ANALYSIS OF RAINFALL CHARACTERISTICS IN TANZANIA FOR CLIMATE CHANGE SIGNALS

PROJECT REPORT

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DECLARATION

I, Emanuel Tumaini, declare that this research project is my original work and has not been presented in any other University for any academic award.

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Dedication

I would like to dedicate this work of my brain and hands to my lovely late father Mr. Albert Tumaini Kidebwana who died in 1989 while I was in the very beginning of my academic journey   and my lovely late mother Mrs. Albert Tumaini Kidebwana (Oliva Simon) who passed away in 2002 the time I started to deal with Meteorological profession as Meteorological assistant trainee. I love you so much and will always miss you and your lovely parental care. I promise to fulfill your academic dreams in my life.

"May Almighty GOD rest your souls in peace of eternal life in his greatest kingdom,
Amen!"

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Abstract

Tanzania as many other countries in Africa depends on rain water for various economic activities in order to achieve its development. The global climate change has not isolated Tanzania, the rainfall climatology of the country has some changes which need to be taken into account while planning for economic activities such as hydro power generation, civil and structural engineering, mining, Agriculture which is the back-borne of the country as it is the main source of employment, foreign currency and revenue.

This study aims at aims examining the rainfall characteristics over Tanzania in order to determine the climate change signals in rainfall characteristics in particular.

The daily, monthly and seasonal rainfall datasets from all the eleven zones in Tanzania covering a period of 48 years from 1961 to 2008 were used. Tanzania meteorological agency is the source of data used.

Arithmetic method was used to estimate the missing data for Loliondo the only station which had missing data. The single line mass curve method was used to test homogeneity of the data for the stations selected to represent each of the eleven zones, results from the mass curve showed all the data from all the seven zones were homogeneous. During analysis, time series and trend methods were used. The eleven zones used in this research project were adopted from the ones used by the Tanzania Meteorological Agency.

This study revealed that all the zones have some changes in their rainfall characteristics as the amounts of seasonal rainfall were found to show decreasing trends in some stations and increasing trends in the others. The time series for the accumulated seasonal rainfall in pentads showed delays in the onsets and cessations while other zones were found to experience delay of onsets and earlier cessations implying the seasons are becoming short. Rainfall characteristics in Tanzania are changing differently in different parts over the country.

The people in the country especially those who are stakeholders of the meteorological services in particular rainfall must be empowered with updates in changes of rainfall climatology. Agriculture as a long time and term back-born of the country should be adequately performed along the current changes in the rainfall characteristics so as to make it sustainable and profitable and therefore avoiding the demerits which normally arise from poor harvests and hence control for the food security.

Chapter One

1.0 Introduction

There has been both increasing and decreasing trend in the change of rainfall characteristics in terms of the delays of rain starts and change in amounts of rain falling over different parts of Tanzania. This study aimed at examining the rainfall characteristics over different regions of Tanzania that is vital for enhancing economic activities such as sustainable Agriculture, Hydro power generation, tourism industry, transportation, civil engineering etc. It important to plan for either economic or social activities in Tanzania with clear knowledge of the climate state and in particular rainfall characteristics such as starts and ends of rain seasons, intensity of the expected rains in different parts of the country as well as the type of the rains that fall in those areas.

Good knowledge of rainfall characteristics over Tanzania is important also in the planning for disaster management. It is clearly known that excess rains result into floods which normally endanger human lives, destroy properties and damage infrastructures and on the other hand excessive deficit of rains cause drought in the country whereby food and commercial crops productions as well as livestock keeping are made difficult and sometimes impossible. Not only agricultural sector is affected but also other economic activities such as hydro power generation. Water that is termed as a vital element in human life as it is greatly used for domestic purposes becomes a problem in case of drought situation.

Climate over the world does not change linearly and therefore the change is not uniformly experienced in all parts in the countries of the world due different natural regional systems influencing climates of the individual countries and anthropogenic activities that take place over the countries of the world.

The analysis of the rainfall dataset from different stations over Tanzania has been done in order to show the trends of changes in the rainfall characteristics over different parts of the country that signals climate change.

1.1 Objectives

Overall Objectives

The overall objective of this study is to examine the rainfall characteristics over Tanzania in order to determine if there are any climate change signals present. The specific objectives include;-

- Determining Quality and consistency of the rainfall data of various stations over Tanzania
- Determining the space and time characteristics of rainfall over Tanzania.

- Determining annual changes and seasonal changes in the rainfall characteristics over Tanzania.

- Carrying out statistical analysis to determine significant trends in the rainfall characteristics over Tanzania.

1.2 Significance of the study

The majority of Tanzanians depend on agriculture for their subsistence living and to some extent for commercial. The development of agriculture in the country has been stagnant for very long time since independence due to poor and luck of latest information on the climate and climatic state of the country in particular rainfall characteristics. On the other hand irrigation agriculture is very important tool for a less developed country like Tanzania as it provides food and commercial produces all year round, but this is only possible with the availability of enough water in the rivers, lakes and dams. Water from these bodies come from rainfall at those areas and neighboring places. Despite the fact that the country is very big as compared to other many neighboring countries and the fertility of the land, Tanzania has frequently been and is still reporting hunger.

Good knowledge of rainfall characteristics of the country is important in the planning for disaster management. Excess rains result into floods which normally endanger human lives, destroy properties and damage infrastructures on the other hand excessive deficit of rain cause drought in the country whereby food production in made impossible as well as commercial crops. Not only agricultural sector is disturbed but also other economic activities such as hydro power generation get worse. Water that is termed as a vital element in human life as it is greatly used for domestic purposes becomes a problem in case of drought situation.

Water for domestic consumption has been a big problem in the country since independence in both rural and urban habitats. There are many reasons contributing to this situation but to a great extent rainfall characteristics play an important role in this matter especially continuous trend of low amounts of rains falling over the country. Domestically water is used for cooking foods, drinking, washing our bodies, cloths and utensils, cleaning environments etc.

Water is also very important in industrial operations as it is used for cooling machines, dilution of materials and washing of different materials for the purpose of cleanliness. In food industry such as production of drinks like sodas, juices, beers etc, the main raw material is water.

Apart from other reasons responsible for problems in hydro power generation such as availability of funds to initiate and run the projects, human capacity etc. availability of sufficient water due to rains is another important reason for the shortage of power in the country as most of the power is produced through hydro power generation. There are several dams in the country which are used for production of electricity such as Kidatu, Nyumba ya mungu, Hagafilo,Mtera,Kihansi etc yet there are power problems in the country and only few people have access to that power especially those in urban areas.

This study aims at determining the characteristics of rainfall over different parts of the country which is vital for enhancing economic activities such as sustainable agriculture , hydro power generation etc.

It is important to plan for both economic and social activities in the country with the clear knowledge of the climate state of the country and in particular rainfall characteristics such as starts and ends of rain seasons, intensity of the expected rain in different parts of the country as well as types of the rains that fall in those areas.

1.3 Area of study

The United Republic of Tanzania lies between latitudes 10°S and 120°S and longitudes 30°E and 40°E. Most part of the western side of the country is covered by waters of Lake Tanganyika; the whole part in the eastern side of the country is bounded by Indian Ocean, where as some parts of it is covered by Lake Victoria and Lake Nyasa in north and south respectively

The neighbouring countries are Kenya and Uganda in the North, Rwanda and Burundi in the North-west, Democratic Republic of Congo to the West, Zambia to the South-west and Malawi and Mozambique to the South.

The United Republic of Tanzania, mainland has an area of about 939,702 square kilometers and the Islands of Zanzibar and Pemba, in the Indian Ocean, occupy an area of 2,643 square kilometers.

The map below shows some regions and islands in an area of study and outside the borders are the neighbouring countries in different sides.

Map 1. A map of The United Republic of Tanzania (source: www.maps.com.© 1997 MAGELLAN Geographix).

1.4 Literature Review

1.4.1 Global Climate Change

Climate change is real and happening now. The average global surface temperature has warmed 0.8°C in the past century and 0.6°C in the past three decades (Hansen *et al.*, 2006,WWF,2006), in large part because of human activities (IPCC, 2001). A recent report produced by the U.S. National Academy of Sciences confirms that the last few decades of the 20th century were in fact the warmest in the past 400 years at the same time, there were distinct changes in the rainfall patterns, an increase in both frequency and severity of extreme weather events, and a rise in sea levels. The impacts of these changes are already being felt and will intensify as further changes take. Another 2-4ºC rise is projected for the current century, mostly as a result of green house gases emissions that have already being emitted, meaning that most of the changes projected to happen in future are inevitable. There are many observed changes in the Earth's climate including atmospheric composition, global average temperatures, ocean conditions, and other climate changes.Arthur *et-al* ,(2008).

1.4.2 Climate change and Rainfall in East Africa

Precipitation patterns in East Africa are more variable; however, historical records indicate that there has been an increase in rainfall over the last century (IPCC, 2001).It is suggested that under intermediate warming scenarios, parts of equatorial East Africa will likely experience 5-20% increased rainfall from December-February and 5-10% decreased rainfall from June-August by 2050. Dry regions are projected to get drier, and wet regions are projected to get wetter:By mid-century, annual average river runoff and water availability are projected to increase by 10-40% at high latitudes and in some wet tropical areas, and decrease by 10-30% over some dry regions at mid-latitudes and in the dry tropics.

1.4.2 Climatology of Rainfall overTanzania

1.4.2.1 Rainfall Seasons

The climate of Tanzania varies with geographical locations; tropical type of climate is experienced along the coast of Indian Ocean whereby it is hot and humid with rain season starting from March to May (MAM).Semi-temperate type of climate is experienced in mountainous areas where short rains are experienced in November –December and long rains during in February-May. Plateau regions are drier with seasonal temperature variation .Rainfall in the country is uniformly distributed throughout the year with the peak in March-May (MAM) season and total rainfall increases northward towards Lake Victoria. Rainfall over Tanzania is governed by two rainfall regimes. Bimodal rainfall, comprised of the long rains of *masika* between March – May and short rains of *vuli* between October – December, is the pattern for the northeastern, northwestern (Lake Victoria basin) and the northern parts of the coastal belt. A Unimodal rainfall pattern, with most of the rainfall during December – April, is more typical of the most of the southern, central, western and southwestern parts of the country (Shardul *et-al*, 2003).

The country's average temperature is between 20°C and 32°C. Average annual rainfall ranges from 600mm to 1,800mm per year under normal conditions and depending on the elevation of a place from sea level. The duration of the dry season is between 5 to 6 months.

The climate over Tanzania is affected by different Climate systems grouped according to the spatial and temporal variations. Both meso scales and macro scale air motions influence the climatology and in particular the rainfall characteristics of the country. These are briefly discussed in the section below.

1.4.2.2 Inter Tropical Convergence Zone (ITCZ)

Inter tropical convergence zone (ITCZ) is the tropical pressure trough characterized with surface wind discontinuity, maximum sea surface temperatures, low level convergence, cloudness and precipitation .The ITCZ is formed by vertical ascent of warm moist air near the equator due to horizontal convergence of air from north to south .The Inter tropical convergence zone plays very significant role in the climate of Tanzania. The ITCZ crosses the equator and always lie within the tropical belt. The movement of the zone with respect to sun's positions in both hemispheres of the earth determines the rainfall variability and so the rainfall seasons over the country. if the sun is in the north of equator, northern parts of Tanzania receives more rains and if the sun is in the southern hemisphere the southern parts of the country receives more rains.

1.4.2.3 Monsoons

Monsoons are flow patterns that reverse their direction with regularity and persistence every year owing to thermal contrasts between continents and oceans. Examples of monsoon circulations include the southeast, southwest, northeast and northwest monsoons .Monsoons originate from Asia and as they move across the Indian Ocean towards Africa they come with a lot of moisture sufficient enough to form clouds and thereafter rains over Africa and so Tanzania.(Opijah .F.J , 2005)

1.4.2.4 Easterlies

Tanzania is within the tropical belt of the planet earth. The tropical belt is characterized by the easterlies, the moisture carried by these easterlies contribute a lot to the humidity content of the atmosphere and therefore rainfall characteristics over the country.

1.4.2.5 Congo Basin Air Mass

Air mass from the Congo basin also plays an important contribution to the climate of Tanzania. The air mass from the westward side of the Lake Tanganyika use to drag sufficient moisture across Lake Tanganyika towards Tanzania. Most parts that are affected by the influence of Congo basin are those areas over the western parts of the country.

1.4.2.6 Jet streams

Jet streams are strong narrow currents concentrated along quasi stationary axis characterized by vertical and lateral wind shears and featured by one or more velocity maxima. There are several Jet streams which drive moisture from the Indian Ocean towards the continent Africa through Tanzania and therefore influencing the climatology of Tanzania in particular seasonal and annual rainfall characteristics of the country. Examples of the influential Jet streams over Tanzania are East Africa low jet stream (EALLJ), Tropical easterly Jets etc. Tilya (2007)

1.4.2.7 Tropical cyclones

Tropics are characterized by high temperatures as a result of intense solar heating all year round. The maximum solar isolation causes tropics to have low pressures and the centers for these pressures are called the tropical cyclones. A tropical cyclone usually consists of a closed circulation vortice with a radial distance of about 100 – 200 kilometers. Tropical cyclones usually occur at pole ward sides of the Inter tropical convergence zone. Tropical cyclone brings about rainfall over Tanzania, if it orients the westerlies or Congo basin air mass to extend towards the country. Sometimes tropical cyclones do the opposite to disorganize the circulations (i.e. the westerlies, Congo basin air mass) hence causing shortage of rainfall over Tanzania (Tilya, 2007).

1.4.2.8 Subtropical Anticyclones

The subtropical Anticyclones are the high pressure centers within the subtropics in the descending arms of the Hadley cells of the atmospheric general circulation. The anticyclones create pressure difference between the equatorial regions and the tropics which are essential in the drive of the tropical easterlies (trade winds).There are four anticyclones which are the Arabian high, Mascarene high, St. Hellena and Azores high, these anticyclones affect the wind flow patterns over Tanzania. The Arabian high drives strong and moist north easterlies towards the country during short rain season while the Mascarene high tend to drive strong and moist winds towards Tanzania during the March – May (MAM) season. Intensification in the strength of the St.Helena high implies stronger moist westerlies and therefore a stronger meridional arm of the ITCZ and therefore cloudness and rainfall over the country. The four anticyclones are most intense during the winter seasons of each Hemisphere and weaker during summer (Tilya, 2007).

1.4.2.9 El Nino Southern Oscillation (ENSO)

The El Nino Southern oscillation refers to the anomalous see-saw pressure pattern at mean sea level that occurs when the atmospheric pressure is abnormally high at Darwin in northern Australia and unusually low at the Pacific island of Tahiti and vice versa. When the El Nino Southern Oscillation is negatively developing, the central and eastern tropical Pacific Ocean become warm and the tropical Pacific easterlies decrease in strength resulting to rainfall over Eastern Africa and Tanzania in particular. The positivity and negativity development of the El Nino Southern oscillation is measured by the Southern Oscillation Index (SOI).When the SOI is positive the opposite of El Nino occurs which is referred to as the La Nina

1.4.2.10 Indian Ocean Dipole (IOD)

The Indian ocean dipole is referred to as the occasional occurrence of simultaneous anomalous warming and cooling or vice versa of sea surface temperatures (SST) anomalies between western equatorial Indian Ocean (50^0 E - 70^0 E, 10^0 S - 10^0 N) and southeastern equatorial Indian Ocean (90^0 E - 110^0E, 10^0 S - equator).The Indian Ocean Dipole has an influence in the rainfall variability over Tanzania due to the fact that when the IOD is positively developing the winds in the equatorial Indian Ocean tend to blow from the east to west in the continental Africa driving moist air and enhance the clouds formations and therefore rainfall over the country. The opposite happens when the IOD is negatively developing. In this case the atmosphere over the east African region and in particular Tanzania becomes stable with cooler temperatures as a result no clouds development and therefore the area lacks rainfall.

1.4.2.11 Quasi Biennial Oscillation

The Quasi Biennial Oscillation abbreviated as QBO is referred to as the quasi reversal oscillation found in the tropospheric and stratospheric zonal wind from easterly to westerly components and vice-versa with periodicity of about 23-30 months. The reversal occurrence of the QBO is associated with the rainfall variability in the Tanzania. The association between the QBO and the rainfall variability is strengthens during boreal summer and weakens during boreal winter season. (Okollah, 2004)

1.4.2.12 Madden Julian Oscillation (MJO)

The Madden-Julian Oscillation is identified as an equatorial traveling pattern of anomalous rainfall. The Madden Julian Oscillation is characterized by an eastward progression of large regions of both enhanced and suppressed tropical rainfall, observed mainly over the Indian Ocean and Pacific Ocean. The anomalous rainfall is usually first evident over the western Indian Ocean, and remains evident as it propagates over the very warm ocean waters of the western and central tropical Pacific before becoming nondescript as it moves over the cooler ocean waters of the eastern Pacific but reappears over the tropical Atlantic and Indian Ocean. The wet phase of enhanced convection and precipitation is followed by a dry phase where convection is suppressed. Each cycle lasts approximately 30-60 days. The MJO sometimes referred as the 30-60 day oscillation or intra seasonal oscillation influences the rainfall variability over the southern parts of Tanzania (Mpeta E.J and Mark R.Jury, 2001)

1.4.2.13 Land and Sea Breezes

The meso scale air motions which play important role in the climate of the country are land and sea breezes. As it is known that the country is bordered by the Indian Ocean in the eastern side. Movement of the moist air from the ocean towards the country add moisture content of the atmosphere and form convective clouds and hence convective rains especially over the coastal areas. This means that availability of rains depends upon the solar isolation over the Indian Ocean which prompts the evaporation process. Sea breezes occur during day times while land breezes occur during night times. During land breezes, air move from the land towards the sea but the air from the land is to a great extent dry but as the air enters the ocean it acquires moisture and sometimes sufficient enough to form clouds and hence rains over the islands of Zanzibar and Pemba.

Chapter Two

2.0 Data and Methodology

2.1 Data

Daily, monthly and seasonal datasets from synoptic stations over different parts of Tanzania have been used during analysis. These data were obtained from the archives of Tanzania Meteorological Agency. The data cover a period of 48 years from 1961 to 2008.During analysis, seasonal rainfall data from the eleven Tanzania's rainfall homogeneous zones were used to show the trends of rainfall amounts for the various zones and incase of starts and ends of rain seasons, daily rainfall data from Bukoba a station from the Bimodal regime was used and on the other end daily rainfall data for the unimodal regime was represented by a station named Songea.

