maximum dry spells.

In 2007, a study in southern Africa found that there was Increases in mean dry spell length and reductions in rain day frequency are also demonstrated over Zambia, Malawi and Zimbabwe during the rainfall season (as defined from planting date to rainfall cessation) (Tadross et al, 2007).

In 2009, it was found that there was a change in the magnitudes of dry spells from 1980s, especially in eastern arid and semi-arid regions of Isfahan province in Iran **(**Nasri and Modarres, 2009**)**.

Studies carried out in 2003 and 2006 respectively in Tanzania indicated that Poor rainfall distribution coupled with drought periods, particularly inter-seasonal dry spells have amplified the problem of moisture stress (Paavola, 2003 ; Tilya and Mhita, 2006).

In 1999 there was a study on climate variability and predictability in tropical southern africa with a focus on dry spells over Malawi and the studies indicated that long dry spells occurrence are as a result of tropical cyclones over east Madagascar (Mwafulirwa, 1999).

CHAPTER THREE

3.0 DATA AND METHODOLOGY

This Chapter outlines the data sets which were used and the methods of analysis adopted to achieve the objectives of the study

3.1 Data

The observed daily rainfall data of 10 main synoptic stations was used in this study. This data was obtained from The Department of Climate Change and Meteorological of Malawi Services for the period 1961 to 2012. The 10 synoptic stations used are just a representation of the many synoptic stations from each of the five homogenous zones found in Malawi; that is two stations have been used from each homogenous zone. The homogenous zones were classified by the Department of Climate Change and Meteorological Services. Table 3.1 shows the stations used and their corresponding homogenous zones while Figure 3.1 shows the spatial distribution of the stations.

Table 3.1: Names of Stations Used in the Study

Homogenous Zone	Station Name	Longitude(deg)	Latitude(deg)	Altitude(m)
Central Areas	Kasungu	33.47	-13.02	1058
	Chitedze	33.63	-13.97	1149
Lakeshore Areas	Karonga	33.95	-9.88	529
	Salima	34.58	-13.75	512
Shire Valley	Ngabu	34.95	-16.5	102
	Chileka	34.97	-15.67	767
Southern Highlands	Bvumbwe	35.67	-15.92	1146
	Dedza	34.25	-14.32	1632
Northern Areas	Chitipa	33.27	-9.7	1285
	Mzimba	33.6	-11.9	1349

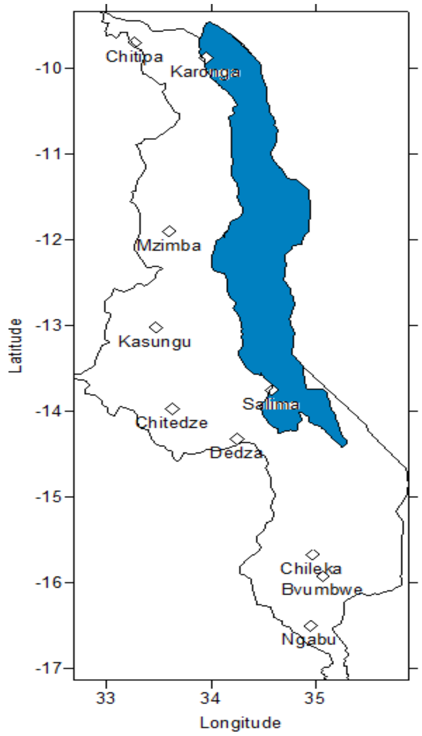


Figure 3.1: Map of Malawi Showing 10 Synoptic Stations Used in the Study

3.1.1 Data Quality Control

Missing data was estimated using the arithmetic mean method that involves replacing missing record with the average values for a given station.

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad \textbf{(3.1)}$$

In Equation 3.1 $\bar{X}$ represents the long term mean, ***n*** represents the number of days in a month and $\boldsymbol{x_i}$ represents the daily rainfall value.

The single mass curve was used to test for homogeneity or consistency of the data records. The method requires plotting cumulative records against time. A single straight line indicates a homogenous record while heterogeneity is indicated by significant deviation of some points from the straight line.

3.2 Methodology

3.2.1 Determining the Frequency of Dry Spells

A dry day is a day without precipitation or with less than 1 mm precipitation. The length of dry spell, which means consecutive dry days (CDD), is the period of consecutive days with no or less than 1 mm precipitation. Number of dry spell periods is the number of occurrence of a given the Length of Dry Spell (LDS). Instat was used to identify dry spells within a year. Then the number of occurrence of a particular dry spell length threshold was manually counted. Table 3.2 indicates the thresholds that exist in literature in relation to the study of dry spells.

Table 3.2: Thresholds Used in the Study of Dry Spells

Category	**Threshold**	**Reason**
Dry day	0 mm of rainfall per day	Theoretical definition **(**Mathugama and Peiris, 2011)
	0.1 mm of rainfall per day	It is used with respect to the usual precision of rain gauges **(**Mathugama and Peiris, 2011)
	1mm of rainfall per day	Rainfall less than this amount is evaporated off directly **(**Mathugama and Peiris, 2011)
LDS	7 CDD	Cause water stress in shallow rooted crops (Simba *et al*., 2012)
	10 CDD	Causes water stress in most crops (Simba *et al*., 2012)
	15 CDD	Causes water stress in deep rooted crops (Simba *et al*., 2012)
	>40 CDD	Sufficient to be defined a drought **(**Mathugama and Peiris, 2011)

In this research a dry day is less than 1 mm per day. In this research, the following lengths of dry spells were used; 7 CDD, 10 CDD, and 15 CDD. Since 7, 10, and 15 CCD's are just thresholds, ranges were used to define the scope of a particular given threshold value. The scope of the range of each dry spell threshold values was defined as in the Table 3.3.

Table 3.3: Range of each Dry Spell Threshold Used in the Study

Threshold	Scope of range
7 CDD	7 CDD to 9 CDD
10 CDD	10 CDD to14 CDD
15 CDD	15 CDD to less than or equal to 40 CDD

3.2.2 Trend Analysis of Dry Spells

This involved time series plots of number of dry spell periods against time in years. The trends were fitted and were analysed using the Mann-Kendall trend test. The Mann-Kendall test is a non-parametric approach that has been widely used for detection of trends in different fields of research including hydrology and climatology (Ampitiyawatta and Guo, 2009). It is used for identifying trends in time series data. Each data value is compared to all subsequent data values. The initial value, S, is assumed to be 0 (no trend). If a data value from a later time period is higher than a data value from an earlier time period, S is incremented by 1. If the data value from later time period is lower than a data value from an earlier time period, S is decremented by 1. The net result of all such increments and decrements yield the final value of S.

Mann Kendall statistic (S) is given by Equation 3.2

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \mathrm{sgn}\left(x_j - x_i\right)$$

(3.2)

In Equation 3.2 S is the Mann-Kendal's test statistics, x_i and x_j are the sequential data values of the time series in the years *i* and j (j > *i)*, *N* is the length of the time series, $\text{sgn}(x_j - x_i)$ is the sign function**.** A positive *S* value indicates an increasing trend and a negative value indicates a decreasing trend in the data series. The sign function is given by Equation 3.3:

$$\text{sgn}(x_j - x_i) = \begin{cases} +1 & if \quad (x_j - x_i) > 0 \\ 0 & if \quad (x_j - x_i) = 0 \\ -1 & if \quad (x_j - x_i) < 0 \end{cases}$$

(3.3)

The variance statistic of *S*, for the situation where there may be ties (that is, equal values) in the *x* values is given by Equation 3.4:

$$Var(S) = \frac{1}{18}\left[N(N-1)(2N+5) - \sum_{i=1}^{m} t_i (t_i - 1)(2t_i + 5)\right]$$

(3.4)

In Equation 3.4 *m* is the number of tied groups in the data set t_i is the number of data points in the *ith* tied group. For *N* larger than 10, Z_{MK} approximates the standard normal distribution (Partal and Kahya, 2006; Yenigun et al., 2008) and is computed using Equation 3.5:

$$Z_{MK} = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & if \quad S < 0 \end{cases}$$

(3.5)

The presence of a statistical trend is evaluated using the Z value. A positive Z_{MK} indicates an increasing trend, whereas a negative Z_{MK} indicates a decreasing trend. The statistic Z_{MK} has a normal distribution to test for either increasing or decreasing monotonic trend at α level of significance (usually 5% with $Z_{0.025=1.96}$), H_0 is reject if the absolute value of Z_{MK} is greater than $Z_{1-\alpha/2}$ (Rejected Ho: $|Z|>Z_{1-\alpha/2}$) where $Z_{1-\alpha/2}$ is the standard normal deviates and α is the significant level for the test.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

This chapter presents and discusses the results that were obtained from the various methods that were used to address the objectives of this study.

