UNIVERSITY OF NAIROBI

DEPARTMENT OF METEOROLOGY

CLIMATE CHANGE SIGNALS BASED ON RAINFALL AND TEMPERATURE TRENDS IN MALAWI

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2014

DECLARATION

This project is my original work and has not been presented for the award of a degree in any other university.

Signature____________________

Date 12 - 08 - 2014

The project work has been submitted with our approval as university supervisors:

1. Dr.J.N.Mutemi

   Signature____________________

   Date 12 - 08 - 2014

2. Dr.R.E.Okoola

   Signature____________________

   Date 12/08/2014

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Thirdly, my profound appreciations should go to my supervisors Dr.J.N.Mutemi and Dr.R.E.Okoola whose hard work, guidance and positive contribution made this work a success.

I also would like to thank my employer, the Department of Climate and Meteorological Services of Malawi, for offering me material and financial support that enabled me to undertake the study.

Finally, to my family, friends and colleagues for the encouragement and support throughout the course.

DEDICATION

I dedicate this work to my grandmother Anaphiri who has always shown love to me, and to my sister Chimwemwe who has always been there in worst and in good moments.

ABSTRACT

The purpose of the study was to determine climate change signals using rainfall and temperature records. This was achieved by performing time series and trend analysis. Time series analysis was done using MATLAB software while trend analysis was done using student's t-test. The student's t-test was used to establish if there are significant changes in the rainfall and temperature trends in order to explain climate change scenario over Malawi. Spatial variability was achieved by creating maps using SURFER software.

The data was obtained from Department of Climate Change and Meteorological Services (DCCMS) of Malawi. Daily rainfall datasets and monthly datasets of maximum and mean minimum temperatures were obtained.

Arithmetic mean method was used to estimate missing values. Outlier values were detected by physical checking and by plotting time series graphs.

The results depicted a tendency towards decrease in seasonal and annual rainfall over most of the stations in the country. The decrease was not very significant. However, some eight stations showed an increasing trend in seasonal rainfall that was not significant. Five other stations showed an increasing trend in annual rainfall that was also not significant.

On the other hand, in the analysis of temperature most stations depicted a tendency towards increase in maximum and minimum temperatures during winter and summer. The increasing trend was significant for most of the stations except for few stations such as Karonga, Dedza, Ngabu and Nkhatabay that showed a decreasing trend in minimum temperatures during winter and summer.

Therefore, the results indicate that rainfall is decreasing over many locations while temperatures are becoming relatively warmer than they used to be. This observation suggests possible indications of a changing climate.

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LIST OF ACRONYMS

DCCMS	Department Of Climate Change and Meteorological Services
ENSO	El-Niño Southern Oscillation
GDP	Gross Domestic Product
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-tropical Convergence Zone
MJJ	May, June, July
NSO	National Statistical Office
SON	September, October, November
Tmn	Minimum temperature
Tmx	Maximum temperature

CHAPTER 1: INTRODUCTION

1.0 Background

Malawi's economy is dependent on rain-fed agricultural production, which is dominated by smallholder farming. Agriculture contributes 35 percent of Malawi's GDP, 80 percent of the country's export earnings and supports livelihoods for over 80 percent of the population. (Zulu et al, 2012).

The dependency of Malawi's economy on rain-fed agricultural production places Malawi in a particularly vulnerable position in the event of climatic extremes. In addition, the rapidly growing population puts enormous pressure on the natural resources such as forests, water and land. (Zulu *et al*, 2012).

The main climate change and environmental challenges facing Malawi include water scarcity, unpredictable weather patterns, including rainfall, flooding, droughts, short rainy seasons and prolonged dry spells during rainy season, drying up of rivers and lakes, low fish supplies, heat waves, landslides, frequent bush fires, increased prevalence of water-borne diseases, low and unstable hydro-electric production, declining flora and fauna, and declining natural species. (Zulu *et al*, 2012). These challenges affect different sectors and hence the socio-economic development of the country.

The challenges brought about by climate change need to be addressed to help people in adaptation and mitigation measures in order to be able to achieve some of the millennium development goals. The authorities and relevant stakeholders need to take holistic approach in combating the challenges. However, to be able to do this climate change knowledge need to be made available.

Therefore, this study has focused on examining trends of rainfall and temperature records to determine climate change signals by employing statistical analysis in order to establish if there are significant changes in the patterns of rainfall and temperature.

1.2 Statement of the problem

As noted by the Intergovernmental Panel on Climate Change (IPCC), global mean temperatures are increasing and sea-levels are rising. Rain is becoming erratic and decreasing in amounts. Frequent droughts and floods are also evidenced in many parts of the world. There are issues of shifts of onset and cessation of rainfall and poor distribution of seasonal rainfall.

African continent and Malawi in particular is no exceptional. For example, over the past decades, Malawi has also suffered from droughts and floods. Recent findings show significant changes in temperature and rainfall. For instance, McSweeney (2010) found out that in Malawi, mean annual temperature has increased by 0.9°C between 1960 and 2006. This increase in temperature has been most rapid in summer and slowest during September, October, and November.

Malawi is more vulnerable to the effects of climate change due to its limited adaptive capacity. The problem of overpopulation also puts pressure on its natural and economic resources. In order to minimize the risk of vulnerabilities due climate change, authorities and stakeholders need to scientific knowledge regarding the status of climate in Malawi. This will help them make informed decisions.

Therefore, the study focused on examining rainfall and temperature patterns to establish if the trends are significant to explain climate change over Malawi.

1.3 Objectives of the study

The main objective was to determine the extent of climate change using rainfall and temperature records over Malawi. To achieve the main objective, the following specific objectives were undertaken:

a) Determine spatial and temporal characteristics of rainfall and temperature over Malawi

b) Determine variability of rainfall and temperature over Malawi

c) Determine if there are climate change signals using rainfall and temperature

1.4 Justification

Malawi's economy is dependent on rain-fed agricultural production, which is dominated by smallholder farming. Agriculture contributes 35 percent of Malawi's GDP, 80 percent of the country's export earnings and supports livelihoods for over 80 percent of the population. (Zulu et al, 2012).

The dependency of Malawi's economy on rain-fed agricultural production places Malawi in a particularly vulnerable position in the event of climatic extremes. In addition, the rapidly growing population puts enormous pressure on the natural resources such as forests, water and land.

Malawi has limited adaptive capacity to climate change. It is therefore imperative to add knowledge that can help to inform decisions on policy, and adaptation and mitigation strategies. Availability of climate change knowledge will help to explore the risks and opportunities that can be realized from climatic extremes.

1.5 Area of the study

1.5.1 Geographical features

Malawi is a small landlocked country located in eastern southern Africa, stretching across longitudes 32◦E and 36◦E and latitudes 9◦S and 18◦S. The country's topography is highly varied. The Great Rift Valley runs North to South through the country, containing Lake Malawi. The land covers about 94,080km^2 while water covers about 24,400 km^2.

1.5.2 Climate

Malawi has a sub-tropical climate, which is relatively dry and strongly seasonal. The warm-wet season stretches from November to April, during which 95% of the annual precipitation takes place (DCCMS, 2014). This is the main rainfall season which is generally associated with the movement of the Inter-tropical Convergence Zone (ITCZ), Congo air mass and occasional tropical cyclones. A cool, dry winter season is evident from May to August with mean temperatures varying between 17 and 27 degrees Celsius. A hot, dry season lasts from

September to October with average temperatures varying between 25 and 37 degrees Celsius. Temperatures are usually high during this time.

Rainfall during the wet season depends on the position of the ITCZ which can vary in its timing and intensity from year to year. In the south of Malawi the wet season normally lasts from November to February but rain continues into March and April in the north of the country as the ITCZ migrates northwards.

Also McSweeney (2012) noted that the inter-annual variability in the wet-season rainfall in Malawi is strongly influenced by Indian Ocean Sea Surface Temperatures due to ENSO, which can vary from one year to another due to variations in patterns of atmospheric and oceanic circulation. Since Malawi is located between two regions of ENSO episodes, it is often not easy to predict the influences of ENSO on the climate of Malawi. The influence of ENSO events has a significant influence on the climate of Malawi.

On a local scale, topographical influences also cause local variations to the rainfall with the highest altitude regions receiving the highest rainfalls. The lake also influences rainfall in areas along the lakeshore.

Figure 1 below is map of Malawi showing some of the meteorological stations that were used in this study.

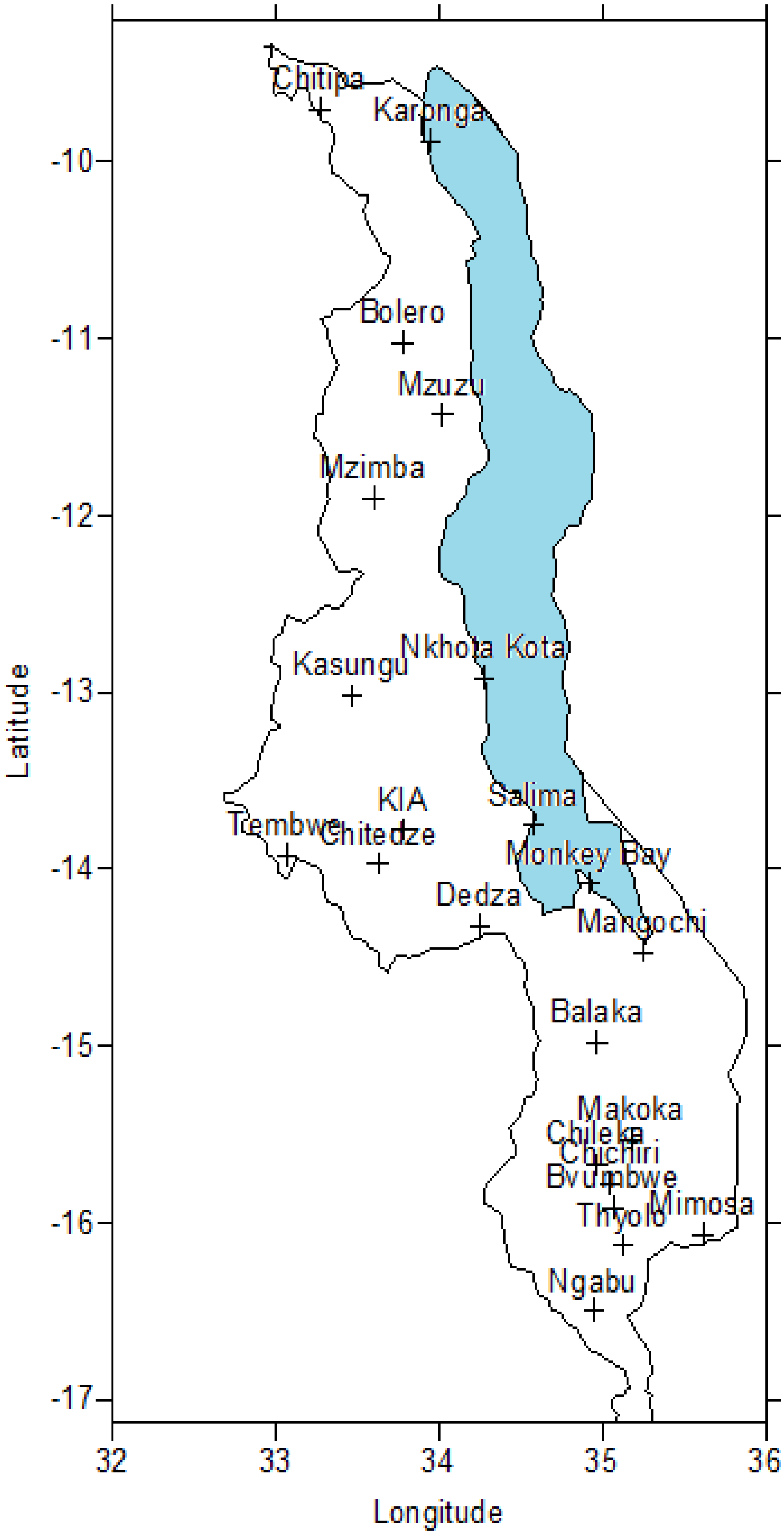

Figure 1: The domain of study, Malawi and meteorological stations with good records used in the study.

CHAPTER 2: LITERATURE REVIEW

Climate change refers to a permanent alteration to the observed climate characteristics. The changes can be due to natural factors or anthropogenic factors. In other words, climate change refers to the deviation from the mean climate that is statistically significant. On the other hand, Climate variability refers to the temporary fluctuations in climate conditions. (Opijah,2005).

Climate change and climate variability have significant impacts on many sectors of the society such as on health, agriculture, water resources and energy. Weather and climate extremes are associated with loss of life, destruction of property and many other socio-economic activities miseries around the world (Ogallo, 2008). Developing countries are more vulnerable to the effects of climate change than developed countries because of their low adaptive capacity. Africa's human existence and development is therefore under threat from the adverse impacts of climate change because most African nations are poor hence limited adaptive capacity to climate extremes. Malawi is also vulnerable to the impacts of climate change because of its limited adaptive capacity.

On a global scale, climate extremes have been observed to increase in frequency. This has been reported by the IPCC. It is very likely that over the past 50 years, cold days, cold nights and frosts have become less frequent over most land areas, and hot days and hot nights have become more frequent. It is likely that heat waves have become more frequent over most land areas, the frequency of heavy precipitation events has increased over most areas, and since 1975 the incidence of extreme high sea level has increased worldwide (IPCC, 2007). The IPCC projects that on the African continent, average temperatures will increase by 1.5 to 3°C by the year 2050.

World over, climate extremes such as frequent droughts and floods are not uncommon. There are issues of shifts of onset and cessation of rainfall and poor distribution of seasonal rainfall. There is no doubt that globally, climate is changing as supported by many research findings such as those by IPCC.

The changing climate has been attributed to natural and anthropogenic causes. Natural causes are a result of the changes in the climate system (i.e. changes in the land surface processes, atmospheric processes, cryospheric processes and oceanic processes). Alteration in the structure of the earth's surface may lead to changes in the observed climate or weather characteristics. For instance, forest fires due to lightning can inject gaseous pollutants and particulates into the atmosphere, such as carbon dioxide and smoke. The ejection may change the atmospheric composition, thereby affecting the amount of radiation received on the surface. Forest fires may also cause deforestation, which may alter the earth‘s reflectivity (Opijah, 2005). On the other hand, anthropogenic processes include such activities like land-use practices, nuclear activities, atmospheric pollution leading to changes in ozone concentration and the release of greenhouse gases into the atmosphere (Opijah, 2005). As reported by the IPCC (2012), there is evidence that some climate extremes have changed as a result of anthropogenic influences, including increases in atmospheric concentrations of greenhouse gases.

While it is undeniable fact that climate is changing, there is a need to provide information to support this fact. Thus studies should be carried out to provide evidence of significant changes in climate variables to answer the question of whether the climate, in general, has become more or less extreme (IPCC, 2012). However the challenge lies in that, the terms ‘more extreme’ and ‘less extreme’ can be defined in different ways, resulting in different characterizations of observed changes in extremes.

IPCC (2012) observes that many weather and climate extremes result from natural climate variability (including phenomena such as El Niño). Even if there were no anthropogenic changes in climate, a wide variety of natural weather and climate extremes would still occur due to changes in the natural climate system. Therefore, there is need to provide objective evidence rather than use subjective conclusion that climate is changing. This study has used the former by using scientific analysis of the characteristic behavior of rainfall and temperature to come up with conclusions on the climate situation over Malawi.

CHAPTER 3: DATA AND METHODOLOGY

3.1 Data

The data used in this study was obtained from Department Of Climate Change and Meteorological Services (DCCMS) in Malawi. Two types of data were obtained namely rainfall (1961-2012) and temperature (1956-2013). Daily rainfall data was obtained for 23 stations while that for temperature (mean monthly maximum and minimum) was obtained for 16 stations. The list of stations used is displayed in Table 1 below;

Table 1: Meteorological stations with their coordinates and altitudes

Station Name	Longitude (deg)	Latitude (deg)	ltitude (m
Balaka	34.97	-14.98	625
Bolero	33.78	-11.02	1100
Bvumbwe	35.07	-15.92	1146
Chichiri	35.05	-15.78	1132
Chileka	34.97	-15.67	767
Chitedze	33.63	-13.97	1149
Chitipa	33.27	-9.7	1285
Dedza	34.25	-14.32	1632
Karonga	33.95	-9.88	529
Kasungu	33.47	-13.02	1058
KIA	33.78	-13.78	1229
Makoka	35.18	-15.53	1029
Mangochi	35.25	-14.47	482
Mimosa	35.62	-16.07	652
Monkey Bay	34.92	-14.08	482
Mzimba	33.6	-11.9	1349
Mzuzu	34.02	-11.43	1254
Ngabu	34.95	-16.5	102
Nkhata Bay	34.3	-11.6	500
Nkhota Kota	34.28	-12.92	500
Salima	34.58	-13.75	512
Tembwe	33.07	-13.92	1097
Thyolo	35.13	-16.13	820

3.2 Data quality control

3.2.1 Estimation of missing data

Missing values of temperature were estimated by replacing them with the mean value for the given month at a particular station. The formula used is as below.

$$A = \frac{1}{n} * \sum_{i=1}^{n} x_i$$ **……………..……………………………………Equation 1**

A = average temperature in a month

n = the number of days in month

x_i = daily values of recorded temperature at a station

On the other hand, missing values of rainfall were filled by using the climatological (long term) mean for a particular day of the month.

Outliers were detected by physical checking and by plotting time series graphs.

3.2.2 Testing for homogeneity

Single mass curves were used to test homogeneity of data. Cumulative rainfall totals and cumulative mean temperatures were plotted against time.

3.3.0 Methods of data analysis

3.3.1 Times series

Time series was done using MATLAB to produce graphs of a parameter against time.

In plotting graphs for inter-annual variability of rainfall, monthly rainfall totals were calculated to come up with the annual rainfall totals. The annual rainfall totals were then plotted against time (years).

In plotting graphs for inter-seasonal variability of rainfall, rainfall totals (November to April) were computed and plotted against time (years).