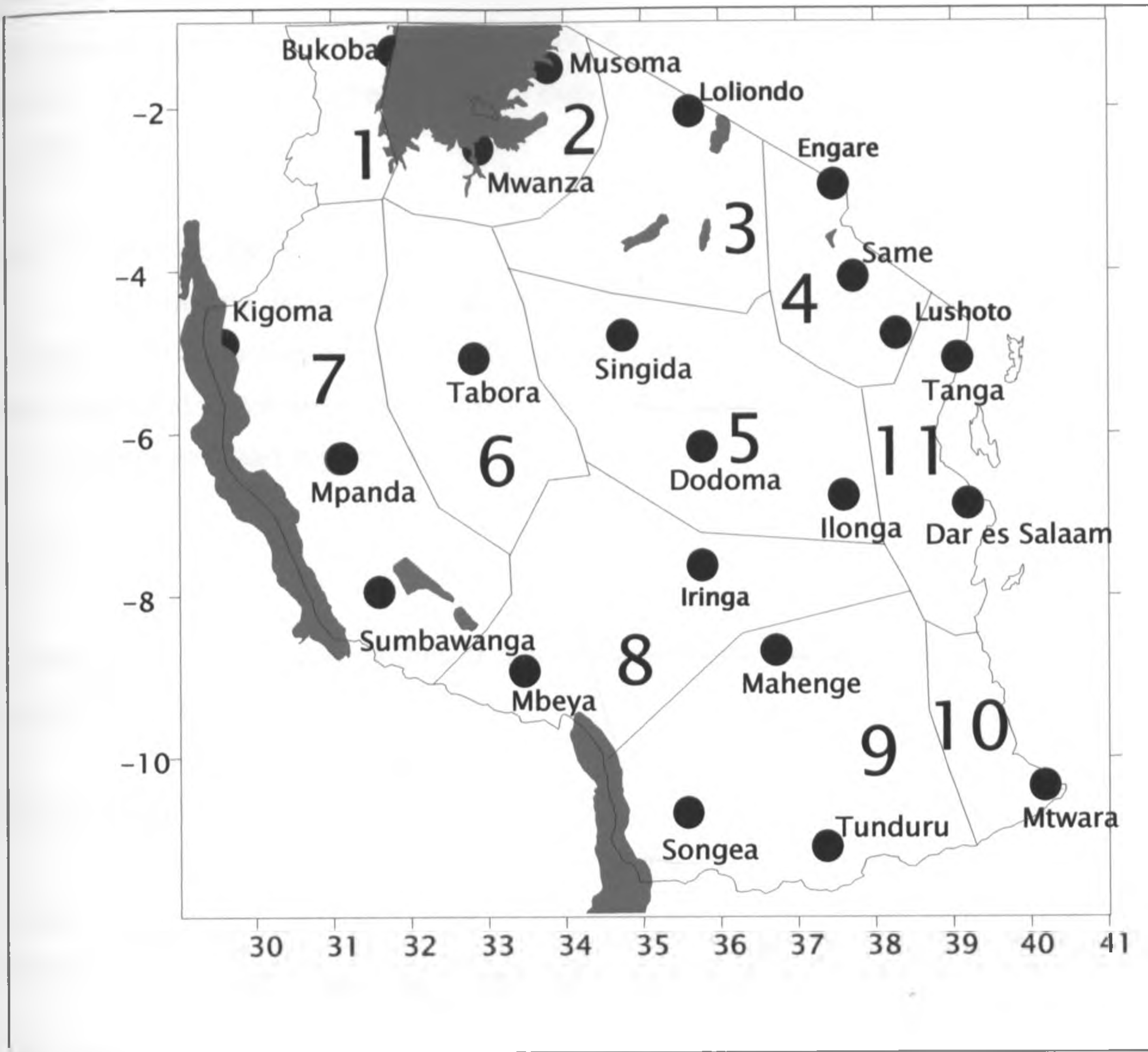
2.2 Rainfall Homogeneous Zones.

The rainfall homogeneous zones represent the areas which experience similar rainfall characteristics. These zones were adopted from the already existing ones that are used by the Tanzania Meteorological Agency. There are eleven zones in the country. Below is the list of regions in all the eleven zones.

Zones	Regions/stations
1	Kagera (Bukoba)
2	Mwanza and Musoma
3	Arusha and Manyara
4	Kilimanjaro (Same ,Engare and Lushoto)
5	Singida, Dodoma
6	Tabora
7	Kigoma, Rukwa (Mpanda and Sumbawanga)
8	Iringa and Mbeya
9	Songea,Tunduru and Mahenge (Morogoro)
10	Mtwara and Lindi
11	Dar es salaam and Tanga

Table 1.Rainfall homogeneous zones with respective stations in Tanzania

Below is the map of Tanzania showing rainfall Homogeneous Zones in Tanzania



Map 2 (Map Source: www.meteo.go.tz,TMA © 1999)

2.3 Methodology

There are several methods which will be used in data quality control and analysis of the data as explained hereunder.

2.3.1 Data Quality Control

Data quality control is a very important procedure that needs to be done in order to clean the dataset and put them in standard format reasonable for analysis. Unclean dataset is normally due to different problems which arise from the way they are acquired, transmitted from the stations to the collection center as well as achieving. In this research work, Arithmetic Mean method and single mass curve method have been used for data quality control and data consistency respectively.

2.3.1.1 Missing Data

All stations with missing data exceeding 10% have been ignored in the research and only those stations with missing data below 10% were considered and subjected to Arithmetic Mean Method for estimations.

The Arithmetic Mean is given by,

$$\left(\frac{1}{n}\right)\cdot\sum_{1}^{n} x_i$$

Where by 'n' is the total number of the elements in the series and x_i is the i^{th} element of the series

2.3.1.2 Data Consistency

Consistency of the dataset has been done using a method called Single mass curve .In this method ,curves of accumulated rainfall dataset against time were plotted in order to check and correct the outliers.

2.3.2 The Time series analysis

The time series analysis has been used to determine the trend or series of change in rainfall characteristics over the 48 years period of time. In Time series analysis graphs of rainfall dataset (i.e. annual, monthly and daily) were plotted against time in order to analyse the daily and seasonal rainfall trends over different zones of Tanzania.

2.3.3 The Trend analysis

The Trend Analysis method was used in order to determine the rainfall trends over various parts of the country with respect to time so as to depict the changes in rainfall characteristics. In this method the aggregated rainfall dataset were plotted against time.

Chapter Three

3.0 Results and Discussions

3.1 Data Quality Control

Missing Data

In case of missing data, arithmetic mean method was used for estimation of a record. The method was applied for estimation of records in zone 4 which is represented by Loliondo, all other stations in all zones had complete data.

Data Consistency

All datasets before analyses must be consistent. Consistency is essential for homogeneity.

In this research project, homogeneity of the data was tested by using single line mass curves for all the seasonal rainfall in all the 11 representative stations of the respective zones for the period of 48 years from 1961 to 2008.cummulated seasonal rainfall records were plotted against time (years) and straight lines along the trends confirmed for the homogeneity of the data in all the zones. below are the samples of the mass curve plots from both rainfall regimes.

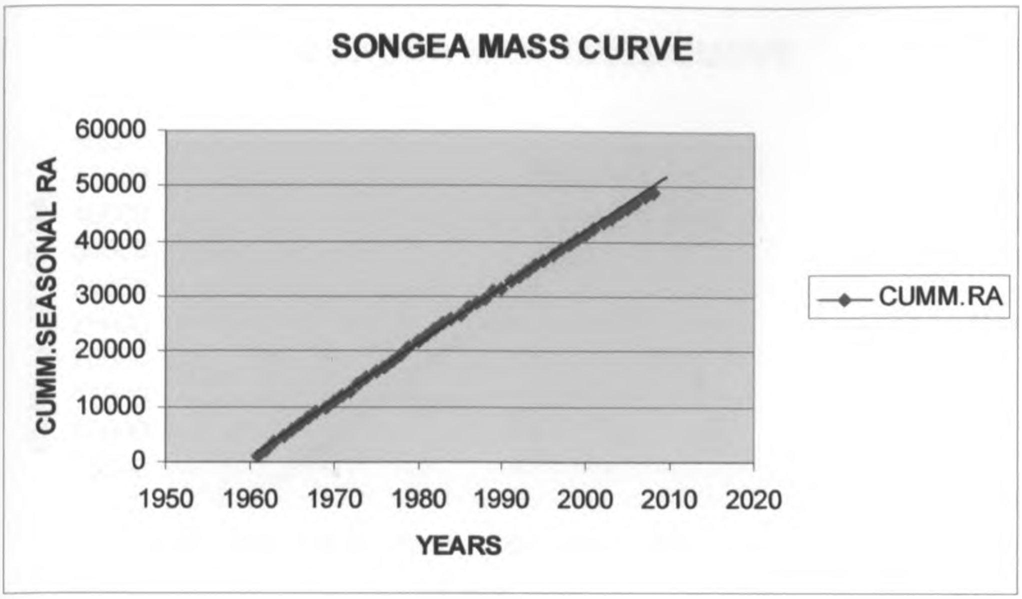


Figure 1 Songea mass curve

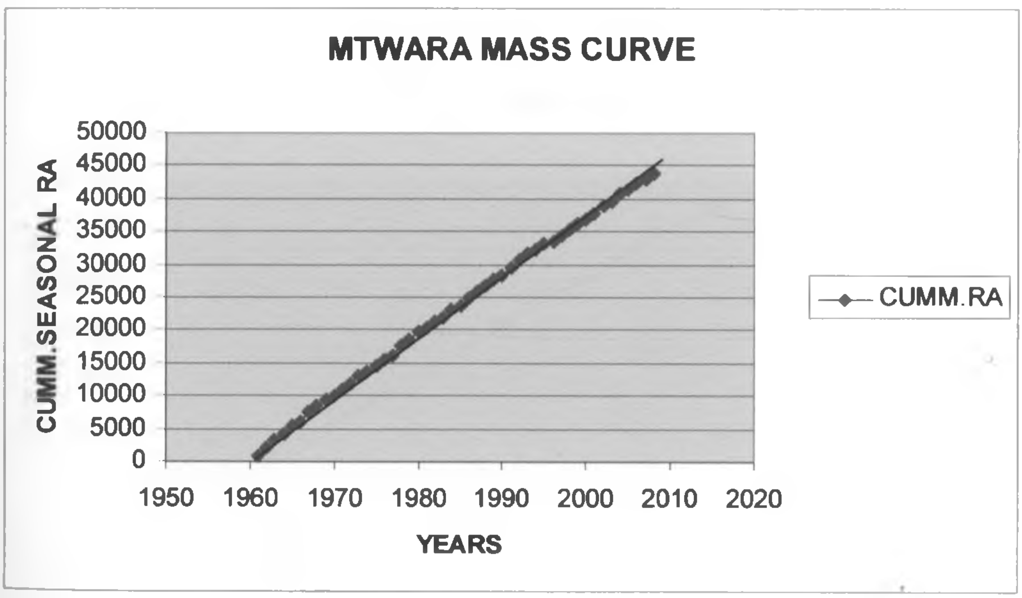


Figure 2 Mtwara mass curve

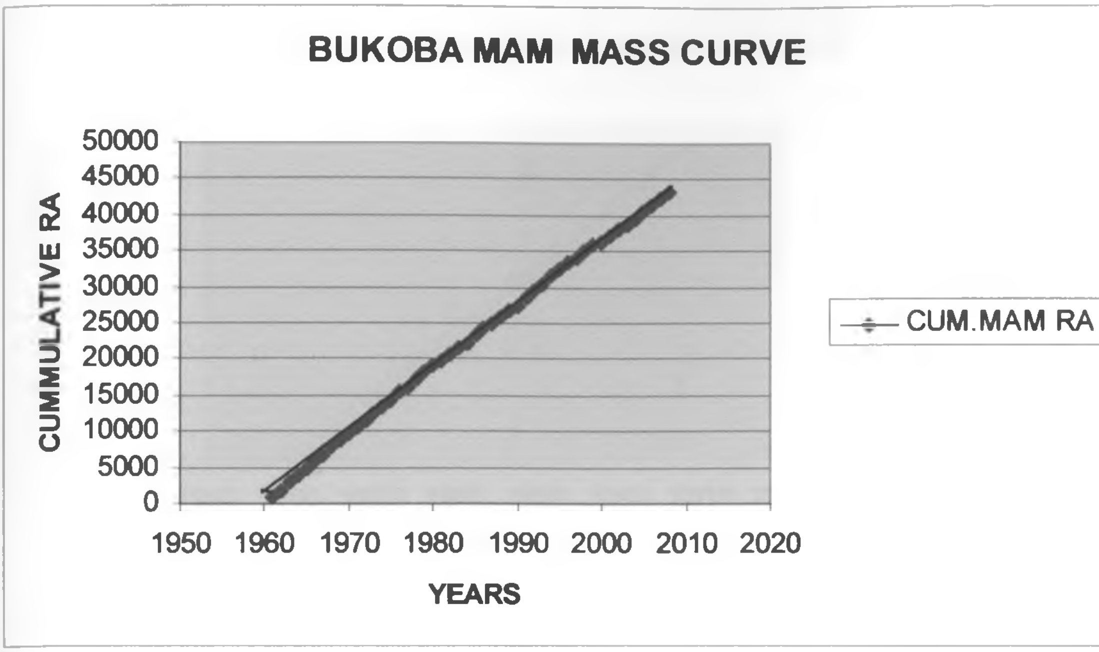


Figure 3 Bukoba mass curve for MAM Season

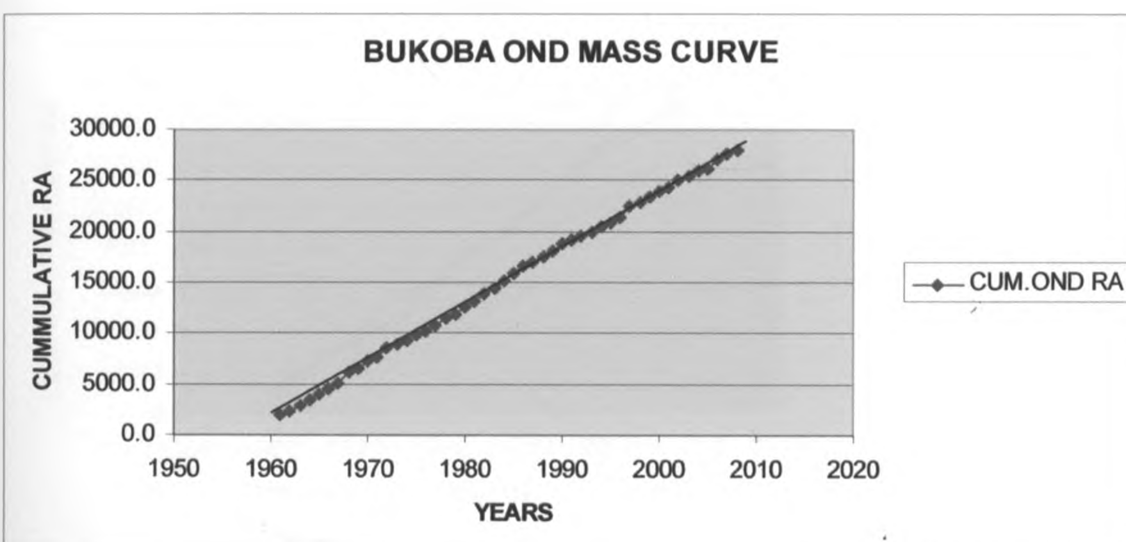


Figure 4 Bukoba mass curve for OND season

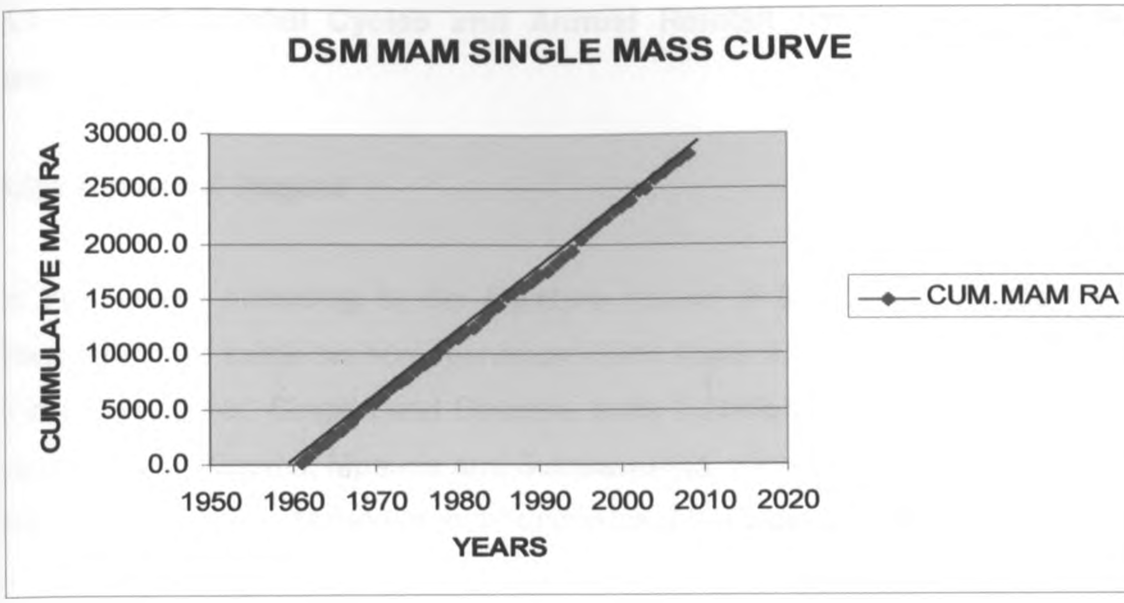


Figure 5 Dar es salaam mass curve for MAM Season

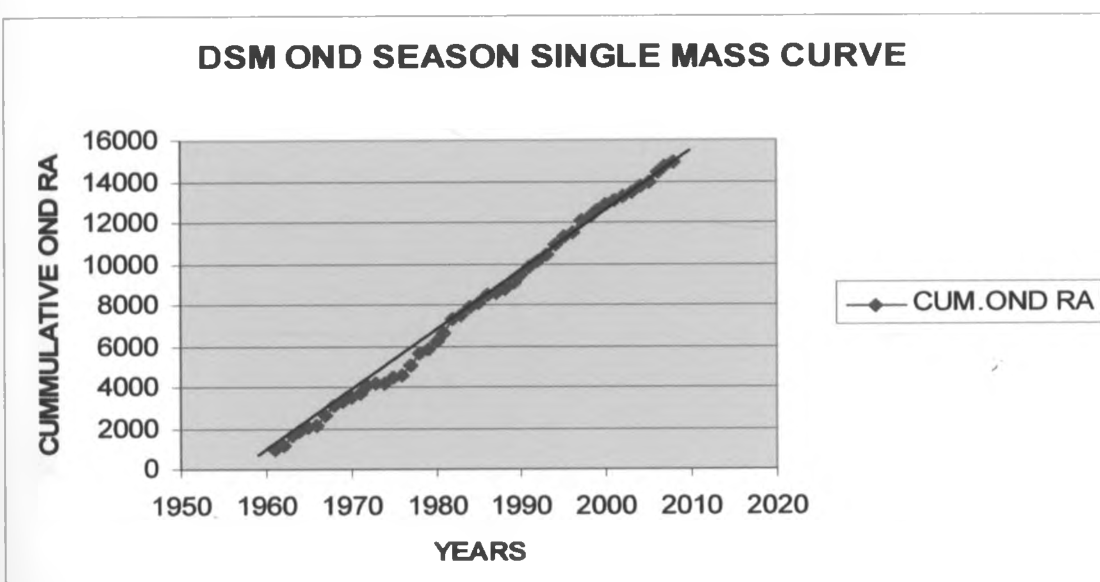


Figure 6 Dar es Salaam mass curve for OND Season

The results and discussion are categorized into two; the one for unimodal rainfall regime and the other is for the bimodal rainfall regime.

