STUDY OF RAINFALL TRENDS AND VARIABILITY OVER TANZANIA

BY

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DECLARATION

I hereby declare that this project work is my work and has not been presented by any one in any university for academic award;

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ABSTRACT

The study deals with the analysis of monthly rainfall trends and variability over Tanzania. The monthly rainfall data from 1982 to 2012 was obtained from the Tanzania Meteorological Agency, Dar es Salaam, Tanzania. The monthly rainfall data from representative stations in the homogeneous rainfall zones over Tanzania were analyzed for trends by graphical and statistical Methods. In order to achieve the main and specific objectives, the data were subjected to various analyses including quality control. The core methodology used in analysis of rainfall trends and variability over Tanzania were the time series analysis, single mass curve analysis, coefficient of variation and spatial analysis using surfer program. The results from the study showed that there were trends in the rainfall data for all stations used. However the trends are not significant except in Tanga and Pemba. Also results from seasonal and annual coefficient of variation found that the largest value of variability was observed during OND at Kilimanjaro while the lowest variability was found in Kigoma, Sumbawanga and Mbeya during November-April (NA) season which implies that rainfall in these regions is very reliable and Kilimanjaro rainfall is less reliable. Moreover result from spatial analysis revealed that Bukoba region has the highest mean annual rainfall followed by Zanzibar and Pemba. The lowest mean annual rainfall was at Kilimanjaro, which confirms that Kilimanjaro received lowest amount of rainfall. Furthermore the study has demonstrated that there are both spatial and temporal variability of rainfall over Tanzania. These findings may be used for monitoring and forecasting extreme weather events like droughts and floods. This would therefore contribute significantly to the effective management and sustainable development of the national social economic activities which are heavily rain- dependent.

DEDICATION

This work is dedicated to my lovely father who passed away in 29 December 2012.

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First and foremost I would like to acknowledge the almighty God for giving me opportunity, strength, protection and good health in my entire studies. Also i would like to acknowledge Tanzania Meteorological Agency and the government of Tanzania for sponsorship of my studies and for providing me data.

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Special thanks go to the chairman Dr. Alfred O. Opere, the academic and support staffs of the department of meteorology university of Nairobi, for the valuable contributions of my postgraduate diploma in meteorology.

My unique thanks go to my roommate's Kapakala and Ahmad for their positive supports, contributions, and encouragement they have made during my studies, God bless them.

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LIST OF ACRONYMS

ANOVA	Analysis of variance
DRI	Daily Rainfall Intensity
ENSO	El Nino Southern Oscillation
EPMS	Environmental Protection and Management Services
GHGs	Greenhouse Gases
GHA	Great Horn of Africa
ICPAC	IGAD Climate Prediction and Application Center
IPCC	Intergovernmental Panel on Climate change
MAM	March, April, May
MJO	Madden Julian Oscillation
NA	November, April
NRD	Number of Rain Days
NAPA	National Adaptation Programme of Action
OND	October, November, December
P	Total Precipitation Amount
SST	Sea Surface Temperature

TBS	Tanzania national Bureau of Statistics
TMA	Tanzania Meteorological Agency
UNEP	United Nations Environment Programme
WMO	World Meteorological Organization

CHAPTER ONE

1.0 INTRODUCTION

Rainfall is very important weather and climate parameter that affects social and economic activities in Tanzania. It has the largest space and time variability therefore making it the most important weather element (Ogallo, 1980). Rainfall variability is the degree to which rainfall amounts vary across an area or through time, it is an important characteristic of the climate of an area and has two components i.e. spatial and temporal variability (Banchiamlak and Mekonnen, 2010). Moreover rainfall variability is associated with too much rainfall or decrease in rainfall amount i.e. it may be associated with drought or floods which are, often linked with food insecurity, energy and water shortages, death of people and animal, destruction of property and many other socioeconomic miseries (Omeny and Okoola, 2008). The rains failure extends from a delayed onset of the rains, an early withdrawal, or short but intense rainfall events separated by long dry spells (Camberlin and Okoola, 2003).

Tanzania population is about 44 928 923 according to census that was conducted in 2012 by Tanzania National Bureau of Statistics. According to Kijazi and Reason(2005) the economies of Tanzania is mainly depend on rain fed agriculture, which is highly vulnerable to the amounts and distribution of rainfall. Efforts to achieve food security, reliable hydroelectric power in most parts of the country have been hampered by floods and droughts that are natural events and if not managed in a timely and effectively can be disastrous (URT, 2007).

Tanzania is among the countries that regularly suffer from various weather and climate related problems, therefore the study of rainfall variability have received much attention due to increases economic losses which sometimes associated to death of people. Good examples are flood over Dar es Salaam and Kilosa that killed people and many of them lost their homes. Tanzania's mainland climate is characterized by two rainfall regimes; these are the long rainfall regime between March and May (MAM), and short rainfall regimes between October and December (OND). Also there is unimodal rainfall regime which starts from November to the end of April (NA). Climate projection model indicates that central, western, and southwestern part of Tanzania might experience decrease in rainfall by 10% to 15% (Nyenzi et al, 1999).

The start and duration of rainfall in semi arid areas are showing random behavior and there is high chance of occurrence of acute dry spell during growing period, such circumstances making farming in semi arid areas a risky business. Insufficient and extreme fluctuation in the amount of water available making many farmers remain at survival level and continuous poverty. Therefore high risk of crops failure and livestock production reduces financing of investments especially in the semi arid region of Tanzania (Mahoo and Mzirai, 1999).

Studies have shown that although shortage of rainfall is stress but most significant problem is often inter and intra seasonal rainfall variability. In fact the performance of a rainy season, for most social economic activities does not only depend on overall total amount, but needs an adequate distribution of the rains throughout the year. Therefore Rainfall distribution influences the population densities over most parts of Tanzania. Hence there is need of study rainfall trends and variability so as to better inform agricultural decision maker, energy sectors and farmers among others. Likewise this knowledge is of great importance when elaborating seasonal rainfall predictions, combating desertification, and reduction of flood impact. This work attempts to study rainfall variability and trends over Tanzania's mainland.