On the other hand, in plotting time series graphs for temperature, monthly mean values were used to compute annual mean temperature values. The annual mean temperature values were plotted against time (years).

Also, time series for the winter month was plotted. The representative month that was used was July. This month was identified by plotting a histogram of monthly mean temperature against the months.

3.3.2 Trend analysis

Trend analysis was used to determine the trends in rainfall and temperature characteristics over the study period. The Student's t-test (two sample assuming unequal variances) was used to determine if the trends observed were significant. The formula for calculating t-statistic value is as shown in Equation 2 below.

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{N_1} + \frac{s_2^2}{N_2}}}$$ ……………**Equation 2**

Where,

$\bar{X}_1$ = Mean of first set of values

$\bar{X}_2$ = 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

3.3.3 Spatial analysis

SURFER software was used to generate spatial maps for rainfall and temperature. This was done to show the distribution of rainfall and temperature over the country.

Station rainfall totals of 17 stations for the period 1961-2012 were mapped to indicate the distribution season rainfall. In doing this, seasonal rainfall totals were calculated separately for each station in order to come up with one value to represent a station in the mapping procedure.

On the other hand, long term means of mean annual temperatures (maximum and minimum) were also computed for the period 1970-2013 to represent station temperatures for the purpose of mapping.

CHAPTER 4: RESULTS AND DISCUSSION

4.0.0 RESULTS FROM DATA QUALITY CONTROL

4.0.1 Missing data

All the stations used had few data gaps which were easily filled by their Long Term Mean (LTM) which is based on the arithmetic mean method

In mapping, some stations were left out due to the need of defining a common period during which all stations had data for the sake of generating maps in SURFER. The periods used in mapping were 1961-2012 and 1970-2012 for rainfall and temperature respectively. The stations left out in the mapping of rainfall and temperature include Makoka, Chichiri, Balaka, Nkhatabay, Tembwe, Bolero, Monkeybay and Kasungu,KIA,Bolero repectively.

4.0.2 Homogeneity test

To test if the data was homogeneous, single mass curves were plotted. This procedure requires plotting cumulative records against time. A straight line graph indicates that data is homogeneous while non-homogeneity is indicated by significant deviations of some data points from the straight line.

It was observed from the single mass curves that all stations had homogeneous rainfall data. On the other hand, temperature data was also homogeneous except for Mzuzu. This station was excluded in the analysis. Results from homogeneity test are presented in figures 2 and 3, and figures 4 and 5 for analysis of rainfall and temperature respectively.

4.0.2.1 Single mass curves for Rainfall

Figures 2 and 3 below are single mass curves of some selected stations.

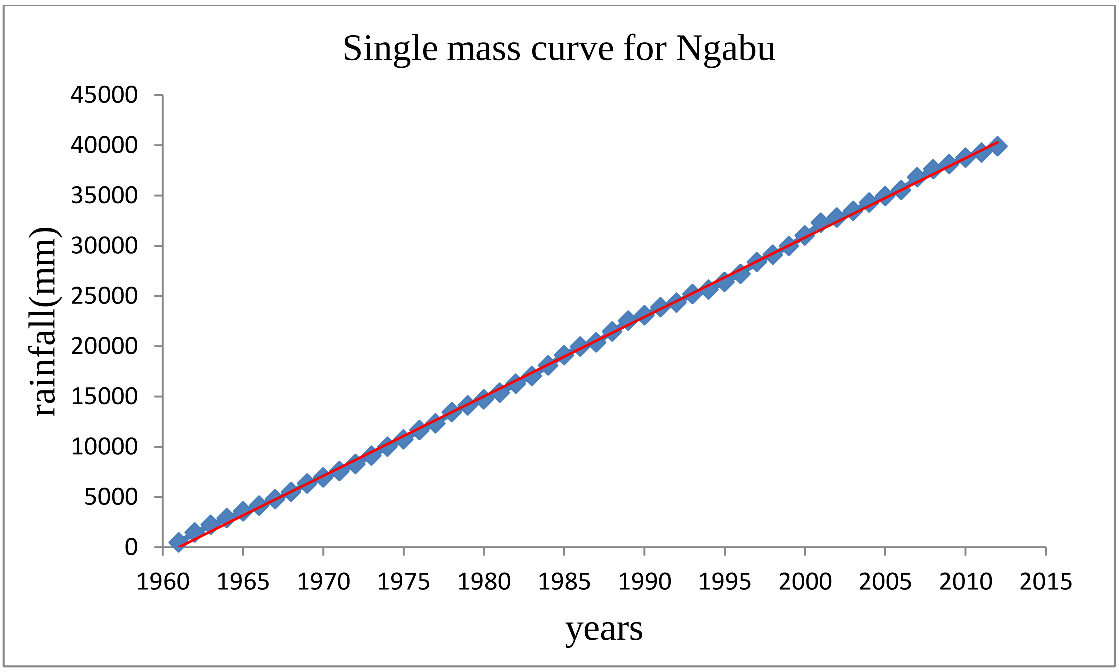

Figure 2: Single mass curve for Ngabu

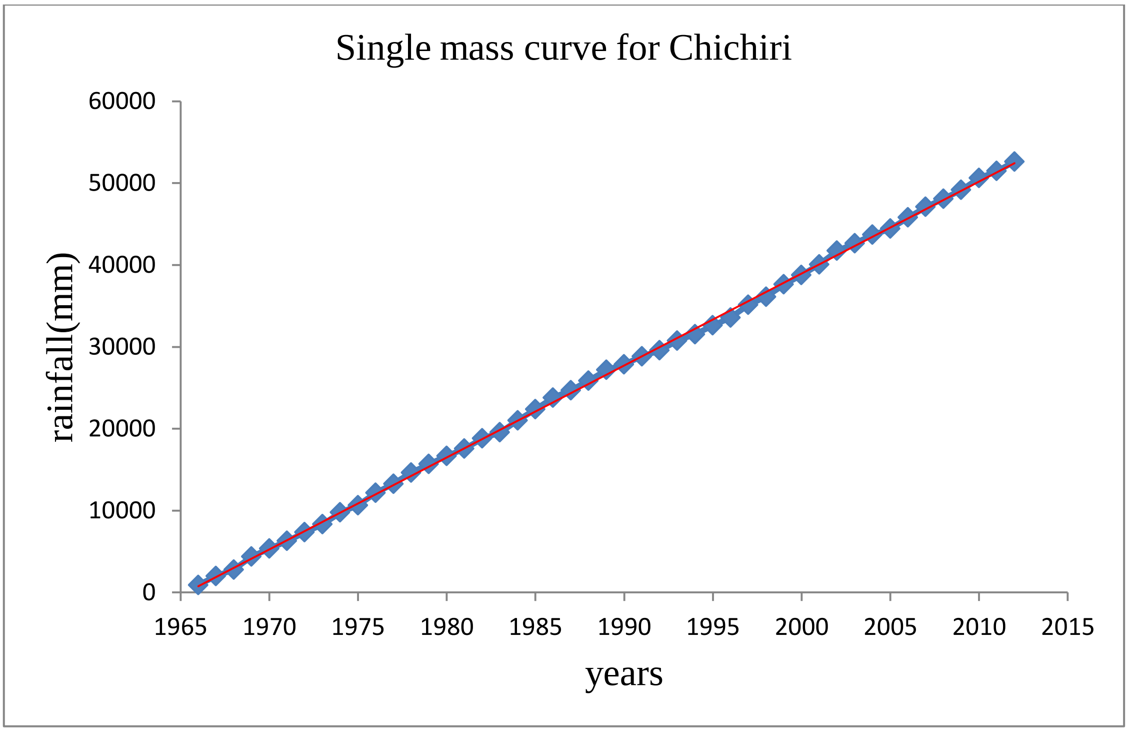

Figure 3: Single mass curve for Chichiri

4.0.2.2 Single mass curves for Maximum and Minimum Temperatures

Figures 4 and 5 below are single mass curves of some selected stations whose temperature data were homogeneous. All the stations had homogeneous temperature data. In the figures, the legends Tmn and Tmx stand for minimum temperature and maximum temperature respectively.

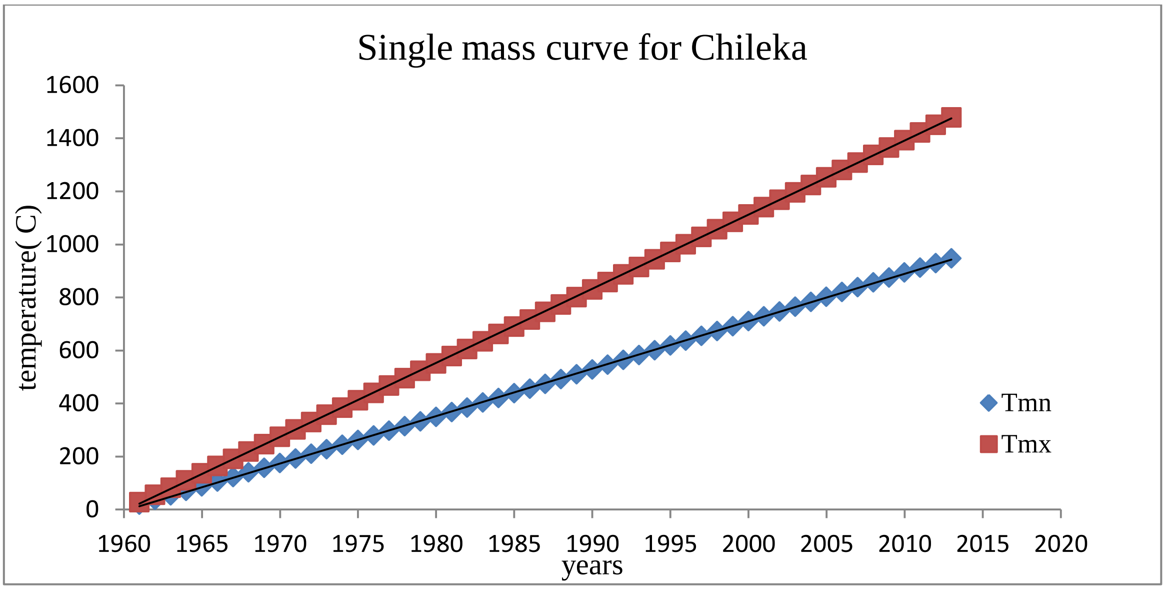

Figure 4: Single mass curve for Chileka

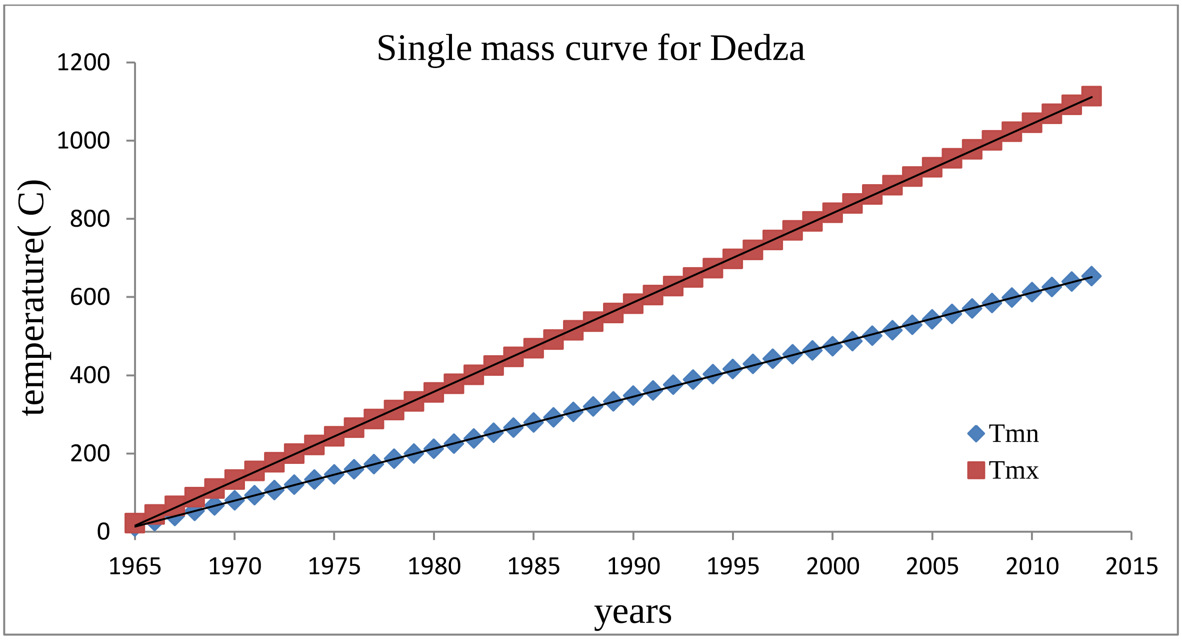

Figure 5: Single mass curve for Dedza

4.1.0 RESULTS FROM TIME SERIES ANALYSIS OF RAINFALL

4.1.1 Analysis of annual rainfall cycle

The figures below represent some stations showing annual rainfall cycle of some selected stations. It was observed that high amounts of rainfall occur between November and April with January recording highest amount. This was observed to be true for all the stations except Mzuzu,Karonga and Nkhotakota that record highest rainfall amount in March.

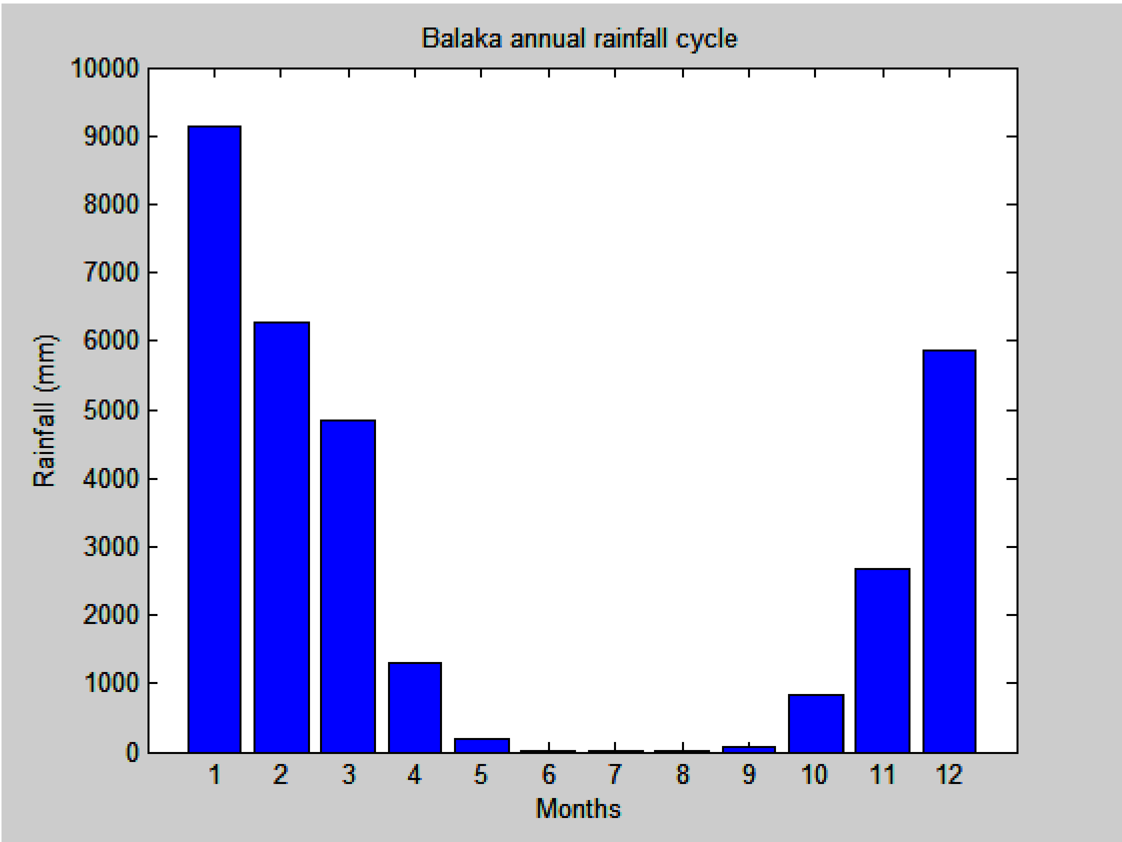

Figure 6: Balaka annual rainfall cycle

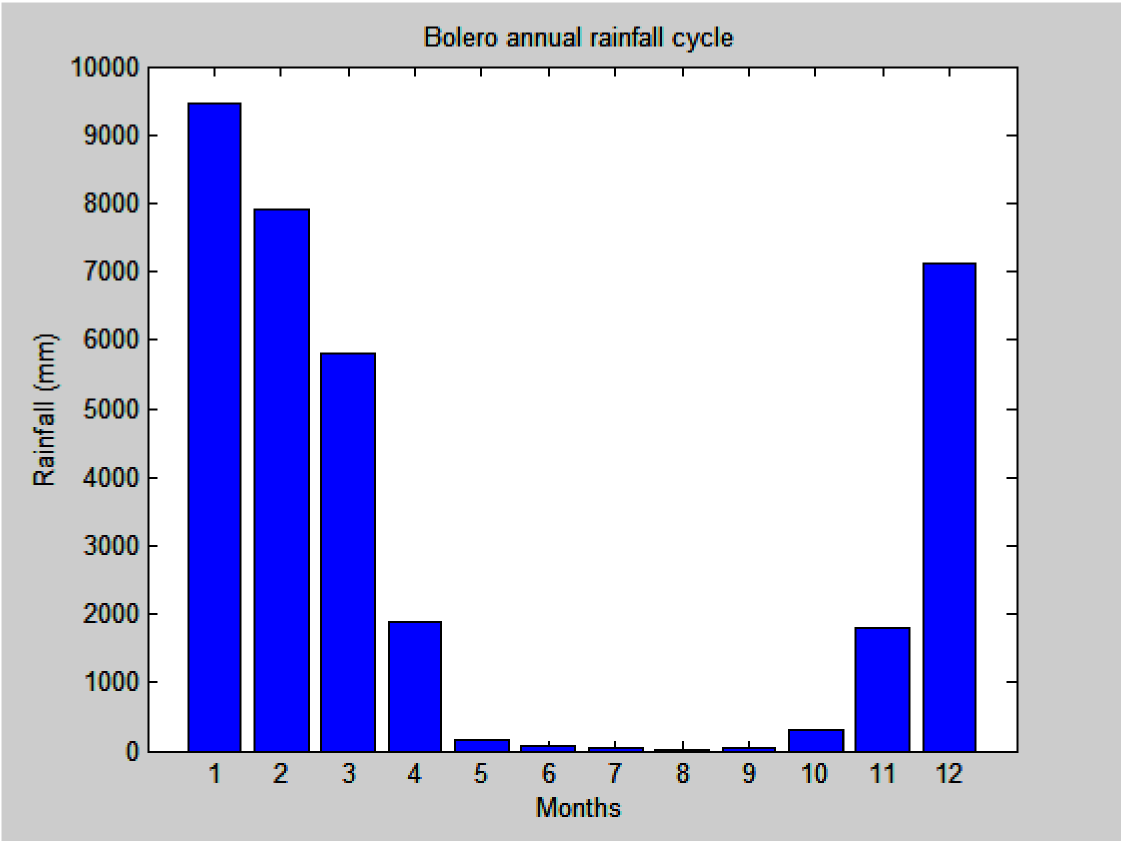

Figure 7: Bolero annual rainfall cycle

4.1.2 Analysis of inter-annual variability of rainfall

The analysis of the inter-annual variability of rainfall shows both increasing and decreasing trends though most stations depicted no significant trends. The figures below are graphs obtained for some selected stations.