3.2 Annual Rainfall Cycles and Annual Rainfall time series and trend analyses

3.2.1 Unimodal Regime

In this regime according to the literature review of the rainfall climatology of Tanzania there exists six homogeneous zones (zone 5,6,7,8,9 and 10).The zone 5 is comprised of Singida and Dodoma, zone 6 comprises of Tabora ,zone 7 is comprised of Kigoma, Mpanda and Sumbawanga, zone 8 has Iringa and Mbeya, zone 9 has Songea ,Mahenge and Tunduru and the zone 10 has Mtwara.

Here below are the rainfalls annual cycles for the zones with a unimodal rainfall regime.

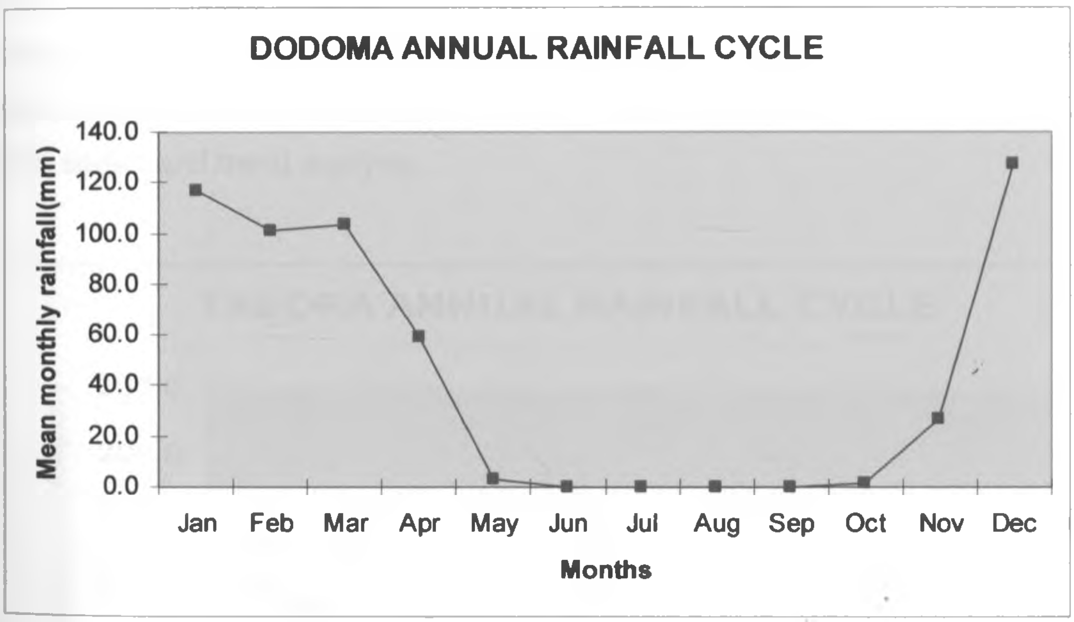


Figure 7 Dodoma annual rainfall cycle

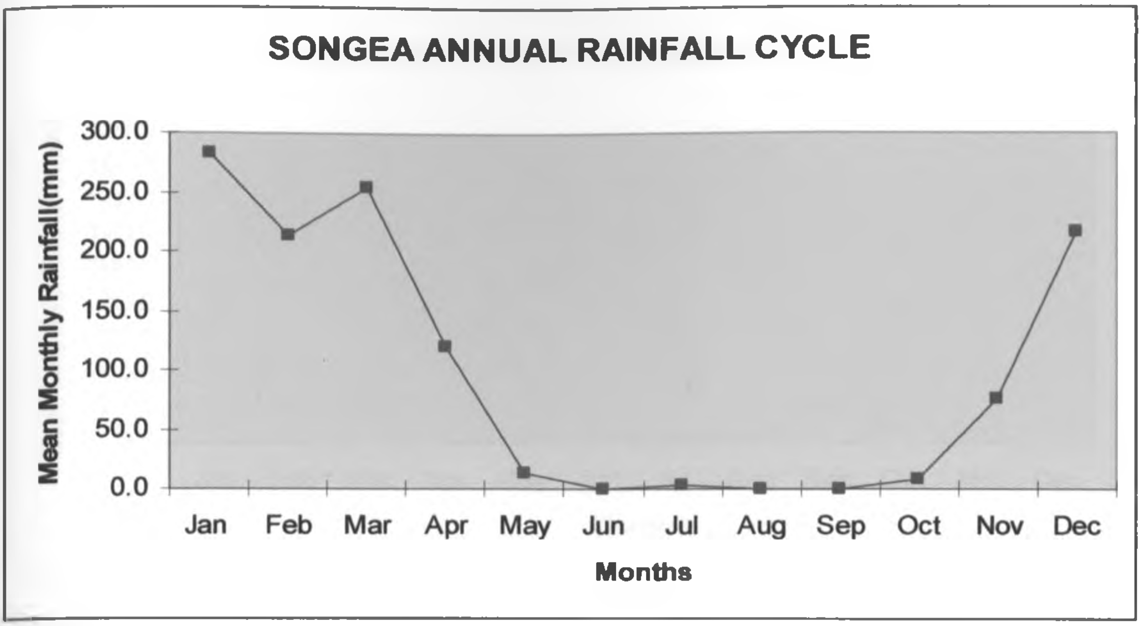


Figure 8 Songea annual rainfall cycle

The figure 8 above is for time analysis of rainfall for the period of 48 years from 1961-2008.

Zone 6 is comprised of only one region which is Tabora. Below are the graphs for time series and trend analysis.

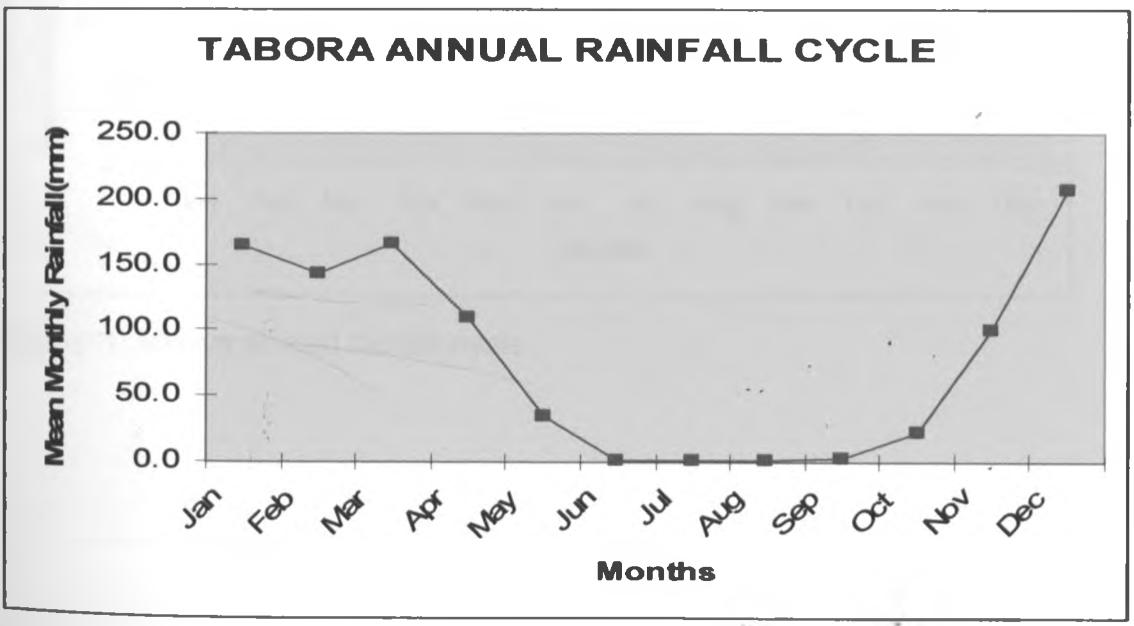


Figure 9Tabora annual rainfall cycle

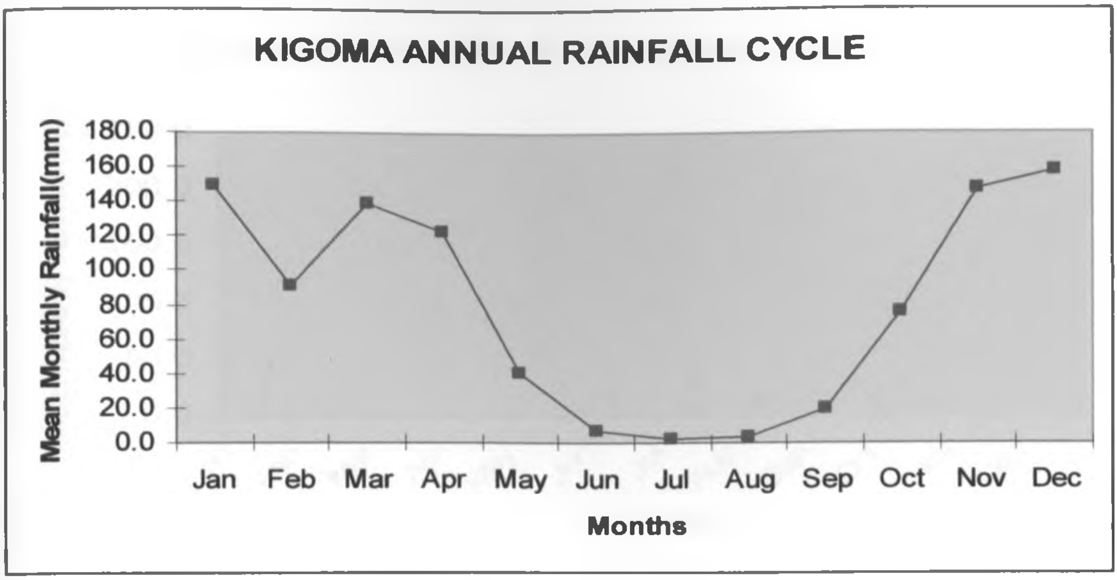


Figure 9 Kigoma annual rainfall cycle

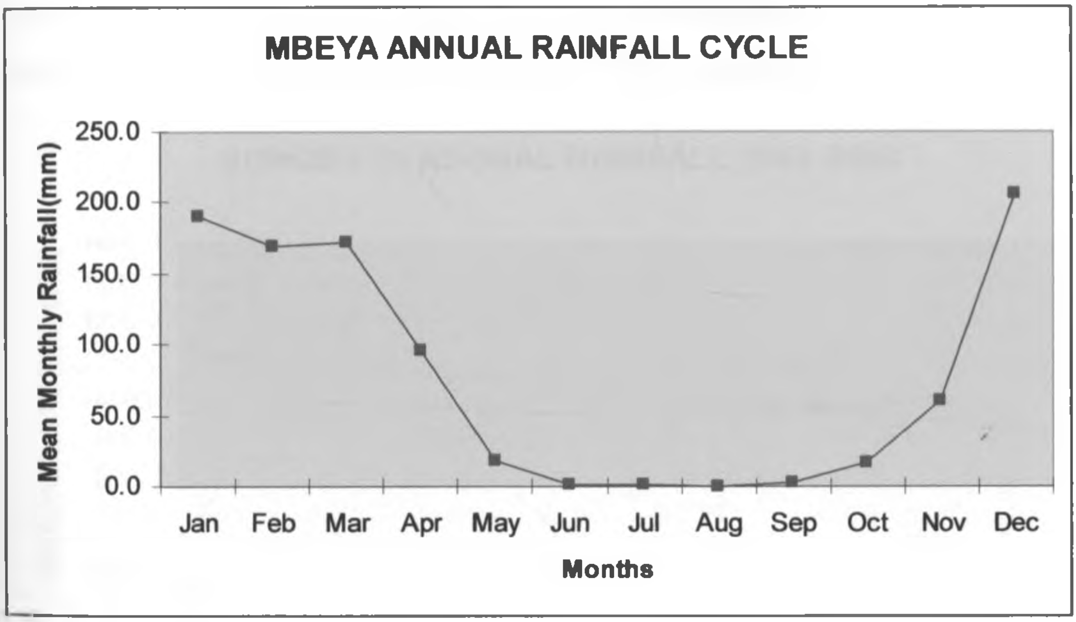


Figure11 .Mbeya annual rainfall cycle

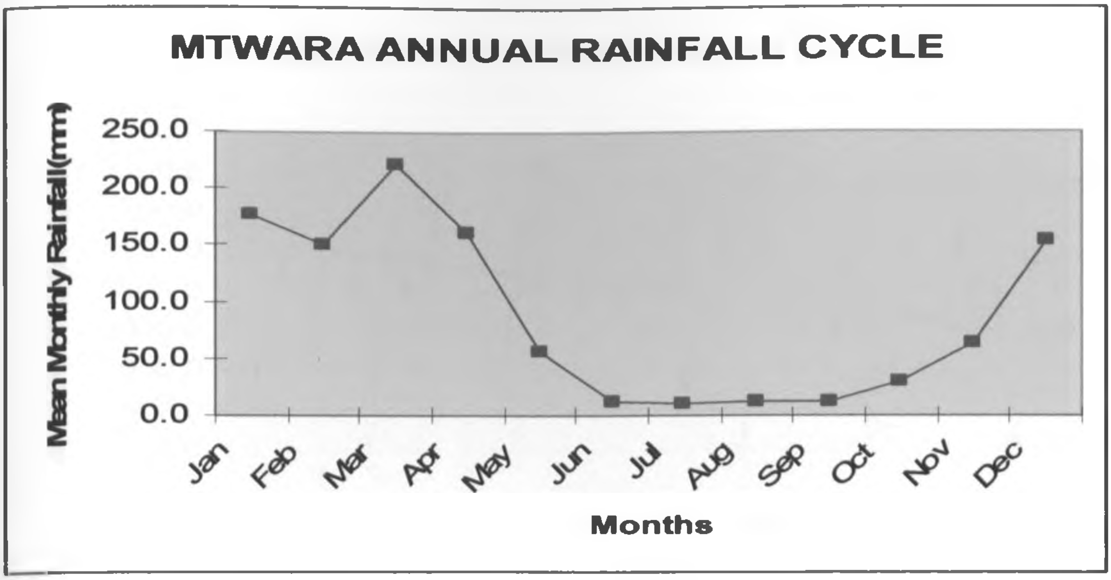


Figure 12.Mtwara annual rainfall cycle

Here below are the plots for time series and trend analyses for the representative stations from the zones with the unimodal rainfall regime

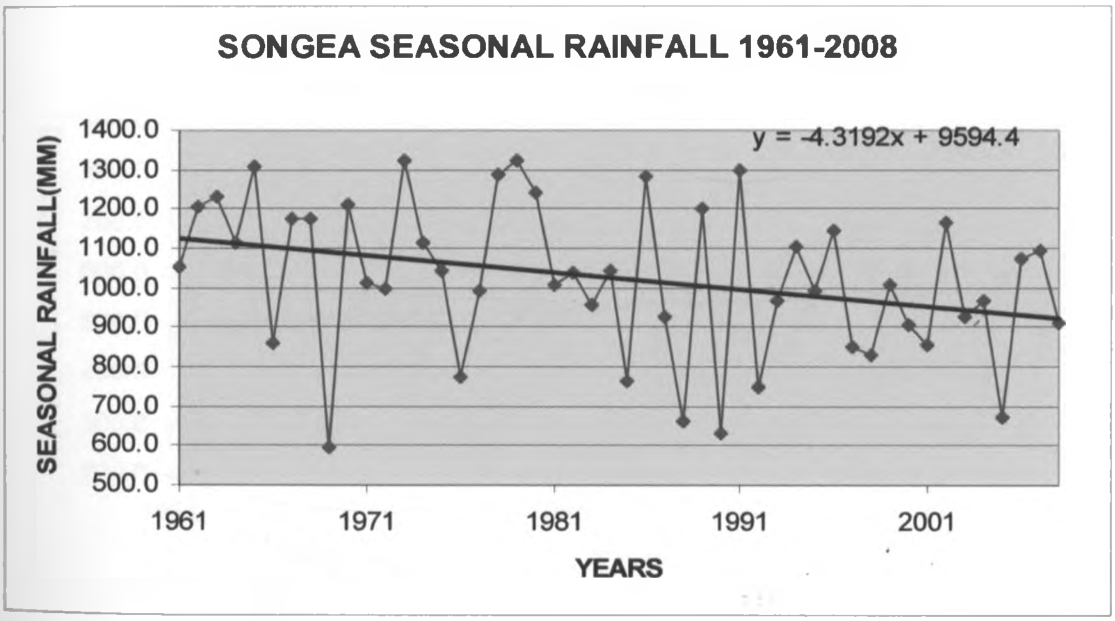


Figure 13 Songea seasonal rainfall time series and trend analysis graph for 1961-2008