1.1 Problem Statement

Rainfall variability in amount and their distribution has significant short and long-term effects on natural resources system, such as lake and Rivers particularly for those who live around the shore of the region's major lakes, wetland and river flood plains. Also rainfall variability is the major cause of yield variation of most major crops in many parts of Tanzania. Although other factors such as soil type, temperature, lack of agricultural inputs and supervision practice may also play a role in reduction of crop yield. Further more rainfall fluctuation has continuing impacts on fisheries and livestock keeping. Therefore the study of rainfall variability and trends in Tanzania is of utmost importance.

1.2 Hypothesis of the Study

If the current rainfall trends and variability is obtained then the information will be very helpful for agricultural decision makers as well as update of the region climatology.

1.3 Objectives of Study

The main objective of this study is analysis of rainfall trends and variability over Tanzania. In order to achieve main objective the following specific objectives was conducted;

(i) Analyze the temporal pattern of rainfall over Tanzania

(ii) Investigate rainfall trends over Tanzania for bimodal and unimodal regions

(iii) Determine seasonal and annual variability as well as reliability of rainfall

(iv) Determine spatial variability of rainfall over Tanzania from 1982 to 2012.

1.4 Justification of Study

Rainfall is an essential input into Tanzania's economy; it influences the performance of agricultural Sector that employs many people in the country, for that reason study of rainfall trends and variability in Tanzania region will be of assistance to better inform farmers as well as agricultural decision makers. Also rainfall amount and distribution play a major role in development of energy sector e.g. Hydropower generation that provides 55% of the country's electricity. Above all rainfall supply water into river basins which in turn provide water for domestic use as well as industrial production in Dar es Salaam, Mwanza, Arusha, Tanga, Iringa and Dodoma which are economically important areas of the country in which Industrial activities are concentrated.

Adequate distribution of rainfall support Tanzania's forests, grasslands, and coastal resources, which in turn provide services such as food, fodder, fuel wood, timber and other products, water purification among others. In addition the Study of rainfall trends and variability is necessary for understanding mechanism of desertification and combating it. Most of all analysis will contribute to the knowledge of rainfall trends and variability to allied industrial decision making in this important agricultural dependent zone. Therefore the study of rainfall variability and trends in Tanzania is of paramount importance. Temporal variability of rainfall may be used both to characterize climate and deduce evidence of climate change. Furthermore rainfall trend is an important area of interest for both hydrology and climatology in order to investigate climate change scenario and enhance climate impact research, Therefore this work is crucial for planning and designing Tanzania's climate change adaptation, water resources management, agriculture practice, hydroelectric power generation among others.

1.5 Area of Study

1.5.1 Overview: Tanzania

Tanzania is located on the eastern coast of Africa and south of the equator between latitudes 1° and 12°S and longitudes 29° and 41°E. It is the largest country in East Africa with a total area of 945,087 km^2, i.e. comprising land area of 883,749 km^2 (881,289km^2 Mainland and 2,460km^2 Zanzibar), plus 59,050 sq. km of inland water bodies, furthermore Tanzania is the third largest country in the Great Horn of Africa(GHA) region after Sudan and Ethiopia. The population of Tanzania is about 44,928,923; the capital city is Dodoma while the business capital is Dar es Salaam. It is bordered by Kenya and Uganda to the North, Rwanda, Burundi and Democratic Republic of Congo to the West, Zambia and Malawi to the South West and Mozambique to the South. Also Tanzania is surrounded by water bodies, namely Indian Ocean, Lake Victoria, Lake Tanganyika and Lake Nyasa. Despite the fact that Lake Victoria is the largest and Lake Tanganyika is the deepest in Tanzania but there are other Lakes such as Lake Manyara, Lake Rukwa, Lake Eyasi, Lake Nyasa, Lake Natron among others. Furthermore there are numerous rivers in Tanzania but the main rivers are Great Ruaha, Rufiji, Ruvu, Pangani, Kilombero among others. Also there are waterfalls such as Materuni, Marangu, Siguri, Sanje among others. Tanzania has mountain Kilimanjaro with an elevation of 5,950 metres above sea level which is the highest point in Africa. Although mountain Kilimanjaro tops the list as Africa's most famous and highest mountain, Tanzania has many other mountains namely: Mt Meru, Mt Udzungwa, Mt Uluguru, Mt Usambara among others (URT, 2007).

1.5.2 Physical Features and Climate Characteristics

Tanzania's mainland is divided into a central plateau, highlands along the north and south, and coastal plains. The climate of Tanzania is different from place to place due to its geographical location, altitude, relief and vegetation cover. In fact region climate is mainly influenced by its location close to the equator, the impact of the Indian Ocean and the physiography in general. As a result, Tanzania experiences a variety of climatic conditions ranging from hot and humid to the coastal plain. The coastal area and all of the islands in the Indian Ocean experience a tropical climate, and most of the country is sub-tropical except for the areas at higher altitudes. Tanzania is mountainous in Northeast where Kilimanjaro and Meru mountains are situated, the climate is cool in high mountainous regions.

