ASSESSING THE SPATIAL AND TEMPORAL CHARACTERISTICS OF TEMPERATURE AND RAINFALL OVER THE CENTRAL AND SOUTHERN REGIONS OF MALAWI DURING THE WINTER SEASON

BY

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DECLARATION

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

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ABSTRACT

Malawi is a land locked country located within the longitudes 33 degrees to 36 degrees East and latitude 9^o 22' to 17^o7'. The total area is 118,480 square km – of which an area of 94,080 square km is occupied by land, and 24,400 square km is covered by water.

Malawi has a tropical type of climate with two seasons: Summer (September to April) and winter(May to August). Most of the rainfall comes during the summer season.The features which influence weather during summer season are Congo air mass, Inter-Tropical Convergence Zone (ITCZ), tropical cyclones and topography. Southeasterly trade winds intensify the orographic rainfall in Malawi.

Malawi is characterized by different types of topographic features such as mountains, highlands, plains, lakes and rivers.

Winter seasons nowadays seem to be different from how they used to be in the past worldwide and Malawi is no exceptional. The assessment of the spatial and temporal characteristics of temperature and rainfall during winter seasons were done, and also examination of the causes of winter rainfall and temperature variability and determine whether these are climate change signals were also done in the Southern and Central Regions of Malawi.

Statistical techniques were used to study the spatial and temporal characteristics of both rainfall and temperature over central and southern regions of Malawi.

The data was obtained from Department of Climate Change and Meteorological Services (DCCMS) in Malawi for ten stations for the mean monthly temperature and mean monthly rainfall from1961 to 2013 for South and Central Regions of Malawi and was subject to quality control before analysis was carried out. The study found out that most of the data in the selected stations were homogenous as attested by single mass curve.

Genstat application was used to analyzing data, t-stat was used to check the trend and Surfer software was used to create maps.

The observations were made using graphical method. With time, the trend for maximum and minimum temperatures over the Southern and Central Regions of Malawi during Winter Seasons are showing that they are all increasing gradually.

The observation of rainfall showed that the general rainfall trend over time, over the Central and Southern Regions of Malawi is not significant during Winter Seasons.

ACKNOWLEDGEMENT

I would like to first of all thank The Almighty God for guiding and protecting me throughout the time I have been doing this.

I would also like to thank all the pastors who have been there for me.

I wish to extend my sincere gratitude to my supervisors, Dr. A. Opere and Dr. C. Oludhe for their great support and guidance.

I wish to extend my appreciation to all who helped me in one way or the other in this research.

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LIST OF ABREVIATIONS

WMO	World Meteorological Organization
ITCZ	Inter-Tropical Convergence Zone
UN	United Nations
DJF	December, January, February
WA	Western Australia

CHAPTER ONE

1.1 INTRODUCTION

Malawi is a land locked country located within the longitude 33 degrees to 36 degrees East and latitude 9° 22’ to 17° 7’. The total area is 118,480 square km of which an area of 94,080 square km is occupied by land, and 24,400 square km is covered by water.

1.2 Local Weather and Climate

Malawi has a tropical type of climate with two seasons: summer (September to April) and winter (May to August). Most of the rainfall comes during the summer season.

Winter season has the mean temperatures varying between 17 and 27 degrees Celsius, with temperatures falling between 4 and 10 degrees Celsius. In addition, frost sometimes occurs in isolated areas in June and July. A hot, dry season lasts from September to October with average temperatures varying between 25 and 37 degrees Celsius. Humidity ranges from 50% for the drier months of September/October to 87% for the wetter months of January/February.

Malawi is divided into 5 climatic zones which are;

a. Shire Valley, which is found on the southern tip of Malawi.
b. Shire Highlands, which covers most areas of southern Malawi.
c. Central Areas, which comprises of most parts of the central Malawi.
d. Lake Shore Areas, which is along Lake Malawi.
e. Northern Areas, which covers northern part of Malawi.

The features which influence weather during summer season are Congo air mass, Inter-Tropical Convergence Zone (ITCZ), tropical cyclones and topography. Southeasterly trade winds intensify the orographic rainfall in Malawi. Southerly winds known as Chiperoni are experienced in winter with light rains and cold moist. Over Lake Malawi weather is fine but there are southerly wind called Mwera winds which are sometimes very strong.

1.2.1Topography and Vegetation

Malawi is characterized by different types of topographic features such as mountains, highlands, plains, lakes and rivers.

The highest point is Mulanje Mountain, about 3,000 meters above sea level and lowest point is about 37 meters above sea level at a junction of Shire River and International Boundary with Mozambique.

The Rift Valley runs meridionally along Lake Malawi and its elevation ranges between 220 meters and 600 meters above mean sea level. Shire Valley lies below 400 meters above sea level, Shire Highlands range between 400 to 900 meters, Central Plains range from 700 to 1,300 meters above sea level and the Northern Highlands range from 1,100 to 1,330 meters above sea level.

1.3 Area of Study

This study will be done in the Southern and Central Regions of Malawi which comprise of ten meteorological stations. Four stations from central region are Chitedze, Kasungu, Dedza and Nkhotakota and six stations from southern region are Chileka Airport, Bvumbwe, Ngabu, Mimosa, Makoka and Mangochi.

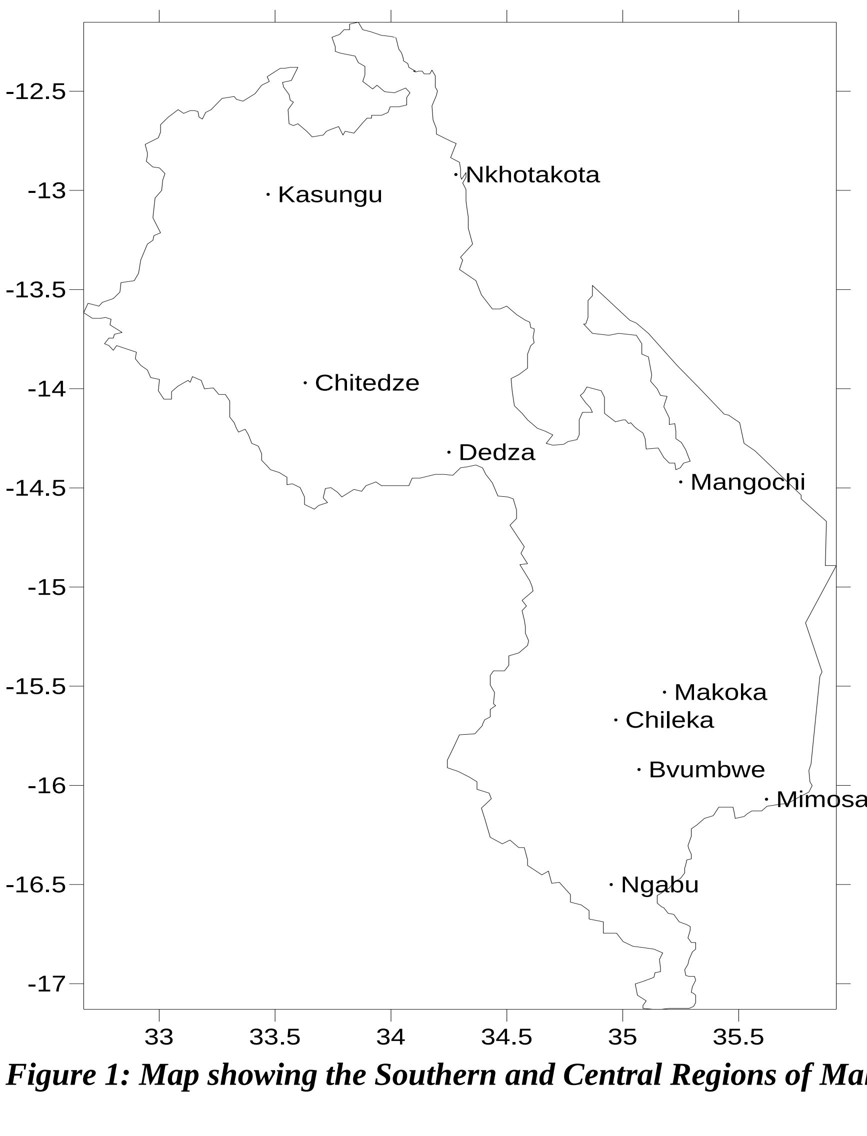

Figure 1: Map showing the Southern and Central Regions of Malawi

1.4 Statement of the problem

It has been observed that winter season nowadays seems to be different from how it used to be in the past worldwide and Malawi is not exceptional. The study is focusing in the Southern and Central Regions of Malawi which are be representatives of the prevailing weather conditions during winter season across Malawi.

1.5 Objectives

The overall objective of this study is to assess the spatial and temporal characteristics of temperature and rainfall during winter seasons.

The specific objectives are;

- To determine the temporal and spatial characteristics of temperature and rainfall during winter seasons
- To examine the causes of winter rainfall and temperature variability and determine whether these are climate change signals.

CHAPTER TWO

2.1 LITERATURE REVIEW

More work is still being carried out on winter season analysis in the southern region of Africa. In Zambia, the average number of ‘cold ‘days per year has decreased by 22 (6% of days) and the average number of ‘cold’ nights per year has also decreased by 35 (9.7% of days). (McSweeney, 2008)

Heatwaves are very likely to occur more frequently and last longer. as the earth warms up, we expect to see currently wet regions receiving more rainfall, and dry regions receiving less, although there will be exceptions. (Stocker, 2013)

As the ocean warms up, and glaciers and ice sheets reduce, global mean sea level will continue to rise, but at a faster rate than we have experienced over the past 40 years.(Qin Dahe, 2013).

Data from weather stations around the world reveal more extreme precipitation events — and more droughts, too. this is firmly in line with the predictions of climate models and is "what is expected from fundamental physics.(The Met Office, 2014)

A warmer atmosphere will contain more energy and more moisture from evaporation The atmosphere already has more energy and more moisture. And, in general, more energy and more moisture will mean wetter storms in many places. (Woollings, 2014)

The first six weeks of 2014 have seen an unusual number of extreme episodes of heat, cold and rain – not just in a few regions as might be expected in any winter season, but these episodes have occurred throughout the world at the same time, with costly disruptions to transport, power systems and food production. (The UN's World Meteorological Organization (WMO), 2014)

The number, frequency and intensity of hot days and heatwaves are increasing, along with an increase in the intensity and number of heavy rainfall events. (UN Intergovernmental Panel, 2013)

In Malawi, the average number of ‘hot’ days per year has increased by 30.5 (an additional 8.3% of days). The rate of increase is seen most strongly in DJF when the average number of hot DJF days has increased by 3.9 days per month (an additional 12.7% of DJF days) over this period. (McSweeney, et al 2006)

Current evidence suggests that tropical and sub-tropical countries will be vulnerable to global warming because they are already experiencing high temperatures. (Turpie, 2013)

Temperatures have risen during the last 30 years, and 2000 to 2009 was the warmest decade ever recorded. A drought is an extended period of dry weather caused by a lack of rain or snow. As temperatures rise due to global climate change, more moisture evaporates from land and water, leaving less water behind. Some places are getting more rain or snow to make up for it, but other places are getting less. Since the 1970s, droughts have become longer and more extreme worldwide, particularly in the tropics and subtropics. Droughts are expected to keep getting longer and more severe, (a student guide to Global climate change, 2013)

Winter rainfall in south-west WA was once considered the most consistent and reliable anywhere in Australia. However, around the mid 1970s there was a shift to consistently drier winter conditions, which have continued to this day. This change occurred simultaneously with a change in the global atmospheric circulation. (Hope, 2005)

CHAPTER THREE

3.1 DATA AND METHODOLOGY

In this section, the data type, source and various methods used in the study are discussed.