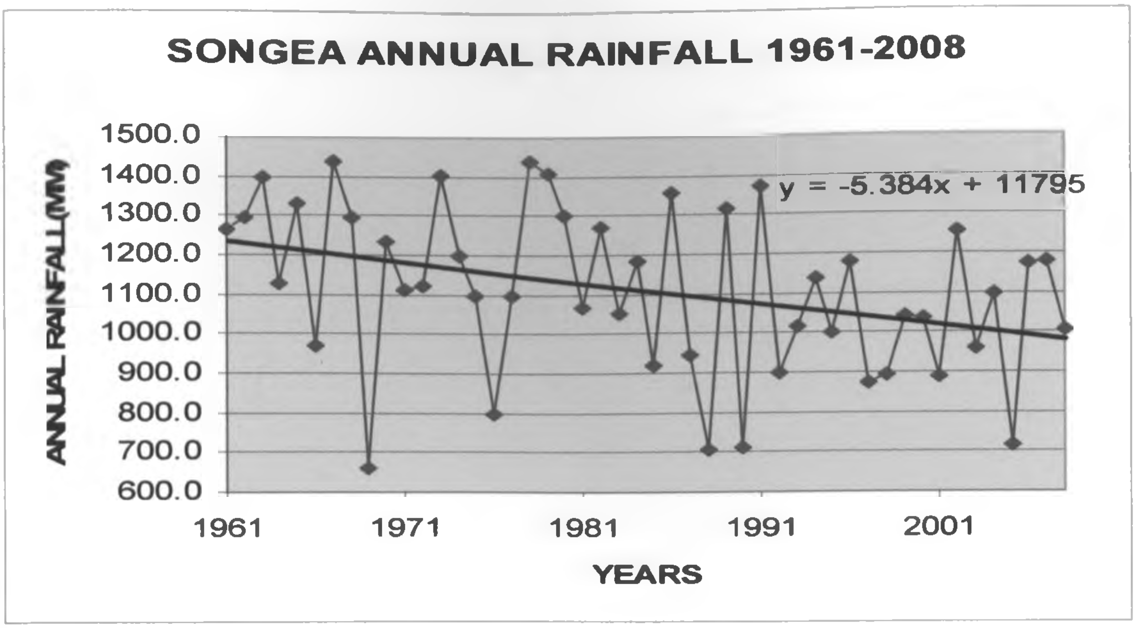


Figure 14. Songea annual rainfall time series and trend analysis graph for 1961-2008

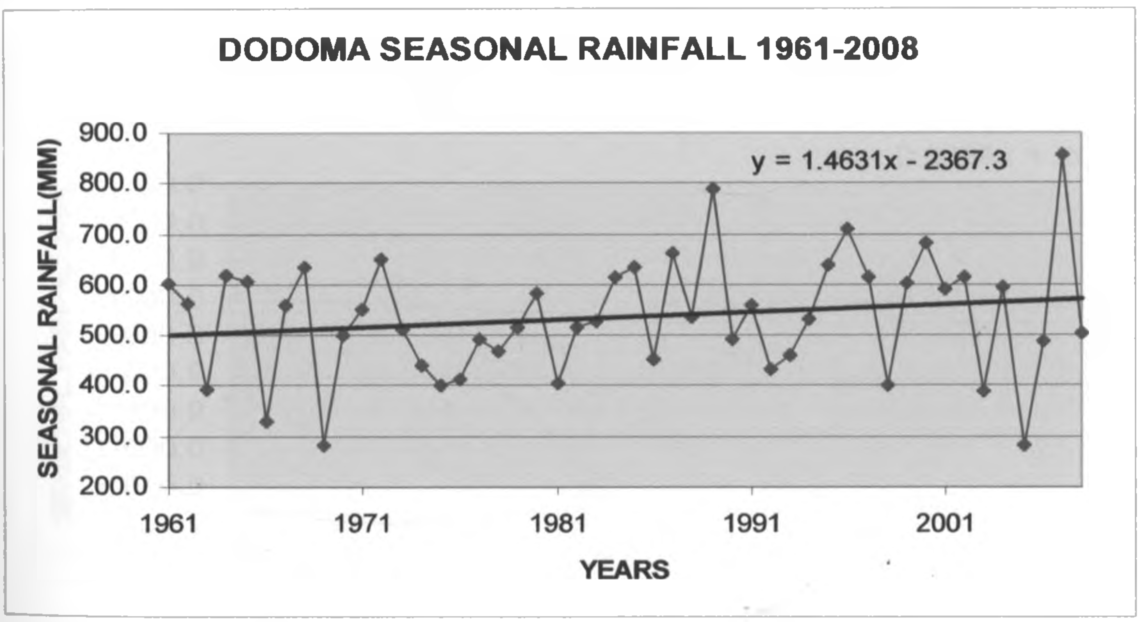


Figure 15. Dodoma seasonal rainfall time series for 1961-2008

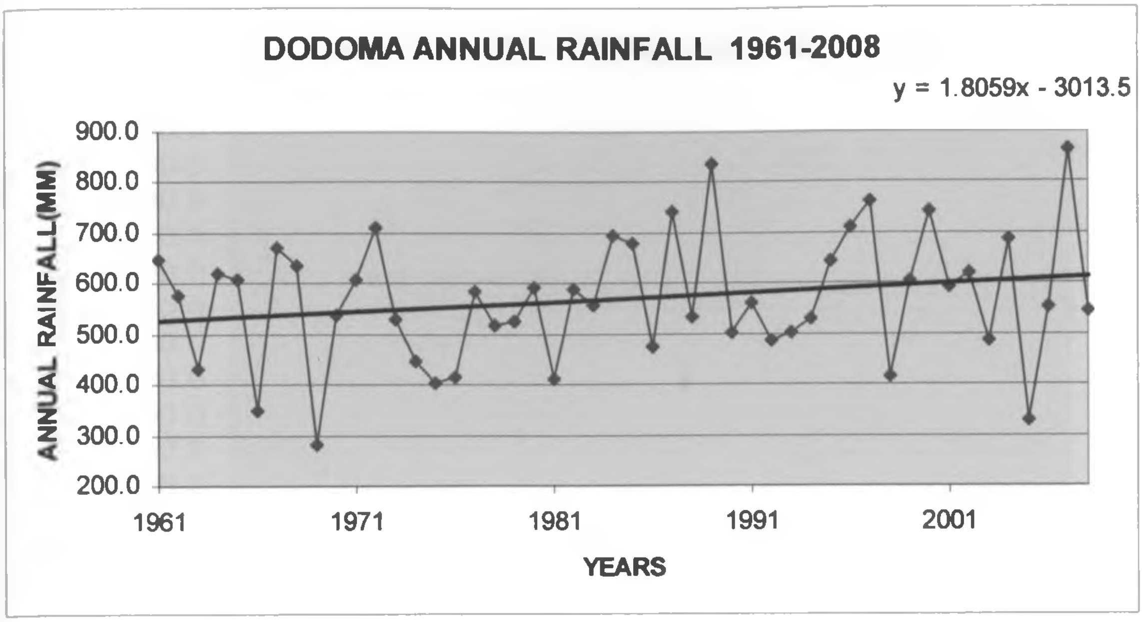


Figure 16. Dodoma annual rainfall time series and trend analysis graph for 1961-2008

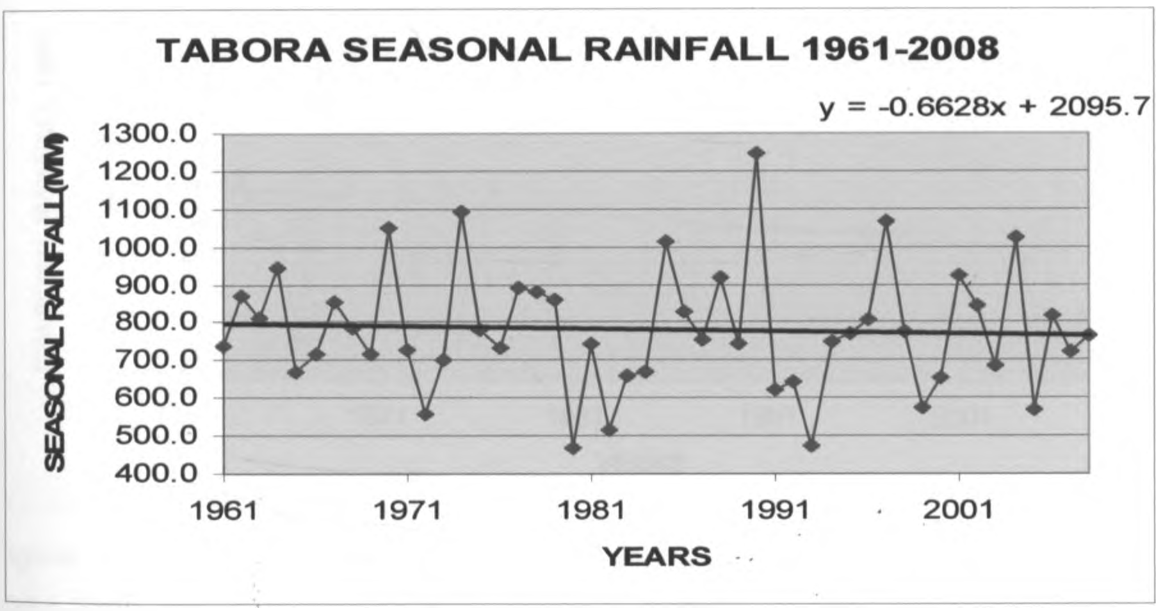


Figure 17. Tabora seasonal rainfall time series and trend analysis graph for 1961-2008

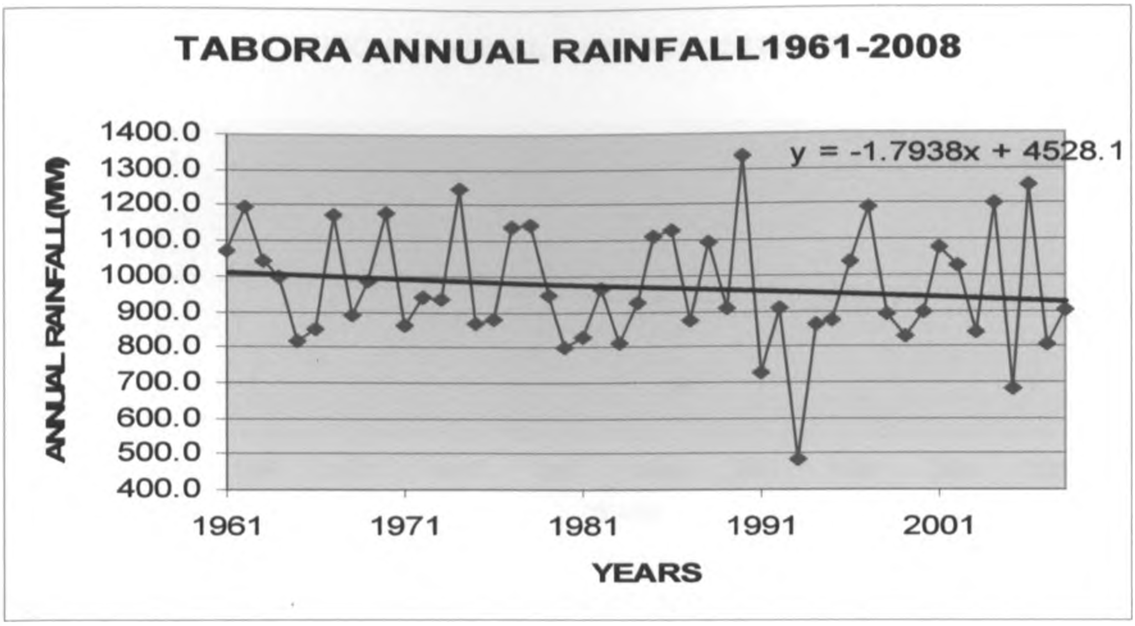


Figure 18 Tabora annual rainfall time series and trend analysis graph for 1961-2008

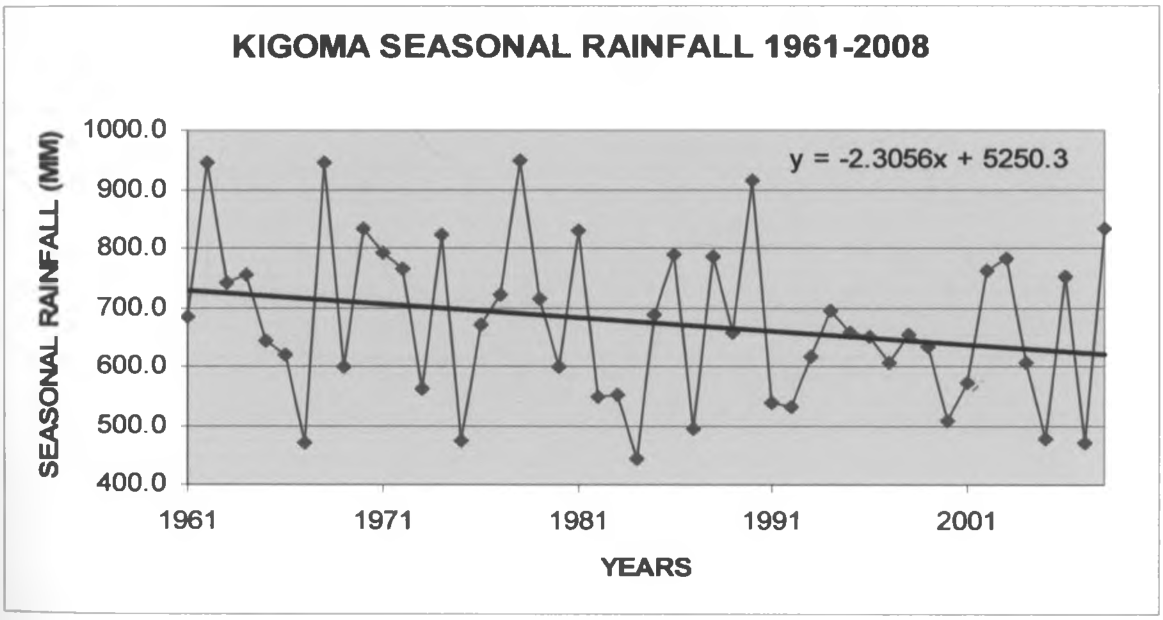


Figure 19 Kigoma seasonal rainfall time series and trend analysis graph for 1961-2008

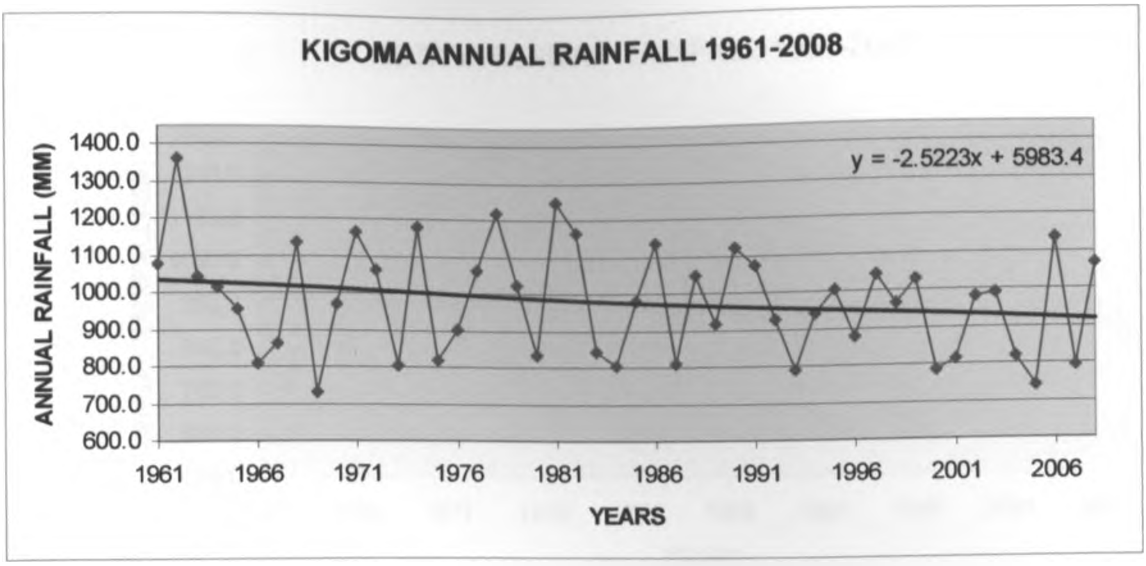


Figure 20. Kigoma annual rainfall time series and trend analysis graph for 1961-2008

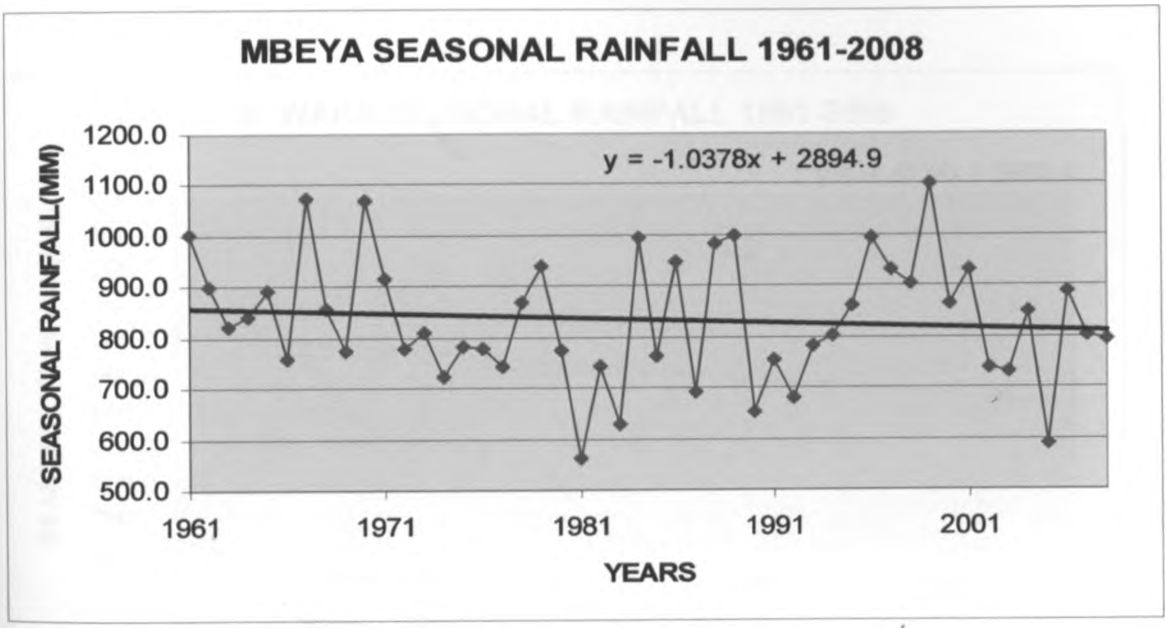


Figure 22 Mbeya annual rainfall time series and trend analysis graph for 1961-2008