The mean annual rainfall varies from 500 millimeters to 2,500 millimeters and above. The average duration of the dry season is 5 to 6 months. Tanzania's rainfall follows two regimes namely unimodal and bimodal patterns, i.e. Northern coast and Zanzibar, North Eastern highlands and Lake Victoria basin have two rainy seasons with long rains between March and May (MAM) and short rains between October and December (OND). Also the southern, central and western parts of the country have a single rainfall season between November and April (Chang'a et al, 2008). Among the Factors known to influence precipitation of Tanzania include the convergence zone between the northeast monsoon and the southeast monsoon referred to as inter-tropical convergence zone (ITCZ) (Asnani, 2005). The ITCZ moves northward passing over East Africa during March to May (MAM), while the southward movement occurs during October to December (OND) (Okoola, 1999). Thus the variation in its position and intensity to a great extent affect the rainfall amount over Tanzania. Other rainfall generating system over study area include Congo air mass, El Niño southern oscillation, Indian ocean dipole, Madden Julian oscillation(MJO), tropical cyclones, high pressure cells such as St Helena and Mascarine, pressure gradient between Atlantic and Indian ocean which determine strength and intensity of Congo air mass(Tilya et al,2008). Furthermore Rainfall of Tanzania is influenced by local features such as topography and existence of large water bodies e.g. Lake Victoria, Lake Tanganyika, Indian Ocean among others, which play a key role in controlling weather and climate over the country leading to spatial variation of rainfall.

Annual means temperature ranging from a mean daily temperature of between 24°C - 34°C. Within the plateau, mean daily temperatures range between 21°C - 24°C while in the highland areas temperatures range from15°C - 20°C. The hottest months are December to February and the coolest months are June to August (TMA, 2005).

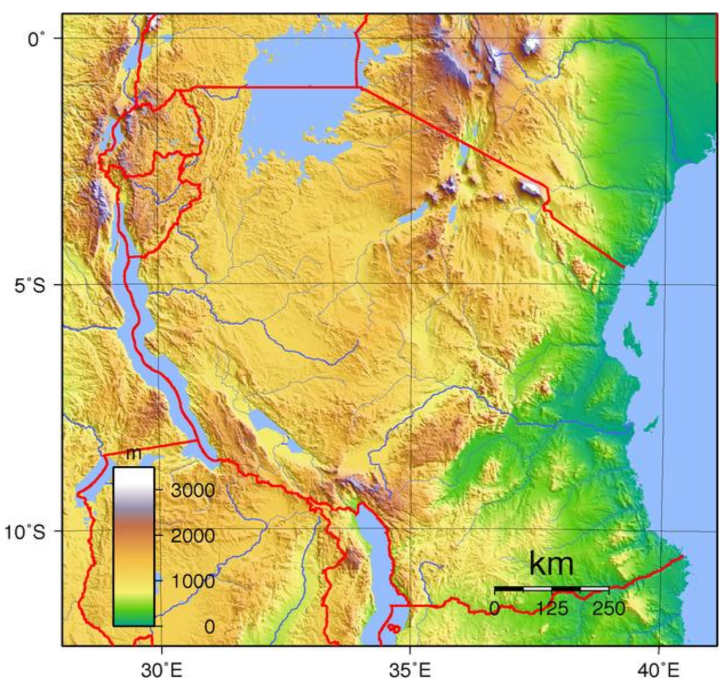

Figure 1: Topographic map of Tanzania (www.emapsworld.com)

CHAPTER TWO

2.0 Literature Review

Rainfall is very important weather and climate parameter that influence economic activities in East Africa as well as Tanzania. It is also climatic parameter over the tropical region with the largest space and time variability (Muhati and Ininda, 2007). The region of east Africa experiences two main rainfall seasons, March-May (MAM) and October-December (OND)(Omeny and Okoola, 2008). Systems that influence rainfall of East Africa include Inter Tropical Convergence Zone (ITCZ), monsoon winds, subtropical high-pressure systems, easterly/westerly waves, tropical cyclones, El Nino Southern Oscillation (ENSO), Quasi Biennial Oscillation (QBO), Southern Oscillation Index (SOI) and Indian Ocean Dipole (IOD). These are sometimes linked with too much or failure of rainfall resulting to floods or droughts (Camberlin and Okoola, 2003).

Over Tanzania rainfall is influenced by ITCZ, jet streams, pressure gradient, regional and local effects (Tilya, 2008). Furthermore the rainfall of Tanzania is affected by Monsoon winds and Congo air mass (Chang'a et al, 2008). In fact the performance of a given rainy season does not only depend in the overall total amount, but also requires an adequate distribution of the rains throughout the year. This is mainly important especially in the regions where they normally receive small amount of rains fall within a limited period of time. The rainfall failure ranges from late onset, rainfall withdrawal before time, or short but intense rainfall events separated by long dry spells (Camberlin and Okoola, 2003). In some parts of Tanzania, agriculture is affected by the length of the rain seasons while in others areas it is restricted by total amount of rainfall (Mhita, 1984). Therefore rainfall information is important to reduce the impacts associated with extreme rainfall events. However rainfall performance is highly affected by intra seasonal variability (Camberlin and Okoola, 2003; Okoola and Ambenje, 2003).

Some of the earlier studies of spatial and temporal variability of rainfall in East Africa were by Ogallo (1980) reported a 3.5 year periodicity in the annual rainfall in East Africa. Using data for 35 stations in East Africa, Rodhe and Virji (1976) observed no definite trend in the annual rainfall, except in northern Kenya where a trend towards increased rainfall in recent years was indicated. Similarly studies on the onset and cessation of the rainfall seasons over Tanzania have been done by Alusa and Gwange (1978), Mhita and Nassib (1987) but there is a need for further rainfall variability investigation in Tanzania.

Significant studies has been conducted in Africa, Some of the more recent works in East Africa have been done: In the study by Owiti and Ogallo (2007) that investigated the influence of IOD on East African seasonal rainfall using statistical approaches, results from the study suggested that there is a significant relationship between the East African rainfall variability and the Indian Ocean Dipole. Likewise Muhati and Ininda (2007) investigated the relationship between ENSO parameters and the trends of periodic fluctuations in the East African seasonal and annual decadal rainfall, who revealed that there is a strong connection between the rainfall variability over East Africa and ENSO parameters. Furthermore Omeny and Okoola (2008) studied the relationship between Madden-Julian Oscillation (MJO) and rainfall over East Africa; again they revealed from the study that there is strong association between East African rainfall variability and MJO to the west of the region particularly around the Lake Victoria. However opposite relationship between the west and the east is also revealed indicating different rain causing mechanisms for two regions. In analysis of inter annual and spatial variability of different rainfall variables over Kenya and northeastern Tanzania by Camberlin and Okoola (2003) showed that there is spatial coherence of seasonal precipitation and number of rain days (NRD). They also showed that inter annual variability of the onset and cessation of the Long Rains are independent of NRD and daily rainfall intensity (DRI) during the rainy season, therefore Long Rains total depends on a combination of virtually unrelated factors, which may account for the difficulty in its prediction.