3.2 Data Type and Source

The data which was used in the study was the mean monthly temperature and mean monthly rainfall from 1961 to 2013 for South and Central Region of Malawi.
The source of data was from The Department of Climate Change and Meteorological Services in Malawi for ten stations which are in the south and central region of Malawi. The following table shows the location of stations used in this study.

Table 1: Name of stations and their locations in Malawi

Number	STATION	LONGITUDE	LATITUDE	ALTITUDE(masl)
1	Kasungu	33.47	-13.02	1058
2	Nkhotakota	34.28	-12.92	500
3	Dedza	34.25	-14.32	1632
4	Chitedze	33.63	-13.97	1149
5	Chileka Airport	34.97	-15.67	767
6	Bvumbwe	35.07	-15.92	1146
7	Ngabu	34.95	-16.50	102
8	Mimosa	35.62	-16.07	652
9	Makoka	35.18	-15.53	1029
10	Mangochi	35.25	-14.47	482

3.2.1 Data Quality

Completeness and consistence of data is important in research work. Meteorological parameters such as temperature and rainfall need careful scrutiny in order to determine their spatial homogeneity over the area. Some of the procedures are: Homogeneity test for population with frequency distribution close to normal, Homogeneity test based on cumulative frequency distribution, regression method, mass curve analysis and Genstat analysis method etc. In this study, single mass curve analysis is used.

3.3 Methodology

Various methods have been used in this study.

3.3.1 Estimation of missing data

Arithmetic mean is most commonly used for estimating missing data.
How arithmetic mean can be used to determine missing data is explained by the example below: Consider different stations S1, S2, S3 and S4, four stations with complete data and another station Sx with missing data. The monthly average temperature over the stations with complete records is computed by:

$\bar{a} = \frac{1}{n}\sum_{i=1}^{n} Si = \frac{1}{4}(\frac{1}{S1} + \frac{1}{S2} + \frac{1}{S3} + \frac{1}{S4})$ ……….(1)

Where n is the total length of data records. After determining the mean temperature for each station over all months of the data taken, mean of mean values of the station is taken that is:

$R = \frac{1}{n}\sum_{i=1}^{n} ai = \frac{1}{4}(\overline{a1} + \overline{a2} + \overline{a3} + \overline{a4})$ ………(2)

Where ai is expressed as a ratio of R

$Yi = \frac{\bar{a}}{\bar{R}}$ ……………(3)

For the station with missing data the average for the available data Sx1 is calculated. To get the missing data Si as a ratio of $Si/_{Sx}$ and equate this with

$\frac{\overline{Si}}{\overline{Sx}} = \frac{\overline{ai}}{\bar{R}}$ ……………..(4)

Using the determined Si, we continue to find the other missing data of the station using determined Sx2 again.

We continue determining the missing values using Sx1, Sx2, …Sxn. Here what should be known is that the missing data of the station should be less or equal to 10% of the existing data of the station.

However, this method was not used in this study because there was no missing data in the data collected.

3.3.2 Mass curve analysis

Mass curve analysis involves the plotting of time series of cumulative values of the observed data starting from most recent data going backwards. Mass curve is used to test the homogeneity or consistency and accuracy of meteorological data. Heterogeneity data records are adjusted using single mass curve analysis.

3.3.3 Genstat analysis

Genstat application is a statistical tool for analyzing data. Within the application, there is a trend analysis tool which is used to investigate whether the weather parameter is increasing or decreasing with time.

CHAPTER FOUR

4.1 RESULTS AND DISCUSSION

The single mass curves for four stations, two from Central Region and two from Southern Region for minimum and maximum temperatures which are representatives of the two regions are given in figures below:

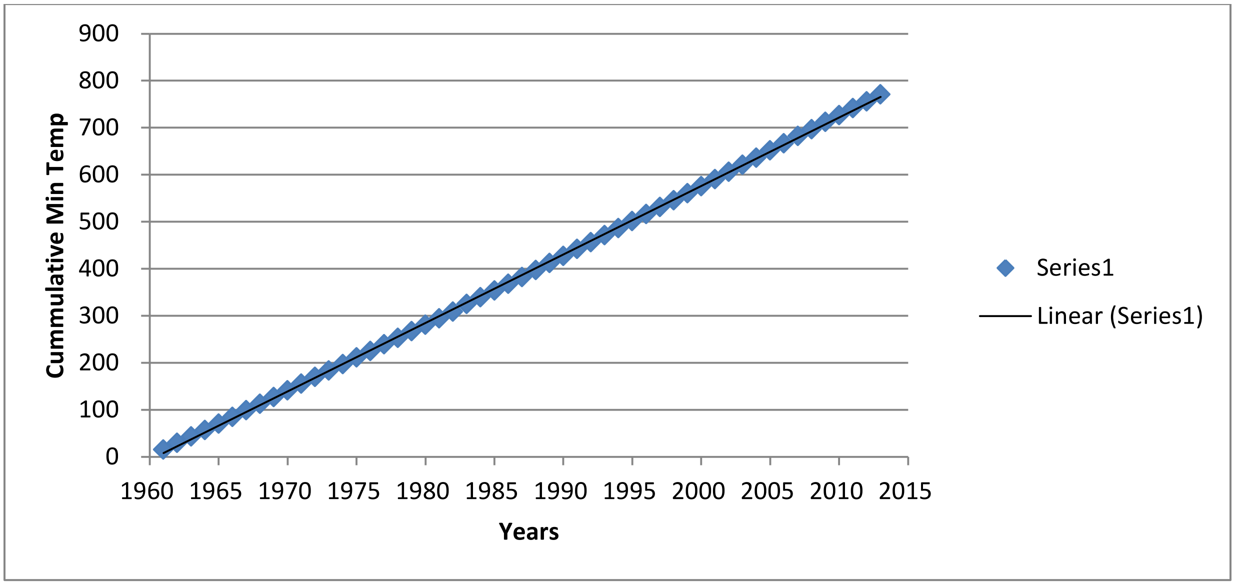

Figure2a: Chileka min temp single mass curve

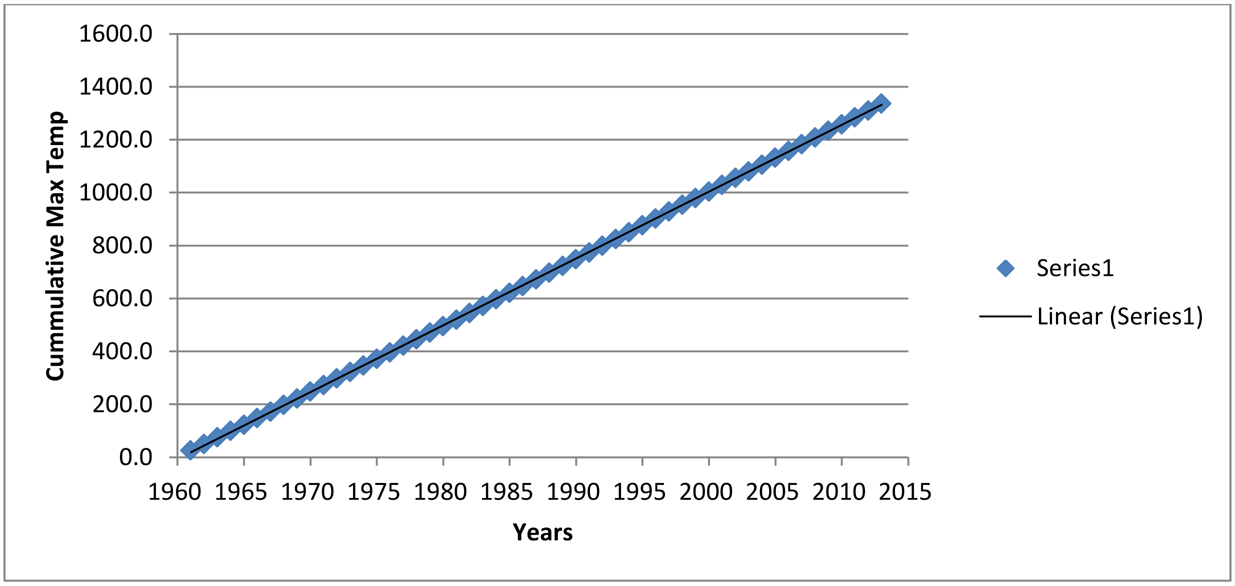

Figure2b: Chileka max temp single mass curve

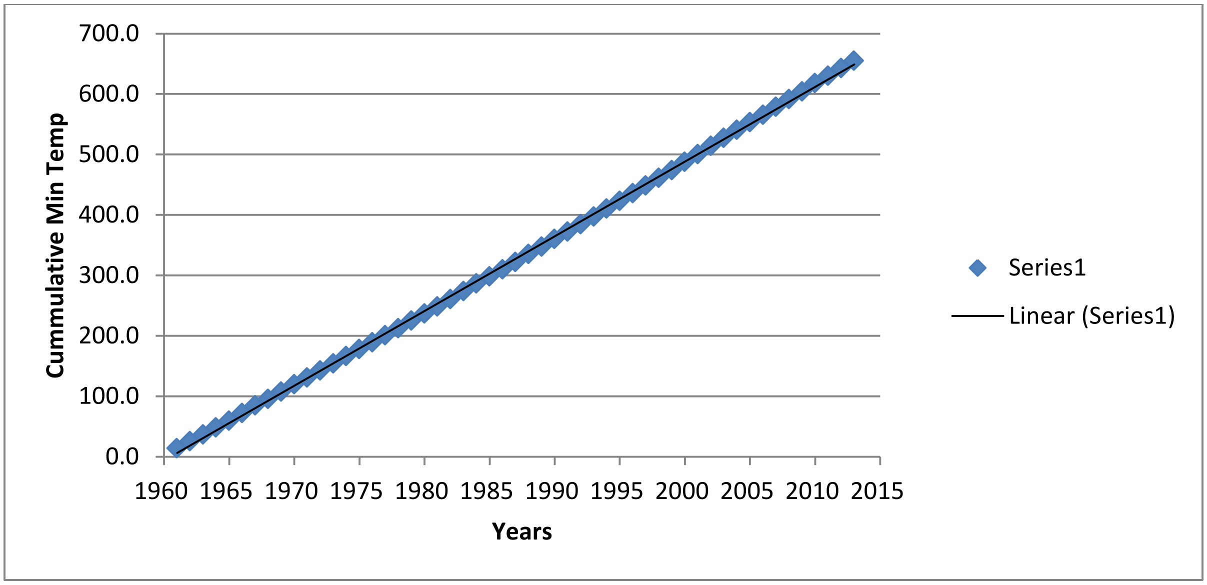

Figure3a: Mimosa min temp single mass curve

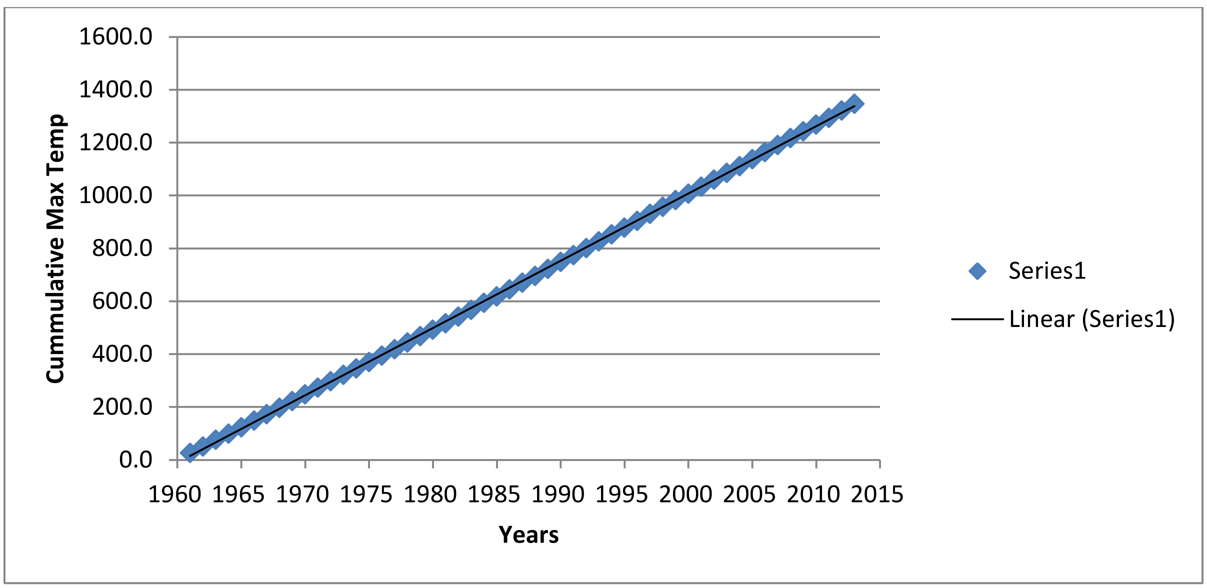

Figure3b: Mimosa max temp single mass curve

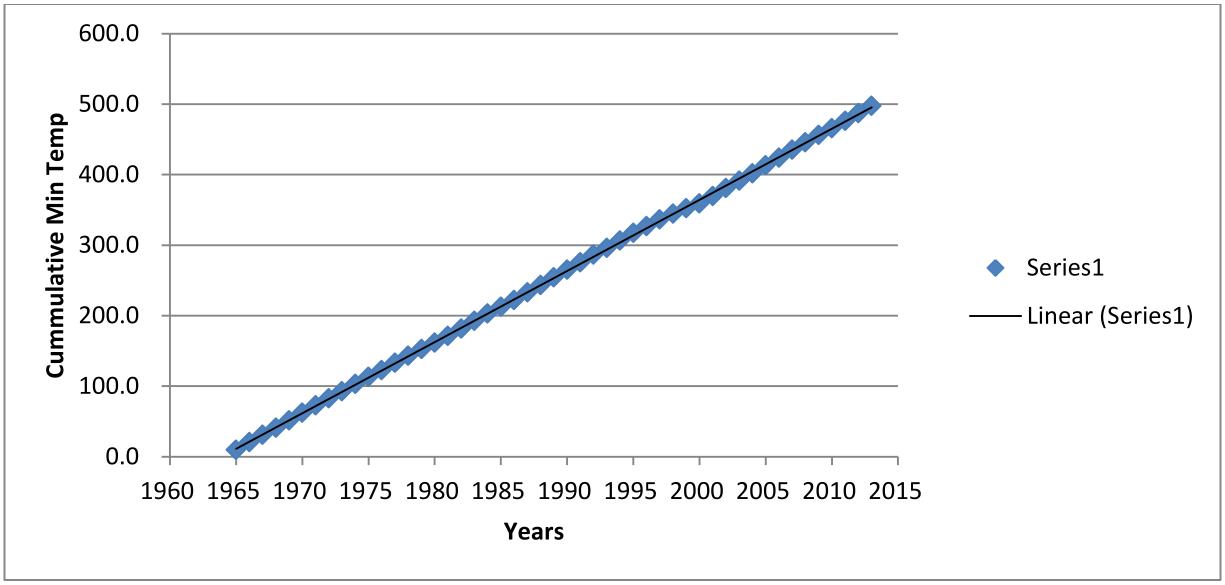

Figure4a: Dedza min temp single mass curve

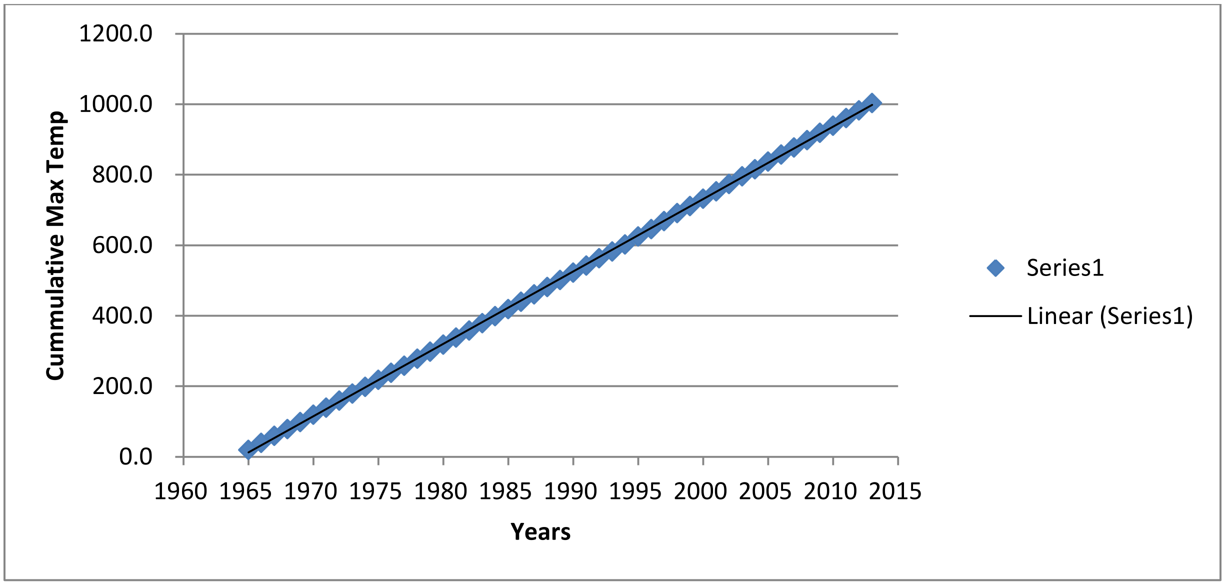

Figure 4b: Dedza max temp single mass curve

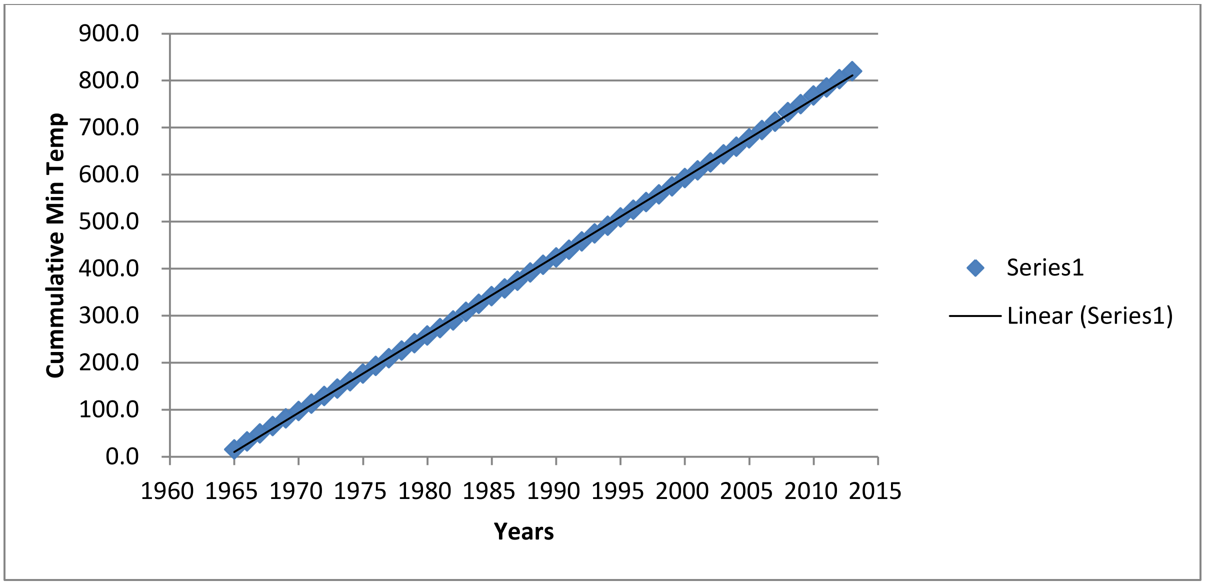

Figure 5a: Nkhotakota min temp single mass curve

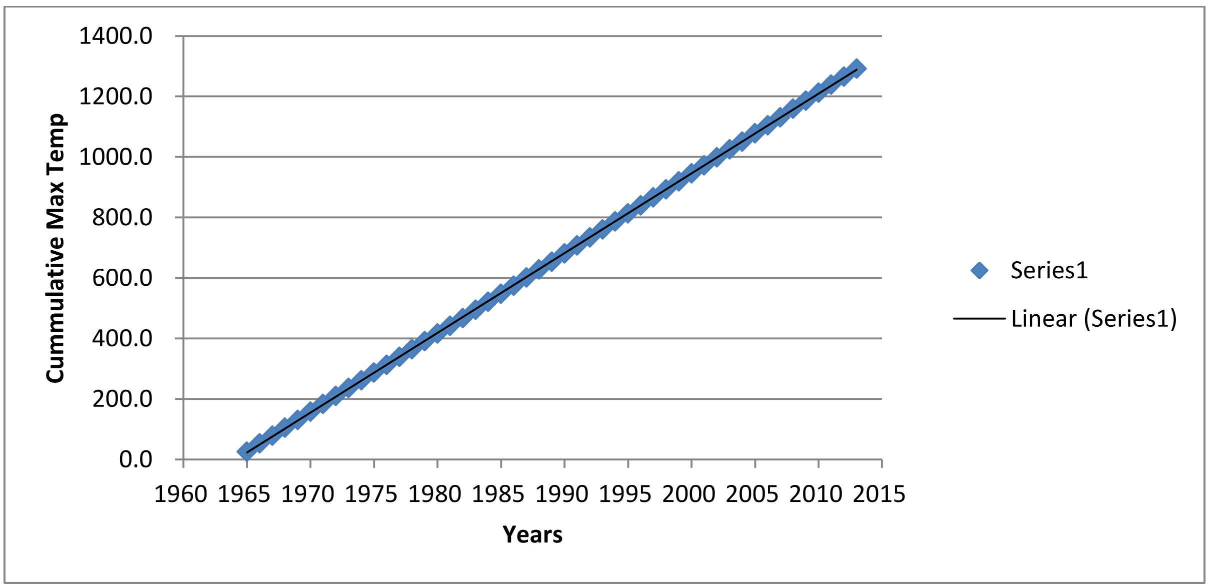

Figure 5b: Nkhotakota max temp single mass curve

The single mass curves from four stations for the rainfall; two from Central Region and two from Southern Region are given in figures below;