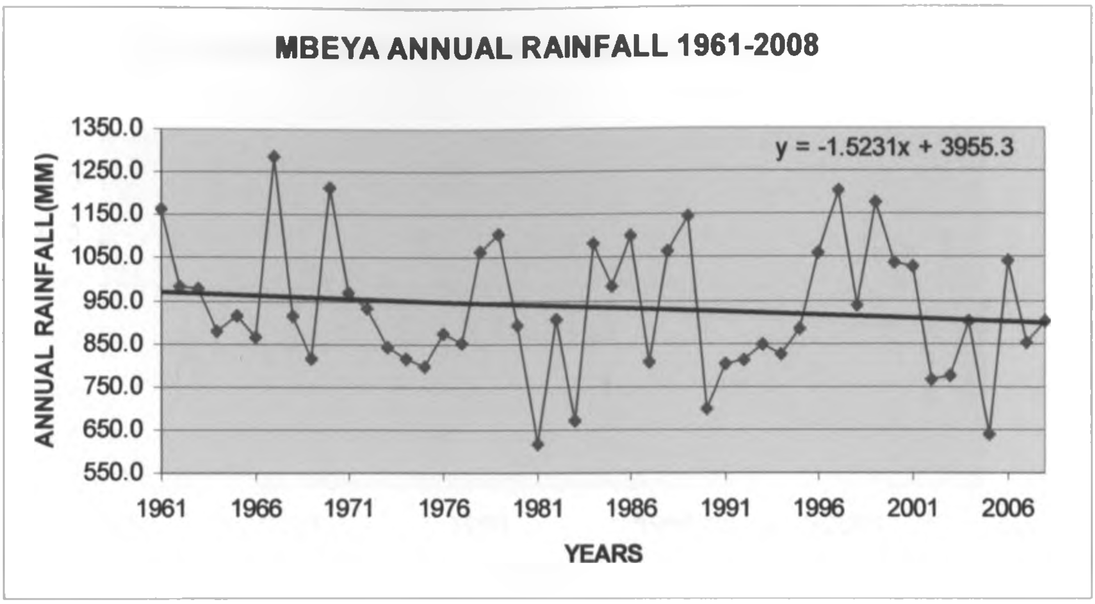


Figure 23 Mbeya annual rainfall time series and trend analysis graph for 1961-2008

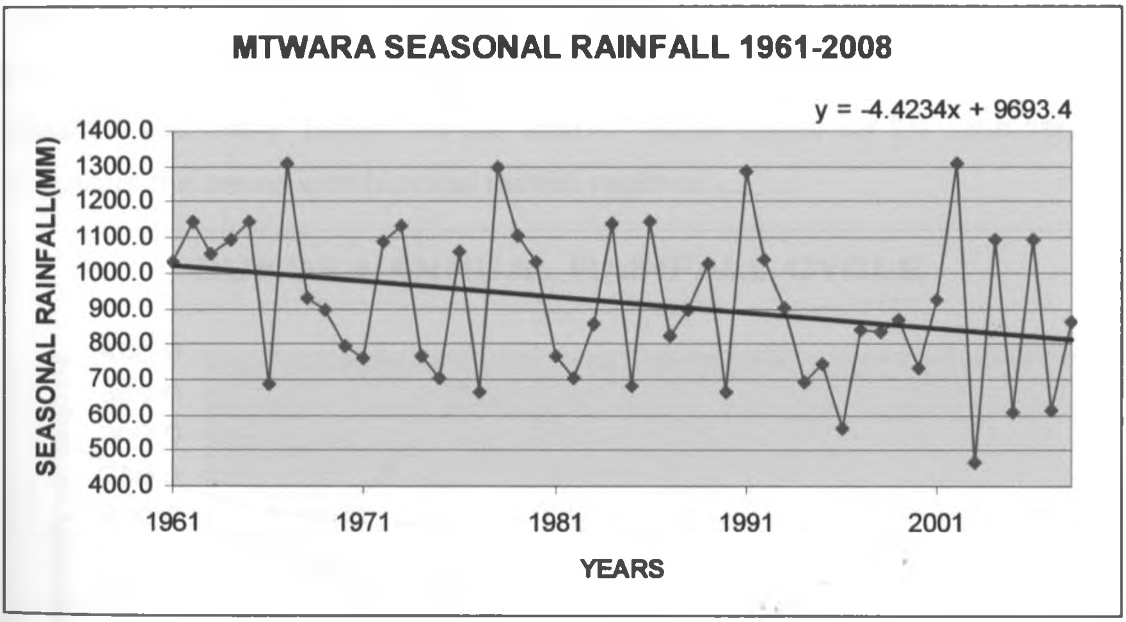


Figure 24. Mtwara seasonal rainfall time series and trend analysis graph for 1961-2008

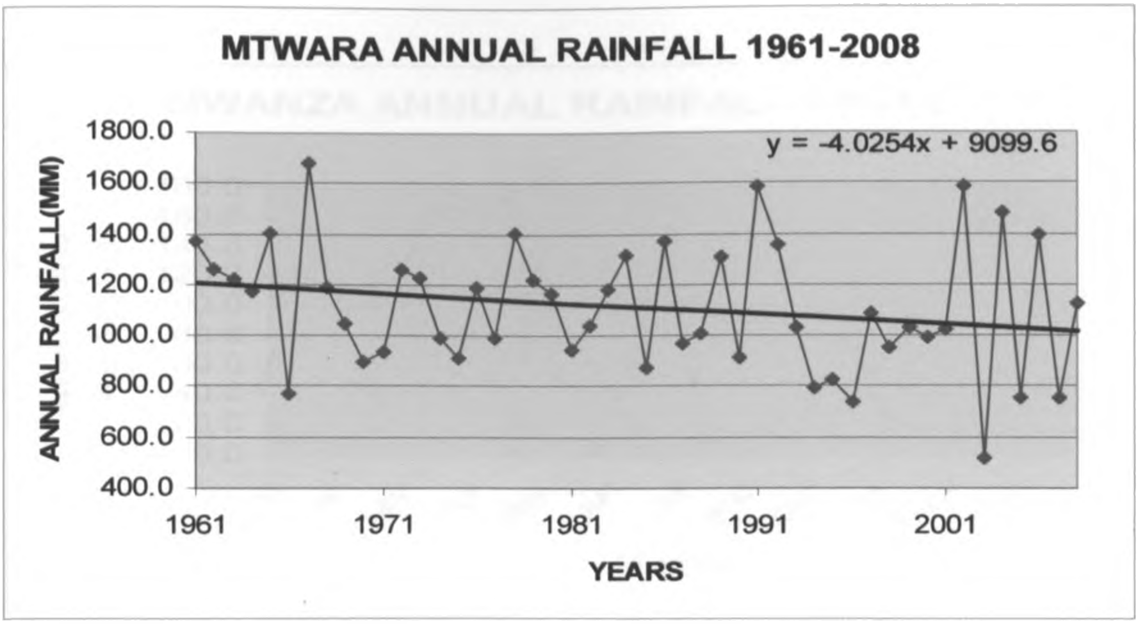


Figure 24. Mtwara annual rainfall time series and trend analysis graph for 1961-2008

3.2.2 Bimodal Rainfall Regime

The bimodal rainfall regime in Tanzania is experienced into 5 zones, zone 1,2,3,4 and 11 with representatives Bukoba, Mwanza, Loliondo, Same and Dar es salaam respectively. Below are the annual rainfall cycles for the representative stations of the zones with bimodal rainfall regimes

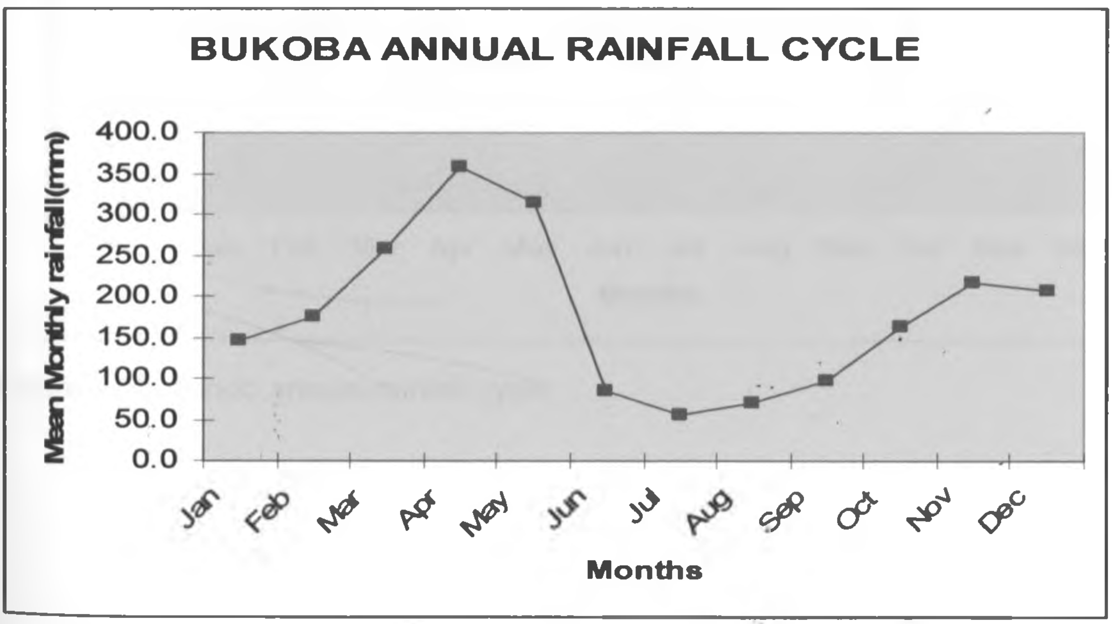


Figure 25.Bukoba annual rainfall cycle

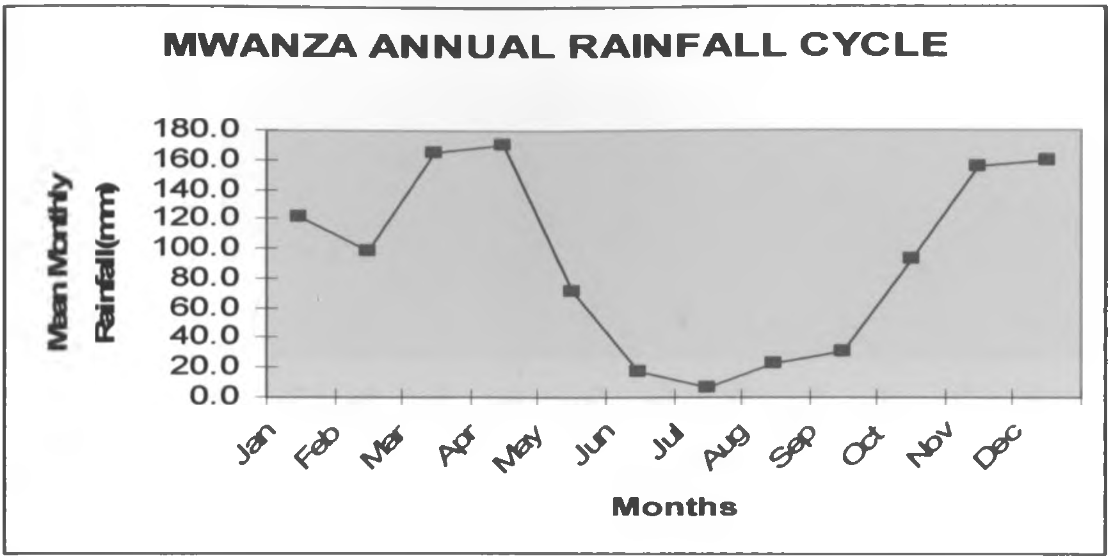


Figure 26 Mwanza annual rainfall time series

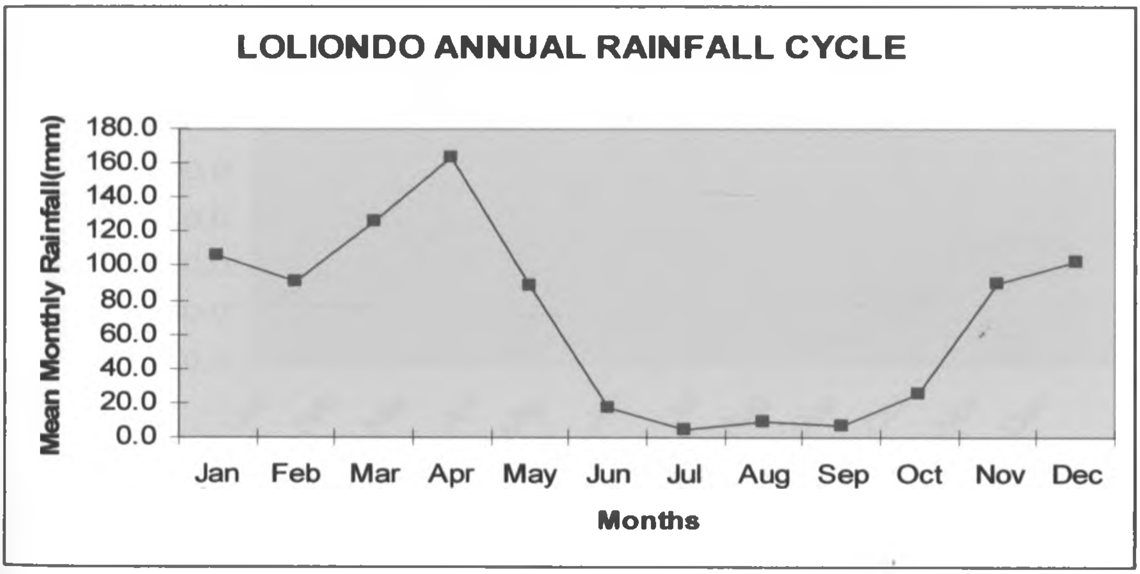


Figure 27.Loliondo annual rainfall cycle

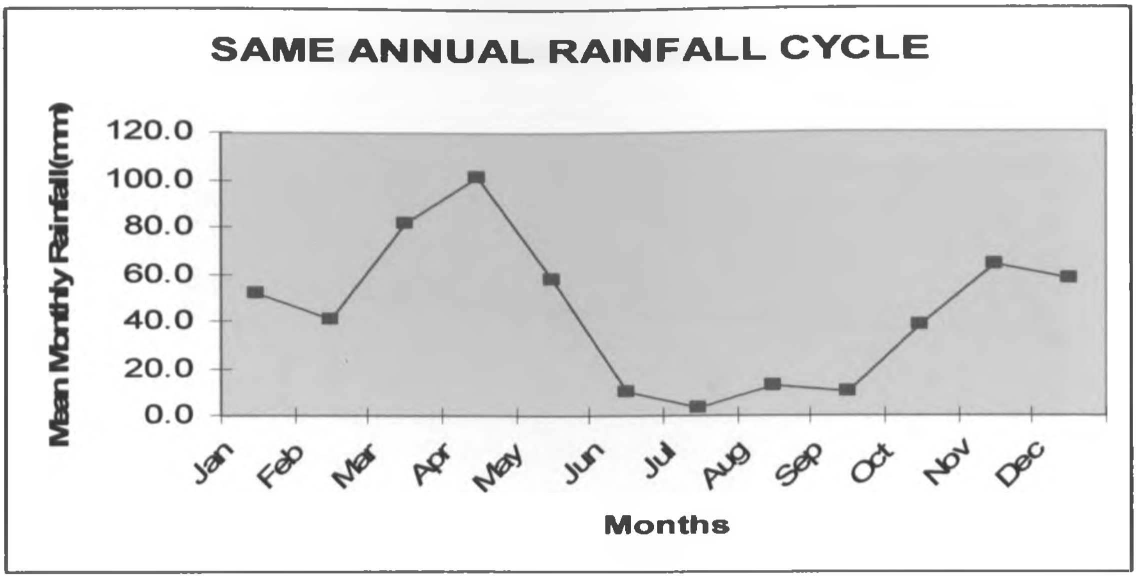


Figure 28.Same annual rainfall cycle

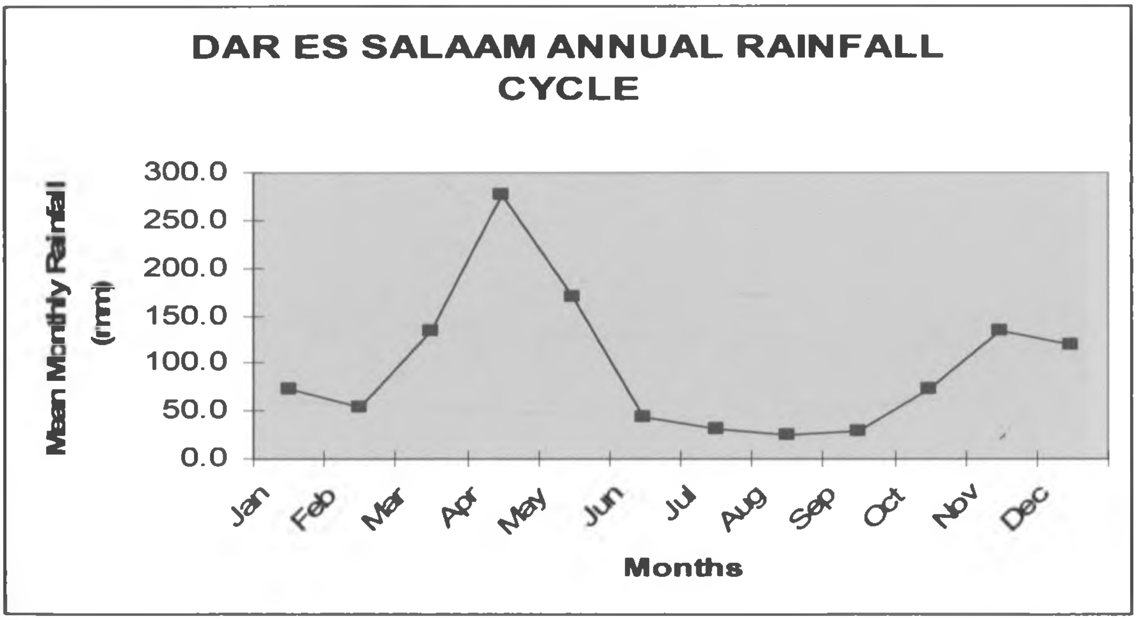


Figure 29 Dar es Salaam annual rainfall cycle

Here below are the plots for the time series and trend analyses for the stations with a bimodal rainfall seasons