4.1 Results of Estimation Missing Rainfall Data

All the stations used did not have missing data.

4.2 Results of Homogeneity Test

Single mass curves were plotted at each of the ten stations to test for data homogeneity. The figures below from Figure 4.1 to Figure 4.10 displays the cumulative rainfall totals plotted against time for the time period of 1961-2012.

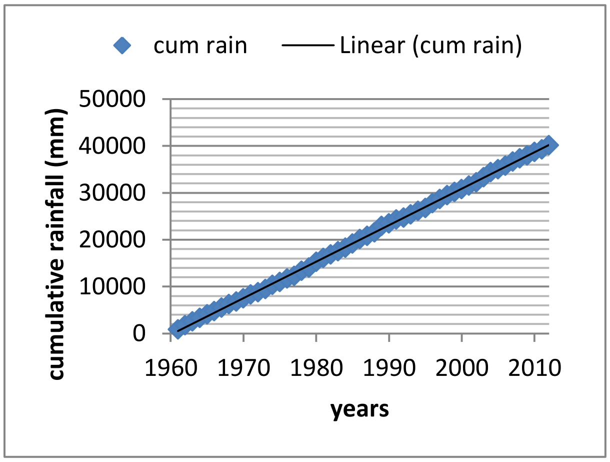


Figure 4.1: Cumulative Rainfall Totals For Kasungu for the Period of 1961 - 2012

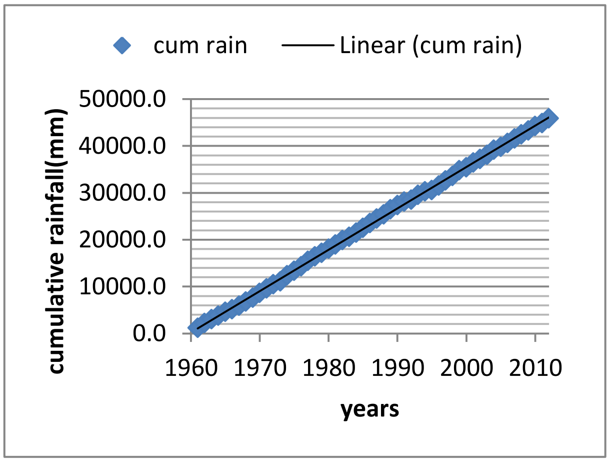
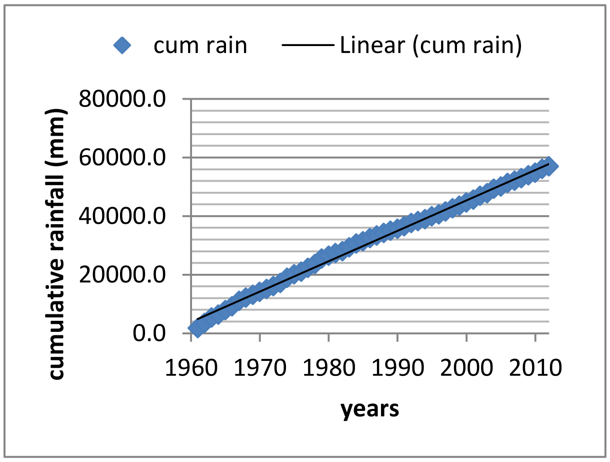


Figure 4.2: Cumulative Rainfall Totals For Chitedze for the Period of 1961 - 2012



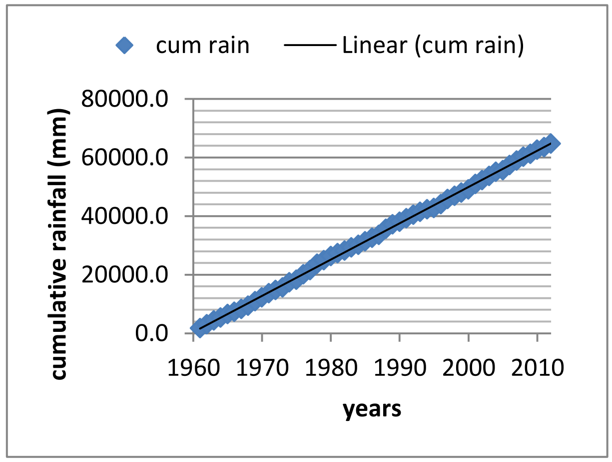
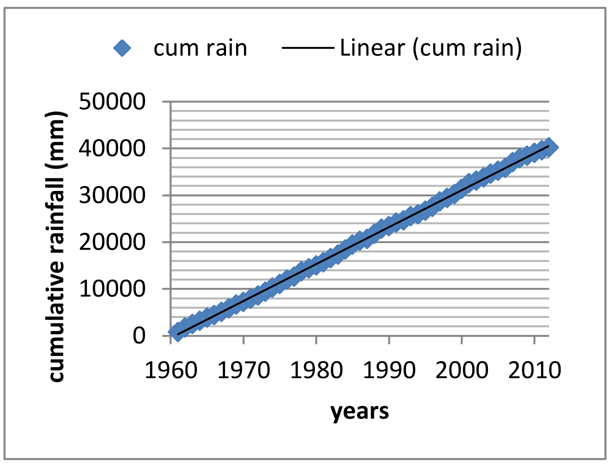