In Tanzania the inter annual rainfall variability of short rains i.e. OND season over northern Tanzania and its associations to the large scale climate forcing was examined by Kabanda and Jury (1999), who found that there are some associations with the ENSO phenomenon and the Quasi-biennial Oscillation. Similarly the relationship between intra seasonal rainfall variability and ENSO over Tanzanian coast during OND and MAM was investigated by Kijazi and Reason (2005); rainfall variability was specifically in the rainfall onset, peak and end dates as well as dry spells. Result from the study revealed that Rainfall in coastal Tanzania is influenced by the El Niño/La Niña South Oscillation (ENSO); Furthermore El Niño is associated with above average rainfall while La Nina associated with below average rainfall over Northern coast of Tanzania and to a lesser extent MAM. In the study of rainfall variability in Northern part of Tanzania during MAM season and its links to large-scale climate forcing by Zorita and Tilya (2002), Shows that MAM precipitation has characteristics different from OND and associated with intra seasonally changing large scale pattern of Sea Surface Temperature(SST), Sea level pressure as well as winds.

Studies have shown that although shortage of rainfall is an important factor but most significant problem in semi arid region is often inter and intra seasonal rainfall variability (Barron et al, 2003). In addition a case study in Tanzania has shown that in spite of the slight improvement in forecasting accuracy, however it is not sufficient and challenges are still many due to the strong spatial and temporal variability nature of rainfall (Zorita and Tilya, 2002).

CHAPTER THREE

3.0 DATA AND METHODOLOGY

This chapter comprised of data used in the present study and various methods which were applied in order to achieve objectives.

3.1 Data

Data used in this study are monthly rainfall totals at 21 rainfall stations.

3.1.1 Rainfall Data

The rainfall data used in this work are monthly rainfall totals that were representative of various climatic rainfall homogeneous zones over Tanzania. Rainfall data cover the period of 31 years i.e. from 1982 to 2012 for 21 meteorological stations. The monthly rainfall data were obtained from Tanzania Meteorological Agency (TMA) headquarters located at Dar es Salaam. The list of rainfall stations are shown in Figure 2 and Table 1.

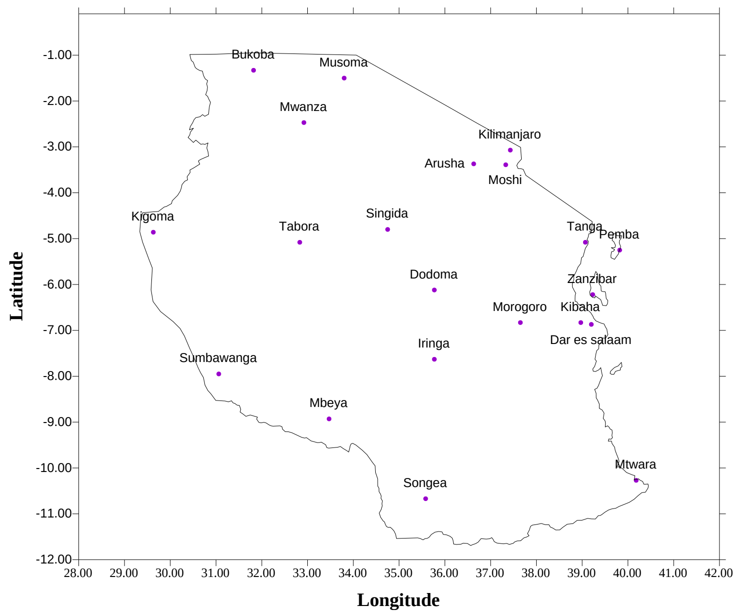

Figure 2. Map of Tanzania showing the distribution of the rainfall stations used in the study

Table 1: List of rainfall stations and their location

No.	Station	Latitude	Longitude	No.	Station	Latitude	Longitude
1	Arusha	3.37°S	36.68°E	12	Singida	4.8°S	34.75°E
2	Tabora	5.08°S	32.83°E	13	Iringa	7.63°S	35.77°E
3	Kigoma	4.88°S	29.9°E	14	Kibaha	7°S	39°E
4	Dodoma	6.17°S	35.77°E	15	Zanzibar	6.22°S	39.22°E
5	Mbeya	8.92°S	33.46°E	16	Musoma	1.5°S	33.8°E
6	Mtwara	10.35°S	40.18°E	17	Bukoba	1.55°S	31.18°E
7	Mwanza	2.5°S	32.9°E	18	Sumbawanga	7.59°S	31.6°E
8	Tanga	5.08°S	39.07°E	19	Kilimanjaro	3.43°S	37.07°E
9	Dar-es Salaam	6.87°S	39.23°E	20	Ruvuma	10°S	37°E
10	Moshi	3.34°S	37.34°E	21	Pemba	5.1°S	39.77°E
11	Morogoro	6.82°S	37.67°E				

3.2 Methodology

To achieve the objective of the study, various methods were used; these methods are discussed in the subsection below.

3.2.1 Data quality control

Consist of tests designed to ensure that meteorological and climatological data meet certain standards; it involves looking for errors in the acquired data sets. Data quality control involves estimation of missing data and homogeneity test.