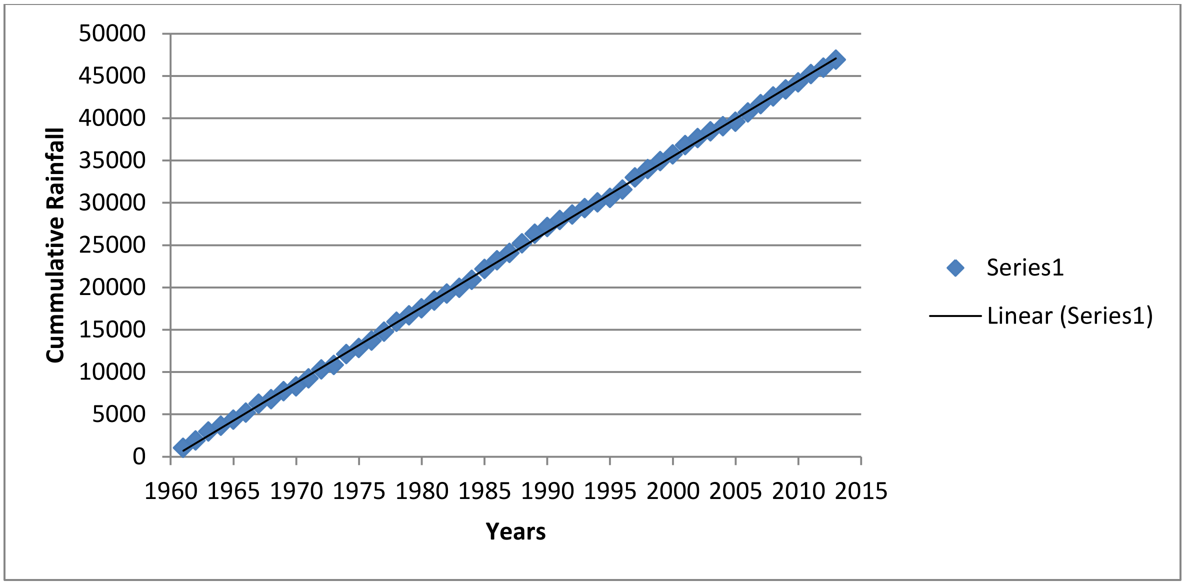

Figure 6: Chileka rainfall single mass curve.

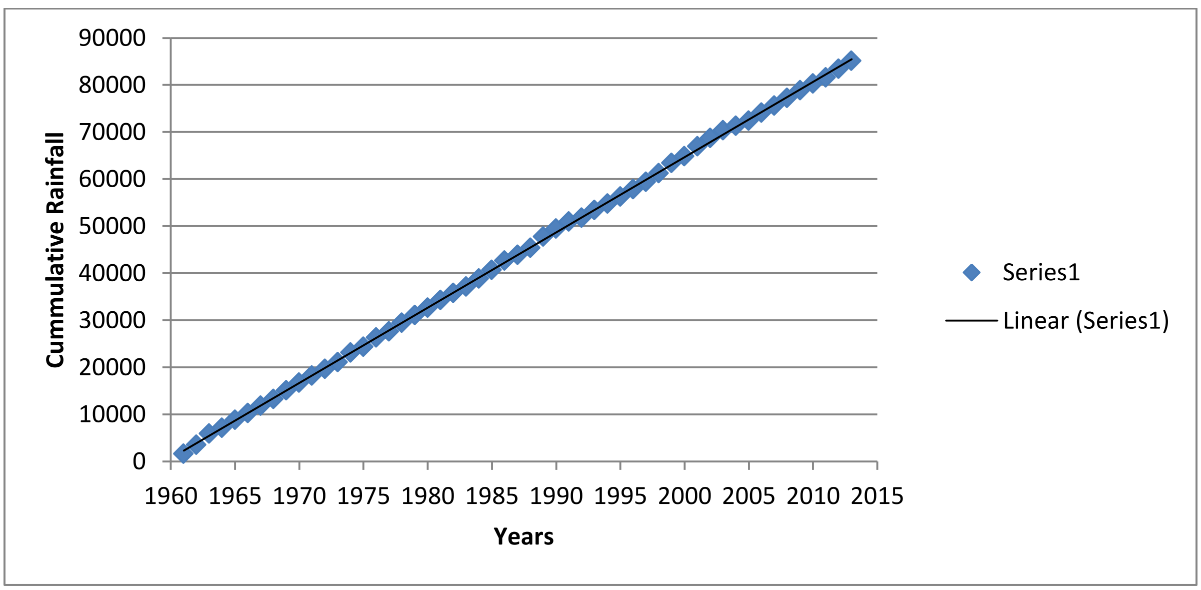

Figure 7: Mimosa rainfall single mass curve

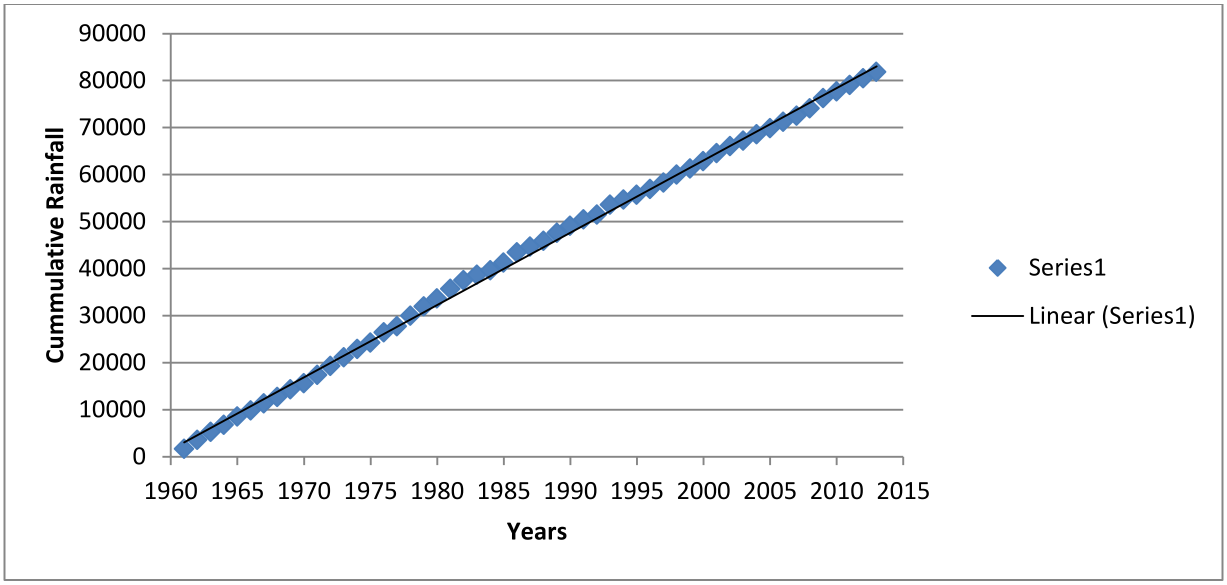

Figure 8: Nkhotakota rainfall single mass curve.

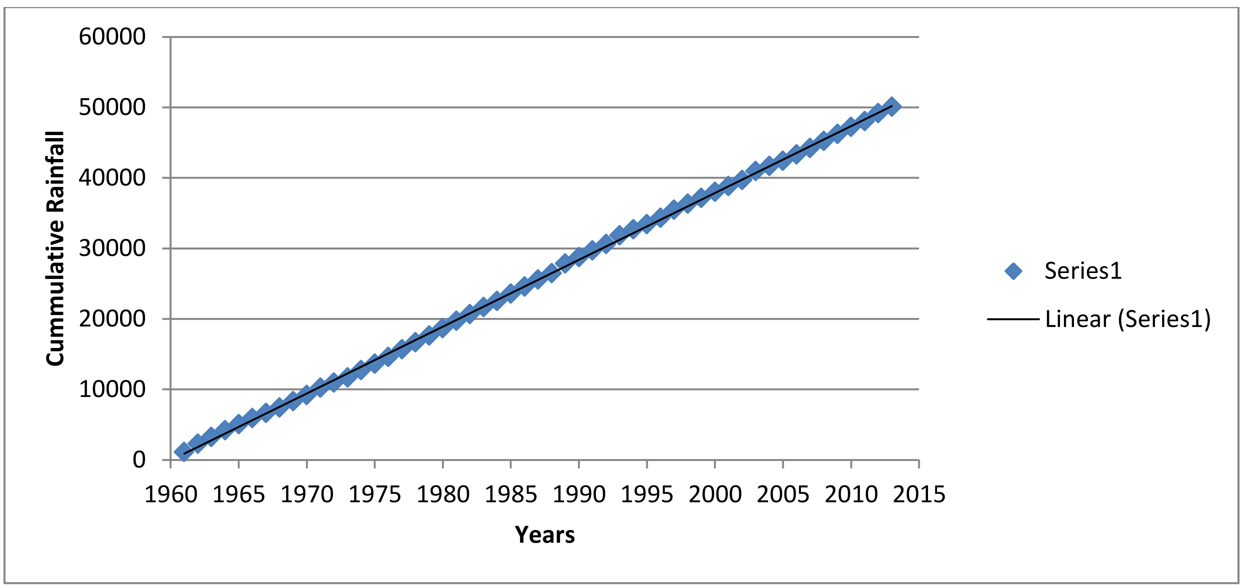

Figure 9: Dedza rainfall single mass curve.