Figure 4.3: Cumulative Rainfall Totals For Karonga for the Period of 1961 - 2012

Figure 4.4: Cumulative Rainfall Totals For Salima for the Period of 1961 - 2012



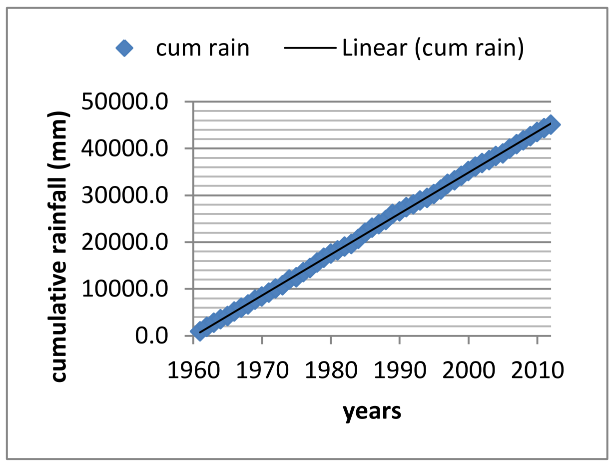


Figure 4.5: Cumulative Rainfall Totals For Ngabu for the Period of 1961 - 2012

Figure 4.6: Cumulative Rainfall Totals For Chileka for the Period of 1961 – 2012

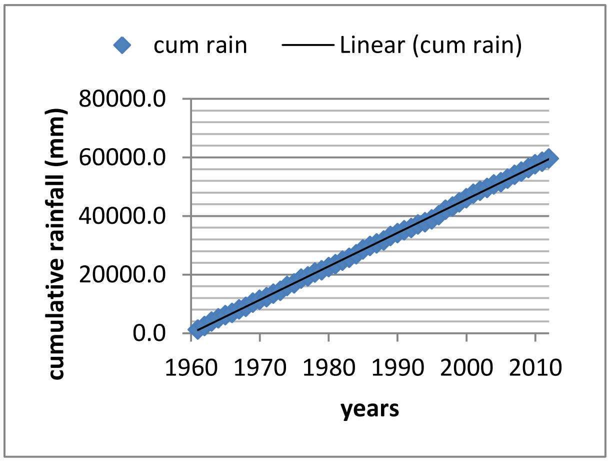


Figure 4.7: Cumulative Rainfall Totals For Bvumbwe for the Period of 1961 - 2012

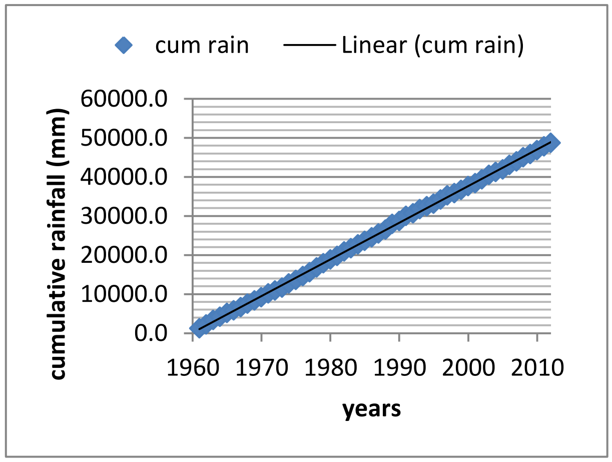


Figure 4.8: Cumulative Rainfall Totals For Dedza for the Period of 1961 - 2012

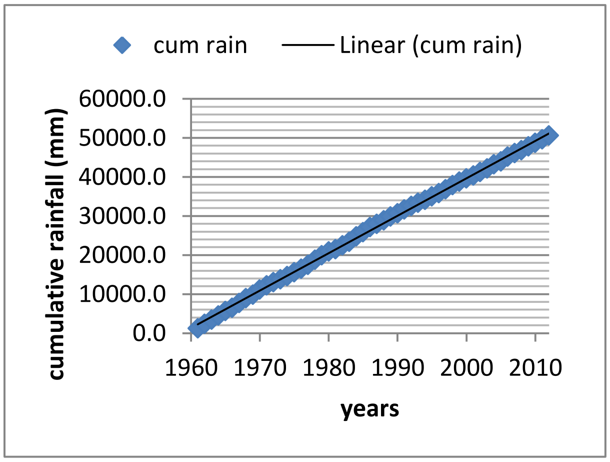


Figure 4.9: Cumulative Rainfall Totals For Chitipa for the Period of 1961 - 2012

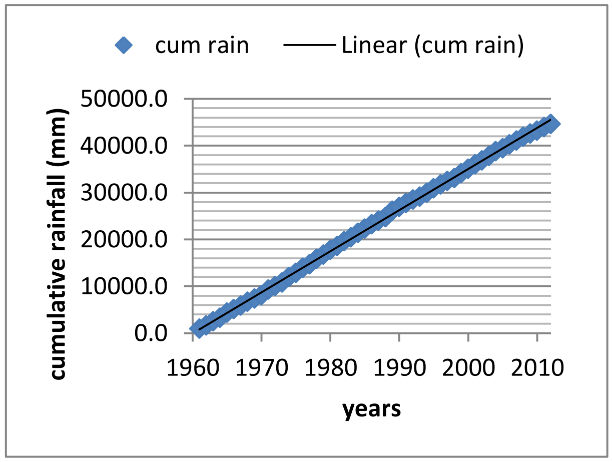


Figure 4.10: Cumulative Rainfall Totals For Mzimba for the Period of 1961 - 2012

The cumulative plots of total rainfall against time as shown by figures'4.1 to 4.10 are all straight lines which indicate that the data used at each of the ten stations was homogenous.

4.3 Results of Determining the Frequency of Dry Spells (Number of Dry Spell Periods)

The Table 4.1 displays the sample output from Instat software of lengths of dry spells for Kasungu for 1961 – 1962 rainfall season.

Table 4.1: Instant Output for Kasungu for 1961 -1962 Rainfall Season

Spell Lengths

Mon	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Day.							
1	1	32	7	--	--	6	--
2	2	33	8	--	--	--	--
3	3	34	9	--	--	1	--
4	4	35	10	1	--	2	1
5	5	36	11	--	1	3	2
6	6	37	--	--	--	4	3
7	7	38	--	--	--	--	4
8	8	39	1	1	1	1	5
9	9	40	--	2	2	2	6
10	10	41	--	--	3	3	--
11	11	42	--	--	4	4	--
12	12	43	1	--	--	--	1
13	13	44	2	1	1	1	2
14	14	45	--	2	2	2	3
15	15	46	--	3	--	3	4
16	16	47	--	--	1	--	5
17	17	--	--	1	2	--	6
18	18	--	--	2	3	1	7
19	19	1	1	3	4	--	8
20	20	--	2	--	--	--	9
21	21	1	3	--	--	--	10
22	22	2	--	--	--	--	11
23	23	--	1	1	--	--	12
24	24	--	2	--	1	--	13
25	25	1	--	1	2	--	14
26	26	2	--	--	3	1	15
27	27	3	--	1	4	2	16
28	28	4	1	--	5	3	17
29	29	5	2	--		4	18
30	30	6	3	--		5	19
31	31		--	1		6	
Maximum					(Overall:	47)	
	31	47	11	3	5	6	19

Table 4.1 shows that the rains started on 17 November 1961 and ended on 11 April 1962. The only dry spell which was picked was that of 11 days which occurred from 25 November 1961 to 5 December 1961. This dry spell was counted under the 10 CDD-category which has the range

of 10 CDD to 14 CDD. The first dry spell and the last dry spell were neglected because they were considered as part of the previous or next dry season. This way of selecting dry spells from Instat tables was done for all the years and for all the stations. The outcomes of selecting dry spells from Instat were recorded in a table. Table 4.2 is showing frequencies of dry spells for Kasungu for the three categories of thresholds used in this research.

Table 4.2: Frequency of Dry Spells for Kasungu for the Period of 1961 – 1980

Year	Number of (frequency of) dry spell periods for 7 CDD	Number of dry spell periods for 10 CDD	Number of dry spell periods for 15 CDD
1961	0	1	1
1962	2	1	1
1963	2	1	0
1964	1	0	0
1965	2	2	2
1966	2	0	2
1967	0	0	2
1968	0	0	2
1969	0	0	2
1970	1	0	2
1971	1	1	1
1972	3	1	1
1973	0	1	1
1974	1	1	2
1975	2	0	2
1976	3	0	1
1977	2	2	0
1978	1	3	1
1979	3	1	0
1980	4	1	0

The Table 4.2 is only showing frequencies of dry spells for Kasungu for 20 years (1961-1980) but it was done for all the 51 years (1961 - 2011) under study and for all stations. Table 4.2 was extracted from a bigger table which contained the results for all the stations and for all the 51 years. The frequencies in the bigger table from which Table 4.2 was extracted are the data which were used to carry out the trend analysis (time series plots and Mann-Kendall trend analysis).

The bigger table has been excluded from this report to avoid repetition of what the time series plots are showing because what the big table contains is shown in the times series plots in the next sub-section.

4.4 Results of Trend Analysis of Dry Spells

The following subsections shows results of time series and Mann-Kendall trend analysis for all the ten stations for the time period of 1961 to 2011 for the thresholds of 7 Consecutive Dry Days, 10 Consecutive Dry Days and 15 Consecutive Dry Days.

4.4.1 Time Series Plots and Mann-Kendall Trend Analysis For 7 CDD for All the Ten Stations

The Figures 4.11 to 4.20 are time series plots for the ten stations from 1961 to 2011. In these plots the number of occurrence of dry spell periods of the 7 Consecutive Dry Days threshold value were plotted against time.