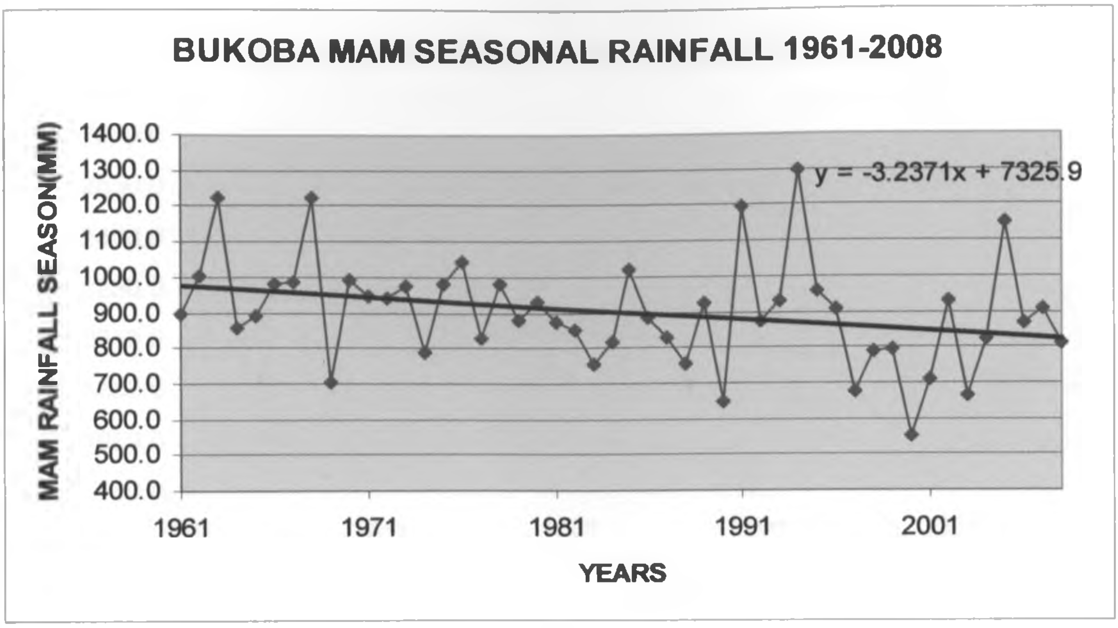


Figure 30.Bukoba MAM seasonal I rainfall time series and trend analysis graph

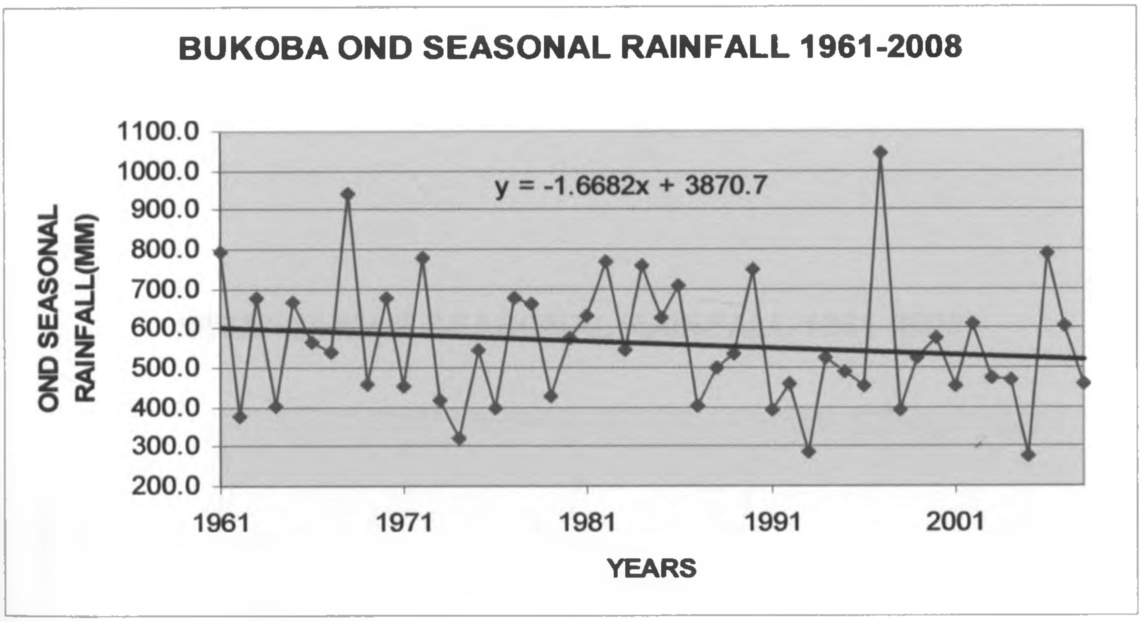


Figure 31.Bukoba OND seasonal rainfall time series and trend analysis graph

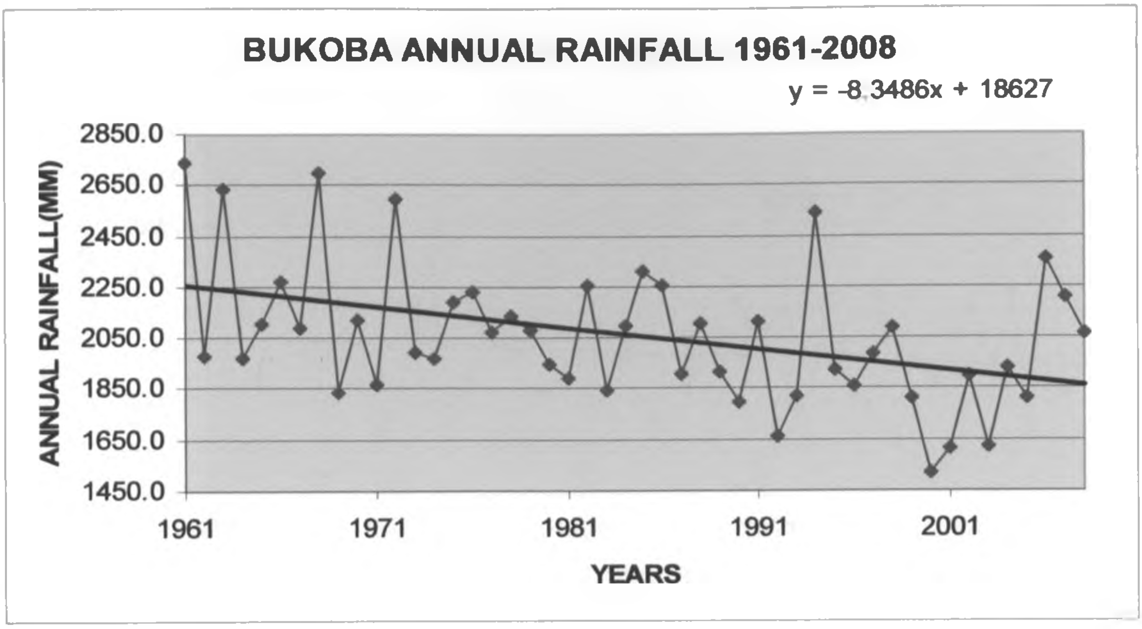


Figure 32.Bukoba annual rainfall time series and trend analysis graph

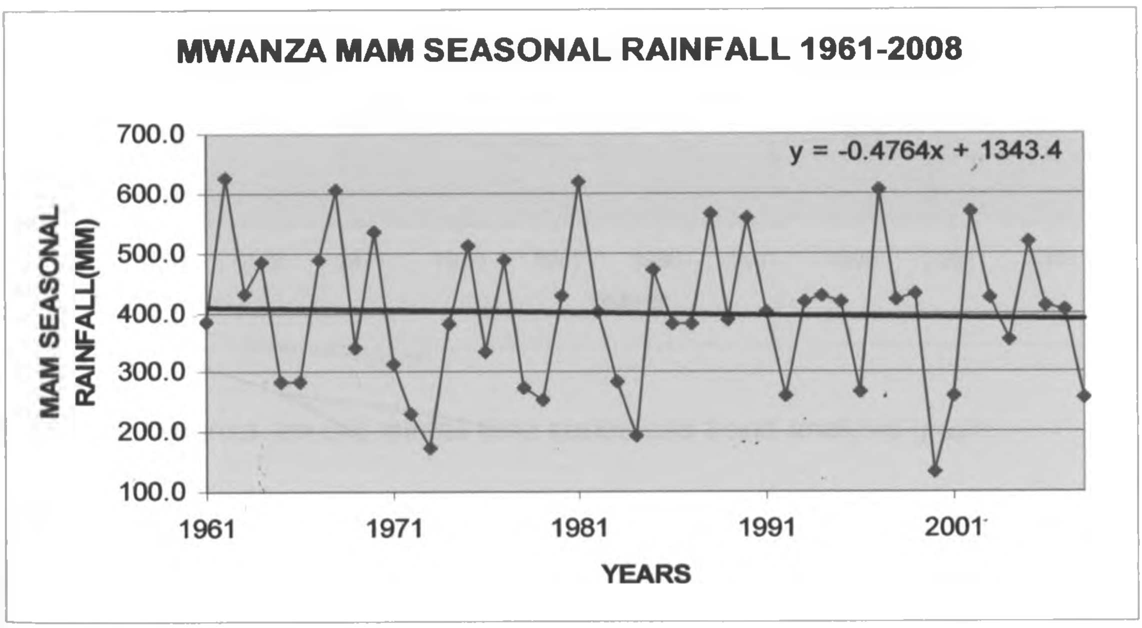


Figure 33 Mwanza MAM seasonal rainfall time series and trend analysis graph

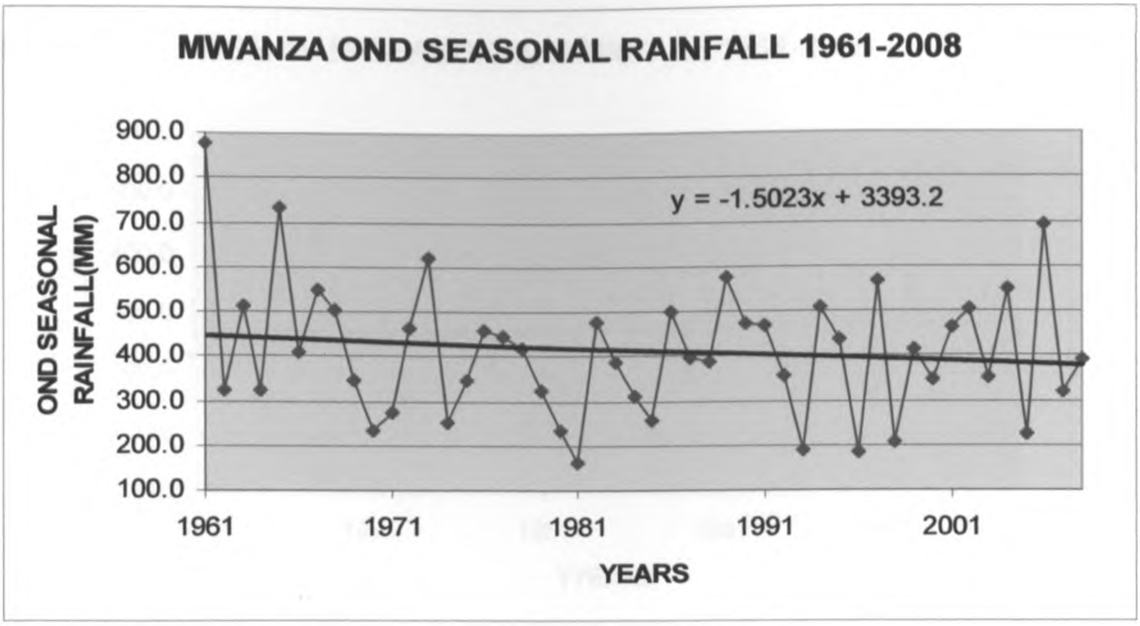


Figure 34.Mwanza OND seasonal rainfall time series and trend analysis graph

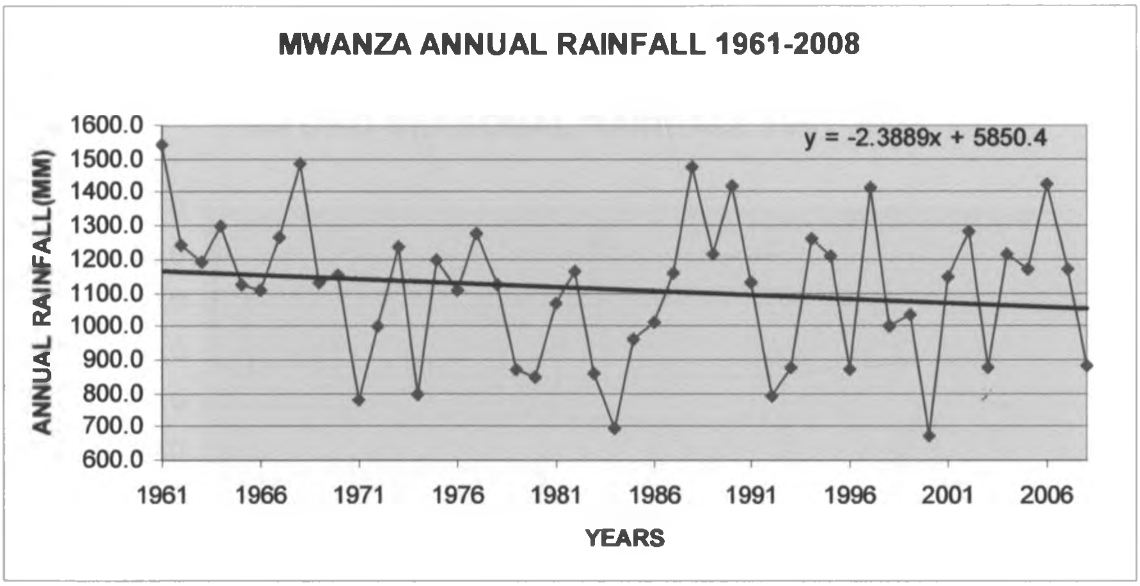


Figure 35.Mwanza annual rainfall time series and trend analysis graph

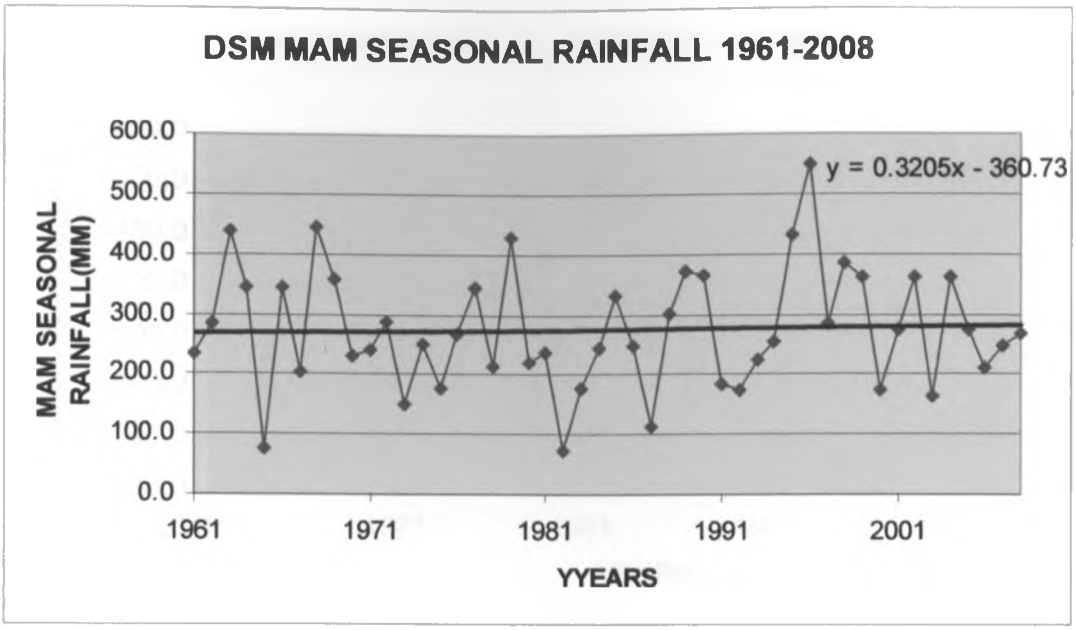


Figure 36.Dar es salaam MAM seasonal rainfall time series and trend analysis graph

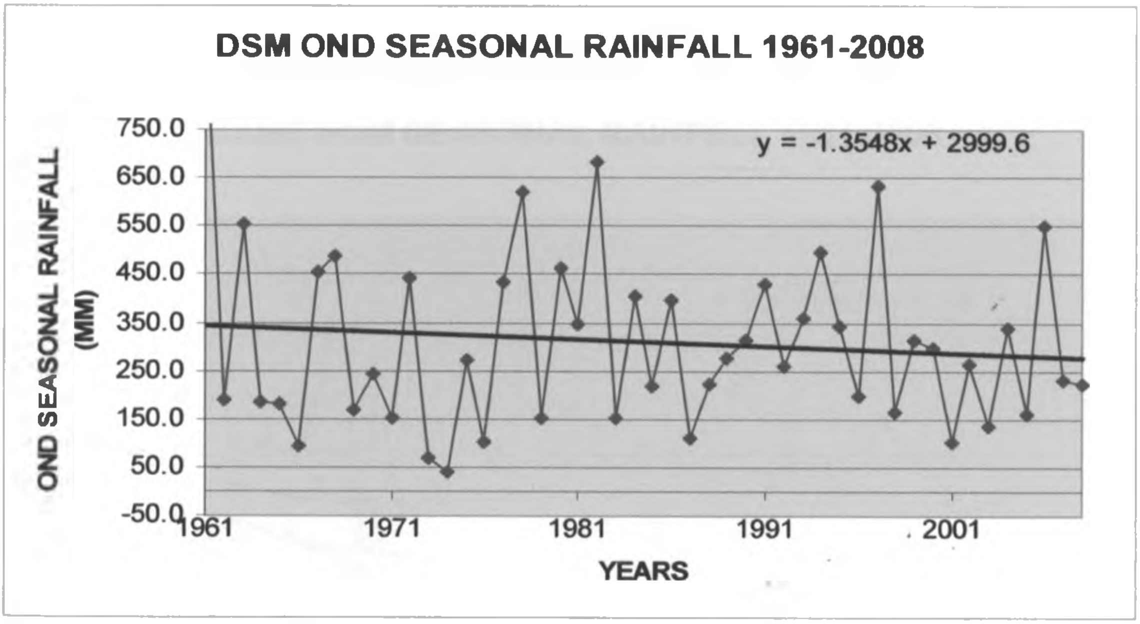


Figure 37.Dar es salaam OND seasonal rainfall time series and trend analysis graph