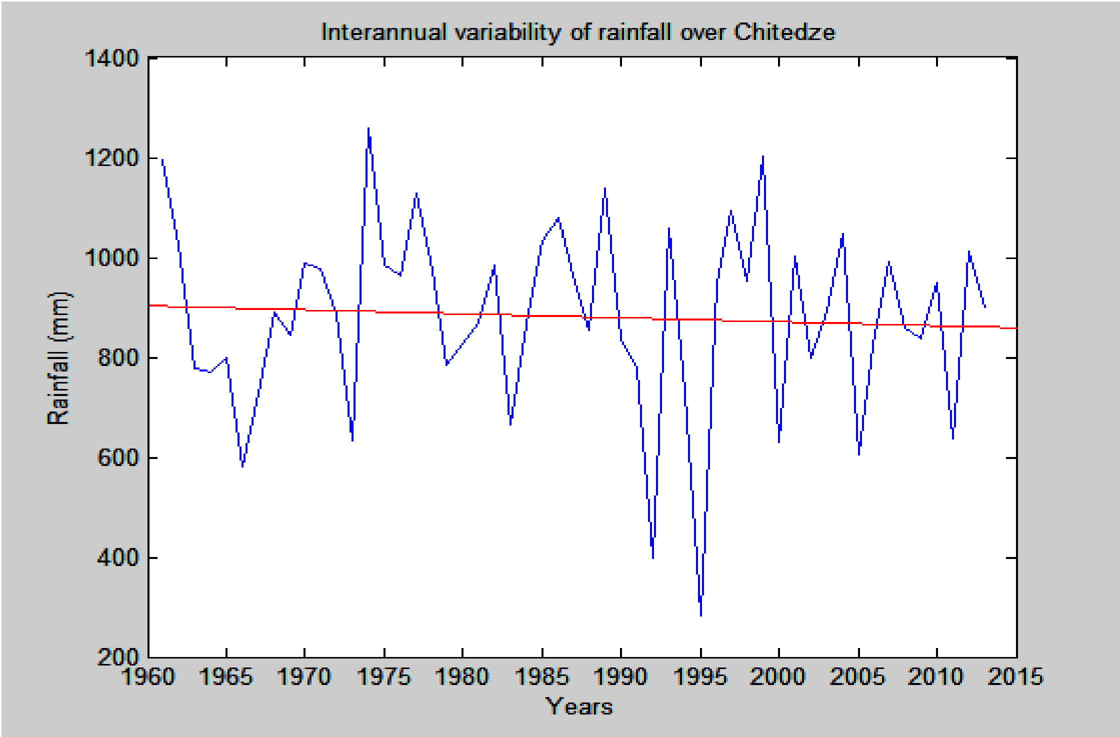

Figure 8: Chitedze inter-annual variability of rainfall

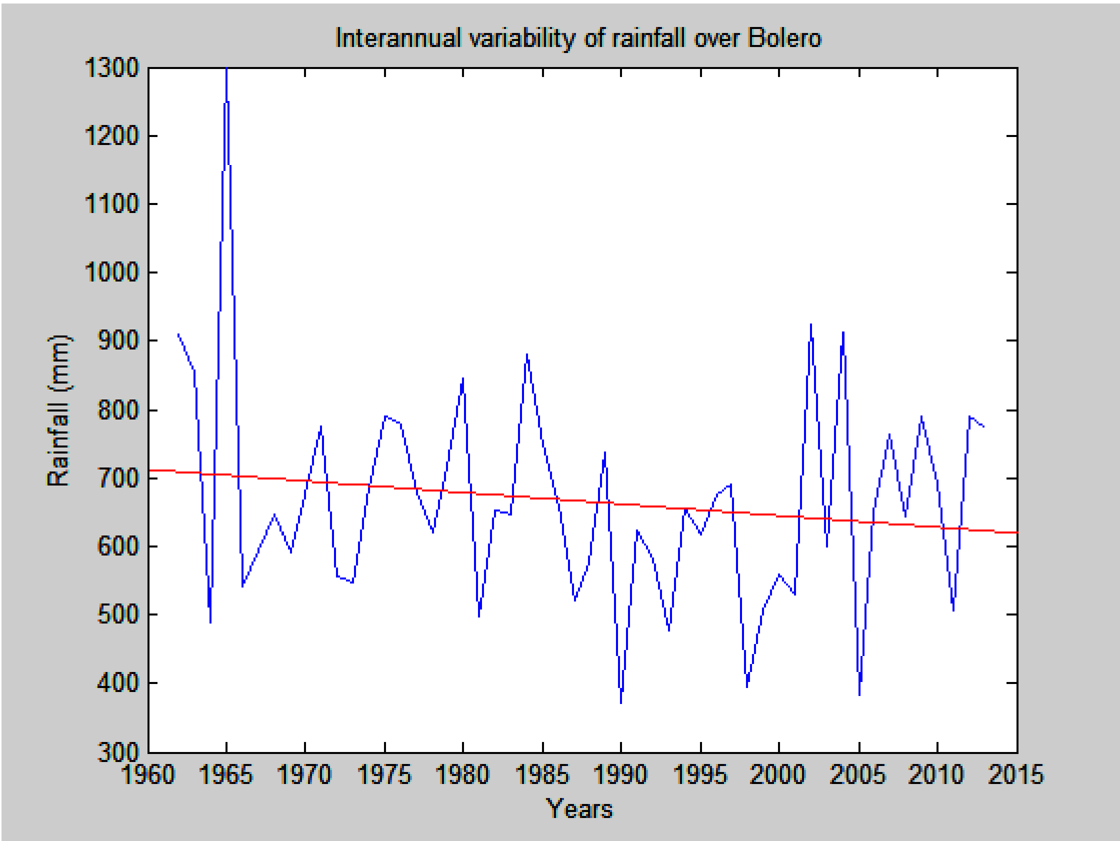

Figure 9: Inter-annual variability of rainfall over Bolero

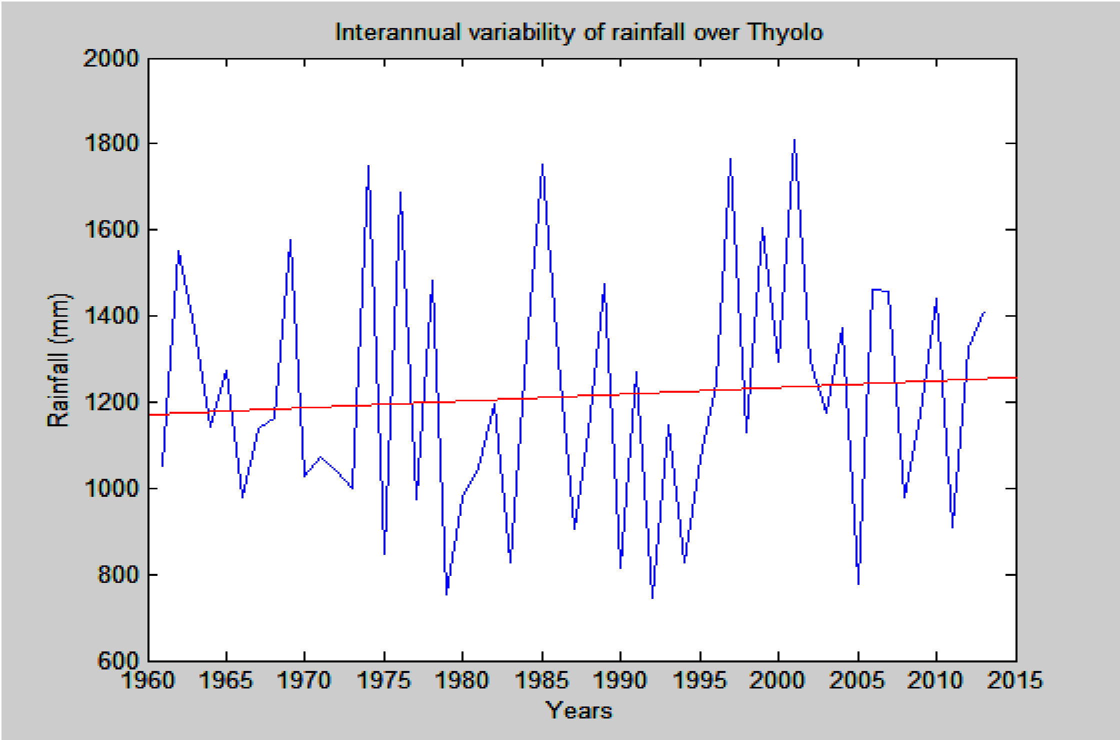

Figure 10: Inter-annual variability of rainfall over Thyolo

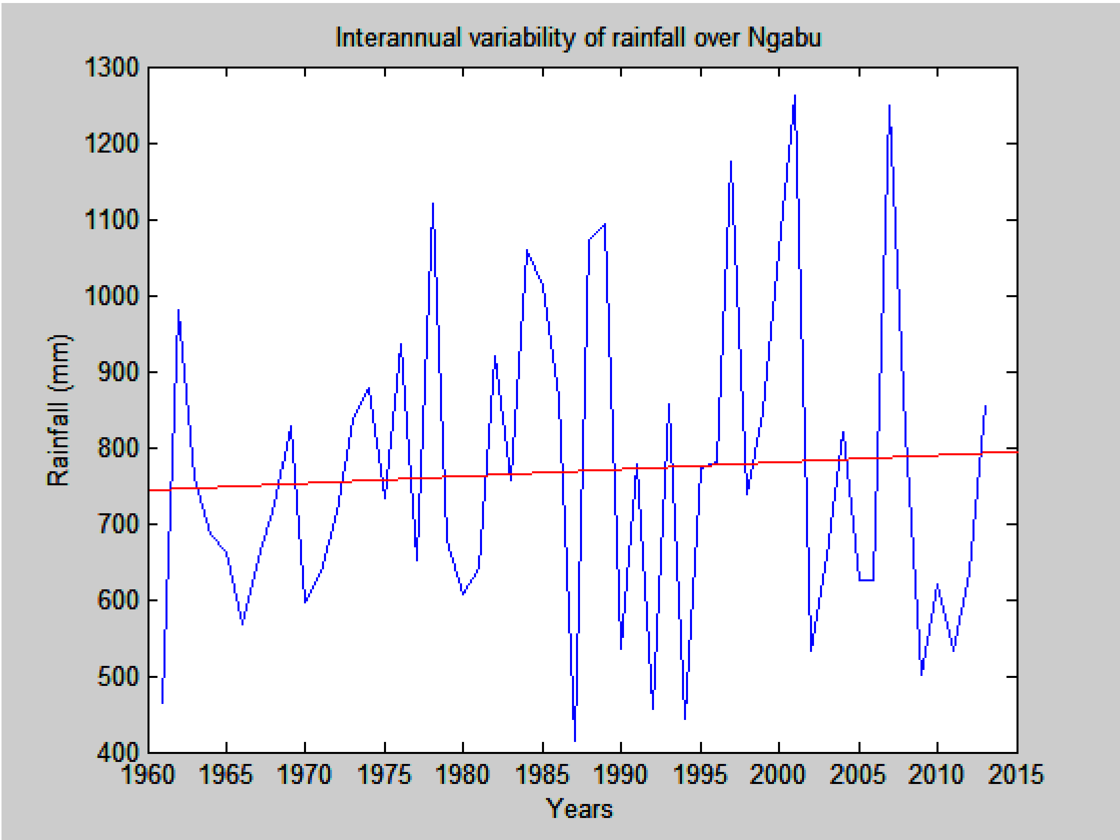

Figure 11: Inter-annual variability of rainfall over Ngabu

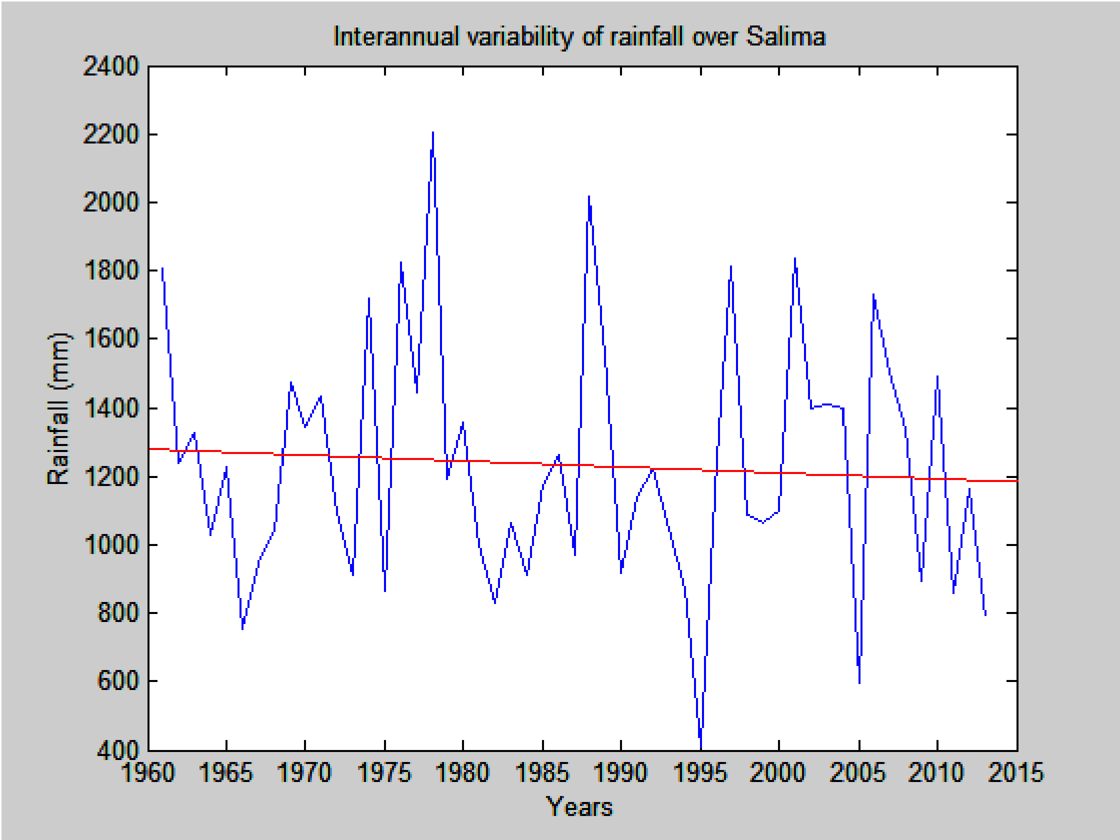

Figure 12: Inter-annual variability of rainfall over Salima

4.1.3 Analysis of inter-season variability of rainfall

The analysis of the inter-season variability of rainfall also shows increasing and decreasing trends. However, the trends are not significant for most stations. The figures below show results obtained for some selected stations.