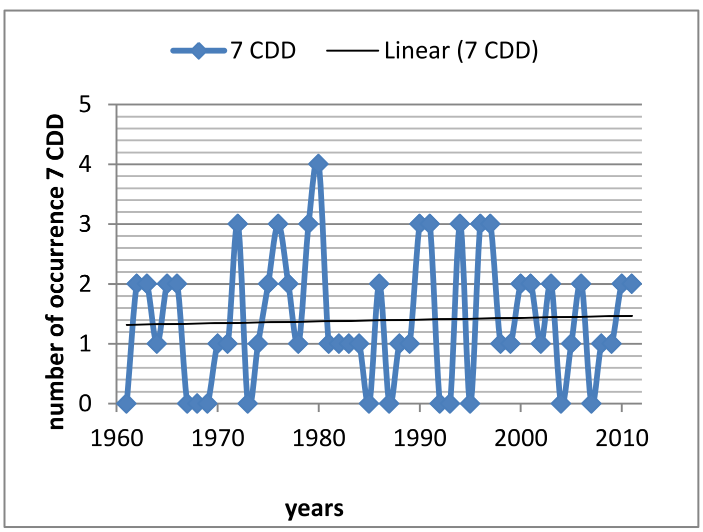


Figure 4.11: Time Series Plot For 7 CDD For Kasungu for the Period of 1961 to 2011

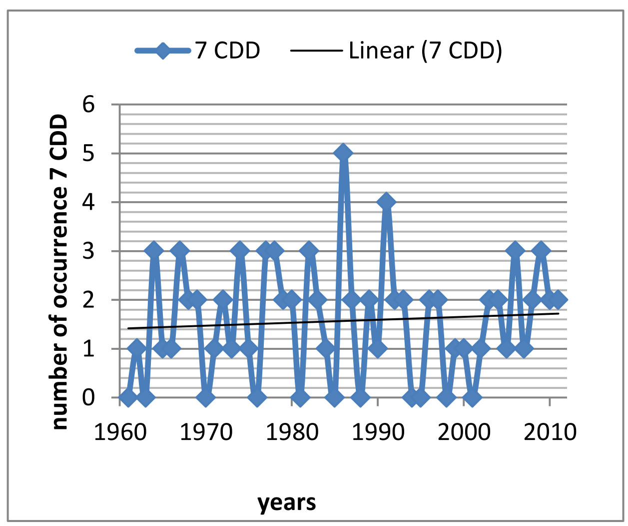
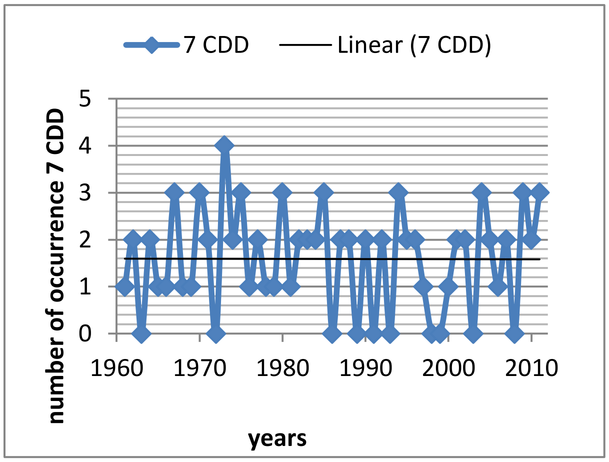


Figure 4.12: Time Series Plot For 7 CDD For Chitedze for the Period of 1961 to 2011



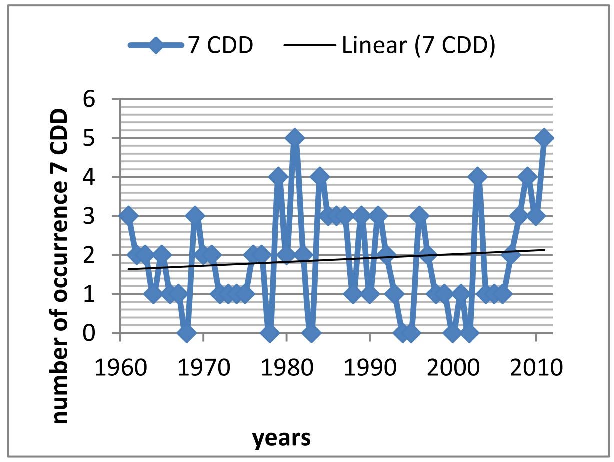
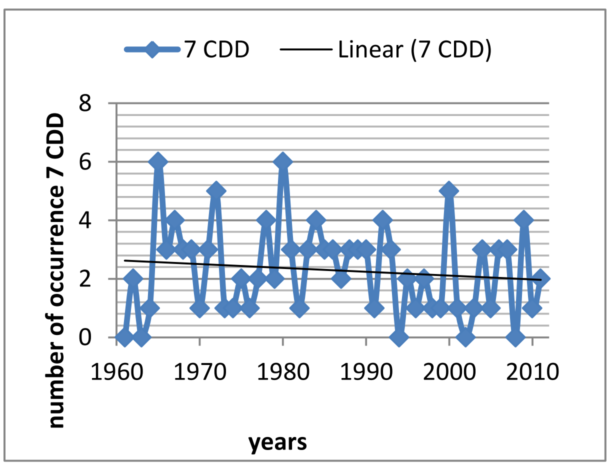


Figure 4.13: Time Series Plot For 7 CDD For Karonga for the Period of 1961 to 2011

Figure 4.14: Time Series Plot For 7 CDD For Salima for the Period of 1961 to 2011



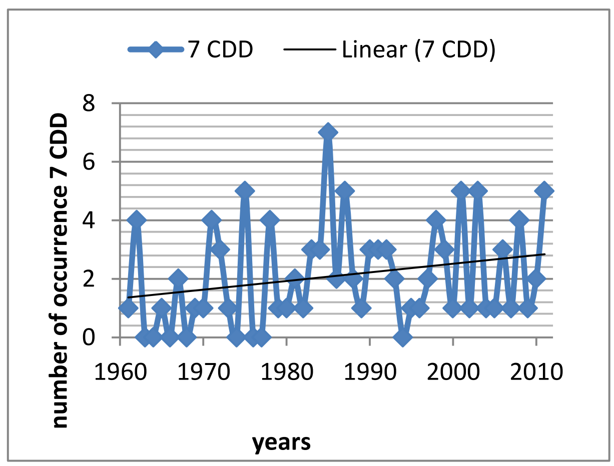


Figure 4.15: Time Series Plot For 7 CDD For Ngabu for the Period of 1961 to 2011

Figure 4.16: Time Series Plot For 7 CDD For Chileka for the Period of 1961 to 2011

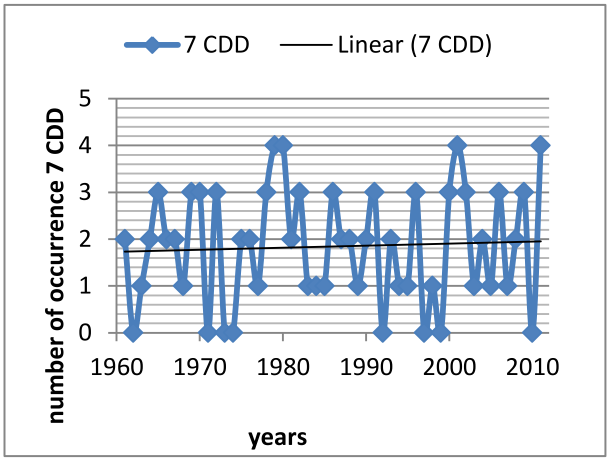


Figure 4.17: Time Series Plot For 7 CDD For Bvumbwe for the Period of 1961 to 2011