3.2.1.1 Estimation of Missing data

Many methods are available for estimation of missing data as recommended by WMO (1966), such as arithmetic mean methods, correlation methods, Isohyetal linear interpolation and mean ratio method. In present study missing rainfall records were encountered in the observed rainfall data from nine stations i.e. Dodoma, Iringa, Arusha, Singida, Pemba, Bukoba, Moshi, Morogoro and Kibaha. The percentage of missing records was found to be 0.002%, given that the study required continuous data therefore mean ratio method was used for estimation of missing records. However before estimation of missing data pairs of nearby stations was selected and their correlation coefficient was computed in order to find strength of association between rainfall data of the stations. The station that depicted the highest correlation with the one that has missing data is selected in determination of missing data. Therefore estimation of missing gaps using mean ratio methods was between the stations which have the highest correlation value. Given annual precipitation value P_1, P_2, P_3… P_m at neighboring M stations of station X 1, 2, 3 & m respectively The normal average precipitation given by N_1, N_2, N_3,…, N_m, N_i… including station X. To find the missing precipitation P_x, of station X the following formula was used to calculate missing gaps.

$$P_x = \frac{N_x}{M}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \ldots + \frac{P_m}{N_m}\right] \tag{1}$$

3.2.1.2 Homogeneity Test

Homogeneity test is important aspect of data quality control. The most proposed methods are double and single mass curves. In this study single mass curve was used to test data homogeneity for all stations. It involves plotting of the cumulative rainfall totals against time.

3.2.2 Temporal Distribution of Rainfall

In this study temporal variability was investigated using a graphical method, thus the monthly rainfall data was subjected to a histogram. Plotting a histogram involved rainfall data against time. Graphical plots i.e. Histogram revealed that rainfall regime over most parts of Tanzania are unimodal and bimodal.

3.2.3 Trend Analysis

A trend refers to long term movement of a time series (Muhati et al, 2007). Many methods are available to describe trends in climatological data. These methods may be classified into several categories, some of which are: graphical, polynomial, and statistical methods. In present study the trend analysis was established through a graphical plot of the rainfall data series and statistical methods.

3.2.3.1 Graphical Method

The graphical method involves plotting seasonal rainfall from November- April (NA) data against time for unimodal stations. Likewise MAM and OND rainfall was plotted against time for bimodal rainfall stations. The advantage of this method is that it provides quick visual observation of the presence trend in a given time series. Moreover the use of the graphical approach for trend analysis is simple. On the other hand graphical methods has shortcoming such as its subjectivity as they depends on individual judgments.

3.2.3.2 Statistical Method

The visual method of determining trends from a graph is very subjective therefore statistical method can also be used. Statistical methods were used to test the statistical significance of the observed trends in a time series. A similar method has been applied by Okoola (2000) and Muhati (2007). These methods are normally categorized in two groups: parametric and non-parametric tests. In present study the parametric tests was used in the analysis of variance (ANOVA) approach whereby a time series was divided into two groups each of at least 15 years record. The means and standard deviations of the subgroups are then calculated and compared using the statistical distribution student t-test that best describes the time series. In this study the null and alternative hypothesis used in testing for the statistical significance of the trends of the rainfall data was that Ho: there is no significance of the trends. The standard error and the student t test expressed by equation 2 and 3 respectively

$$s_{\bar{X}_1-\bar{X}_2} = \sqrt{\frac{s_1}{n_1}^2 + \frac{s_2}{n_2}^2} \qquad (2)$$

$$t = \frac{\bar{X}_1 - \bar{X}_2}{s_{\bar{X}_1 - \bar{X}_2}} \quad (3)$$

3.2.4 Rainfall Variability and Reliability

In this study an attempt has been made to examine reliability and variability of seasonal and annual rainfall records. It involves both time and space variability, some methods that was used to examine rainfall variability and reliability include spatial plot and coefficient of variability.

3.2.4.1 Coefficient of Variability (CV)

This is a measure of degree of variability; it is also expressed as a percentage. The coefficient of variation (C_V) is defined as the percentage ratio of the standard deviation to the mean;

$$C_V = 100\frac{\sigma}{\bar{X}} \quad (4)$$

The reliability of annual and seasonal stations rainfall records were examined using method of coefficient of variation. High coefficient of variability means that low reliability of rainfall and vice versa is true. Reliability (R) is given by the formula;

$$R = 100 - C_V \quad (5)$$

3.2.4.2 Spatial Plot

Spatial map of annual coefficient of variation was drawn using surfer software to show how the rainfall is distributed with space.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

This chapter outlines the results and discussions from the analysis.

4.1 Result from Data Quality Control

The quality of what obtained from this study depends on the quality of data used, In order to ensure that results from data analysis have proper meaning and interpretation it was first subjected to quality control. The objective of data quality control is to detect and remove errors in the data sets. Furthermore data quality control involves estimation of missing gaps and homogeneity test.

4.1.1 Missing Data

In actual practice it is common to obtain missing rainfall data from the set of records. There are numerous reasons why rainfall data may be missing from the database; some of them are effect of natural hazards such as floods and human related problems such as temporary absence of people in charge of reading gages. In this study missing rainfall records were encountered in the observed rainfall data from nine stations i.e. Dodoma, Iringa, Arusha, Singida, Pemba, Bukoba, Moshi, Morogoro and Kibaha. The percentage of missing records was found to be 0.002%, given that the study required continuous data therefore mean ratio method was used for estimation of missing records.

4.1.2 Test for Data Homogeneity

The methods that are normally employed to detect and correct inconsistence in the data set are Single and double mass curves. The single mass curve was used in this study to tests for the homogeneity of the data. Single mass curve is a plot of annual cumulative rainfall against time;

the mass curves for most of the stations were almost straight lines indicating that data from most stations are homogeneous. Figure 3 up to 8 are examples of single mass curves for some selected stations based on Tanzania homogenous zones, other stations can be found in (Appendix A). These figures show straight lines indicating data is of good quality.