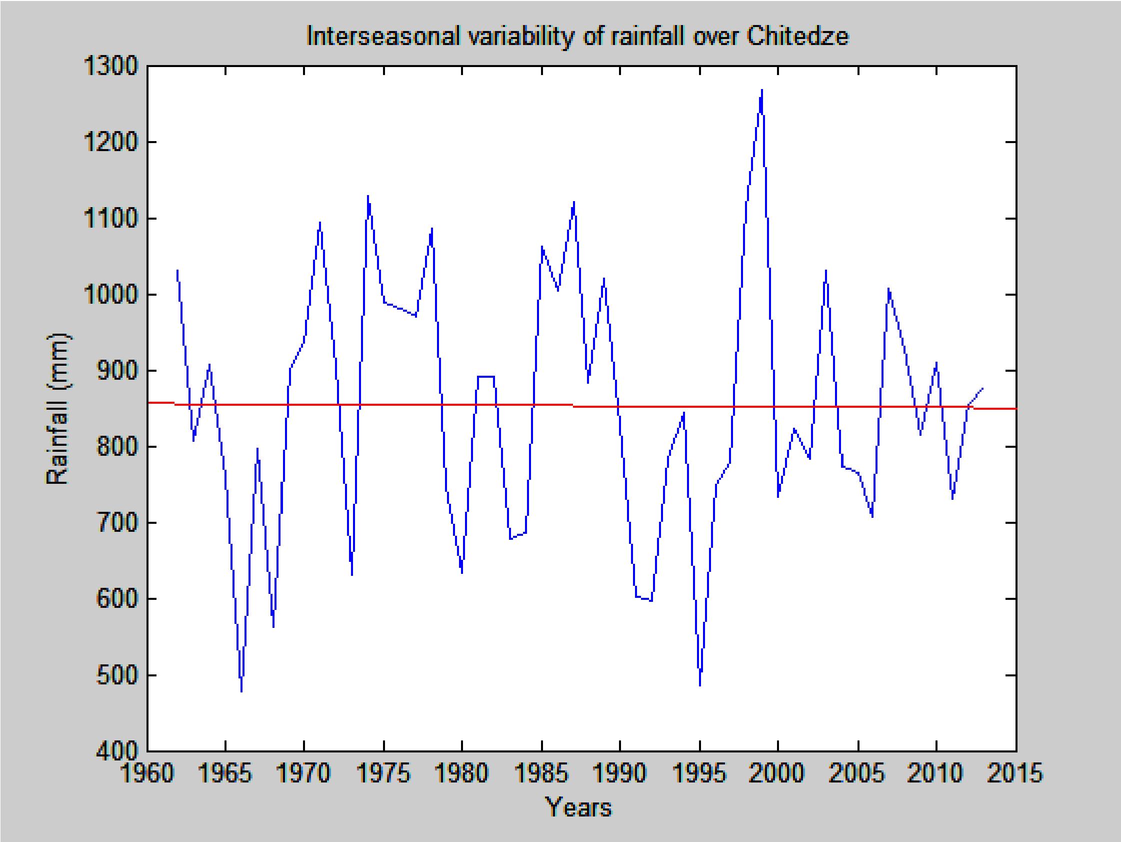

Figure 13: Inter-seasonal variability of rainfall over Chitedze

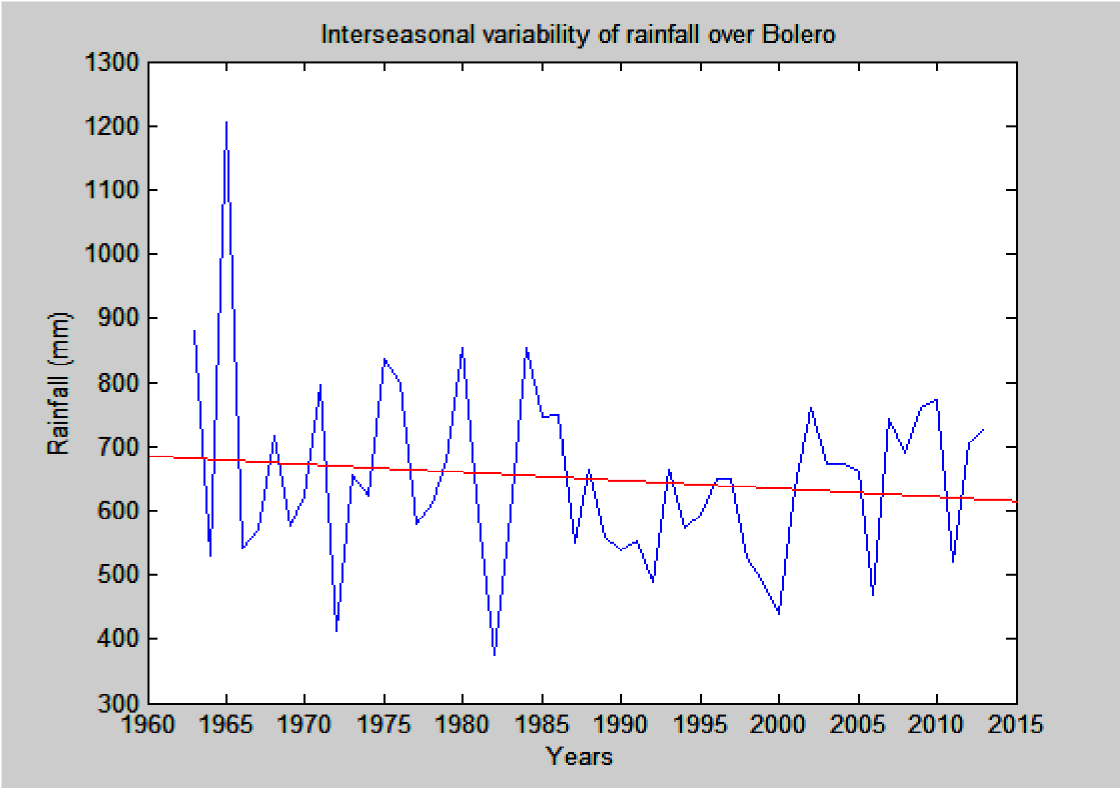

Figure 14: Inter-seasonal variability of rainfall over Bolero

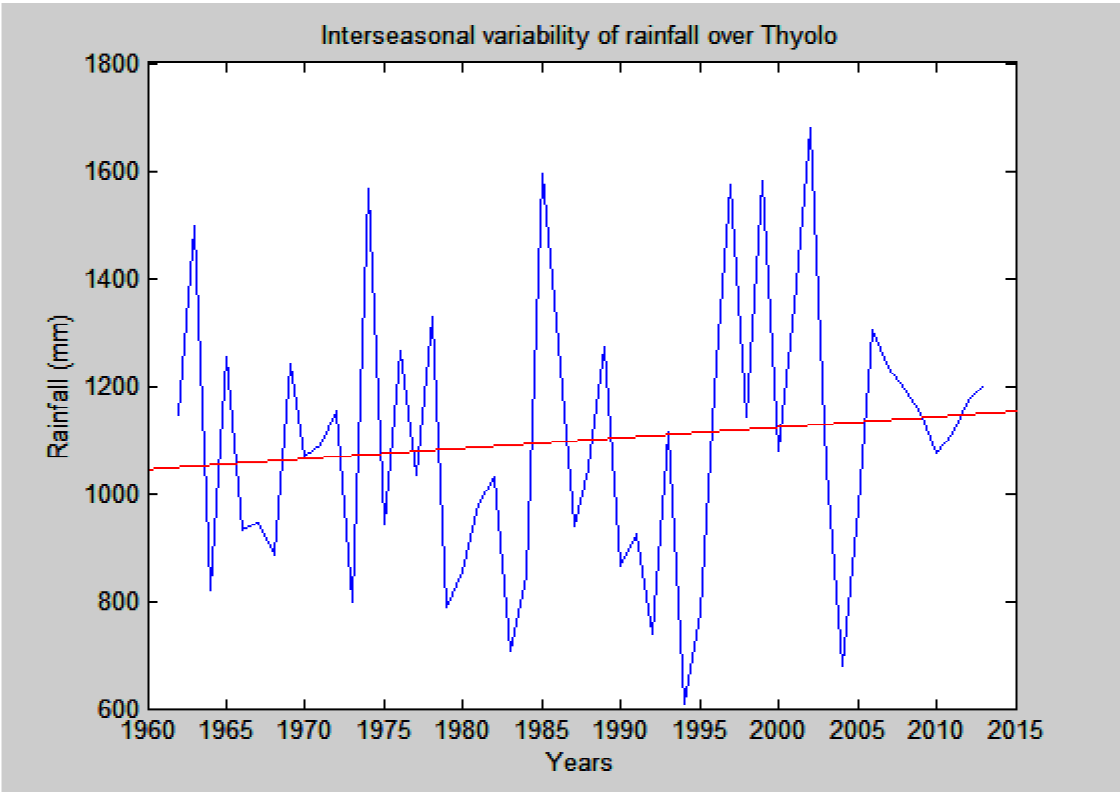

Figure 15: Inter-seasonal variability of rainfall over Thyolo

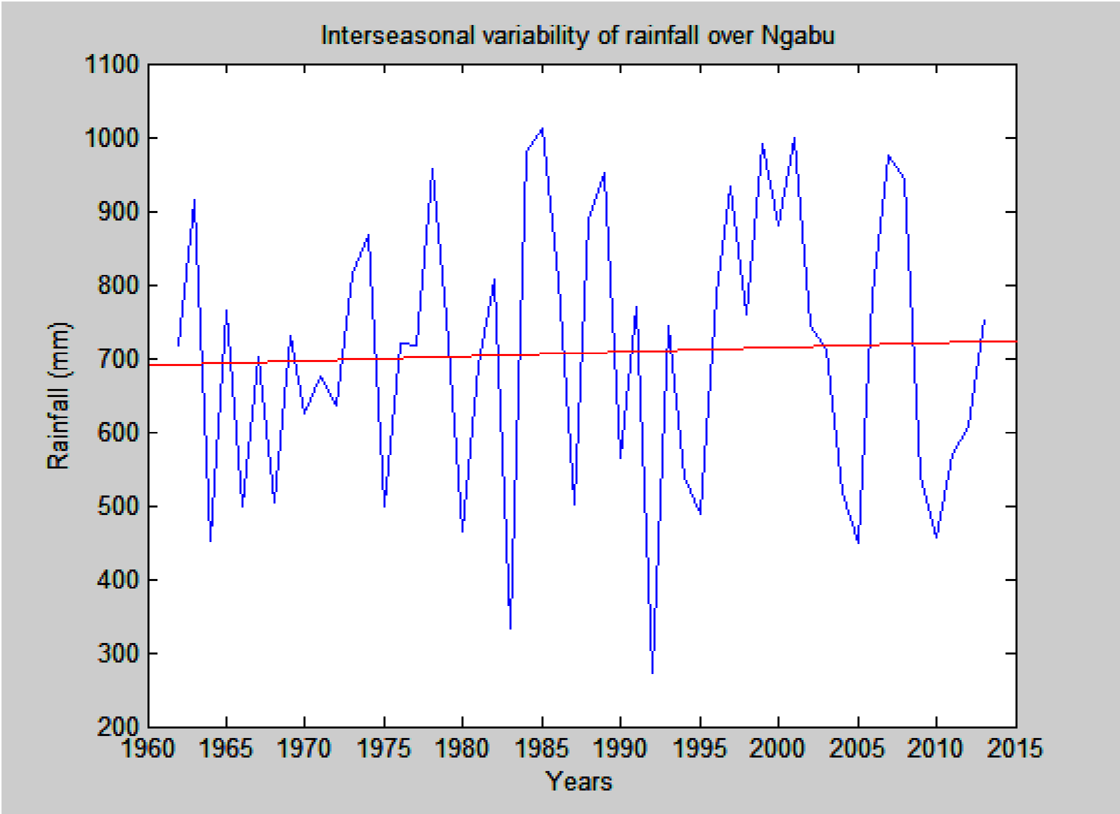

Figure 16: Inter-seasonal variability of rainfall over Ngabu

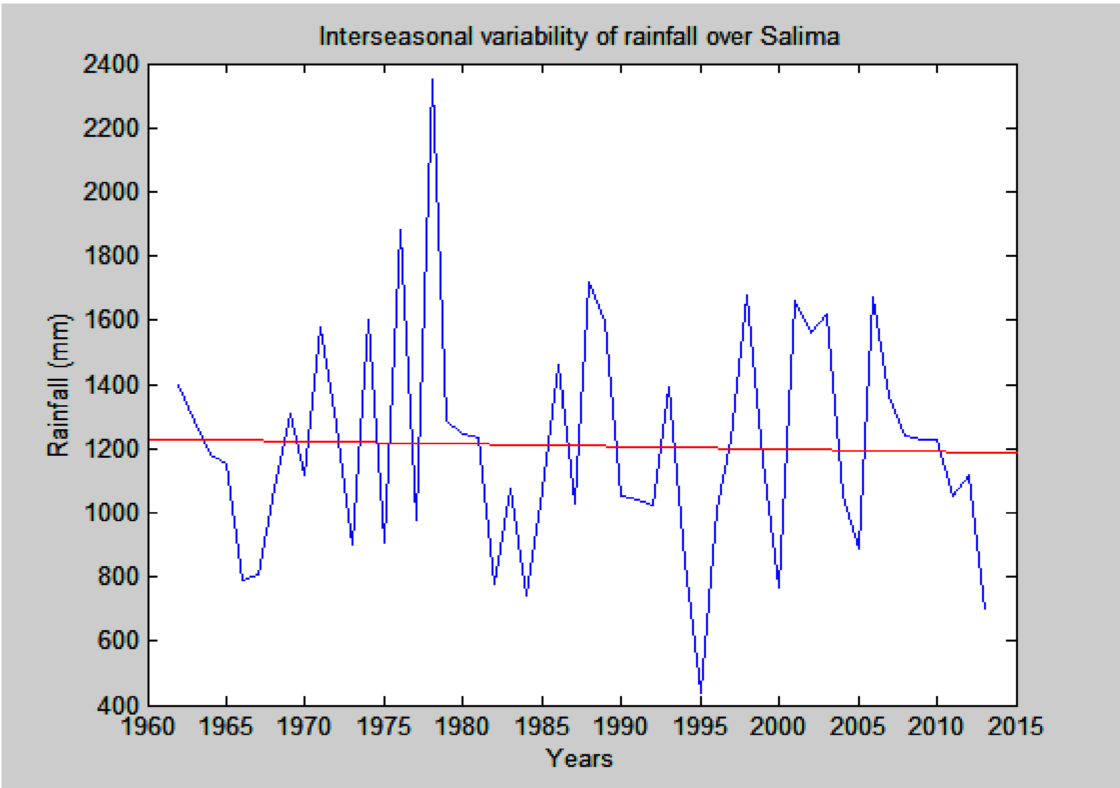

Figure 17: Inter-seasonal variability of rainfall over Salima

4.2.0 RESULTS FROM TIME SERIES ANALYSIS OF TEMPERATURE

4.2.1 Analysis of monthly mean temperatures

The figures below represent some stations showing annual temperature cycle over Malawi. It was observed that for most of the stations, the lowest minimum and maximum temperatures are recorded between May and July. The month of July records the lowest temperatures while highest temperatures are recorded in October.

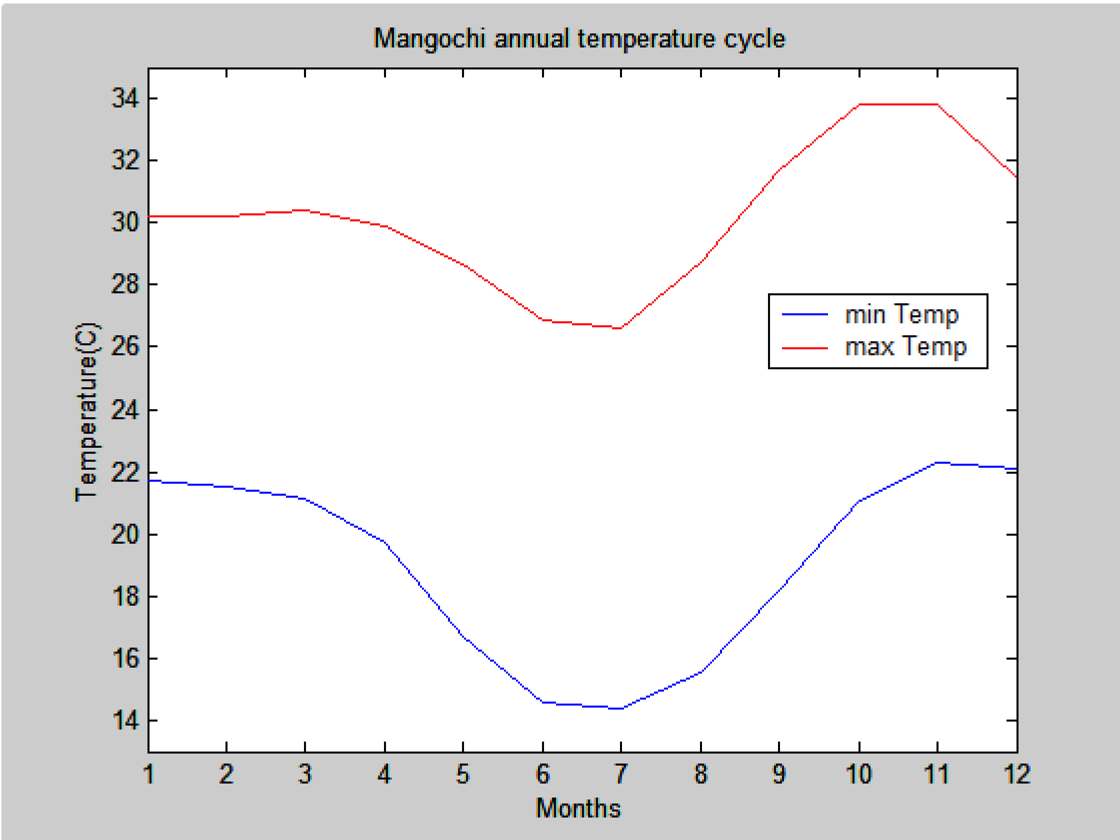

Figure 18: Mangochi annual temperature cycle

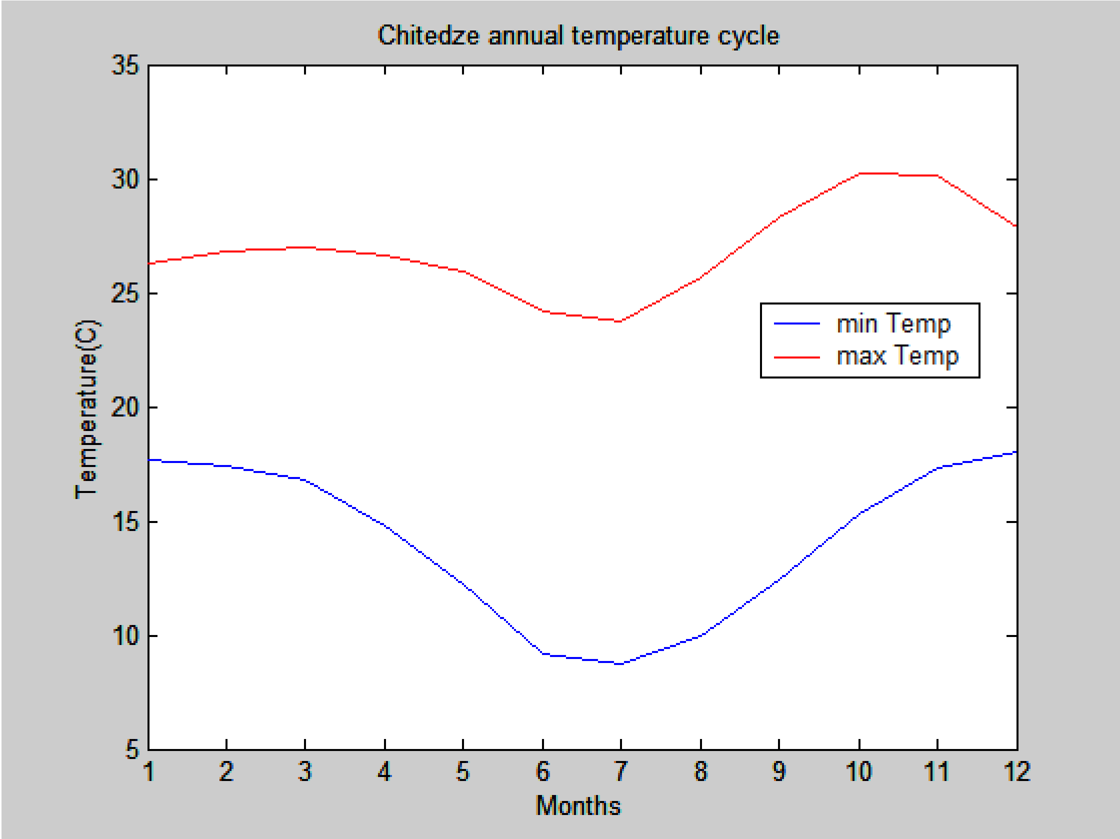

Figure 19: Chitedze annual temperature cycle

4.2.2 Analysis of winter temperatures (MJJ season)

The following figures show the time series based on winter mean temperatures (May, June and July) for some selected stations. It was found out that stations showed increasing trend. Nine stations showed significant increase in minimum temperatures while 14 stations showed significant increase in maximum temperatures. Some few stations showed a decreasing trend that was not significant.