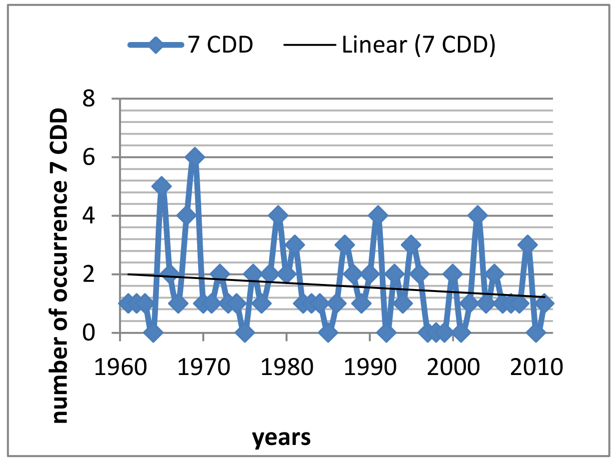


Figure 4.18: Time Series Plot For 7 CDD For Dedza for the Period of 1961 to 2011

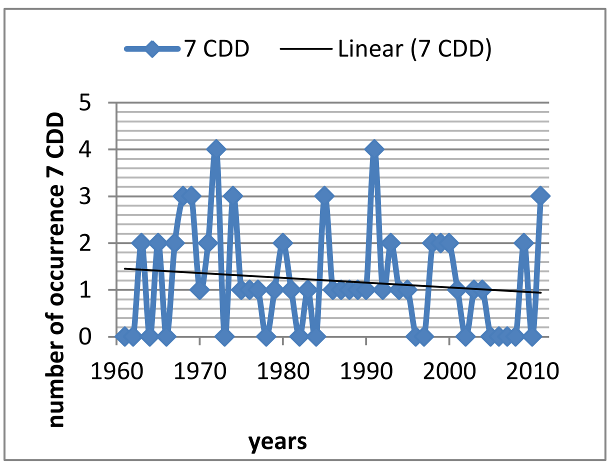


Figure 4.19: Time Series Plot For 7 CDD For Chitipa for the Period of 1961 to 2011

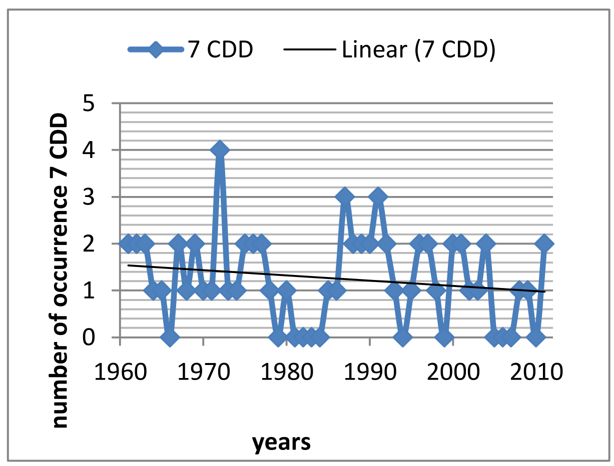


Figure 4.20: Time Series Plot For 7 CDD For Mzimba for the Period of 1961 to 2011

The time series plots for 5 stations for 7 consecutive dry days are showing increasing trends. The trend lines of stations which are showing increasing trends are as follows Kasungu (Figure 4.11), Chitedze (Figure 4.12), Salima (Figure 4.14), Chileka (Figure 4.16) and Bvumbwe (Figure 4.17).

The time series plots for 4 stations for 7 consecutive dry days are showing decreasing trends. The trend lines of stations which are showing decreasing trends are as follows Ngabu (Figure 4.15), Dedza (Figure 4.18), Chitipa (Figure 4.19), and Mzimba (Figure 4.20).

The time series plot for Karonga (Figure 4.13) for 7 consecutive dry days is difficult to tell whether the trend line is increasing or decreasing.

Table 4.3 is showing the results of Mann-Kendall trend analysis for all the ten stations for the threshold value of 7 consecutive dry days.

Table 4.3: Mann-Kendall Trend Analysis for 7 CDD for Ten Stations for the Period of 1961 – 2011

Station Name	**M-k S**	**Var S**	$\mathbf{Z_{MK}}$	**Trend**
Kasungu	10	15135	0.073156227	Increasing but not significant
Chitedze	37	15148.33	0.292496096	Increasing but not significant
Karonga	13	15147.67	0.097500844	Increasing but not significant
Salima	8	15136.33	0.0569781	Increasing but not significant
Ngabu	-107	15149.67	-0.861200606	Decreasing but not significant
Chileka	209	15147.67	1.696014634	Increasing but not significant
Bvumbwe	22	15147.67	0.176626477	Increasing but not significant
Dedza	-146	15141.67	-1.178368601	Decreasing but not significant
Chitipa	-135	15120.67	-1.089731058	Decreasing but not significant
Mzimba	-166	15127	-1.341552092	Decreasing but not significant

The Table 4.3 is showing that all the $|Z_{MK}|$ values are less than 1.96 hence the trend lines are not significant at a confidence level of 95%.

4.4.2 Time Series Plot and Mann-Kendall Trend Analysis for 10 CDD for All the Ten Stations

The figures 4.21 to 4.30 are time series plots for the ten stations from 1961 to 2011. In these figures the number of occurrence of dry spell periods of the 10 Consecutive Dry Days threshold value were plotted against time.

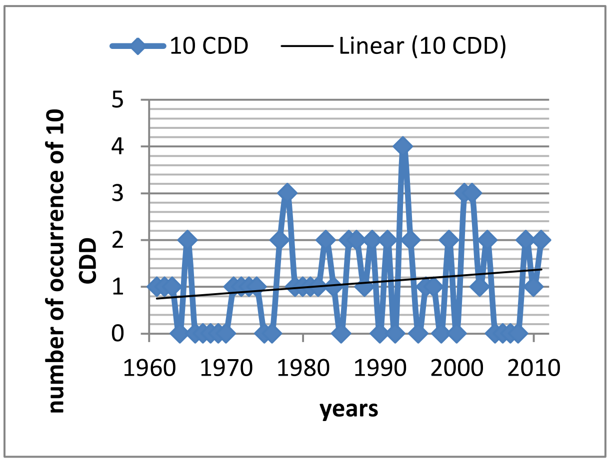


Figure 4.21: Time Series Plot For 10 CDD For Kasungu for the Period of 1961 to 2011

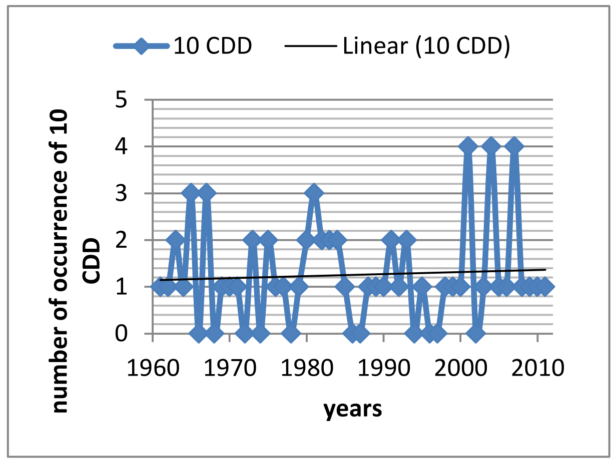


Figure 4.22: Time Series Plot For 10 CDD For Chitedze for the Period of 1961 to 2011

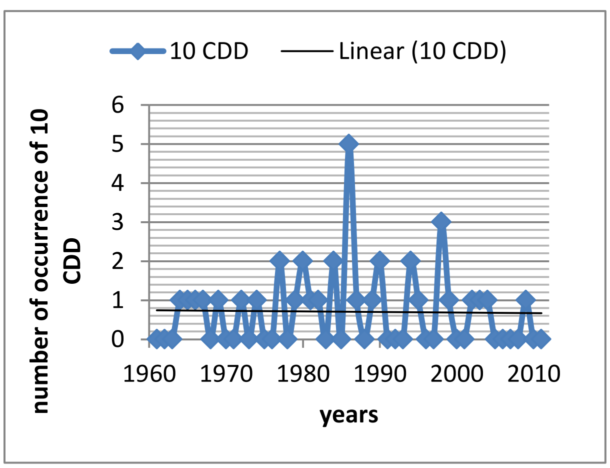


Figure 4.23: Time Series Plot For 10 CDD For Karonga for the Period of 1961 to 2011