4.2.1 Trend of Temperature and Rainfall in the Central and Southern Regions of Malawi

In terms of temporal and spatial characteristics, temperatures during winter seasons are increasing while winter rainfall is decreasing in Central and Southern Regions of Malawi

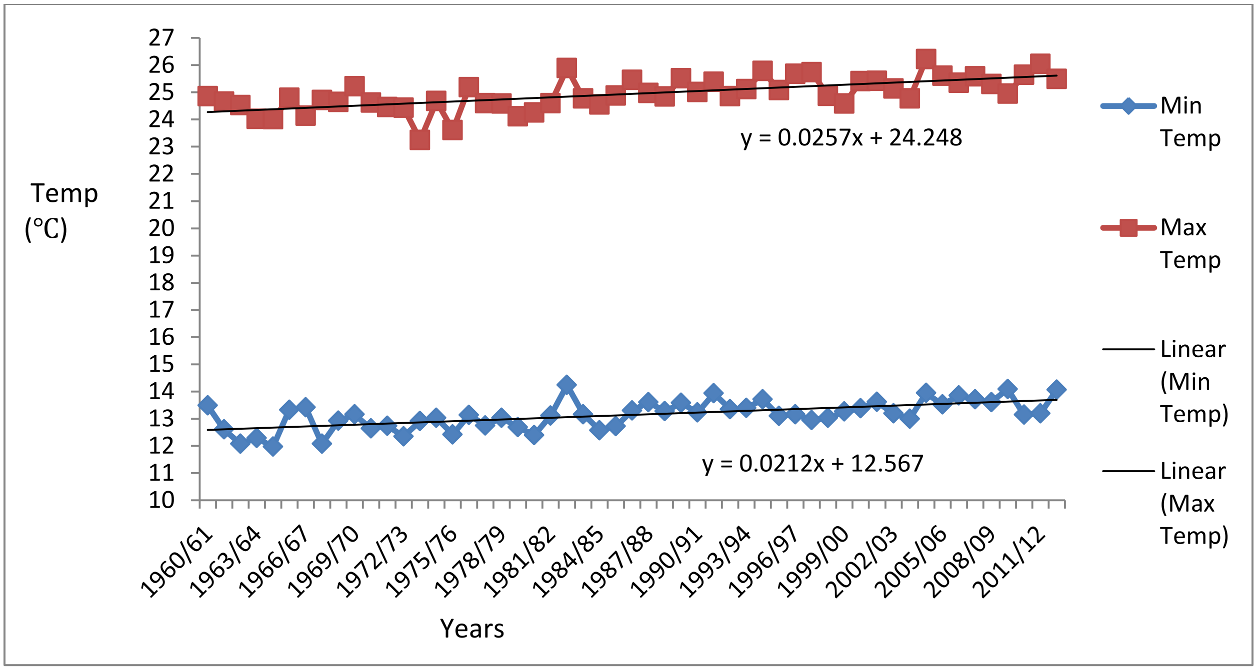

Figure 10: The temporal characteristics of temperature.

Figure 10 above shows that with time, minimum temperature is increasing and also maximum temperature is increasing during Winter Seasons.

From Table 2 below, it shows that the trend of minimum and maximum temperatures is increasing during winter seasons.

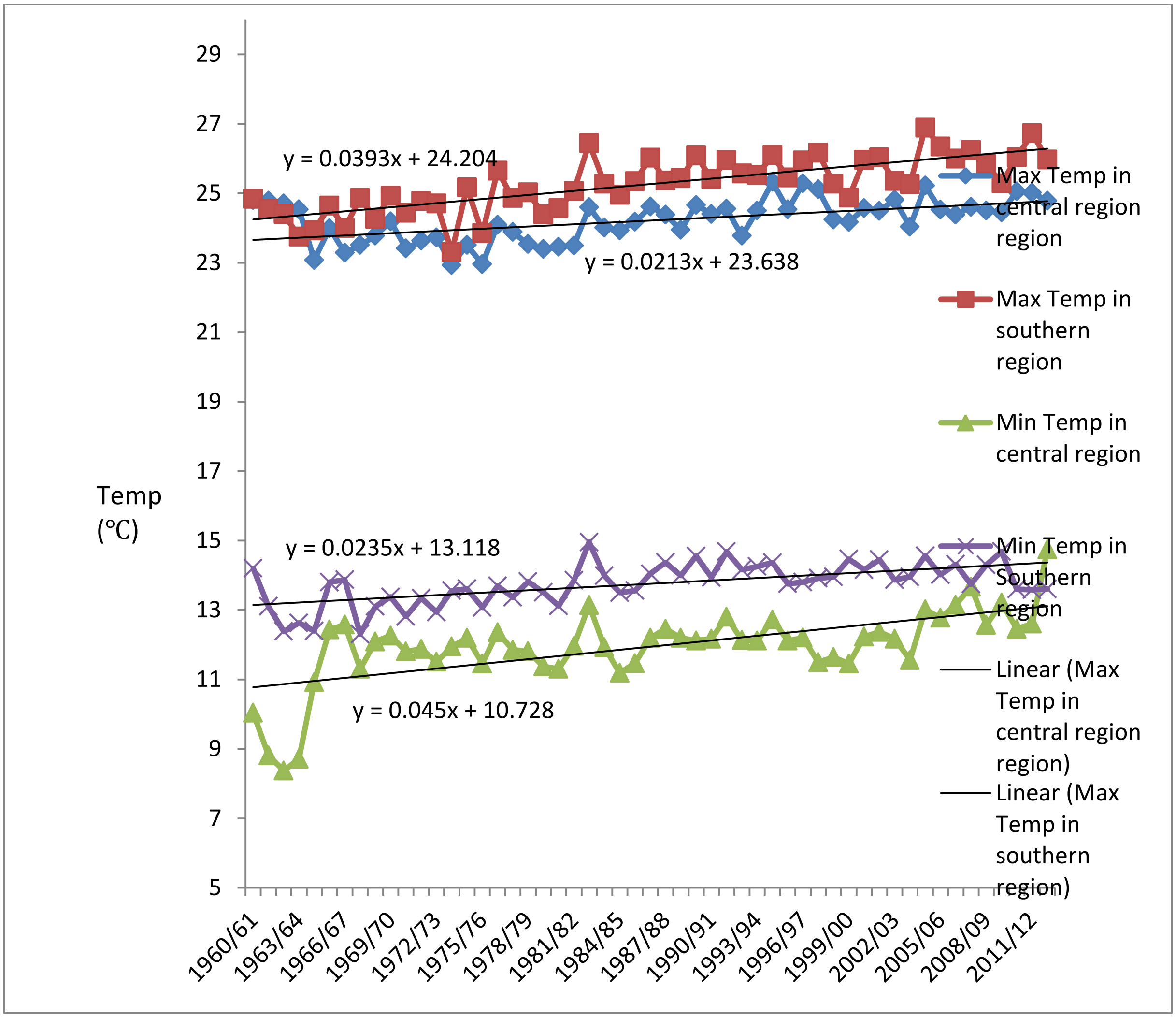

Figure 11: The trends for minimum and maximum temperatures for Southern and Central Region of Malawi.

The Figure 11 above shows that the minimum and maximum temperatures over the Central and Southern Regions of Malawi are increasing gradually over time during Winter Seasons.

From the Table 2 below, the trend of minimum and maximum temperatures in the Central and Southern Regions of Malawi is increasing over time during winter season.

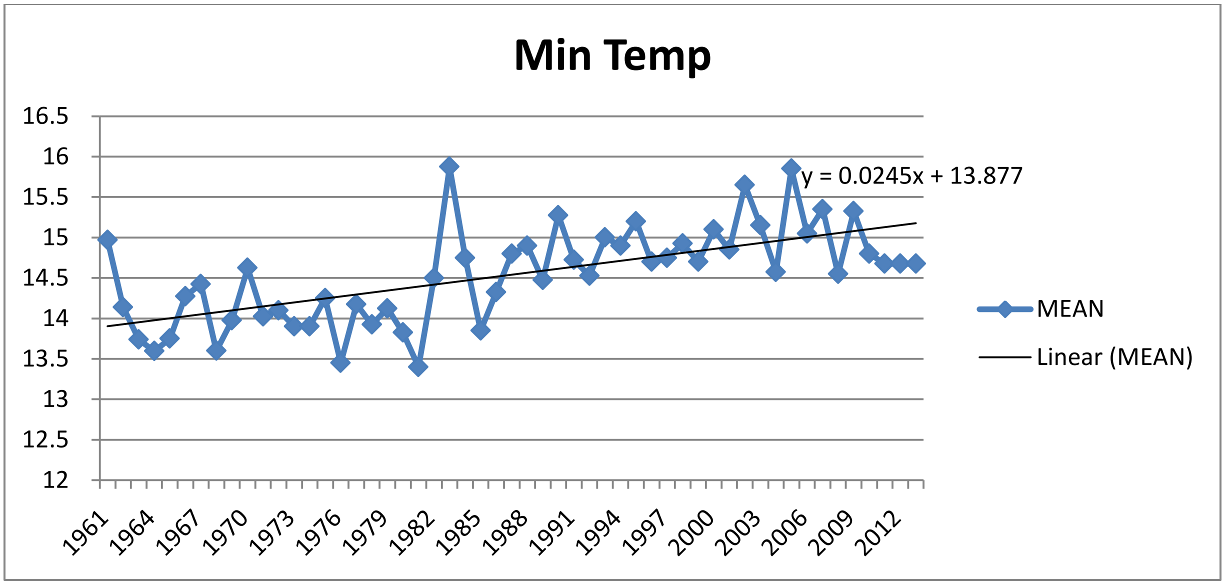

Figure 12: The trend for Chileka minimum temperature.

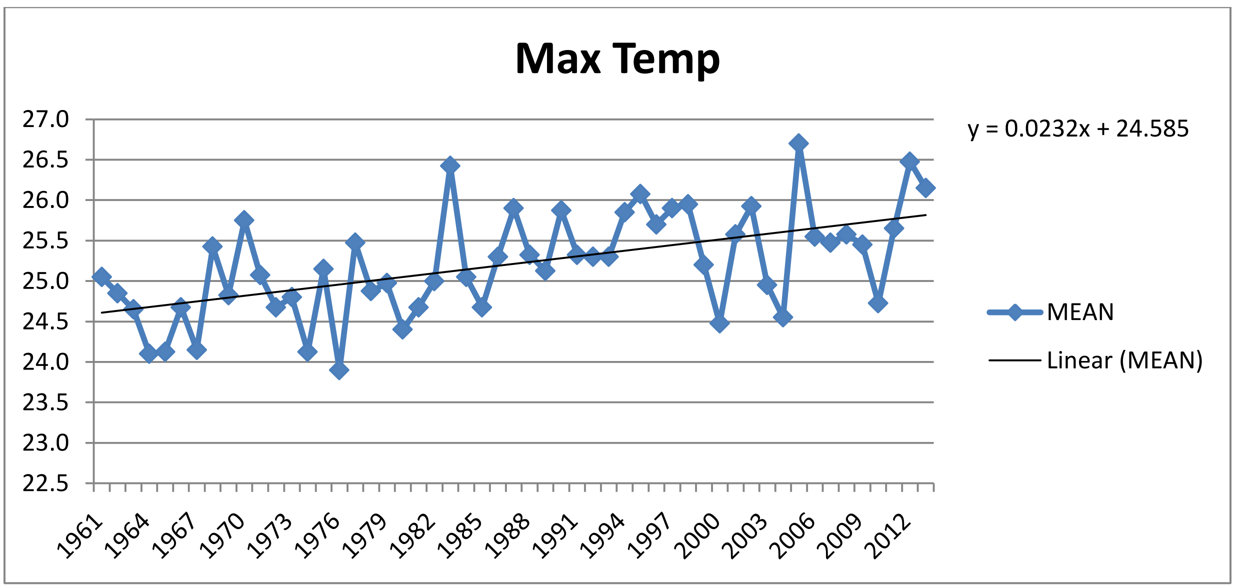

Figure 13: The trend for Chileka maximum temperature.