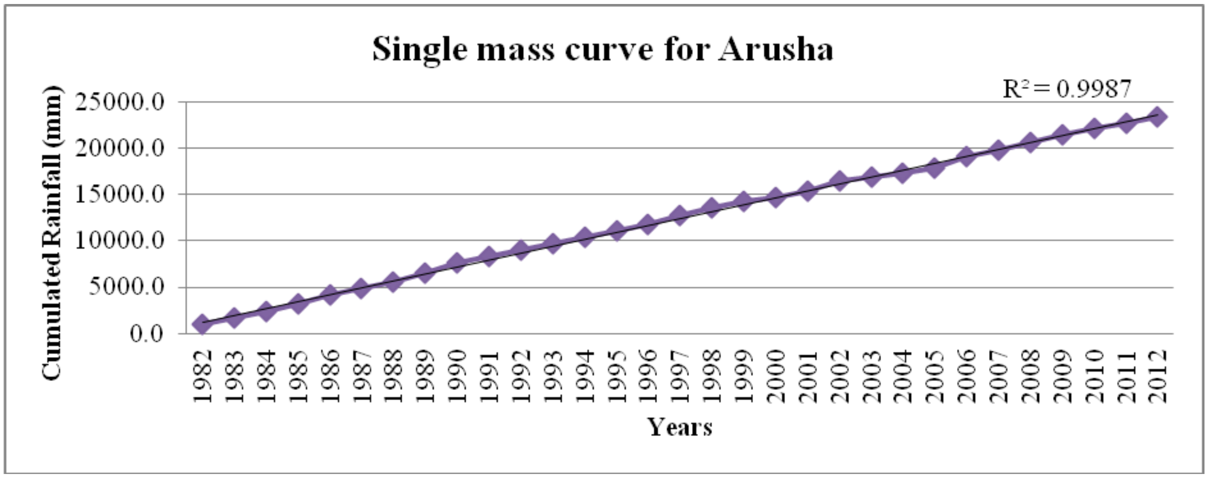

Figure 3: Single mass curve for Arusha (1982/2012)

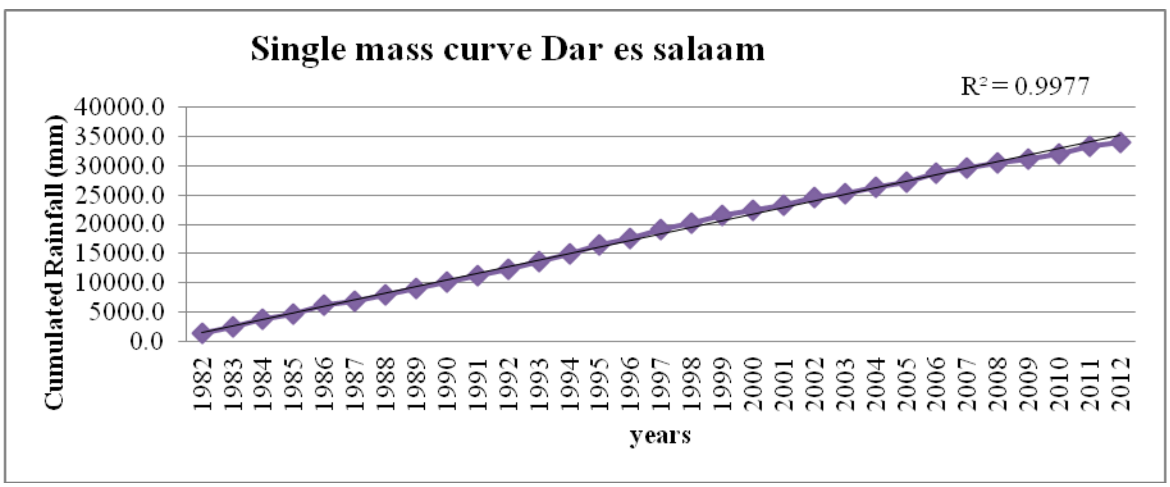

Figure 4: Single mass curve for Dar es Salaam (1982/2012)

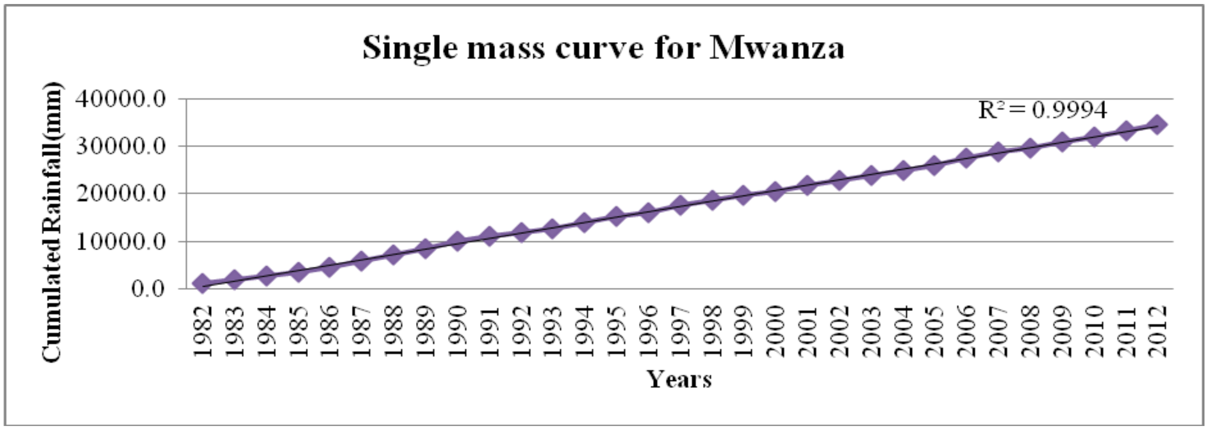

Figure 5: Single mass curve for Mwanza (1982/2012)