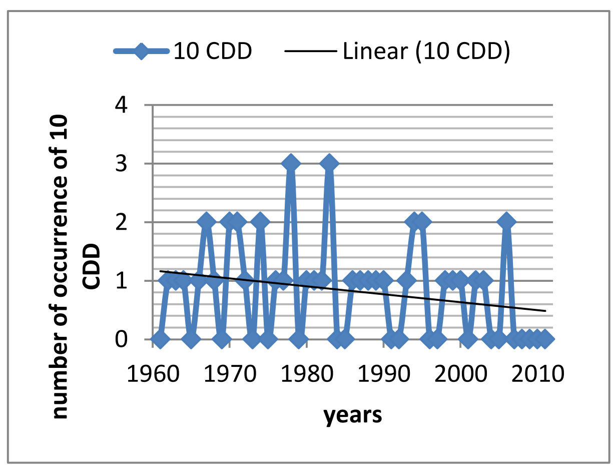


Figure 4.24: Time Series Plot For 10 CDD For Salima for the Period of 1961 to 2011

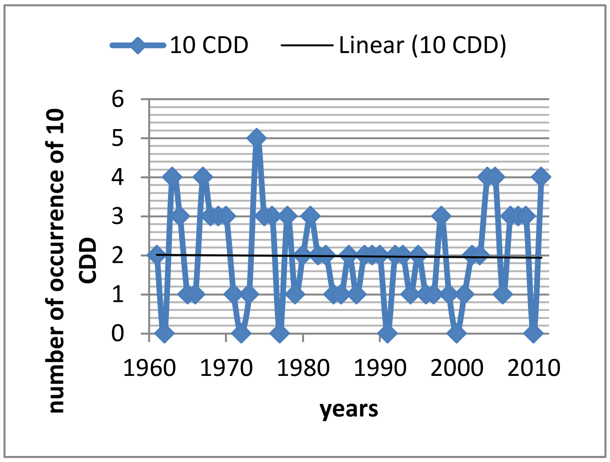


Figure 4.25: Time Series Plot For 10 CDD For Ngabu for the Period of 1961 to 2011

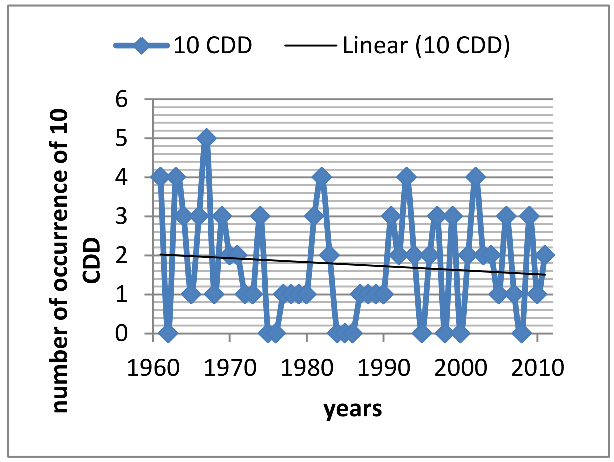


Figure 4.26: Time Series Plot For 10 CDD For Chileka for the Period of 1961 to 2011

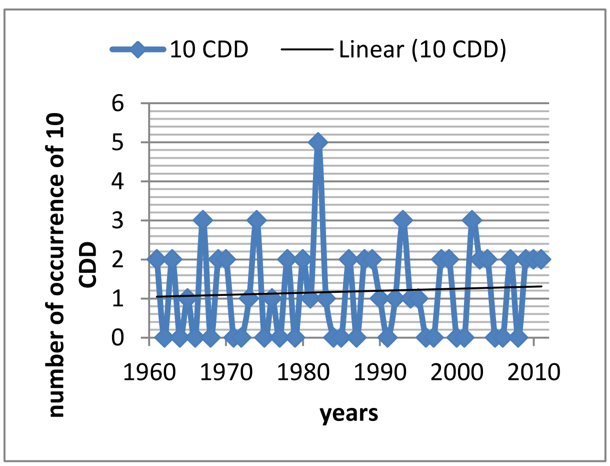


Figure 4.27: Time Series Plot For 10 CDD For Bvumbwe for the Period of 1961 to 2011

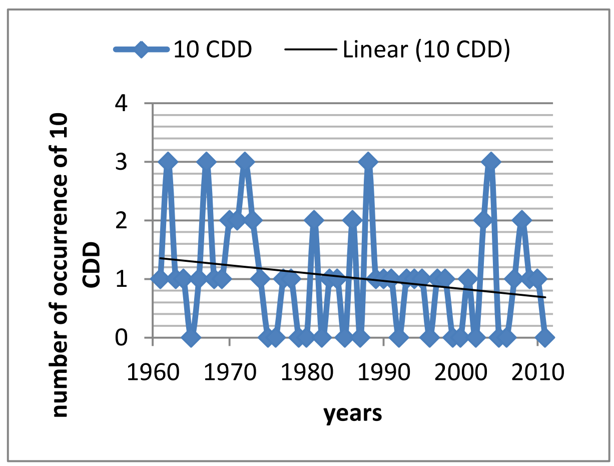


Figure 4.28: Time Series Plot For 10 CDD For Dedza for the Period of 1961 to 2011

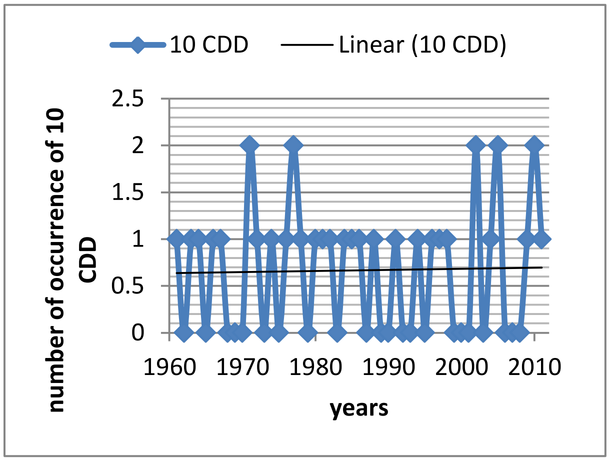


Figure 4.29: Time Series Plot For 10 CDD For Chitipa for the Period of 1961 to 2011

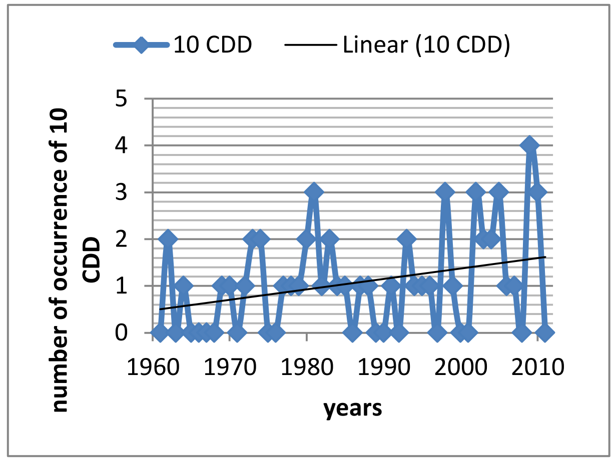


Figure 4.30: Time Series Plot For 10 CDD For Mzimba for the Period of 1961 to 2011

The time series plots for 3 stations for 10 consecutive dry days are showing increasing trends. The trend lines of stations which are showing increasing trends are as follows Kasungu (Figure 4.21), Mzimba (Figure 4.30), and Bvumbwe (Figure 4.27).

The time series plots for 3 stations for 10 consecutive dry days are showing decreasing trends. The trend lines of stations which are showing decreasing trends are as follows, Salima (Figure 4.24), Chileka(4.26) and Dedza (Figure 4.28)

The time series plots for Chitedze (Figure 4.22), Karonga (Figure 4.23), Ngabu (Figure 4.25), and Chitipa (Figure 4.29) for 10 consecutive dry days are difficult to tell whether the trend line is increasing or decreasing.

Table 4.4 is showing the results of Mann-Kendall trend analysis for all the ten stations for the threshold value of 10 consecutive dry days.