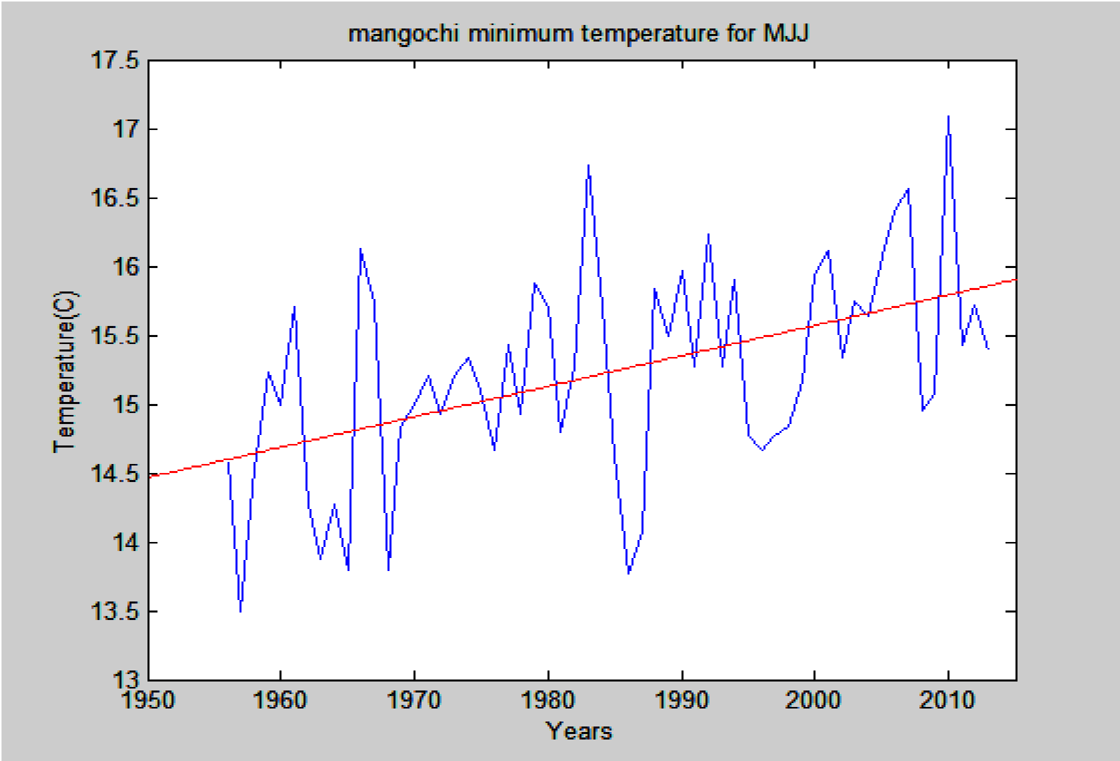

Figure 20: Mangochi minimum temperature trend for MJJ season

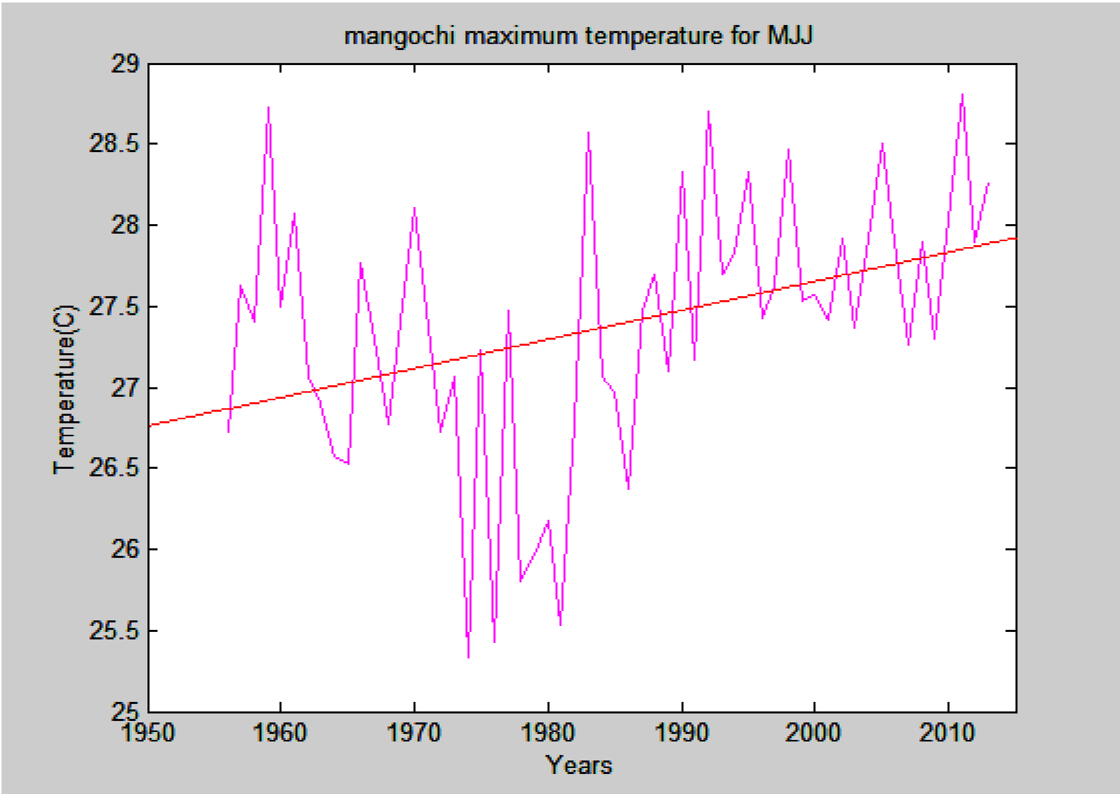

Figure 21: Mangochi maximum temperature trend for MJJ

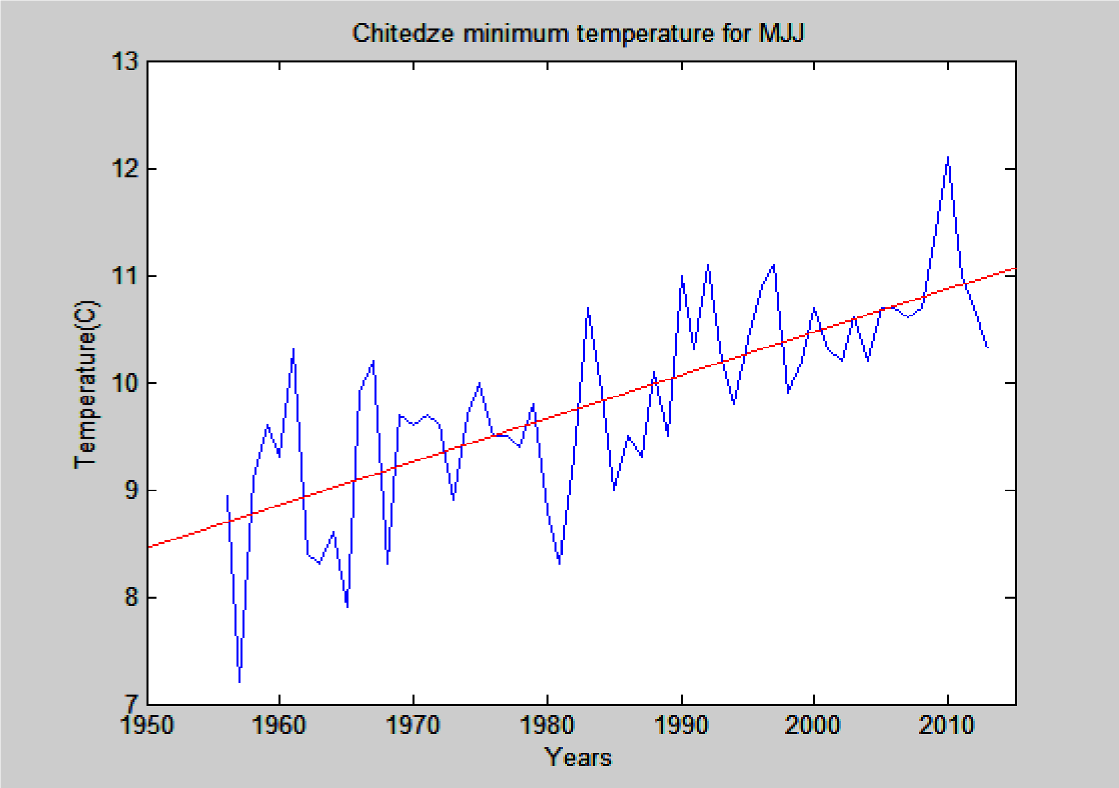

Figure 22: Chitedze minimum temperature trend for MJJ

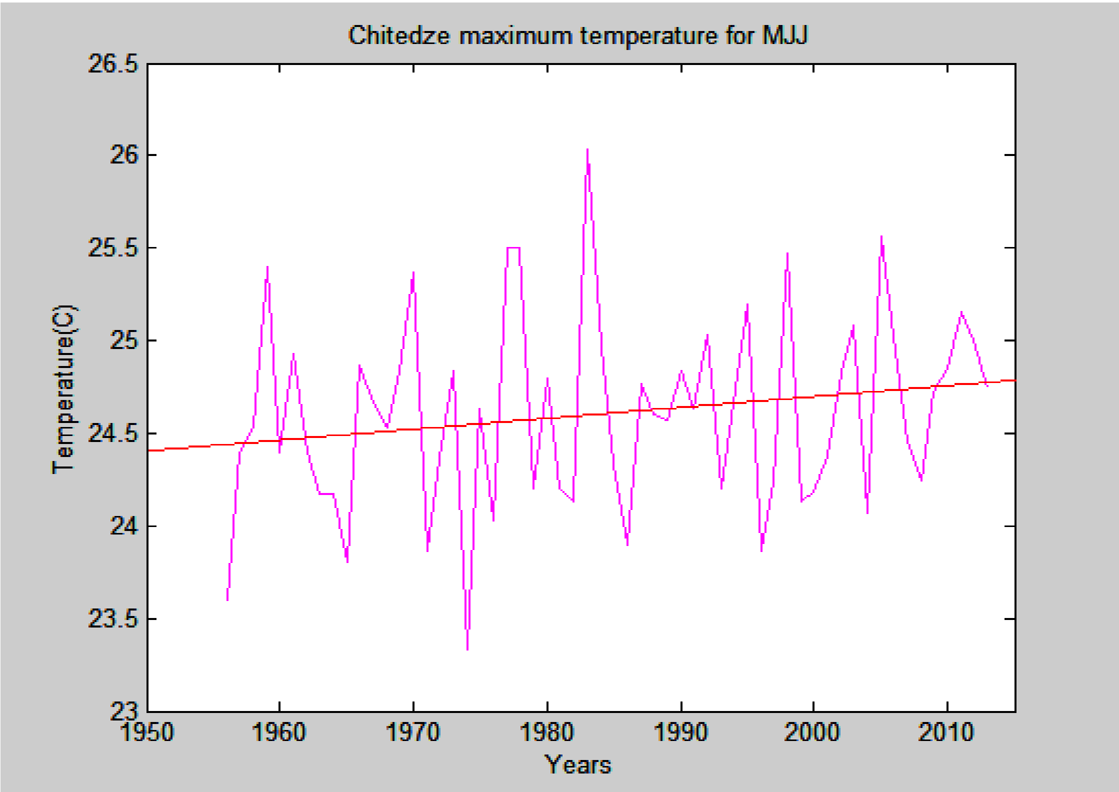

Figure 23: Chitedze maximum temperature trend for MJJ

4.2.3 Analysis of summer temperatures (SON season)

The figures below show the time series based on SON season (September, October and November) temperatures for some selected stations.