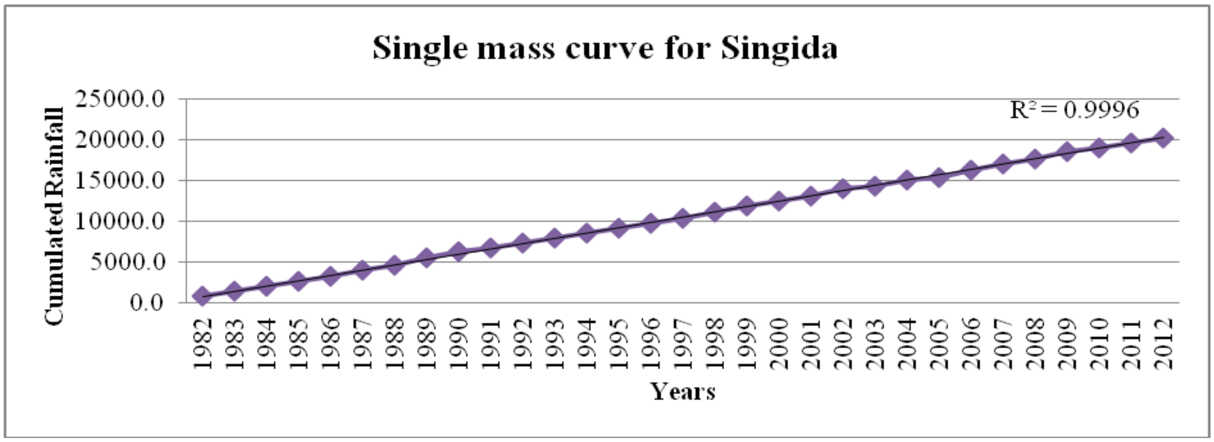

Figure 6: Single mass curve for Singida (1982/2012)

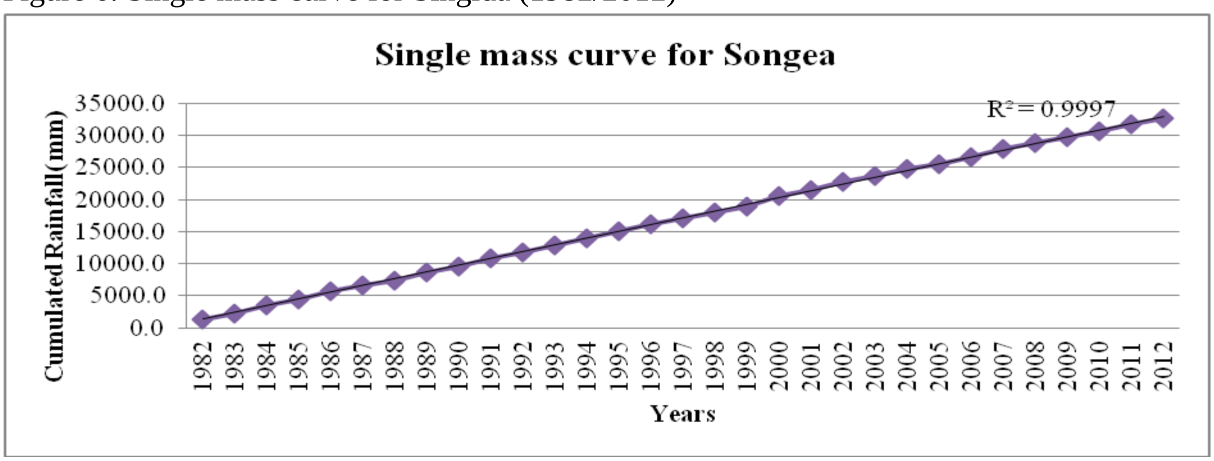

Figure 7: Single mass curve for Songea (1982/2012)

4.2 Results from Temporal Distribution of Mean Monthly Rainfall

The temporal distribution of rainfall over the study region was investigated. The rainfall regime over most parts of Tanzania was found to be unimodal and bimodal as indicated in figures 8-12. Northern part of the country and northern coast experience bimodal rainfall regime i.e. the long rains occur in the March–May (MAM) season and the short rains season extends from October to December (OND). However central, south and western region have unimodal rainfall regime starting from October to May. Examples of the temporal distribution of rainfall over Tanzania for some stations are shown in Figures 8–12, other stations can be found in Appendix B.

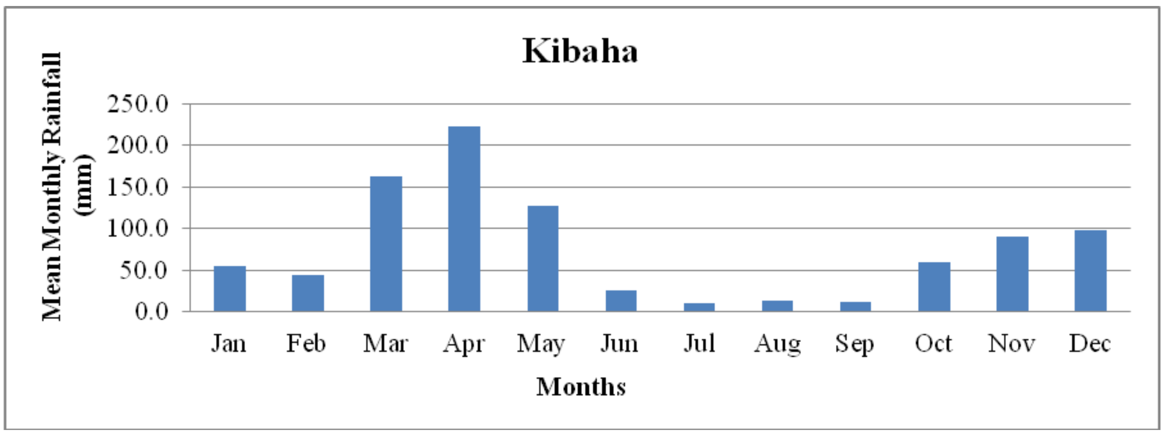

Figure 8: Mean monthly rainfall at Kibaha (1982/2012)