Table 4.4: Mann-Kendall trend analysis for 10 CDD for ten stations for the period of 1961 – 2011

Station Name	M-K S	Var S	Z_{MK}	Trend
Kasungu	121	15108	0.976287566	Increasing but not significant
Chitedze	-25	15126.33	-0.19513915	Decreasing but not significant
Karonga	-72	15124	-0.577331182	Decreasing but not significant
Salima	-239	15106	-1.93643184	Decreasing but not significant
Ngabu	-58	15139.33	-0.463256456	Decreasing but not significant
Chileka	-95	15133.33	-0.764118219	Decreasing but not significant
Bvumbwe	32	15144.67	0.251902127	Increasing but not significant
Dedza	-213	15140	-1.722950988	Decreasing but not significant
Chitipa	-17	15132.33	-0.130066973	Decreasing but not significant
Mzimba	185	15129.67	1.495902001	Increasing but not significant

The Table 4.4 is showing that all the $|Z_{MK}|$ values are less than 1.96 hence the trend lines are not significant at a confidence level of 95%.

4.4.1 Time Series Plot and Mann-Kendall Trend Analysis for 15 CDD for the Ten Stations

The figures 4.31 to 4.40 are time series plots for the ten stations from 1961 to 2011. In these figures the number of occurrence of dry spell periods of the 15 consecutive dry days threshold value were plotted against time.

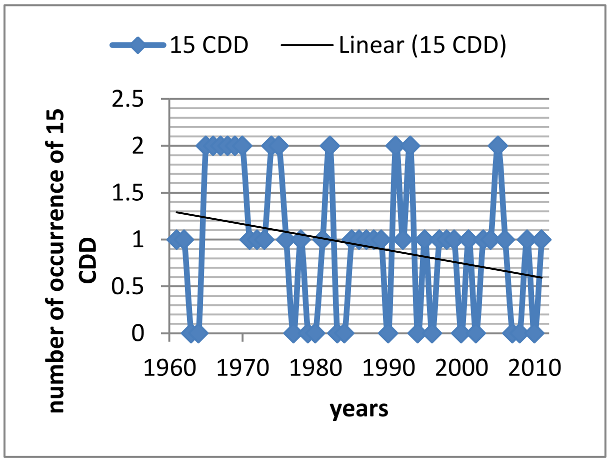


Figure 4.31: Time Series Plot For 15 CDD For Kasungu for the Period of 1961 to 2011

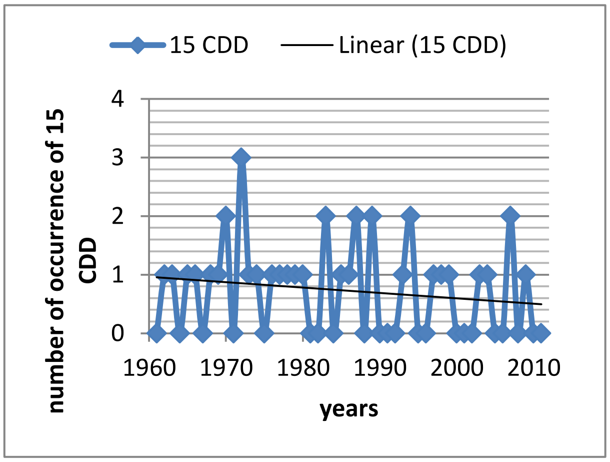


Figure 4.32: Time Series Plot For 15 CDD For Chitedze for the Period of 1961 to 2011

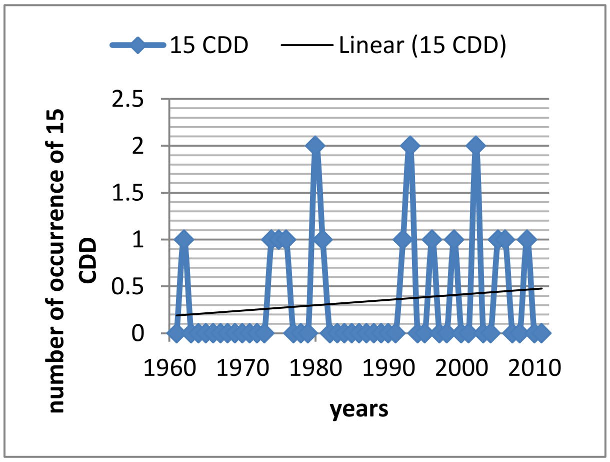


Figure 4.33: Time Series Plot For 15 CDD For Karonga for the Period of 1961 to 2011

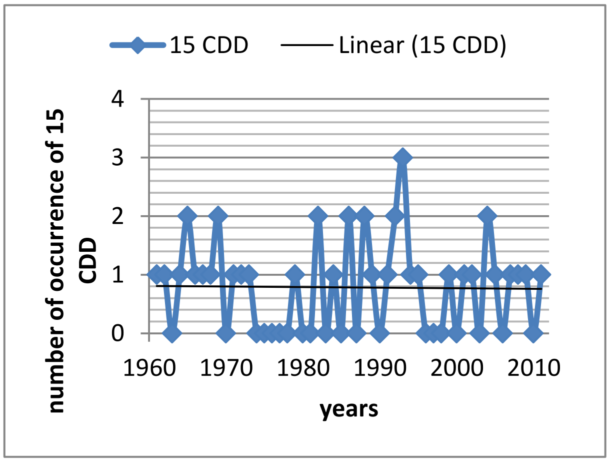


Figure 4.34: Time Series Plot For 15 CDD For Salima for the Period of 1961 to 2011

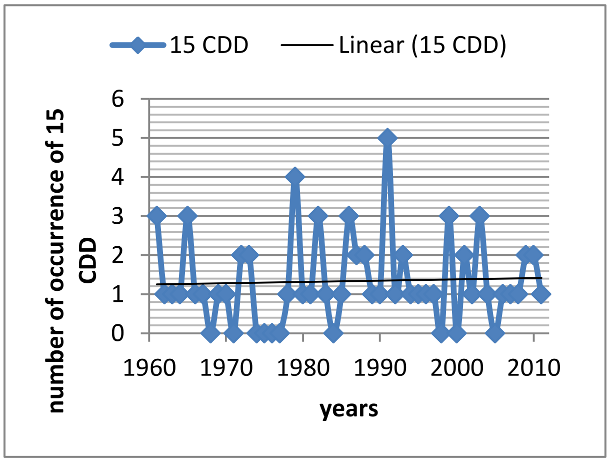


Figure 4.35: Time Series Plot For 15 CDD For Ngabu for the Period of 1961 to 2011

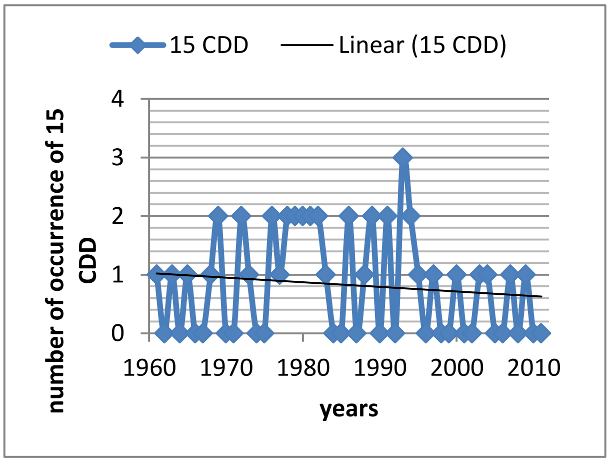


Figure 4.36: Time Series Plot For 15 CDD For Chileka for the Period of 1961 to 2011

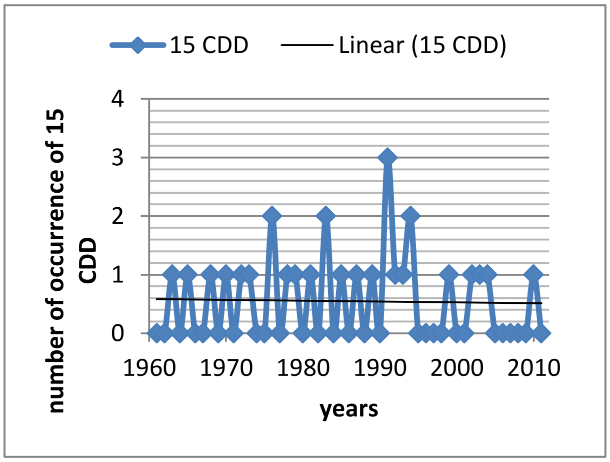


Figure 4.37: Time Series Plot For 15 CDD For Bvumbwe for the Period of 1961 to 2011