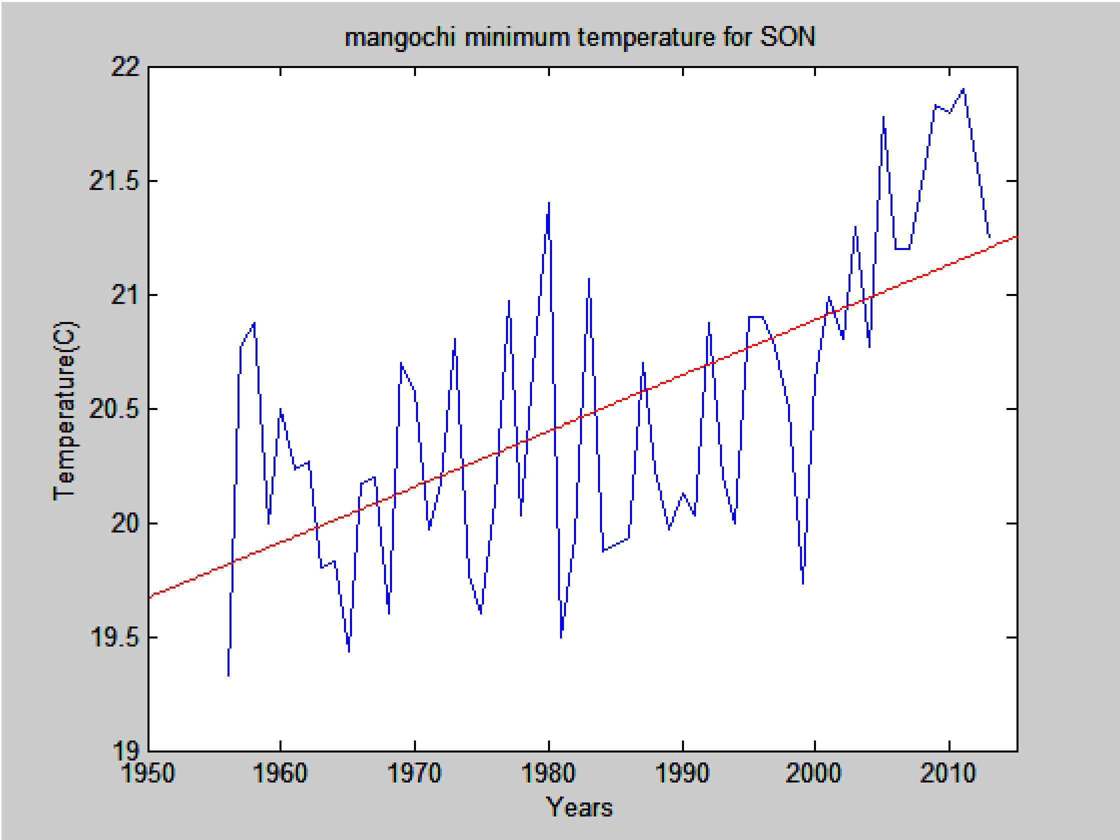

Figure 24: Mangochi minimum temperature trend for SON

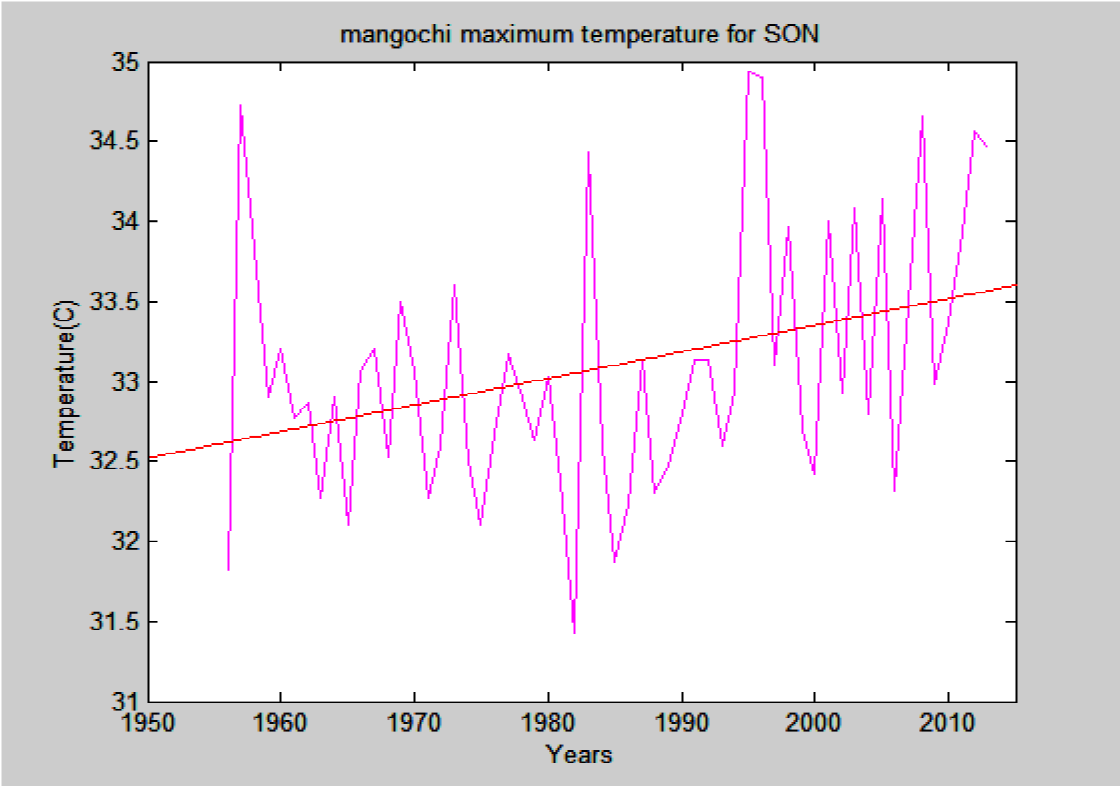

Figure 25: Mangochi maximum temperature trend for SON

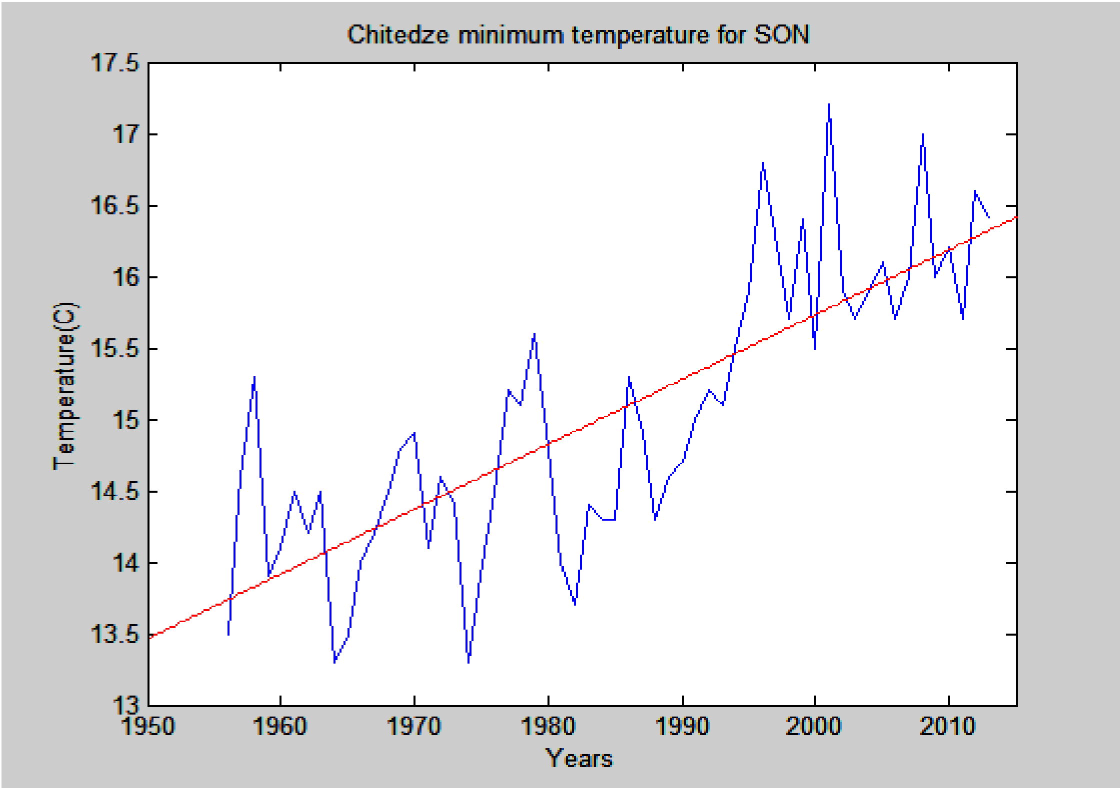

Figure 26: Chitedze minimum temperature trend for SON

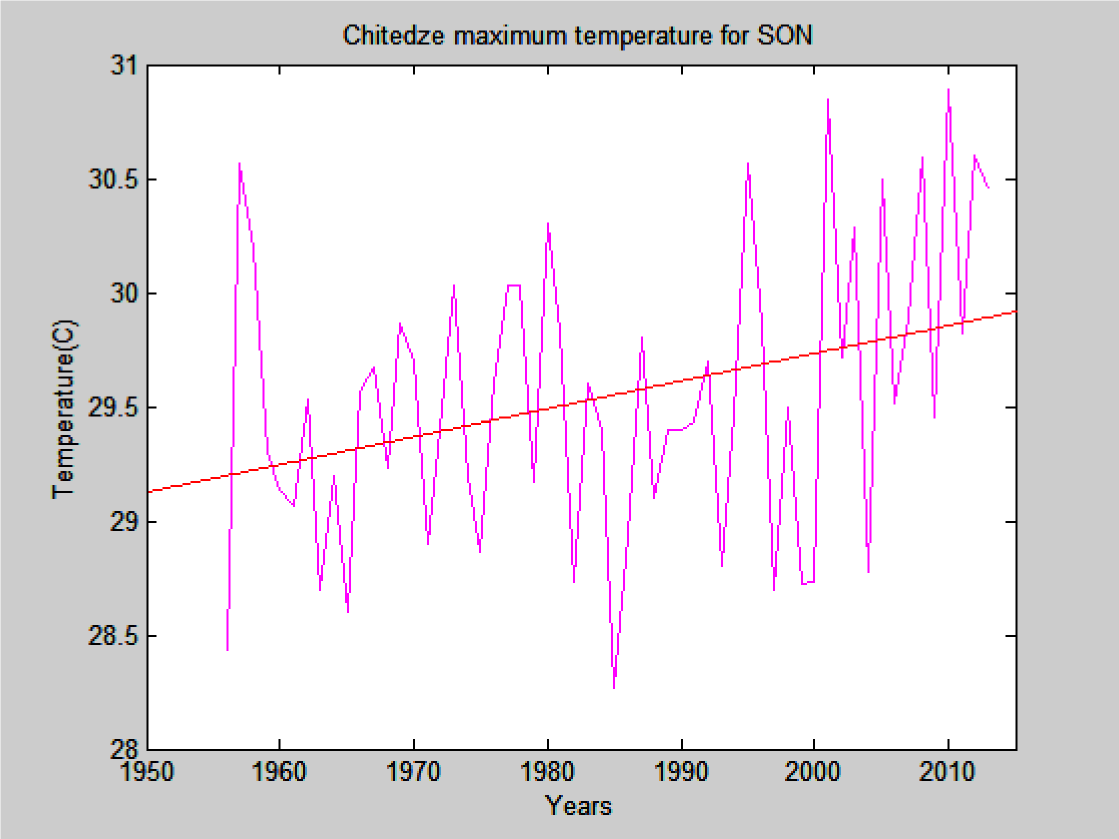

Figure 27: Chitedze maximum temperature trend for SON

4.3.0 RESULTS FROM TREND ANALYSIS (t-TEST)

To establish significance of the trends observed in the time series graphs, a two-sample student's t -test analysis was conducted on the data. The data was split into two sets. The value of t-stat, t-critical and means of the two data sets are presented in tables. Stations were then mapped to indicate their observed trends in space in rainfall and temperature as in figures 28 to 29.

4.3.1 Trend analysis of rainfall

The tables below show results obtained from t test for 22 stations. Tables 2 and 3 show results from analysis of seasonal rainfall and annual rainfall respectively. A summary of the results using a map and a pie chart is present after tables 2 and 3.

Table 2: t-test results of inter- seasonal rainfall

Station Name	mean 1	mean 2	t-stat	t1	t2	Remarks
Chileka	834.86	815.83	0.35	1.68	2.01	decreasing but not significan
Chitedze	863.33	844.02	0.40	1.68	2.01	decreasing but not significant
Kasungu	764.55	760.63	0.08	1.68	2.01	decreasing but not significan
KIA	822.88	819.21	0.08	1.68	2.01	decreasing but not significan
Mangochi	756.65	715.40	0.66	1.68	2.01	decreasing but not significan
Mimosa	1375.68	1347.62	0.29	1.68	2.01	decreasing but not significant
Mzimba	879.16	816.90	1.47	1.68	2.01	decreasing but not significant
Salima	1225.49	1218.85	0.07	1.68	2.01	decreasing but not significan
Tembwe	998.46	904.58	1.41	1.68	2.02	decreasing but not significant
Bolero	684.75	615.45	1.71	1.69	2.03	decreasing significantly
Chitipa	1023.76	898.80	2.07	1.68	2.02	decreasing significantly
Karonga	1180.51	935.78	3.63	1.68	2.01	decreasing significantly
Mzuzu	1125.55	985.08	2.39	1.68	2.01	decreasing significantly
Nkhota Kota	1596.99	1264.89	4.14	1.68	2.01	decreasing significantly
Balaka	794.28	807.43	-0.12	1.70	2.05	increasing but not significant
Bvumbwe	1031.21	1060.31	-0.40	1.68	2.01	increasing but not significant
Chichiri	1034.44	1049.11	-0.21	1.68	2.02	increasing but not significant
Makoka	923.87	952.61	-0.42	1.68	2.01	increasing but not significant
Monkey Bay	798.32	881.27	-1.11	1.70	2.05	increasing but not significant
Ngabu	705.88	707.72	-0.03	1.68	2.01	increasing but not significant
Thyolo	1082.01	1111.74	-0.41	1.68	2.01	increasing but not significant
Dedza	906.95	910.69	-0.09	1.68	2.01	increasing but not significant

Table 3: t-test results of inter-annual rainfall

Station Name	**Mean 1**	**Mean 2**	**t-stat**	**t1**	**t2**	**Remarks**
Chichiri	1134.57	1107.16	0.34	1.68	2.01	decreasing but not significant
Chileka	886.71	848.44	0.69	1.68	2.01	decreasing but not significant
Chitedze	894.25	855.10	0.73	1.68	2.02	decreasing but not significant
Dedza	945.06	928.74	0.32	1.68	2.01	decreasing but not significant
Kasungu	773.90	769.52	0.09	1.67	2.01	decreasing but not significant
KIA	844.04	837.54	0.13	0.90	2.00	decreasing but not significant
Makoka	983.26	982.73	0.01	1.68	2.01	decreasing but not significant
Mimosa	1661.66	1565.34	1.10	1.68	2.01	decreasing but not significant
Mzimba	894.24	824.13	1.62	1.68	2.01	decreasing but not significant
Ngabu	768.04	766.67	0.02	1.68	2.02	decreasing but not significant
Salima	1254.68	1235.09	0.19	1.68	2.01	decreasing but not significant
Tembwe	1011.52	961.90	0.64	1.68	2.02	decreasing but not significant
Bolero	708.61	622.13	1.95	1.68	2.01	decreasing significantly
Chitipa	1039.89	902.62	3.01	1.68	2.02	decreasing very significantly
Karonga	1249.85	941.37	3.64	1.68	2.01	decreasing very significantly
Mzuzu	1315.18	1131.20	2.37	1.68	2.01	decreasing very significantly
Nkhota Kota	1666.58	1315.71	4.13	1.68	2.02	decreasing very significantly
Balaka	825.41	830.77	-0.06	1.70	2.00	increasing but not significant
Bvumbwe	1140.49	1152.44	-0.17	1.68	2.00	increasing but not significant
Mangochi	831.28	838.32	-0.10	1.68	2.01	increasing but not significant
Monkey Bay	240.79	243.82	-0.06	1.70	2.04	increasing but not significant
Thyolo	1196.33	1225.92	-0.36	1.68	2.01	increasing but not significant

Figures 28 and 29 below summarize the information from tables 2 and 3 respectively. The figures depict the trends of seasonal and annual rainfall on a map. (i. e. depicts which stations are showing increasing or decreasing trend in seasonal and annual rainfall.)

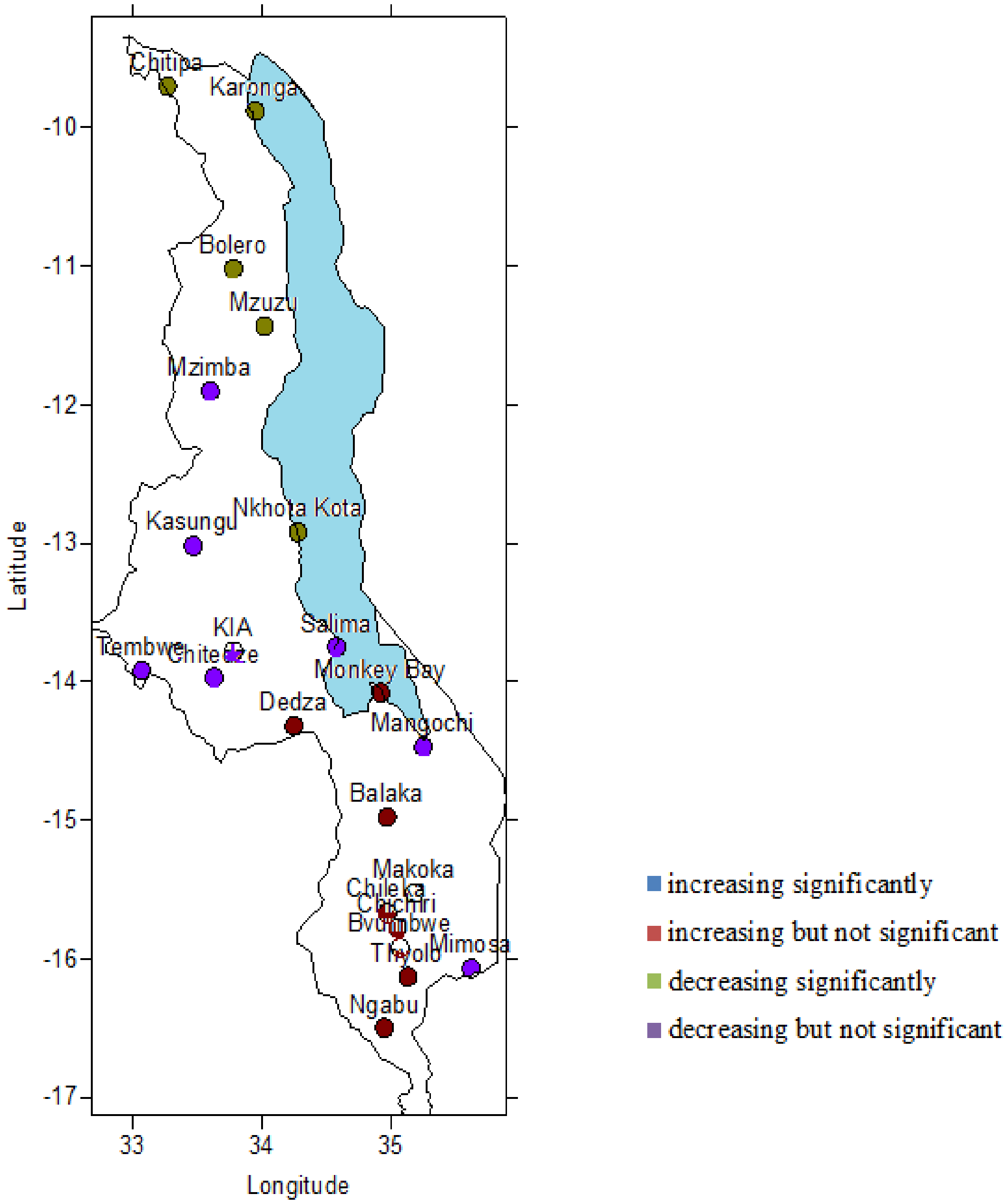

Figure 28: Trend of seasonal rainfall over Malawi

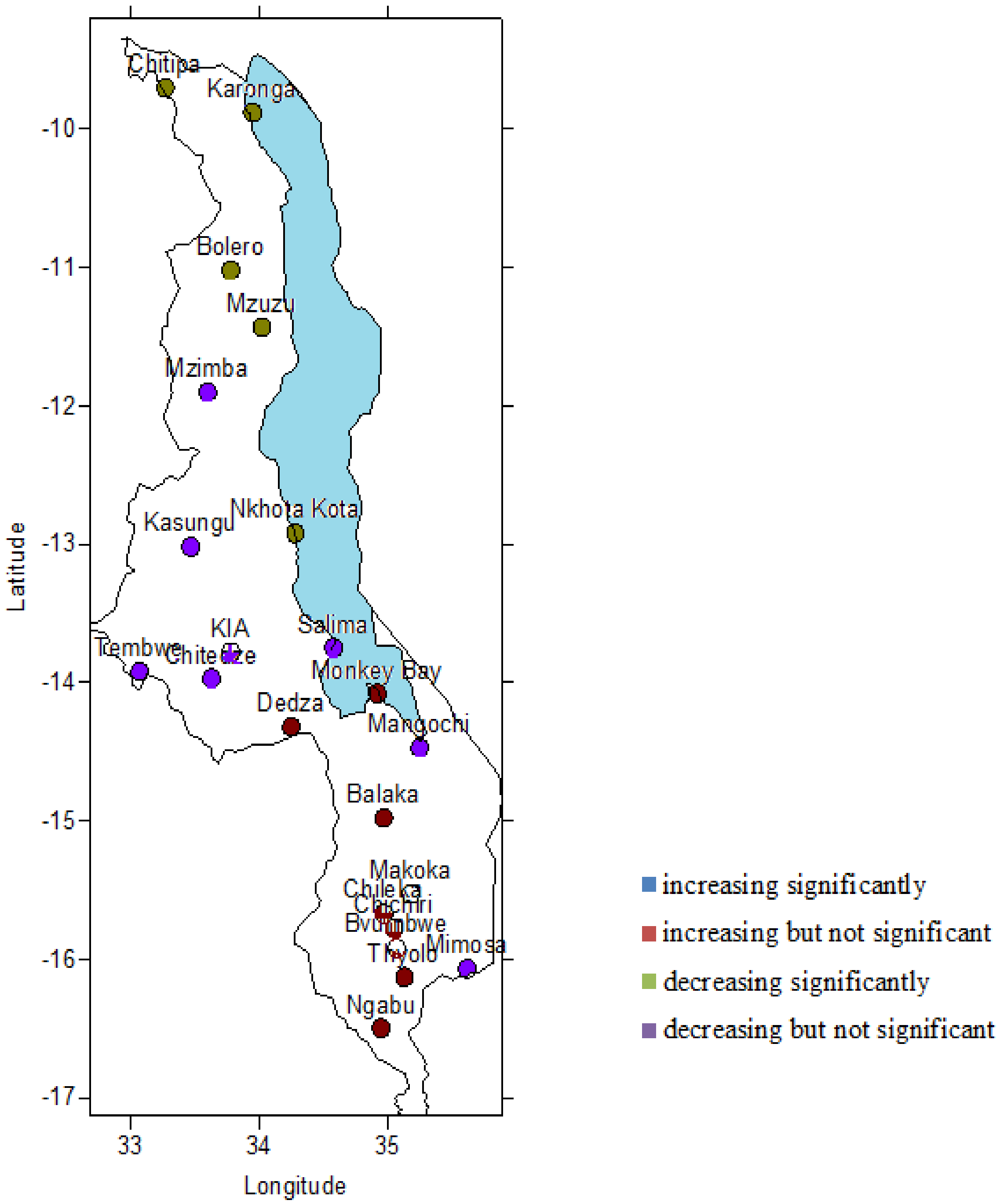

Figure 29: Trend of annual rainfall over Malawi

4.3.2 Trend analysis of temperature

The following tables show results from the analysis of minimum and maximum temperature for the MJJ (May, June, July) season and SON (September, October, November) season. These months were picked to represent the winter season and summer season respectively. From the annual temperature cycle, it was observed that the lowest temperatures are recorded in July while the highest temperatures are recorded in October.