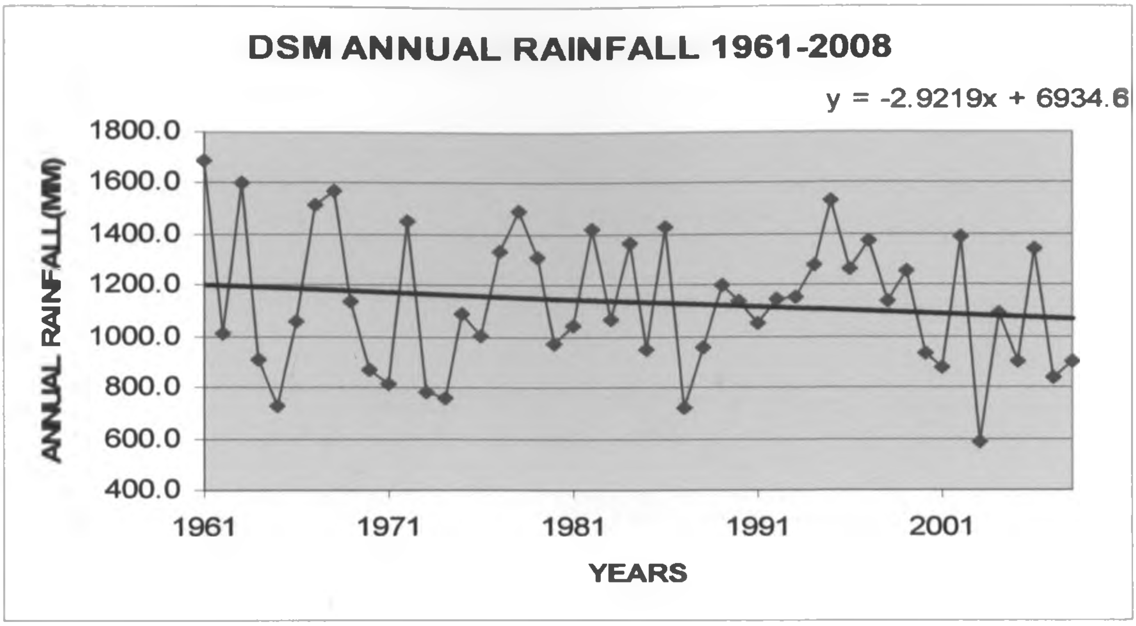


Figure 38.Dar es salaam annual rainfall time series and trend analysis graph

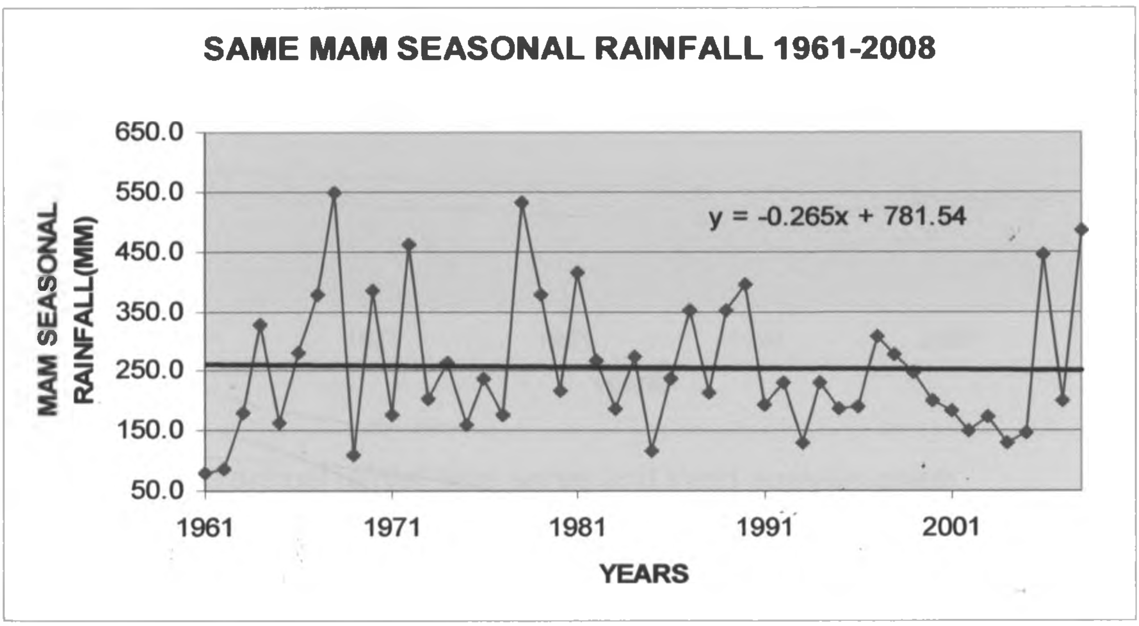


Figure 39.Same MAM seasonal rainfall time series and trend analysis graph

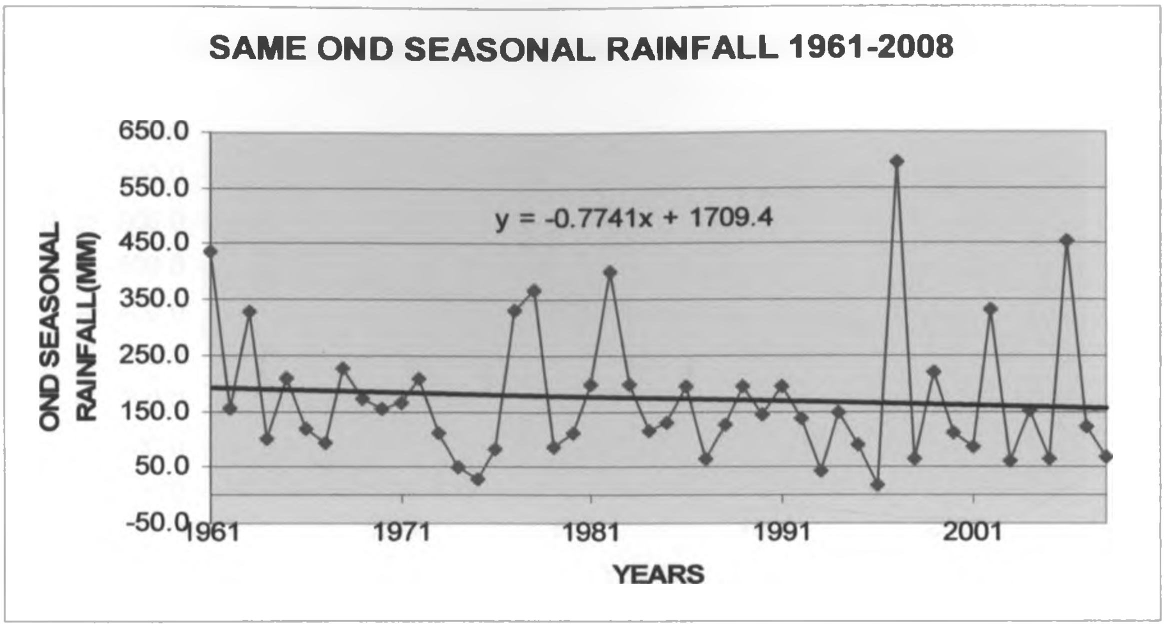


Figure 40.Same OND seasonal rainfall time series and trend analysis graph

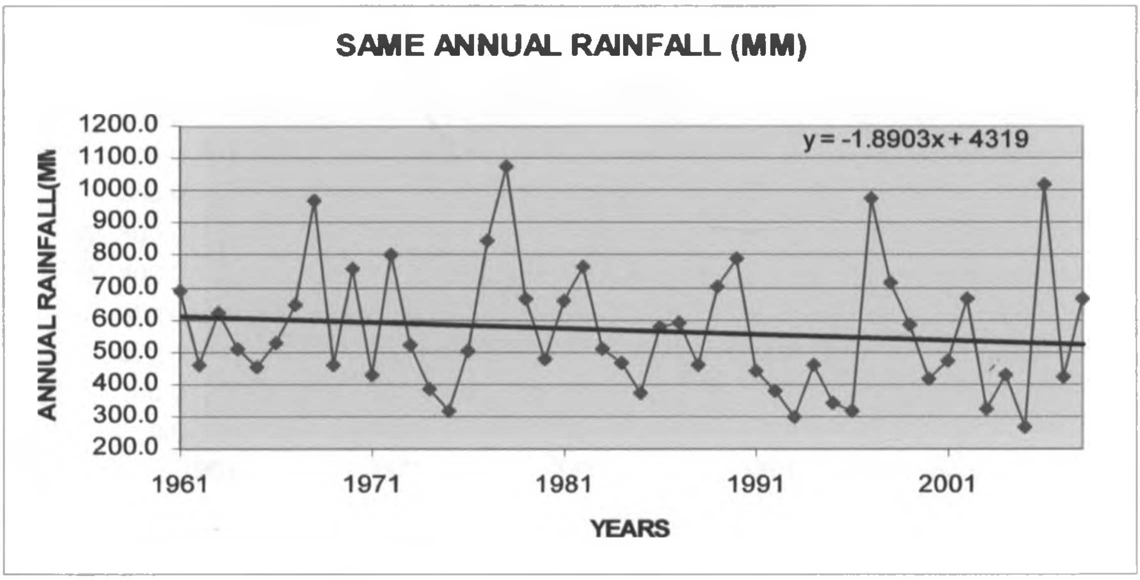


Figure 41.Same annual rainfall time series and trend analysis graph

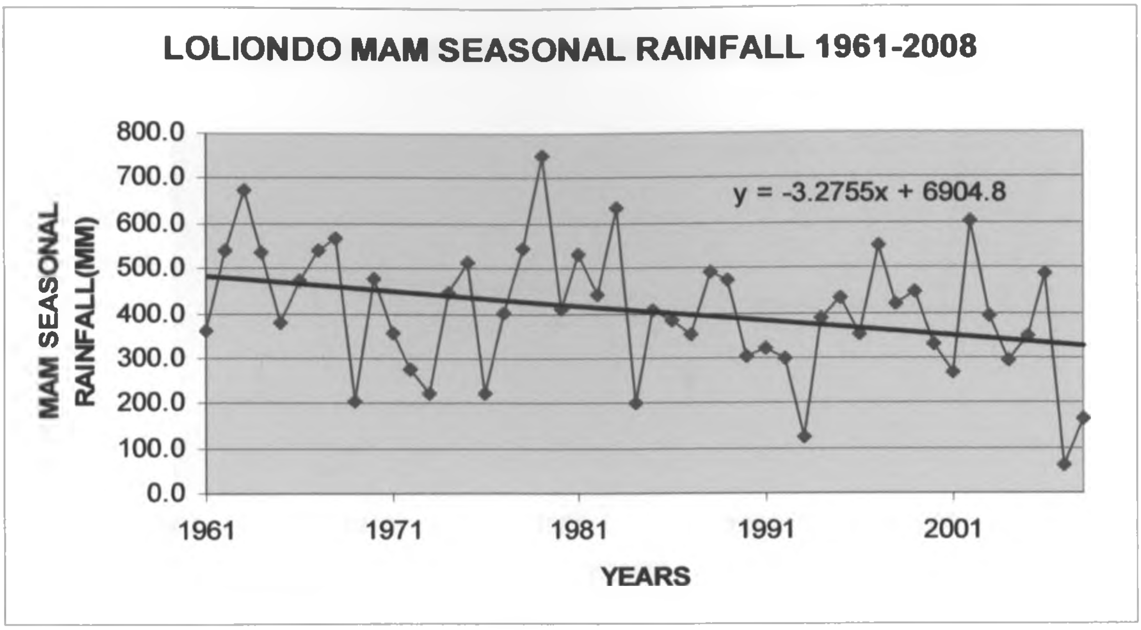


Figure 42.Loliondo MAM seasonal rainfall time series and trend analysis graph

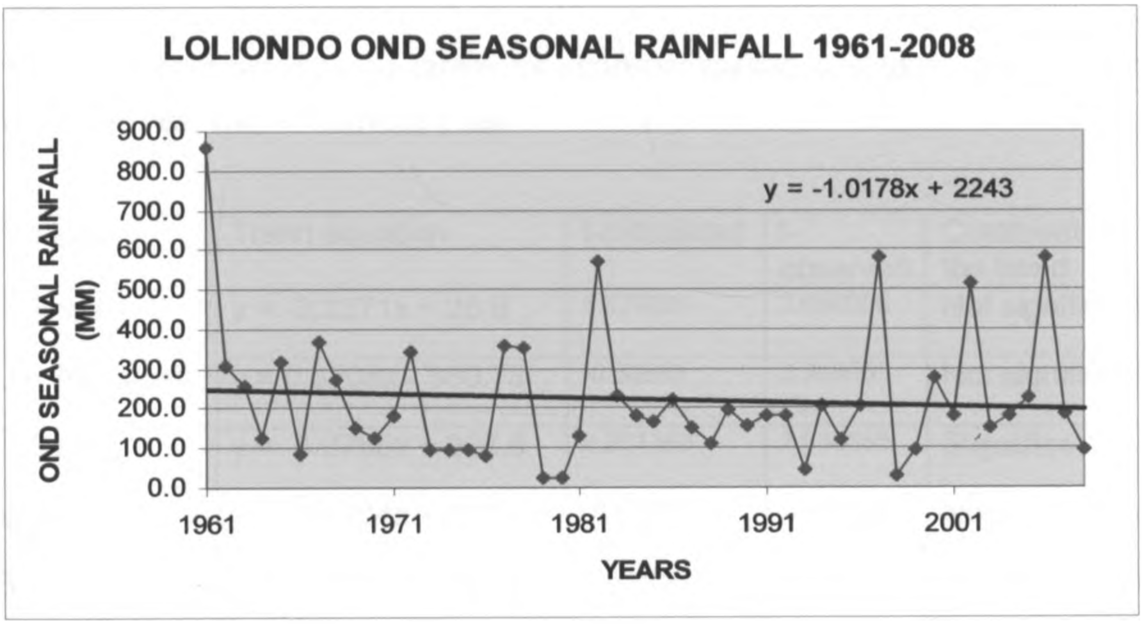


Figure 43.Loliondo OND seasonal rainfall time series and trend analysis graph

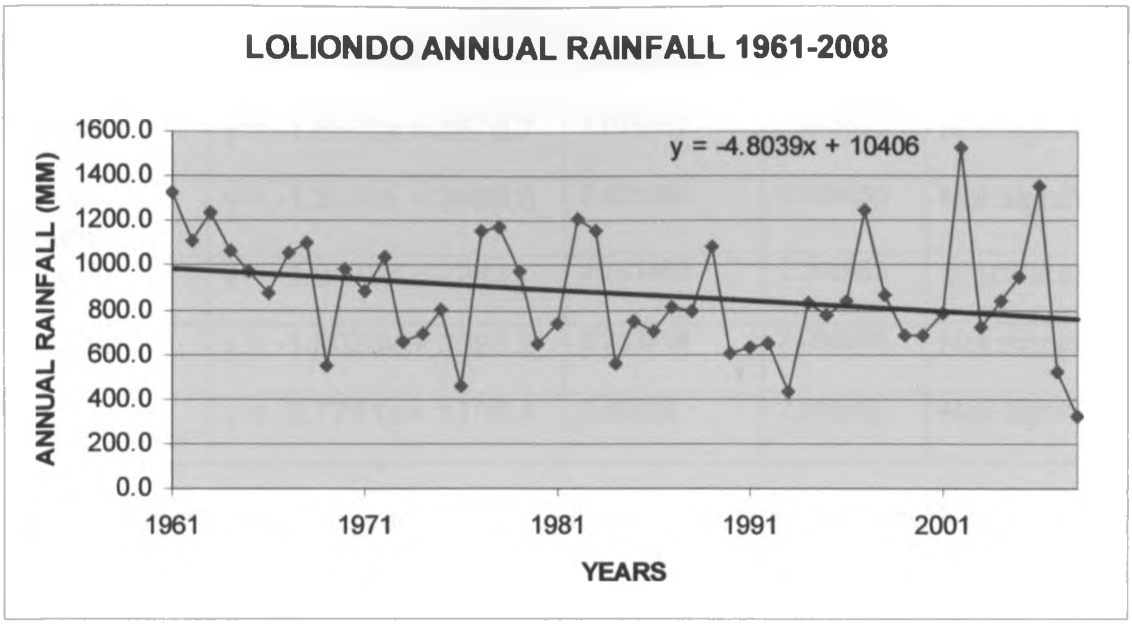


Figure 44.Loliondo annual rainfall time series and trend analysis graph

Here below are significance tables for seasonal rainfall of stations representing the zones with values from the t-test

Stations	Trend equation	t-calculated	t-observed	Comment on the trend
Bukoba	y = -3.2371x + 25.9	1.370001	2.068655	Not significant
Dar es salaam	y = 0.3205x - 360.73	-0.80666	2.068655	Not significant
Loliondo	y = -3.2755x + 904.8	2.201462	2.068655	**Significant**
Mwanza	y = -0.4764x + 343.4	-0.43788	2.068655	Not significant
Same	y = -0.265x + 781.54	0.833993	2.068655	Not significant

Table 2.Significance Table for MAM rainfall season over zones with bimodal rainfall regime

Stations	Trend equation	t-calculated	t-observed	Comment on the trend
Bukoba	y = -1.6682x + 3870.7	1.075557	2.068655	Not significant
Dar es salaam	y = -1.3548x + 2999.6	0.601995	2.068655	Not significant
Loliondo	y = -1.0178x + 2243	2.201462	2.068655	**Significant**
Mwanza	y = -1.5023x + 3393.2	0.233518	2.068655	Not significant
Same	y = -0.7741x + 1709.4	0.80606	2.068655	Not significant

Table 3 .Significance Table for OND rainfall season over zones with bimodal rainfall regime

Stations	Trend equation	t-calculated	t-observed	Comment on the trend
Dodoma	y = 1.4631x - 2367.3	-1.90712	2.068655	Not significant
Kigoma	y = -2.3056x + 250.3	1.084217	2.068655	Not significant
Mbeya	y = -1.0378x + 894.9	0.001276	2.068655	Not significant
Mtwara	y = -4.4234x +9693.4	2.112569	2.068655	**Significant**
Songea	y = -4.3192x +9594.4	2.837495	2.068655	**Significant**
Tabora	y = -0.6628x + 095.7	-0.44697	2.068655	Not significant

Table 4 Significance Table for seasonal rainfall over zones with unimodal rainfall regime