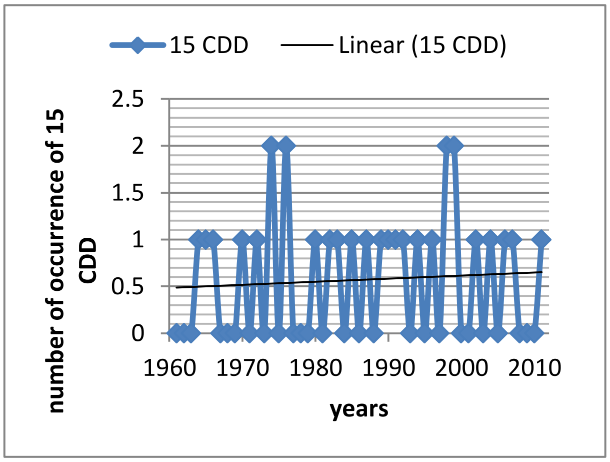
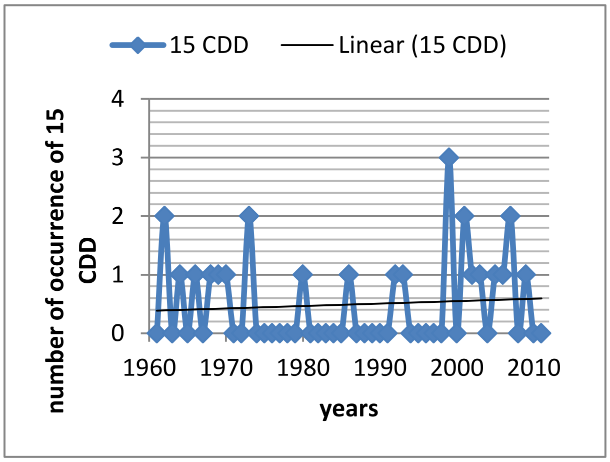


Figure 4.38: Time Series Plot For 15 CDD For Dedza for the Period of 1961 to 2011



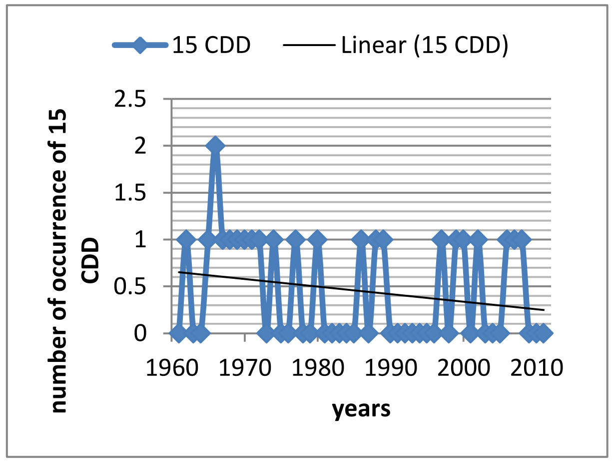


Figure 4.39: Time Series Plot For 15 CDD For Chitipa for the Period of 1961 to 2011

Figure 4.40: Time Series Plot For 15 CDD For Mzimba for the Period of 1961 to 2011

The time series plots for 3 stations for 15 consecutive dry days are showing increasing trends. The trend lines of stations which are showing increasing trends are as follows Karonga (Figure 4.33), Dedza (Figure 4.38), and Chitipa (4.39).

The time series plots for 4 stations for 15consecutive dry days are showing decreasing trends. The trend lines of stations which are showing decreasing trends are as follows Kasungu (Figure 4.31), Chitedze (Figure 4.32), Chileka(4.36) and Mzimba (Figure 4.40)

The time series plots for Salima (Figure 4.34), Ngabu (4.35), and Bvumbwe (Figure 4.37) for 15 consecutive dry days are difficult to tell whether the trend line is increasing or decreasing.

Table 4.5 is showing the results of Mann-Kendall trend analysis for all the ten stations for the threshold value of 15 consecutive dry days.

Table 4.5: Mann-Kendall Trend Analysis for 15 CDD for Ten Stations for the Period of 1961 – 2011

Station Name	M-K S	Var S	Z_{MK}	Trend
Kasungu	-254	15099	-2.05	Decreasing
Chitedze	-184	15120.67	-1.488214803	Decreasing but not significant
Karonga	79	14854	0.63998955	Increasing but not significant
Salima	-39	15123	-0.309004369	Decreasing but not significant
Ngabu	12	15126.67	0.089437792	Increasing but not significant
Chileka	-136	15132.67	-1.097427997	Decreasing but not significant
Bvumbwe	-70	15122.33	-0.561099249	Decreasing but not significant
Dedza	55	15127.33	0.439048575	Increasing but not significant
Chitipa	13	15104.67	0.097639528	Increasing but not significant
Mzimba	-170	15097.33	-1.375423951	Decreasing but not significant

The Table 4.5 has shown that the $|Z_{MK}|$ value for Kasungu is greater than 1.96 which means the decreasing trend is significant at a confidence level of 95%. With the exception of Kasungu, none of the increasing or decreasing trends is significant at a confidence level of 95% since all the $|Z_{MK}|$ values are less than 1.96.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY

For 7 CDD the time series plots for 5 stations (kasungu, chitedze, salima, chileka,bvumbwe) showed increasing trends, for 4 stations (ngabu, dedza,chitipa, mzimba) showed decreasing trends and for 1 station (karonga), it was difficult to tell whether the trend was increasing or decreasing. The Mann-Kendal trend analysis at a confidence level of 95% showed that 6 stations (kasungu, chitedze, karonga, salima, chileka, bvumbwe) had increasing trends which were not significant and 4 (ngabu, dedza, chitipa, mzimba) stations had decreasing trends which were also not significant.

For 10 CDD the time series plots for 3 stations (kasungu, bvumbwe, mzimba) showed increasing trends, for 3 stations (salima, chileka, dedza) showed decreasing trends and for 4 stations (chitedze, karonga, ngabu, chitipa), it was difficult to tell whether the trend was increasing or decreasing. The Mann-Kendal trend analysis at a confidence level of 95% showed that 3 stations (kasungu, bvumbwe, mzimba) had increasing trends but were not significant and 7 stations (chitedze, karonga, salima, ngabu, chileka, dedza, chitipa) had decreasing trends but were also not significant.

For 15 CDD the time series plots for 3 stations (karonga, dedza, chitipa) showed increasing trends, for 4 stations (kasungu, chitedze, chileka, mzimba)showed decreasing trends and for 3 stations (salima, ngabu, bvumbwe), it was difficult to tell whether the trend was increasing or decreasing. The Mann-Kendal trend analysis at a confidence level of 95% showed that 4 stations (karonga, ngabu, dedza, chitipa) had increasing trends but were not significant and 5 stations (chitedze, salima, chileka, bvumbwe, mzimba) had decreasing trends but were also not significant but it showed 1 station (kasungu) with a significant decreasing trend.

5.2 CONCLUSIONS

For the stations studied we can conclude that dry spells are occurring but they do not have significant trends since out of the 10 stations studied and out of three threshold categories used, only one station and one category showed a significant decreasing trend.

5.3 RECOMMENDATIONS

The timing of the occurrence of the dry spells was not tied to growing phases of crops but dry spells causes most significant water stress in crops during their first 30 days of their life cycles so studying the time of occurrence of a particular dry spell is very important and hence further research in regard to time is recommended.

I studied one variable about dry spells that is number of occurrence of dry spell periods. There are other variables that I have not studied and they are as follows; maximum length of the dry spell (MLDS) and annual maximum dry spell length (AMDSL). Carrying a study on these two variables can also be helpful in coming up with the state of dry spells in the country.

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