Table 4: t-test results for MJJ minimum temperature

STATION	mean 1	mean 2	t stat	t1	t2	Remarks
Dedza	10.02	9.99	0.09	1.69	2.03	decreasing but not significan
Karonga	18.29	18.17	0.57	1.68	2.02	decreasing but not significan
Ngabu	16.51	16.35	0.45	1.68	2.02	decreasing but not significan
Nkhata Bay	16.26	14.70	6.92	1.68	2.02	decreasing significantly
Bvumbwe	11.70	12.14	-1.89	1.67	2.00	increasing but not significant
Makoka	12.25	12.36	-0.46	1.70	2.05	increasing but not significant
Mzimba	11.57	12.03	-1.96	1.68	2.00	increasing but not significant
Chichiri	12.09	12.95	-4.61	1.67	2.01	increasing significantly
Chitipa	12.93	13.52	-3.70	1.67	2.01	increasing significantly
Chileka	14.06	14.88	-5.73	1.68	2.02	increasing significantly
Chitedze	9.24	10.40	-6.78	1.67	2.00	increasing significantly
Mangochi	14.82	15.48	-3.55	1.67	2.00	increasing significantly
Mimosa	12.09	12.75	-3.59	1.67	2.00	increasing significantly
Mzuzu	8.52	9.77	-4.64	1.68	2.01	increasing significantly
Nkhota Kota	16.40	17.18	-3.27	1.68	2.02	increasing significantly
Salima	16.53	17.44	-5.07	1.68	2.02	increasing significantly

Table 5: t-test results for MJJ maximum temperature

STATION	mean 1	mean 2	t stat	t1	t2	Remarks
Chitedze	24.57	24.65	-0.55	1.68	2.00	increasing but not significant
Ngabu	28.83	29.06	-0.85	1.68	2.02	increasing but not significant
Bvumbwe	20.52	21.35	-4.02	1.67	2.00	increasing significantly
Chichiri	21.65	22.80	-4.51	1.68	2.02	increasing significantly
Chitipa	23.95	24.57	-3.84	1.68	2.01	increasing significantly
Chileka	24.46	25.19	-4.07	1.68	2.02	increasing significantly
Dedza	19.86	20.71	-4.39	1.68	2.01	increasing significantly
Karonga	27.83	28.41	-3.22	1.68	2.02	increasing significantly
Makoka	22.59	23.71	-2.53	1.71	2.06	increasing significantly
Mangochi	27.00	27.75	-3.94	1.68	2.01	increasing significantly
Mimosa	24.36	25.70	-6.36	1.68	2.01	increasing significantly
Mzimba	23.22	24.42	-7.10	1.68	2.02	increasing significantly
Mzuzu	21.05	21.81	-3.48	1.69	2.03	increasing significantly
Nkhata Bay	26.18	26.83	-3.23	1.68	2.02	increasing significantly
Nkhota Kota	25.92	26.37	-2.81	1.68	2.02	increasing significantly
Salima	26.67	27.11	-2.77	1.68	2.02	increasing significantly

Table 6: t- test results for SON minimum temperature

STATION	mean 1	mean 2	t stat	t1	t2	Remarks
Karonga	21.48	21.43	0.26	1.68	2.02	decreasing but not significnat
Nkhata Bay	19.60	17.24	11.29	1.69	2.04	decreasing significantly
Bvumbwe	15.60	15.90	-1.63	1.67	2.00	increasing but not significant
Chitipa	17.39	17.61	-1.04	1.69	2.04	increasing but not significant
Dedza	14.61	14.70	-0.27	1.70	2.05	increasing but not significant
Ngabu	21.89	22.25	-1.42	1.69	2.03	increasing but not significant
Nkhota Kota	19.88	20.75	-1.47	1.69	2.03	increasing but not significant
Chichiri	16.18	17.08	-5.38	1.68	2.00	increasing significantly
Chileka	18.96	19.70	-4.90	1.68	2.01	increasing significantly
Chitedze	14.32	15.77	-8.44	1.68	2.00	increasing significantly
Makoka	16.67	17.07	-2.59	1.69	2.03	increasing significantly
Mangochi	20.16	20.74	-3.84	1.67	2.00	increasing significantly
Mimosa	16.00	16.83	-5.07	1.68	2.00	increasing significantly
Mzimba	16.12	16.71	-2.93	1.68	2.02	increasing significantly
Mzuzu	11.52	13.20	-6.54	1.68	2.02	increasing significantly
Salima	20.75	21.71	-6.89	1.68	2.01	increasing significantly

Table 7: t-test results for SON maximum temperature

STATION	mean 1	mean 2	t stat	t1	t2	Remarks
Chitedze	29.44	29.65	-1.21	1.67	2.01	increasing but not significant
Ngabu	35.33	35.70	-1.10	1.68	2.02	increasing but not significant
Nkhota Kota	30.98	31.04	-0.23	1.69	2.03	increasing but not significant
Bvumbwe	26.64	27.15	-2.11	1.67	2.00	increasing significantly
Chichiri	27.00	28.23	-4.48	1.68	2.01	increasing significantly
Chitipa	29.04	29.50	-2.86	1.68	2.01	increasing significantly
Chileka	30.34	31.08	-3.24	1.68	2.01	increasing significantly
Dedza	24.47	25.25	-2.65	1.70	2.04	increasing significantly
Karonga	31.83	32.67	-5.26	1.68	2.01	increasing significantly
Makoka	28.20	29.17	-4.70	1.68	2.02	increasing significantly
Mangochi	32.87	33.32	-2.19	1.67	2.00	increasing significantly
Mimosa	30.38	31.37	-3.53	1.67	2.00	increasing significantly
Mzimba	27.49	28.53	-4.67	1.68	2.01	increasing significantly
Mzuzu	26.47	27.14	-2.45	1.69	2.03	increasing significantly
Nkhata Bay	29.72	32.30	-11.68	1.68	2.02	increasing significantly
Salima	31.77	32.28	-2.27	1.68	2.01	increasing significantly

Figures 30, 31, 32 and 33 below summarize the information from tables 4, 5, 6 and 7 respectively. These figures show trends of temperature during the MJJ and SON seasons at different locations.