From the Table 2 below, the trend of minimum and maximum temperatures for Chileka is increasing over time during winter season.

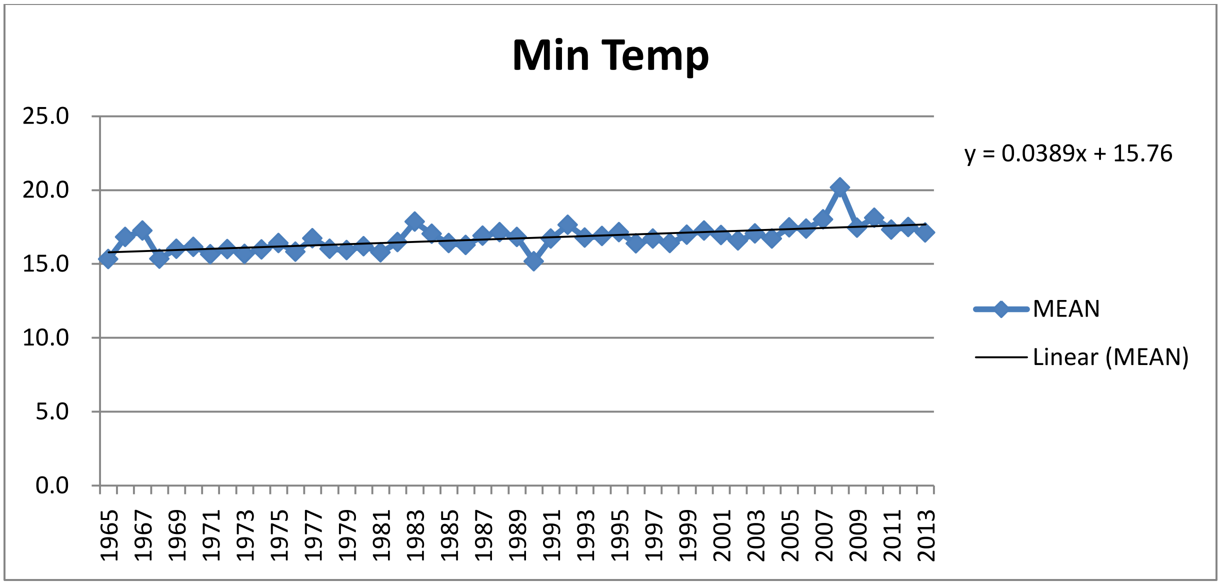

Figure 14: The trend for Nkhotakota minimum temperature.

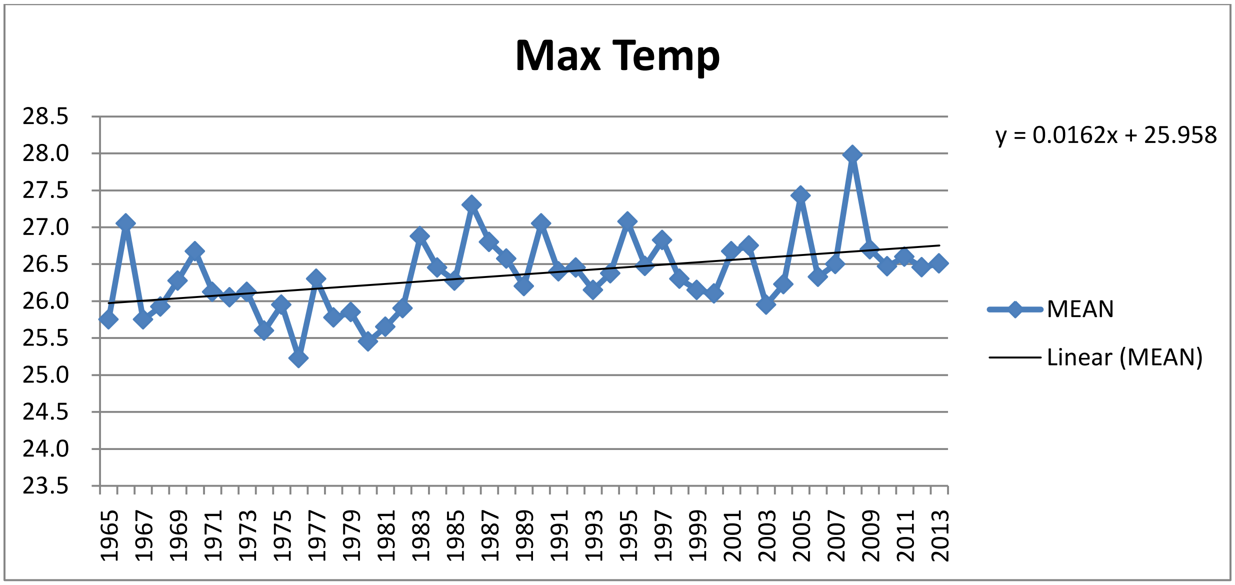

Figure 15: The trend for Nkhotakota maximum temperature.

From the Table 2 below, the trend of minimum and maximum temperatures for Nkhotakota is increasing over time during winter season.

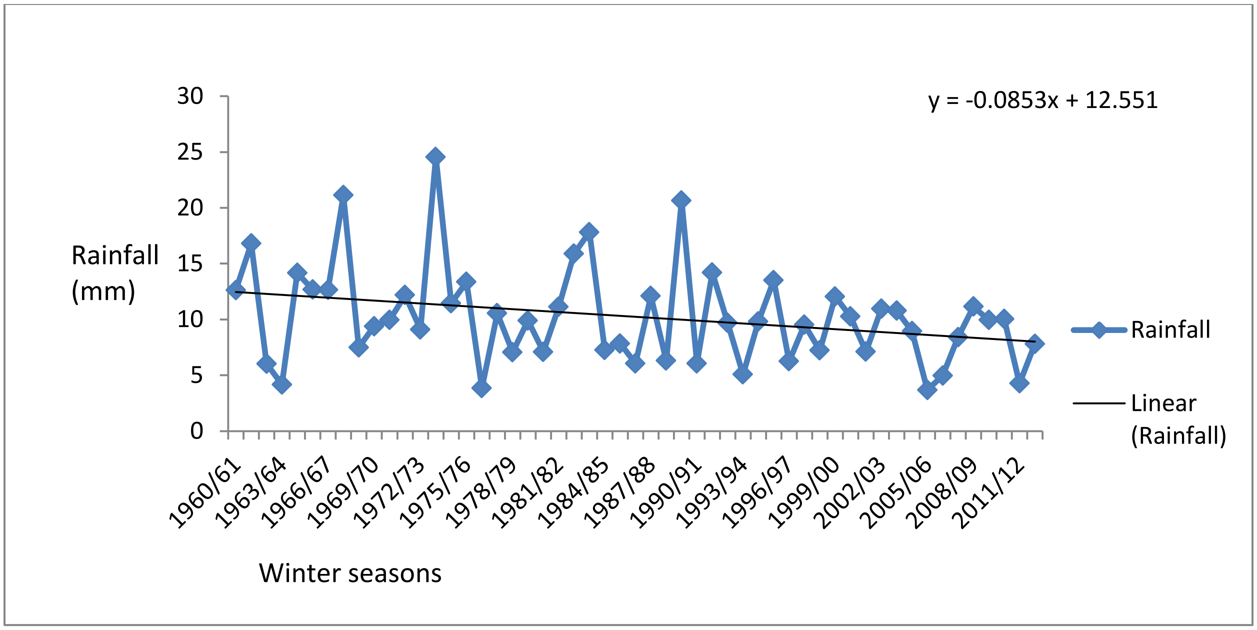

Figure 16: The trend of the general rainfall over the Central and Southern Regions of Malawi.

The above figure shows that the general rainfall trend over the Central and Southern Regions of Malawi during winter is not significant over time.

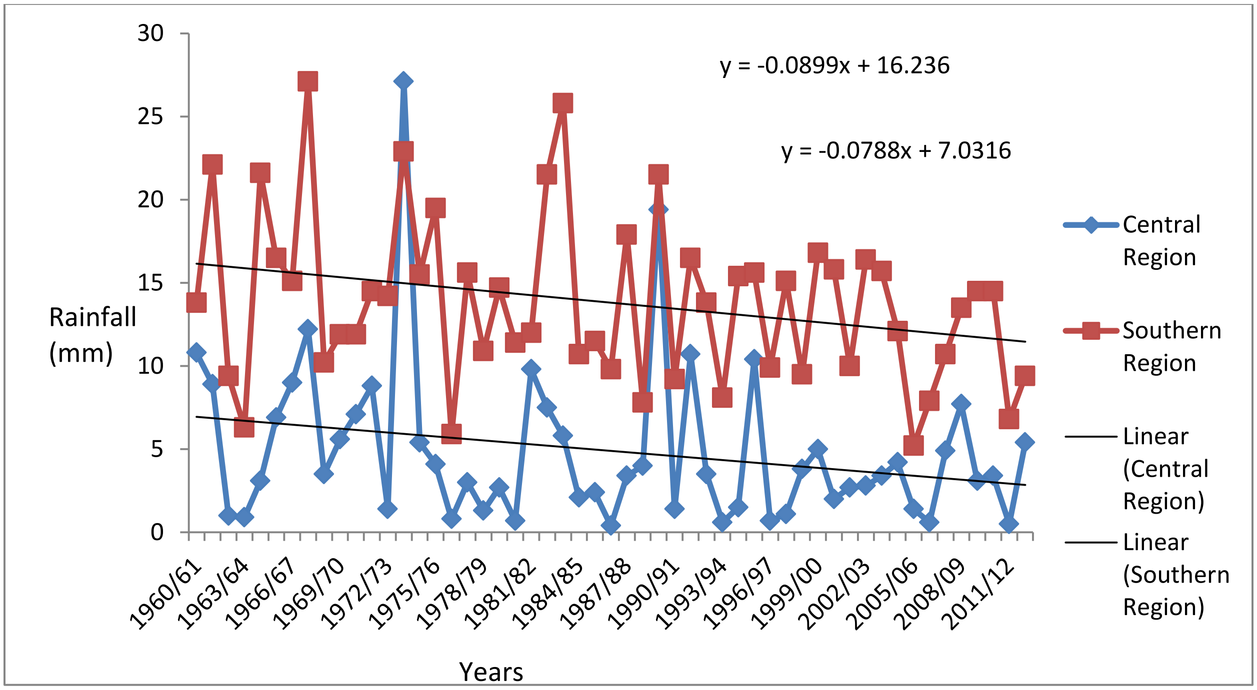

Figure 17: The temporal characteristics of rainfall over Central and Southern Regions of Malawi.