Below is a significance table for stations with values from the t-test

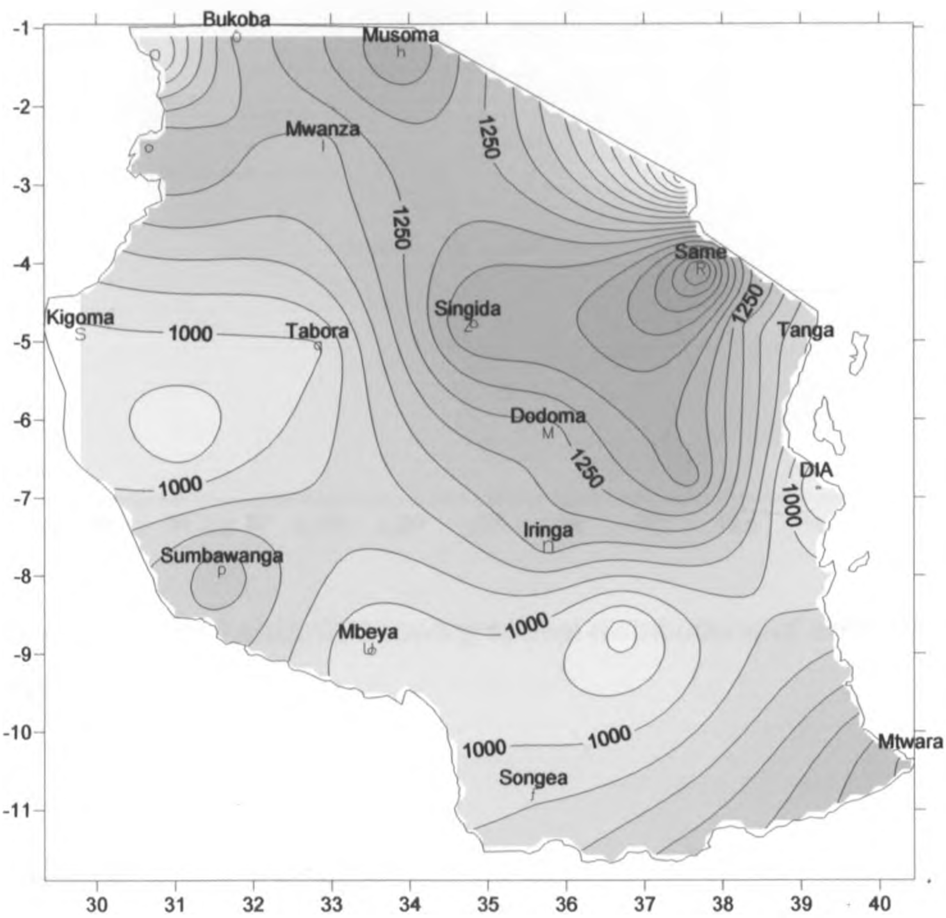
Station	Trend equation	t-calculated	t-observed	Comment on the trend
Bukoba	y =-8.3486x + 18627	2.413784	2.068655	**Significant**
Dodoma	y = 1.8059x - 3013.5	-1.96387	2.068655	Not Significant
Dar es salaam	y =-2.9219x+ 6934.6	0.733701	2.068655	Not Significant
Kigoma	y =-2.5223x+ 5983.4	1.335945	2.068655	Not Significant
Loliondo	y =-4.8039x + 10406	1.326796	2.068655	Not Significant
Mbeya	y = -1.5231x + 3955.3	0.133941	2.068655	Not Significant
Mtwara	y =-4.0254x+ 9099.6	1.796778	2.068655	Not Significant
Mwanza	y =-2.3889x+ 5850.4	-0.05305	2.068655	Not Significant
Same	y = -1.8903x + 4319	1.294892	2.068655	Not Significant
Songea	y = -5.384x + 11795	3.486276	2.068655	**Significant**
Tabora	y =-1.7938x+ 4528.1	0.483065	2.068655	Not Significant

Table 5.Significance table for annual rainfall

The above table shows the results from the time series and trend analysis for eleven zones each from a different one. By using a student's t-test the values of t were calculated and compared with their respective t values from the table. The t-test shows that only two zones represented by Bukoba (from zone 1) and Songea (from zone 9) have significant increasing and decreasing trends respectively of annual rainfall otherwise rest of the zones have either increasing or decreasing trends which are not significant as the values of t-calculated are less than the ones observed from the t-table.

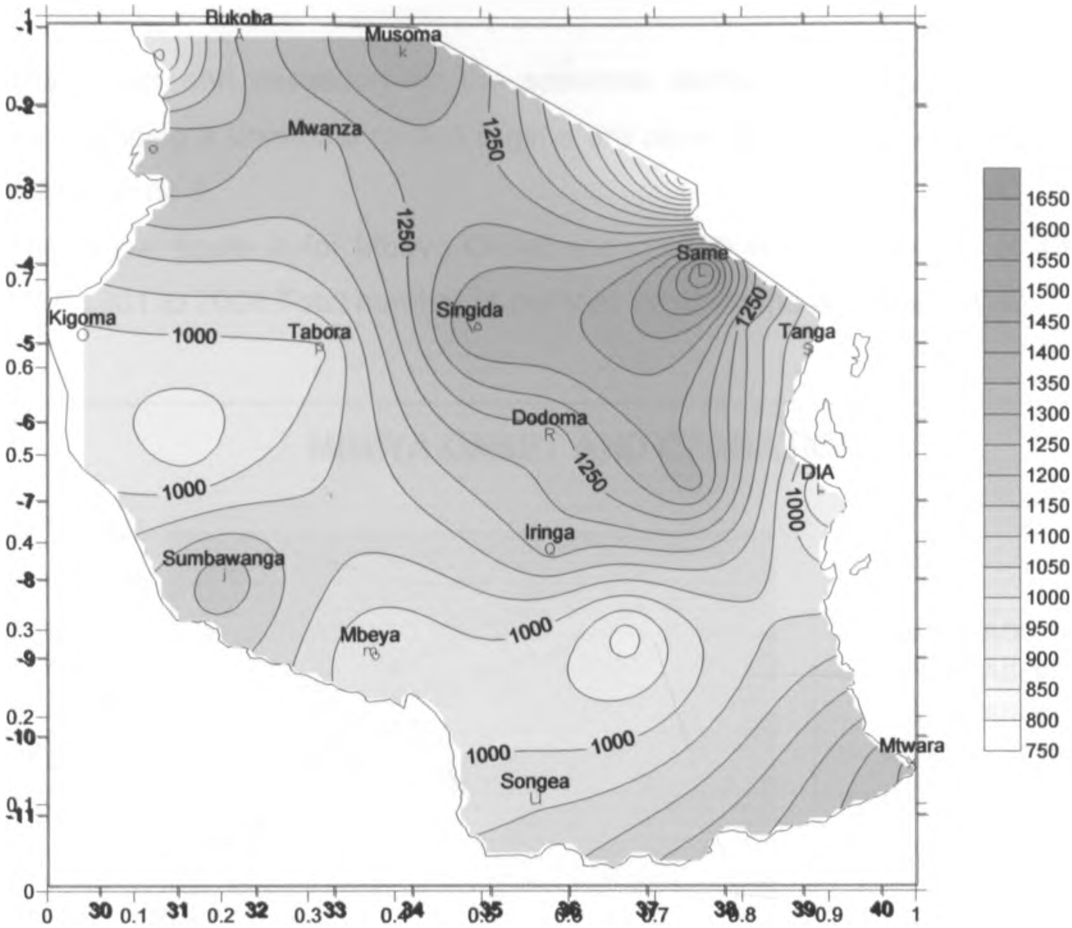
3.2.1 Spatial Distribution of Rainfall

The spatial distributions of annual rainfall over Tanzania for the period between 1961 to 1984



Map 3.Map of Tanzania showing spatial distributions of annual rainfall for 1961 - 1984

The spatial distributions of annual rainfall over Tanzania for the period between 1961 to 1984



Map 4.Map of Tanzania showing spatial distributions of annual rainfall for 1961 - 1984

3.2.3 Onset and Cessation

3.2.3.1 Onset and Cessation for Unimodal Rainfall Regime

The Onset and cessation for the seasonal rainfall for the parts of Tanzania experiencing a unimodal rainfall regime are represented by Mbeya region which is from zone 8.

The below figure is for Mbeya Onset and cessation for the period of 48 years from 1961 to 2008.Total number of pentads used for the analysis are 33.

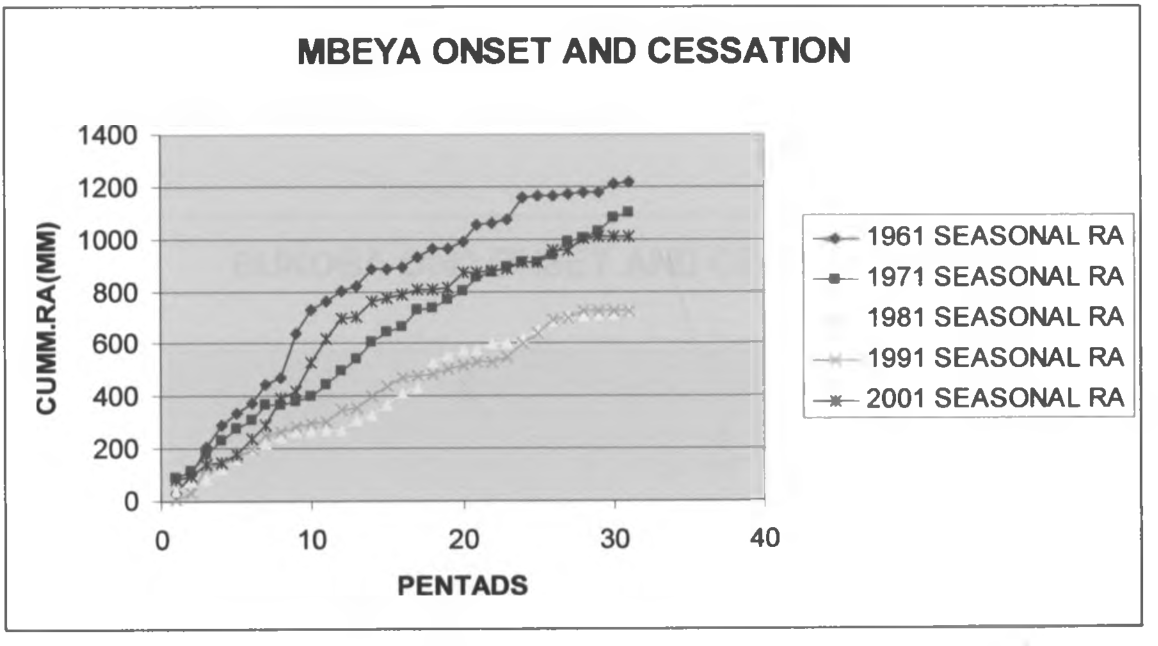


Figure 45. Mbeya onset and cessation

3.2.3.2 Onset and Cessation for Bimodal Rainfall Regime

The Onset and cessation for the seasonal rainfall for the parts of Tanzania experiencing a bimodal rainfall regime are represented by the Bukoba region. Bukoba is from zone 1 and the plot for the pentads of accumulated seasonal rains is as seen below.

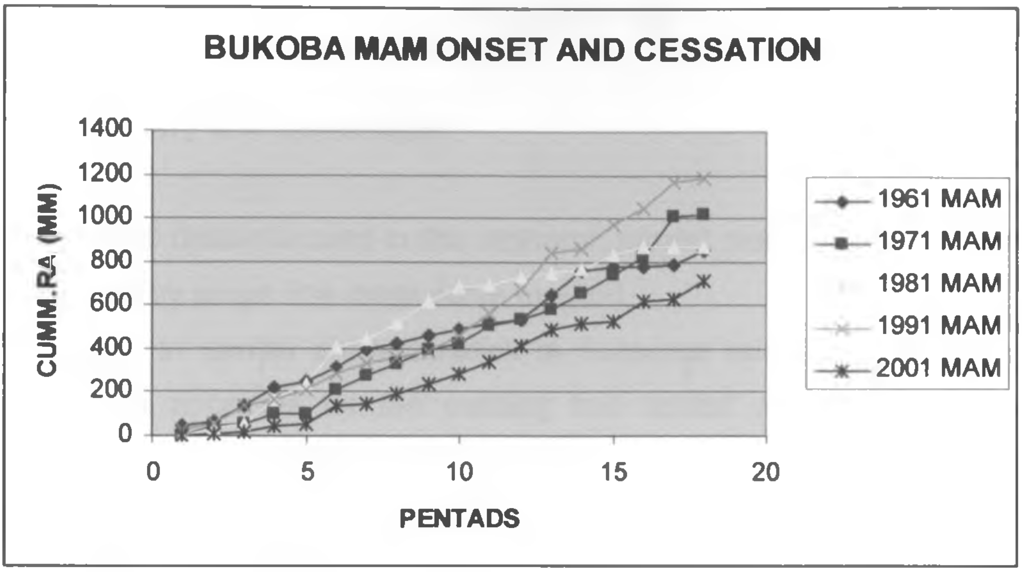


Figure 46 Bukoba MAM Onset and Cessation

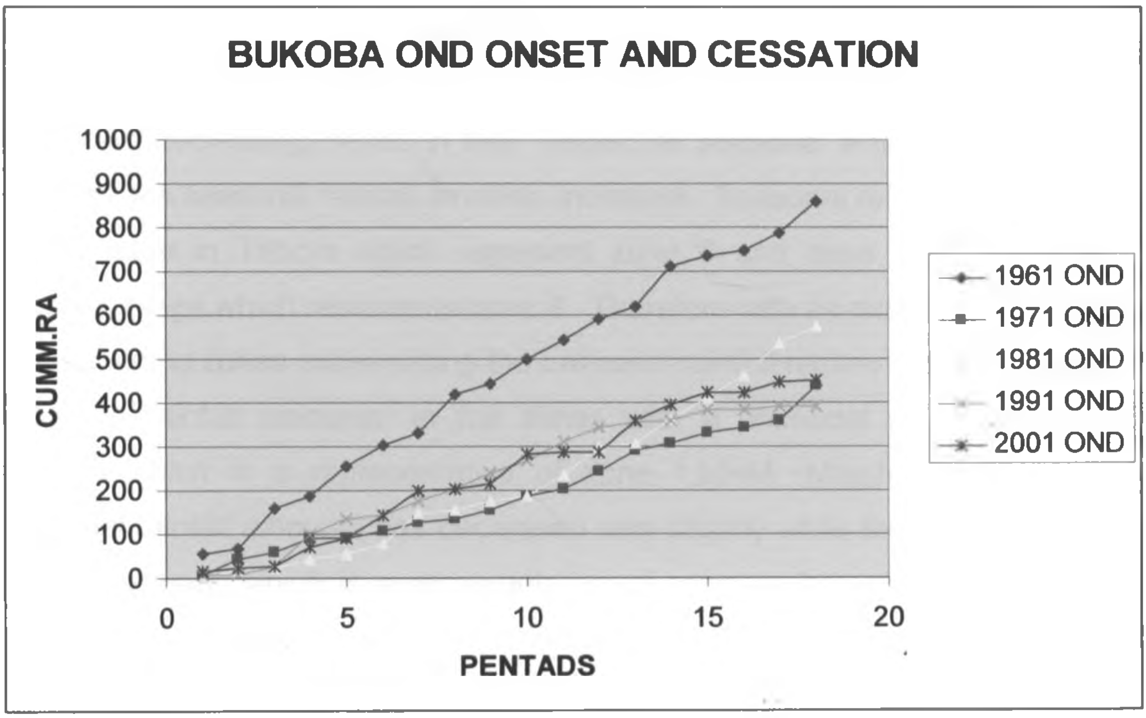


Figure 47 Bukoba OND Onset and Cessation

Chapter Four

4.1 Summary and Conclusion

The rainfall datasets used in this research project were in required standards as confirmed by single line mass curve method.

Variations in rainfall characteristics in seasonal rainfall amounts, onsets and cessations approves for the existing two rainfall regimes and climatological rainfall homogeneous zones in Tanzania.

The variability in rainfall characteristics shows trends either increasing or decreasing in almost all the zones through their respective representative stations alerting the likelihood presence of changes in the climatology over various parts of the country. But results from the analyses show that four zones which are zone 1 with representative station Bukoba,zone 3 with representative station Loliondo and zone 9 which is represented by Songea and zone 10 have significant decreasing trends in their respective seasonal amounts of rainfall. In Dodoma the seasonal rainfall amounts increases. Seasonal rainfall amounts tend to decrease in Tabora which represent zone 6 and zone 7 represented by Kigoma, Iringa which represents zone 8 . Therefore with an exception of Dodoma, the remaining zones experiencing the unimodal rainfall regime face a decrease in seasonal rainfall amounts. In the zones with a unimodal rainfall regime, in Bukoba which is a representative of zone 1,MAM (March ,April and May) seasonal rainfall amounts has decreased very slightly while the MAM season for Dar es salaam which is a representative of zone 11 has shown a very slight increase. In the remaining zones (zone 2 and 4), MAM seasonal rainfall amounts decrease. In the OND (October, November and December) season, all zones of a bimodal regime have decreasing trends in the seasonal rainfall amounts.

In the zones with unimodal rainfall regime.Mbeya was selected as representative in the onset and cessation analyses. The onsets were observed in the first pentad while the cessations were observed in the pentad 24,28,27,28 and 28 of the years 1961,1971,1981,1991 and 2001 respectively. There is no change on the onset as well as cessation. The zones under the bimodal rainfall regime are represented by Bukoba from zone 1.The onsets in 1961, 1971, 1981, 1991 and 2001 were observed in pentads 2,5,5,2 and 5 respectively. The onset trend does not show significant changes. The cessation in 1961, 1971, 1981, 1991 and 2001 were observed in pentads 15,17,16,18 and 18 respectively. The trend shows a delay in cessation but the trend is not significant.

The Bukoba OND onsets in 1961, 1971, 1981, 1991 and 2001 were observed in pentads 2,1,1,3 and 3 respectively. The onset trend does not show significant changes. The cessation in 1961, 1971, 1981, 1991 and 2001 were observed in pentads 18,18,18,17 and 18 respectively. There is no change in cessation period.

What is happening in Tanzania since 1961 to 2008 is rainfall characteristic variability in almost all parts over the country and as to a very large extent those variabilities in the rainfall characteristics are not significant

4.2 Recommendations

Rainfall characteristics in Tanzania are changing differently in different parts over the country. People in the country especially those who are stakeholders of the meteorological services in particular rainfall must be empowered with updates in changes (variabilities) of the rainfall climatology.

Agriculture as a long time and term back-born of the country should be adequately performed along the current changes in the rainfall characteristics so as to avoid demerits from poor harvests and hence control for the food security.

4.3 Acknowledgement

God, the almighty is the first above all to be thanked for he has given me life, strength and courage to do this very hard work and do what I have been doing in my education. Secondly I would like to thank my supervisors Dr. Christopher Oludhe and Dr. G. Ouma for their sincere technical and moral support all the time from the start to the end of this project. Third I would like to thank the Management of Tanzania meteorological Agency for granting me financial support and data for the project.

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