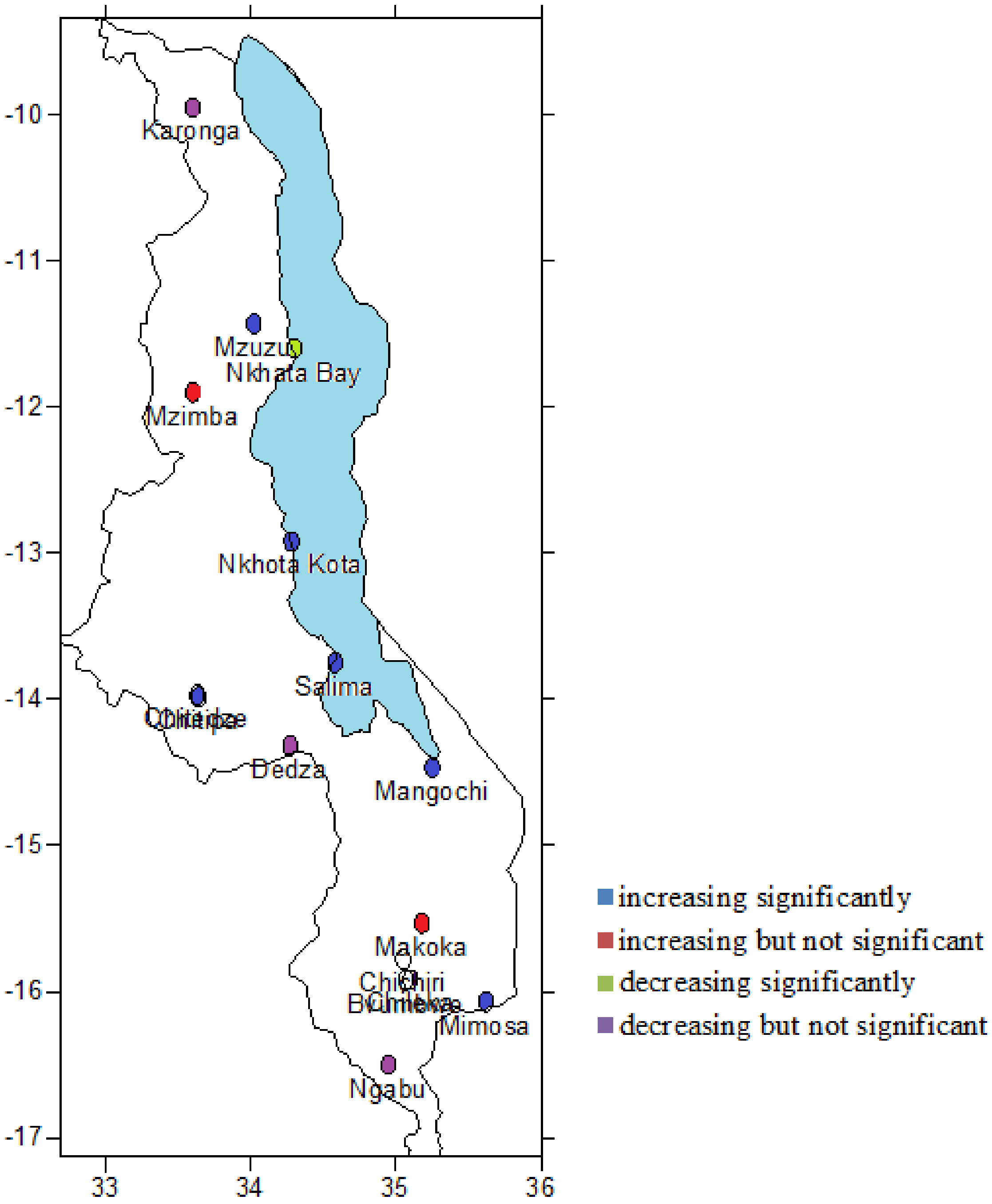

Figure 30: Trend of minimum temperatures for MJJ season

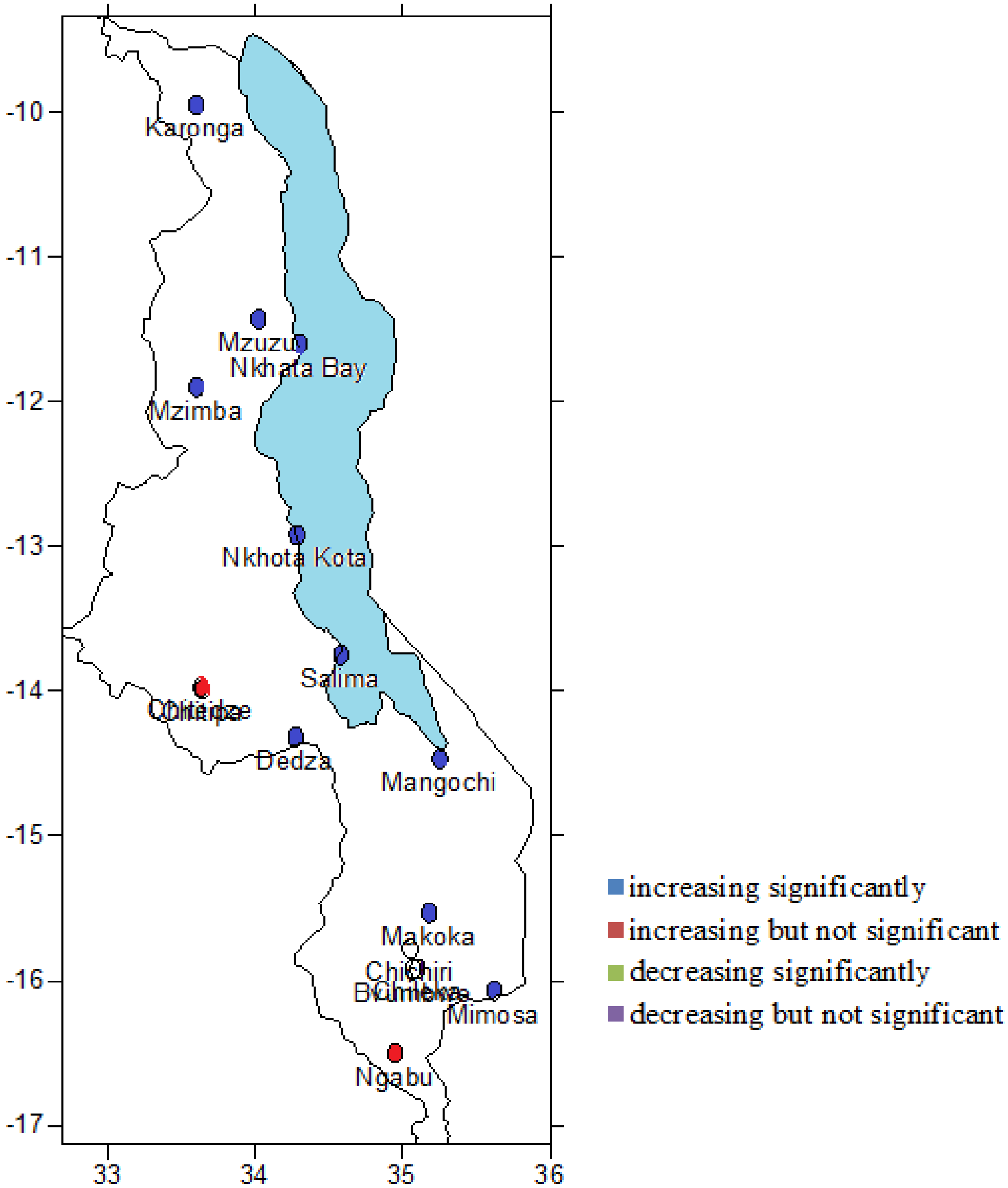

Figure 31: Trend of maximum temperatures for MJJ season

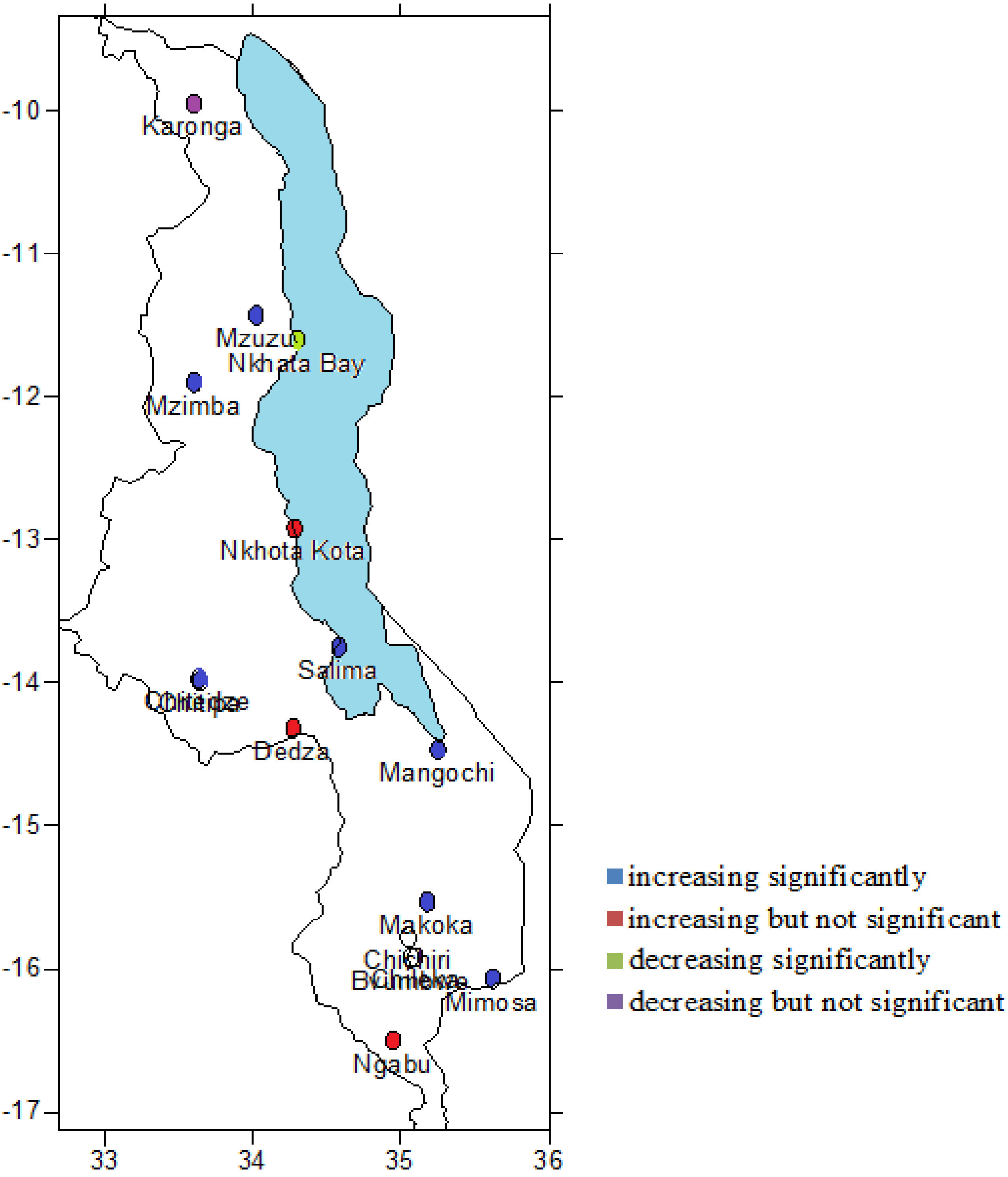

Figure 32: Trend of minimum temperatures for SON season

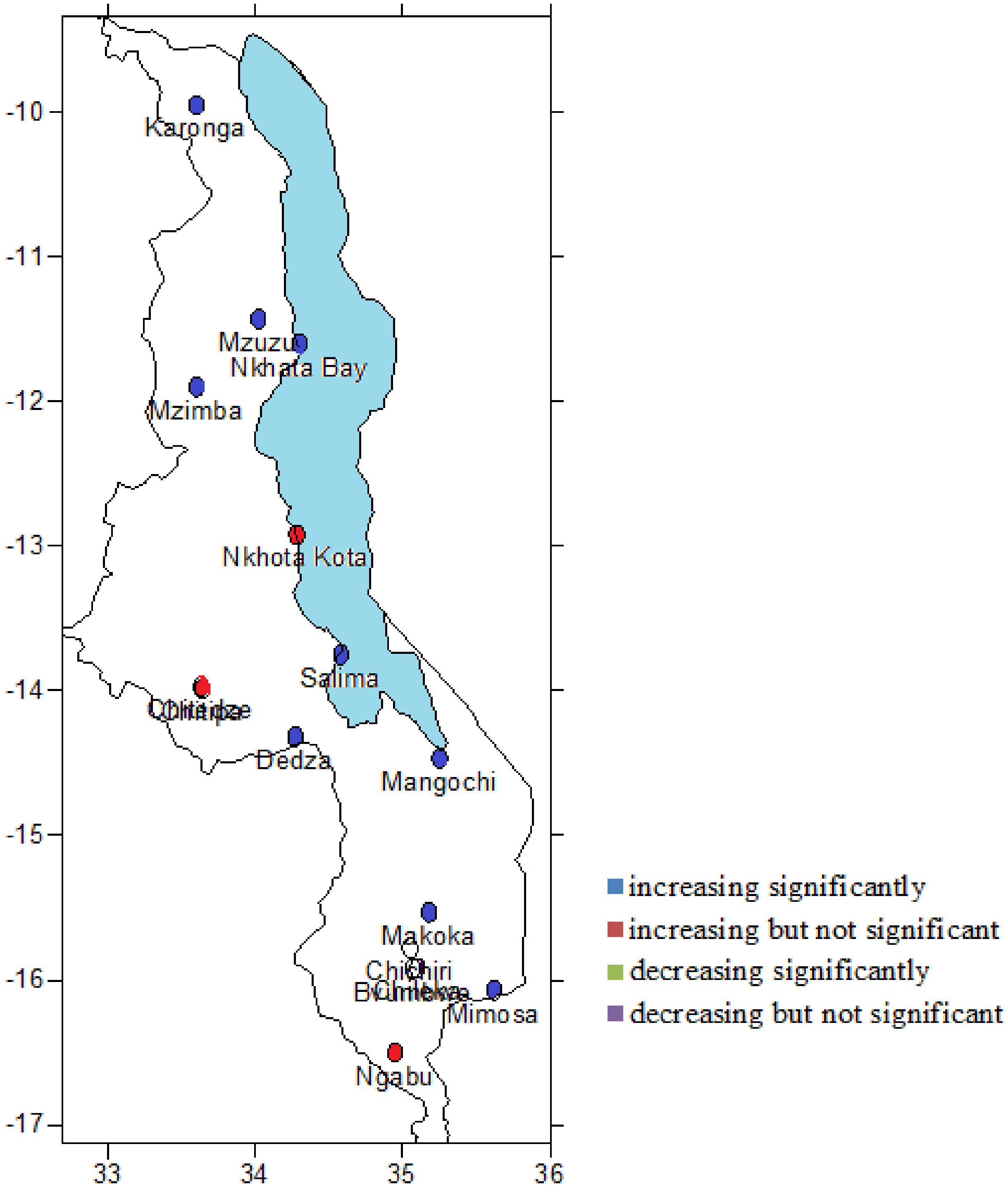

Figure 33: Trend of maximum temperatures for SON season

4.4.0 RESULTS FROM SPATIAL PATTERNS

4.4.1 Mapping of rainfall

Seasonal rainfall distribution over Malawi was mapped in SURFER. This is represented in Figure 34. The map depicts that high amounts of rainfall are received in the areas along the lake and in the southeastern part of the country. The eastern sector receives relatively high amount of rainfall than the western sector across the length of the country. The highlands in southern part and the lake affect rainfall distribution in these areas. Highlands in the southern part of the country bring in the influence topography while areas along the lake are significantly influenced by the lake that contributes to the rainfall. Therefore, apart from the main weather systems such as the ITCZ and Congo air mass influencing rainfall, the amount of rain received is also influenced by these factors.

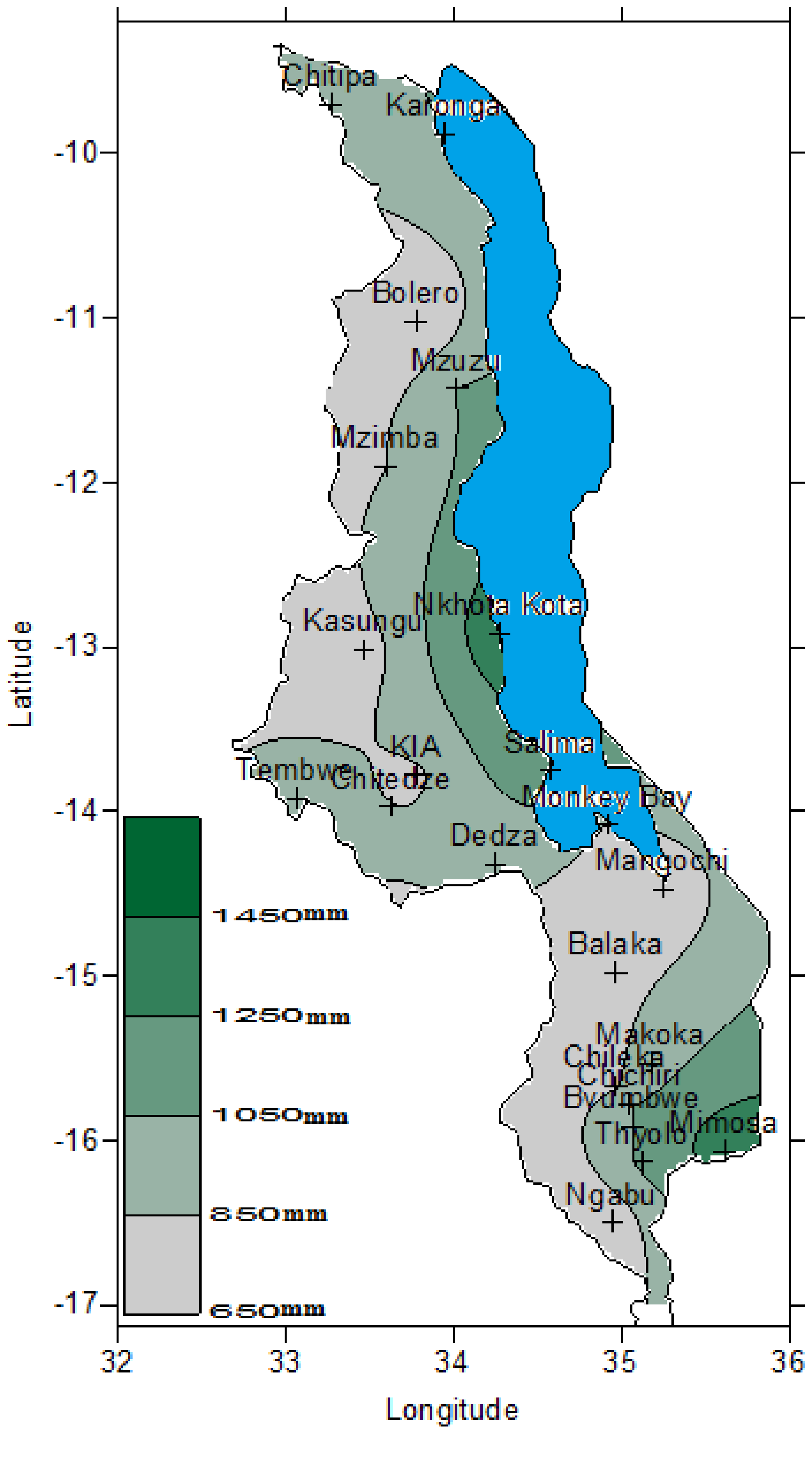

Figure 34: Distribution of seasonal rainfall over Malawi

4.4.2 Mapping of temperature

The spatial distribution of maximum and minimum temperatures both show that high temperatures are recorded in areas along the lakeshore and the Lower shire valley. On the other hand low temperatures are recorded in most of the central areas and the southern highlands. The lake has a moderating effect on temperatures while the Shire valley is at a very low altitude of about 102 meters above sea level.

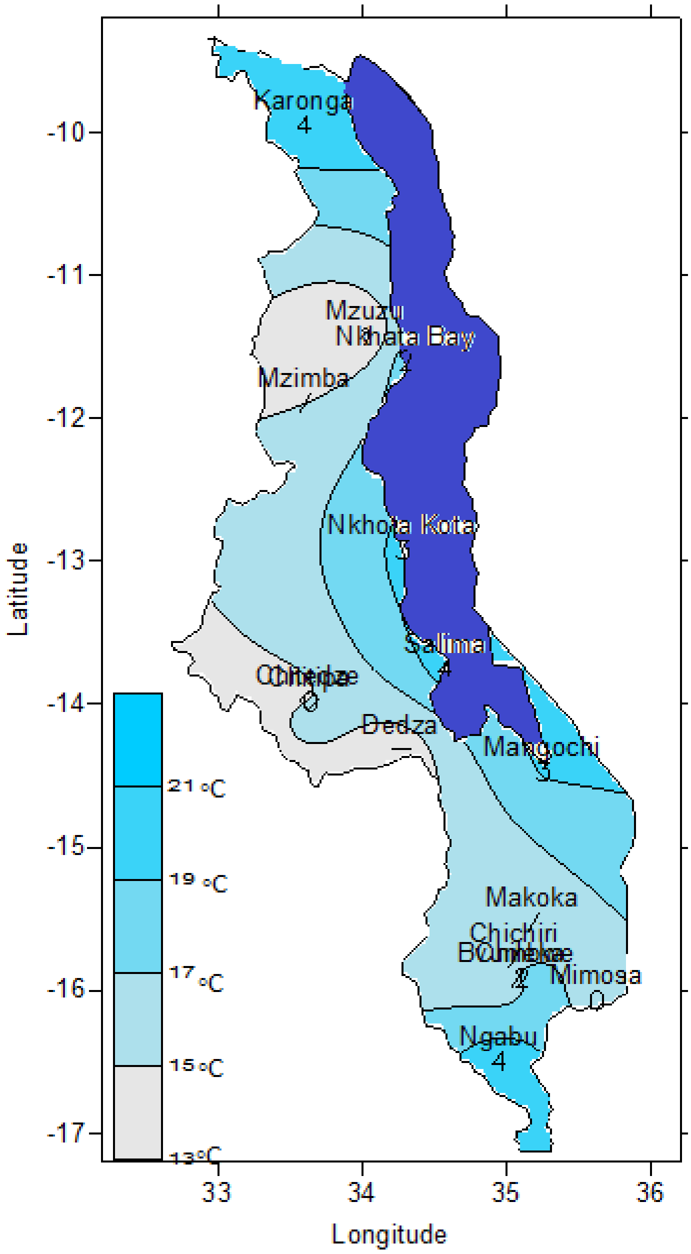

Figure 35: Distribution of minimum temperatures over Malawi

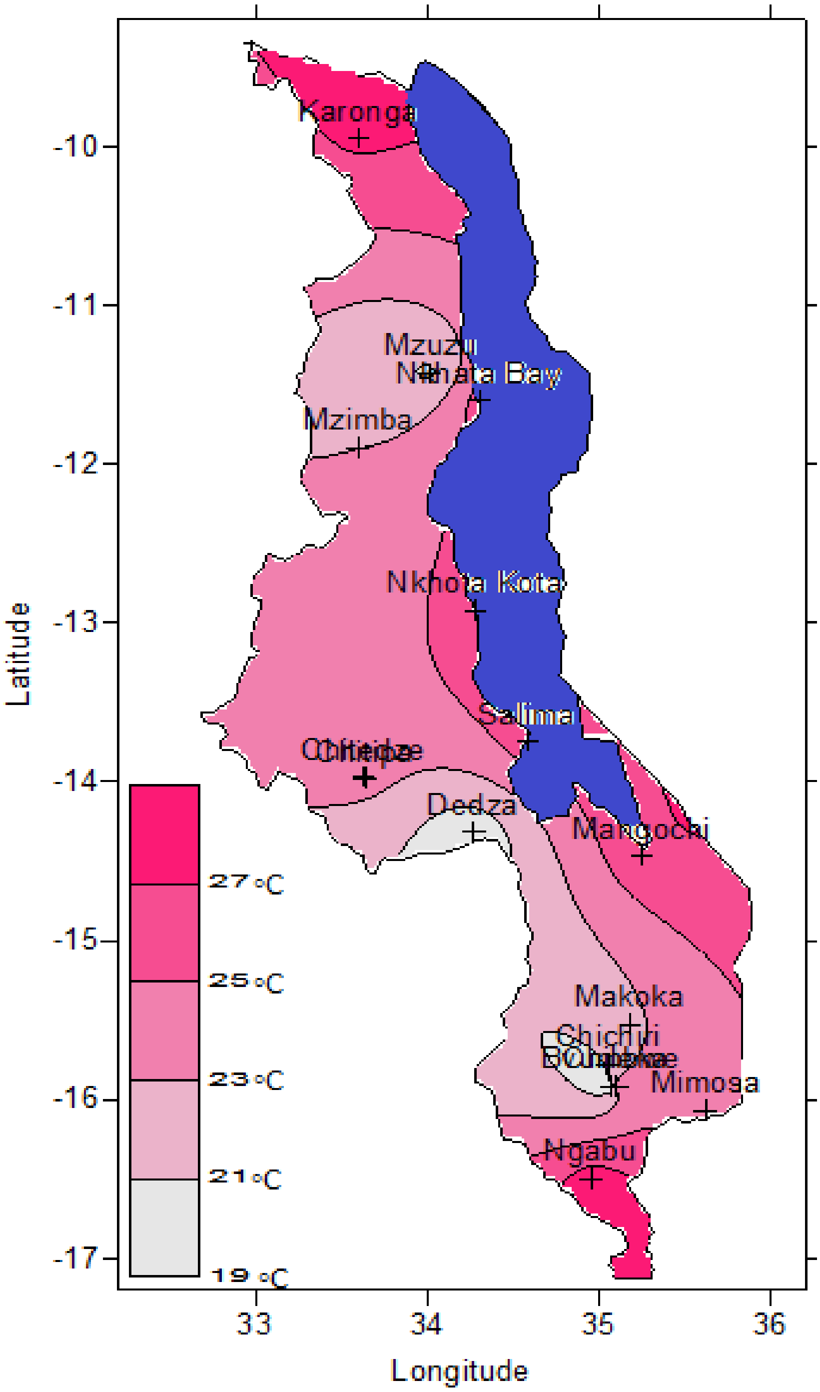

Figure 36: Distribution of maximum temperatures over Malawi

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Summary

The study has examined trends in the rainfall and temperature. This was done by conducting time series and trend analysis. The spatial variability was done using SURFER software to create maps. Temporal variability was also done using time series where graphs were generated using MATLAB software. A student’s t-test was performed to establish if the observed trends were significant.

5.2 Conclusion

Analysis of past climate variations is an important part of understanding climate change. In this study, analysis of rainfall and temperature was done to determine climate change signals. The results from the analysis depict both increasing and decreasing trends in the rainfall and temperature.

Seasonal rainfall and annual rainfall depicted a decreasing trend though not significant over most places. There is a tendency towards a decrease in rainfall compared to increase in rainfall at most places. In addition, there are also significant variations (extremes) in rainfall. This variability in rainfall and the tendency towards decrease is an indication of changing climate.

On the other hand, it was found out that temperatures are increasing. Temperatures during winter and summer season depict a tendency towards increase both in the maximum and minimum temperatures. The trend is significant for most stations.

Therefore, the results suggest that winter and summer temperatures are becoming warmer. Rainfall is decreasing though the trend is not significant. The decrease rainfall and the increase in temperature is an indication of changing climate.

5.3 Recommendation

Climate change studies should be encouraged in order to gain scientific knowledge that can be used to advice policy making. National meteorological services should take a leading role in climate change research and projects. Weather and climate information should be made available and suited for the needs of the users such as farmers.

Further research can be carried out to compare trends of climate parameters to their climatological means to establish if the recent observed climate and weather is becoming more or less extreme. An analysis can be done say for the most recent 10 or 15 years.

In this study, the data available for most of the stations was of less than 60 years. To establish significance of the observed trends, the data was split into two to perform the t-test. The splitting of the data into two sets meant the two sets did not necessarily constitute climatology. Therefore, there is need to analyze data of at least sixty years to come up with good results.

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