The above figure shows that with time, the trend of winter rainfall in all regions is not significant.

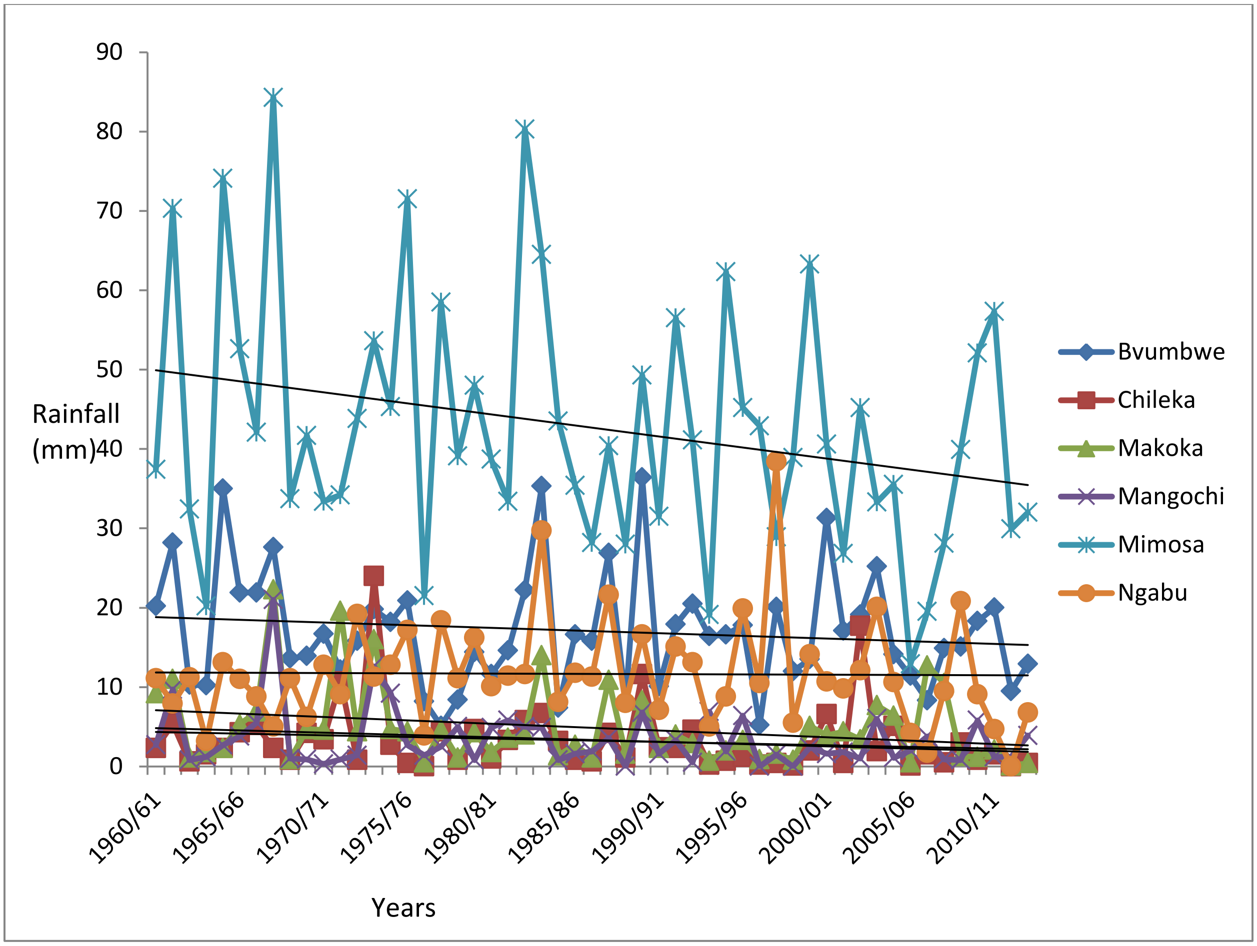

Figure 18: Rainfall trend for the stations in the Southern Region

The figure above is showing that with time, the winter rainfall trend is decreasing in all stations in the Southern Region of Malawi.

From Table 2 below, the trend for winter rainfall at Makoka and Mangochi is not significant while at Bvumbwe, Mimosa and Ngabu is decreasing and Chileka is increasing in the Southern Region of Malawi.

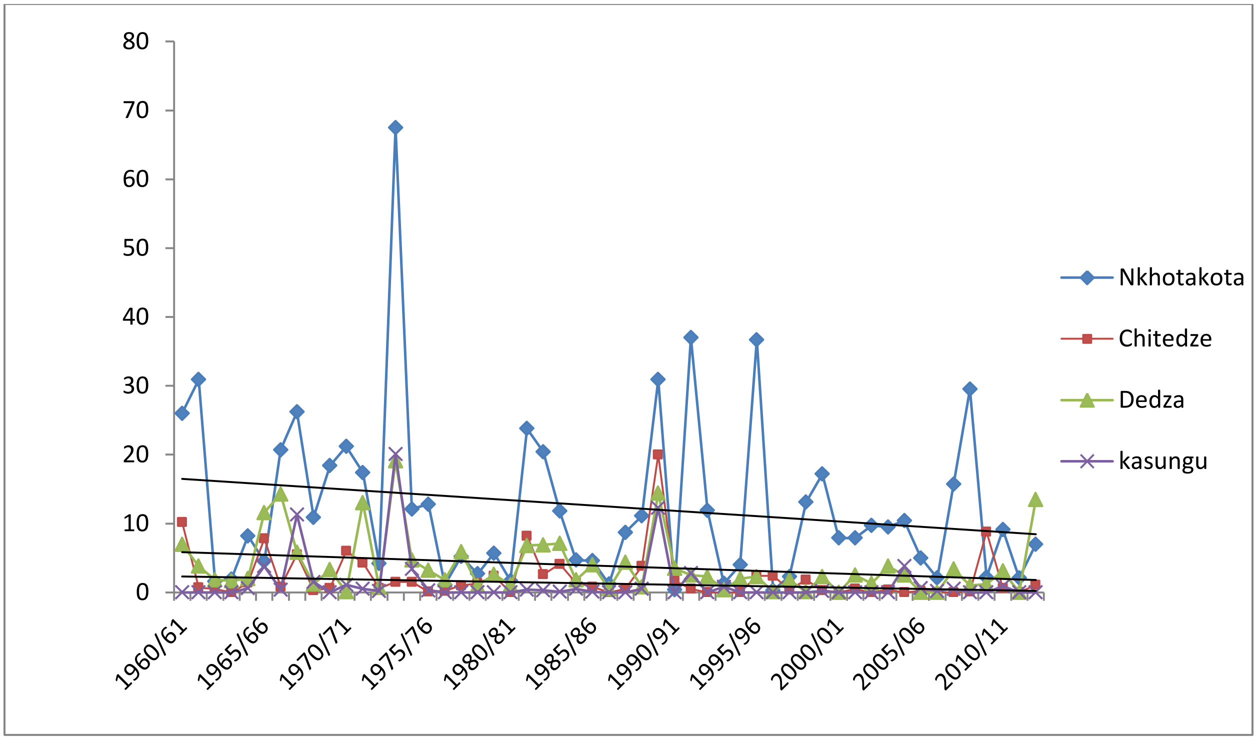

Figure 19: Rainfall trend for the stations in the Central Region

The figure above is showing that with time, the winter rainfall trend is decreasing in all stations in the Central Region of Malawi.

From Table 2 below, the trend for winter rainfall in all stations in the Central Region shows that it is not significant.

Table 2: t-test results.

Station	**Weather Element**	**Mean1**	**Mean2**	**t -stat**	**T Critical one-tail**	**T Critical two-tail**	**Results**
Central Region	Min Temp	11.50	12.47	-3.90	1.71	2.06	Increasing
	Max Temp	23.82	24.59	-5.967	1.56	2.06	Increasing
	Rainfall	5.44	4.14	0.95	1.71	2.06	Not significant
Chitedze	Min Temp	9.30	10.98	-4.37	1.71	2.06	Increasing
	Max Temp	24.80	24.95	-1.25	1.71	2.06	Increasing
	Rainfall	1.40	1.35	0.37	1.71	2.06	Not significant
Dedza	Min Temp	10.19	10.15	0.16	1.71	2.07	Not significant
	Max Temp	20.06	20.92	-4.40	1.71	2.07	Increasing
	Rainfall	3.23	3.10	0.69	1.71	2.06	Not significant
Kasungu	Min Temp	11.38	11.48	-0.33	1.76	2.14	Increasing
	Max Temp	25.70	25.98	-2.00	1.76	2.14	Increasing
	Rainfall	0.79	0.87	-0.55	1.71	2.06	Not significant
Nkhotakot a	Min Temp	16.36	17.16	-4.14	1.71	2.07	Increasing
	Max Temp	26.17	26.58	-3.33	1.71	2.07	Increasing
	Rainfall	9.03	8.46	0.82	1.71	2.06	Not significant
Southern Region	Min Temp	13.37	14.12	-5.63	3.69	2.06	Increasing
	Max Temp	24.74	25.81	-7.19	7.68	2.06	Increasing
	Rainfall	14.94	12.68	1.62	1.71	2.06	Not significant
Chileka	Min Temp	14.13	14.94	-6.31	1.71	2.06	Increasing
	Max Temp	24.89	25.54	-4.62	1.71	2.0	Increasing
	Rainfall	2.50	3.21	-2.72	1.71	2.06	Increasing
Ngabu	Min Temp	16.61	16.49	0.44	1.72	2.09	Not significant
	Max Temp	29.27	29.54	-1.26	1.72	2.09	Not significant
	Rainfall	10.44	8.90	2.20	1.71	2.06	Decreasing

Mimosa	Min Temp	11.86	12.81	-6.38	1.71	2.06	Increasing
	Max Temp	24.80	26.02	-5.96	1.71	2.06	Increasing
	Rainfall	41.29	37.36	2.79	1.71	2.06	Decreasing
Bvumbwe	Min Temp	11.73	12.13	-2.19	1.71	2.06	Increasing
	Max Temp	20.86	21.73	-4.37	1.71	2.06	Increasing
	Rainfall	16.94	14.87	2.89	1.71	2.06	Decreasing
Mangochi	Min Temp	15.06	15.67	-3.38	1.71	2.06	Increasing
	Max Temp	27.20	28.18	-6.57	1.71	2.06	Increasing
	Rainfall	3.45	3.12	0.99	1.71	2.06	Not significant
Makoka	Min Temp	12.30	12.42	-0.58	1.72	2.08	Not significant
	Max Temp	23.05	23.94	-2.70	1.72	2.08	Increasing
	Rainfall	4.64	4.31	1.07	1.71	2.06	Not significant
All Stations	Min Temp	12.81	13.46	-6.52	1.71	2.06	Increasing
	Max Temp	24.57	25.32	-6.29	1.71	2.06	Increasing
	Rainfall	11.12	9.26	1.52	1.71	2.06	Not significant

4.2.2 Spatial Distribution of Maximum Temperature

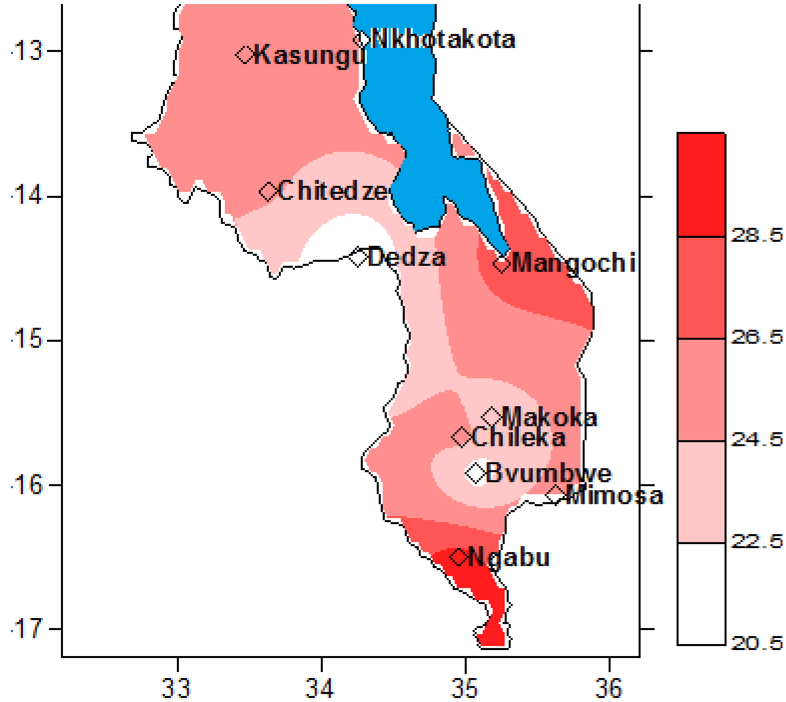

Figure 20: Spatial distribution of maximum temperatures over Central and Southern Regions of Malawi.

Figure 20 above shows that Ngabu has the highest maximum temperature while Bvumbwe and Dedza have the lowest maximum temperatures during Winter Seasons.

The cause of variability in maximum temperatures is elevation. Ngabu is located on the low altitude: this is the reason why it has a highest maximum temperature. On the other hand, Bvumbwe and Dedza have the lowest maximum temperatures because they are located on the high altitudes.

4.2.3 Spatial Distribution of Minimum Temperature

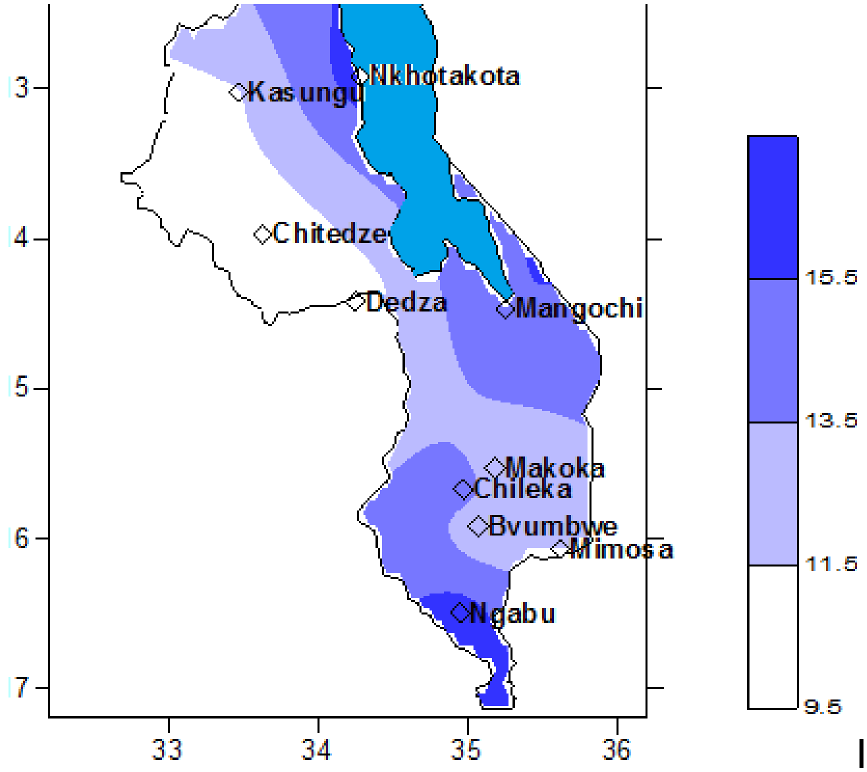

Figure21: Spatial distribution of minimum temperature over the Central and Southern Regions of Malawi.

Figure 21 above shows that Dedza, Chitedze and Mimosa have the lowest minimum temperature while Ngabu and Nkhotakota have the highest minimum temperatures during Winter Seasons.

Some of the causes of variability in minimum temperatures is elevation. Like Ngabu and Nkhotakota are located on low altitudes while Dedza, Chitedze and Mimosa are located on high altitudes.

4.2.4 Spatial Distribution of Rainfall

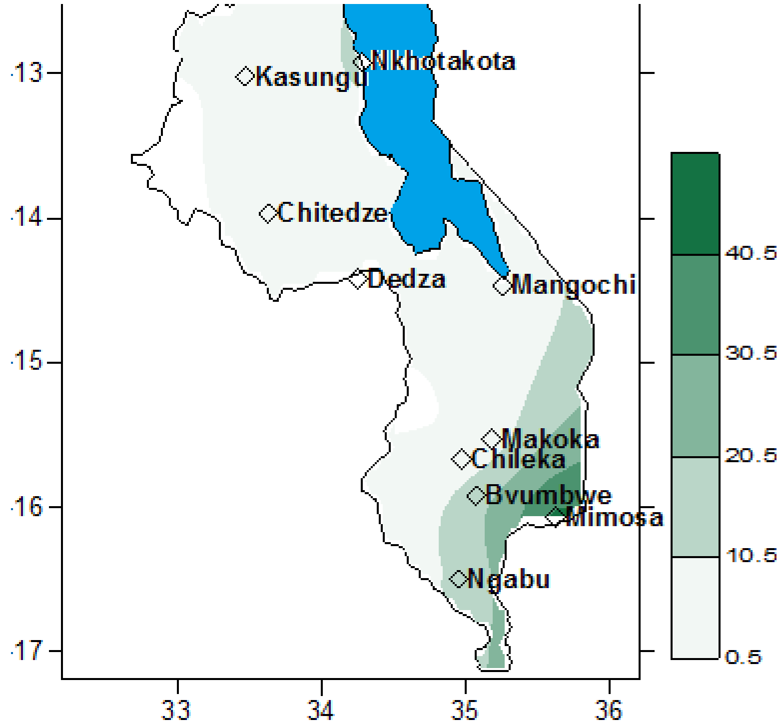

Figure22: Spatial distribution of rainfall over the Central and Southern Regions of Malawi.

Figure 22 above shows that Mimosa has the highest amount of winter rainfall while Dedza has the lowest amount of rainfall during Winter Seasons.

There is variability in rainfall during Winter Season; this is so because of topography and elevation. Like Mimosa lies within the highest point of Shire Highlands which is highly affected by South-Easterly winds locally known as Chiperoni winds which are usually moist from Indian Ocean while Dedza lies on the lee ward side of Dedza Mountain and Kirk Range Mountain, that is why it has the lowest amount of winter rainfall.

The determination of whether these are climate change signals

From the findings, it shows that temperatures during winter seasons are increasing and winter rainfall is decreasing. From climatology point of view these are climate change signals.

CHAPTER FIVE

5.1 SUMMARY, CONCLUSION AND RECOMMENDATION

The conclusion of results of the study and recommendations about the features studied are included in this chapter.

5.1.1 Summary of the Results

The results of the study show that both parameters, temperature and rainfall recordings were homogeneous and were used in the study.

The trends minimum and maximum temperatures over the Central and Southern Regions of Malawi are increasing with time and space during winter season. Dedza, Mimosa and Chitedze had lowest minimum temperatures while Ngabu and Nkhotakota had highest minimum temperatures. In terms of maximum temperatures, Ngabu had the highest maximum temperatures while Dedza and Bvumbwe had the lowest maximum temperatures.

Some of the causes of variability in minimum temperatures are topography and elevation. Like Ngabu and Nkhotakota are located on low altitudes while Dedza, Chitedze and Mimosa are located on high altitudes this is so because the higher you go, the cooler it becomes.

In terms of space, Dedza, Chitedze and Mimosa have the lowest minimum temperature while Ngabu and Nkhotakota have the highest minimum temperatures during Winter Seasons.

The cause of variability in maximum temperatures is elevation. Ngabu is located on the low altitude; this is the reason why it has a high maximum temperature. On the other hand, Bvumbwe and Dedza have the lowest maximum temperatures because they are located on the high altitudes.

The general rainfall trend over the Central and Southern Regions of Malawi during winter is not significant over time.

The trend of winter rainfall in some stations in the Southern Region of Malawi shows that they are decreasing, like Bvumbwe, Mimosa and Ngabu while other in the same region show that there is no significant change.

The trend of winter rainfall in all stations in the Central Region of Malawi shows that there is no significant change.

In terms of space, Mimosa has the highest amount of rainfall while Dedza have the lowest amount of rainfall during Winter Seasons. Dedza lies on the lee ward side of the Kirk Range Mountain and Dedza Mountain that is why it has the lowest amount of winter rainfall.

There is variability in rainfall during Winter Seasons; this is so because of topography and elevation. Like Mimosa station lies within the highest point of Shire Highlands which is highly affected by Chiperoni Winds (Mwera) which are usually moist from Indian Ocean.

The determination of whether these are climate change signals was done by referring to other write up on climate change.

From the above writing, it shows that an increase in temperature and a decrease in winter rainfall these are the climate change signals.

5.1.2Conclusion of the Results

From the above findings, it shows that minimum and maximum temperatures are increasing during winter and winter rainfall in some stations in the Southern Region of Malawi are decreasing and others show no significant change, while all stations in Central Region of Malawi show no significant change.

5.1.3 Recommendations

In this study, an attempt was made to see if temperatures and rainfall are increasing or decreasing in the past fifty two years. It is seen that temperatures during winter seasons are increasing gradually in Southern Region and also in Central Region. Further studies should be carried out and focus on these increase in temperatures.

It is seen that in some stations in the Southern Region, winter rainfall are decreasing while other stations show no significant change. Further studies should be carried out and focus on the decrease in winter rainfall.

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