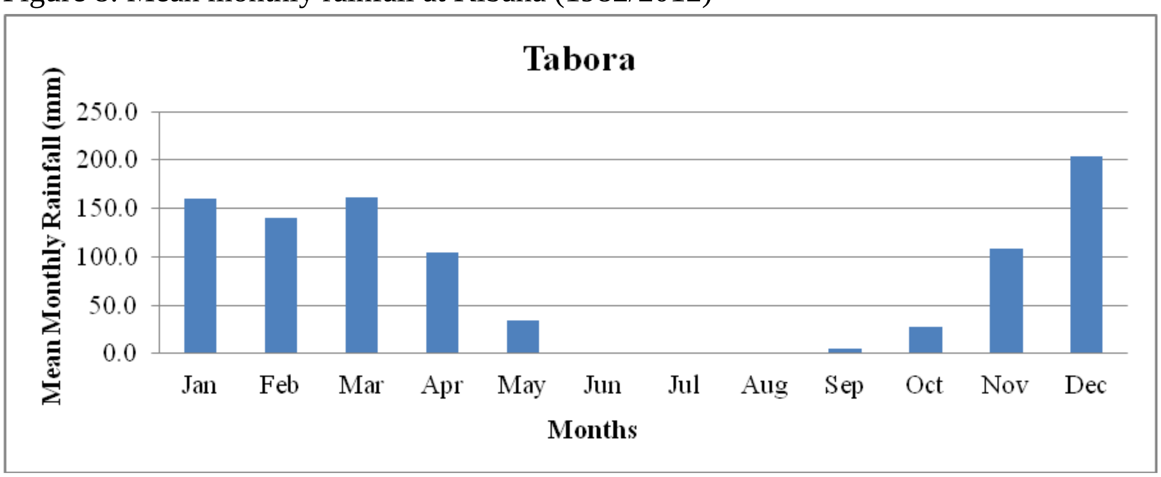

Figure 9: Mean monthly rainfall at Tabora (1982/2012)

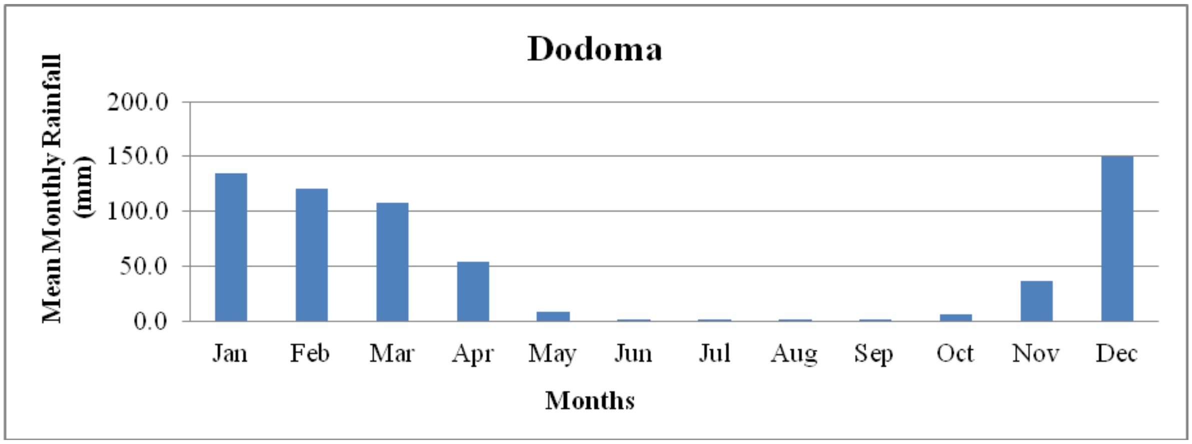

Figure 10: Mean monthly rainfall at Dodoma (1982/2012)

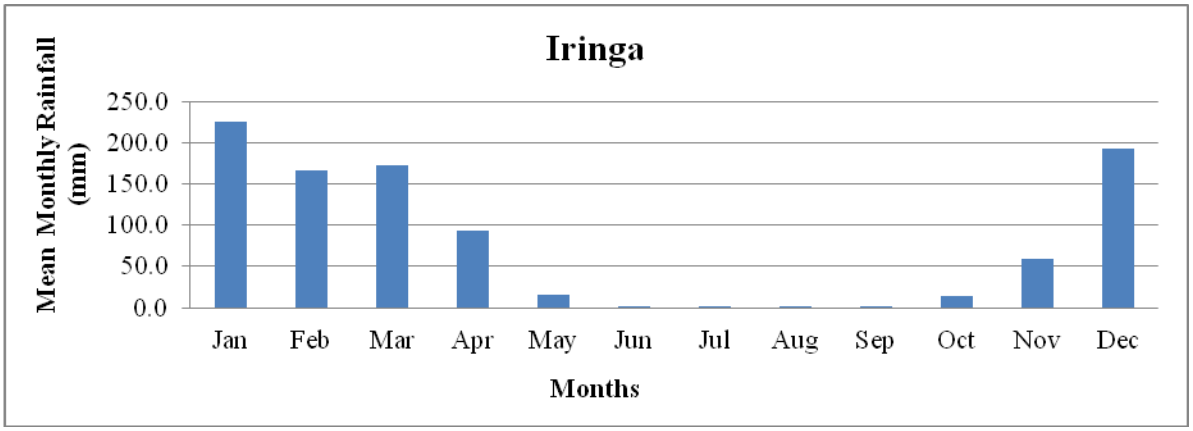

Figure 11: Mean monthly rainfall at Iringa (1982/2012)

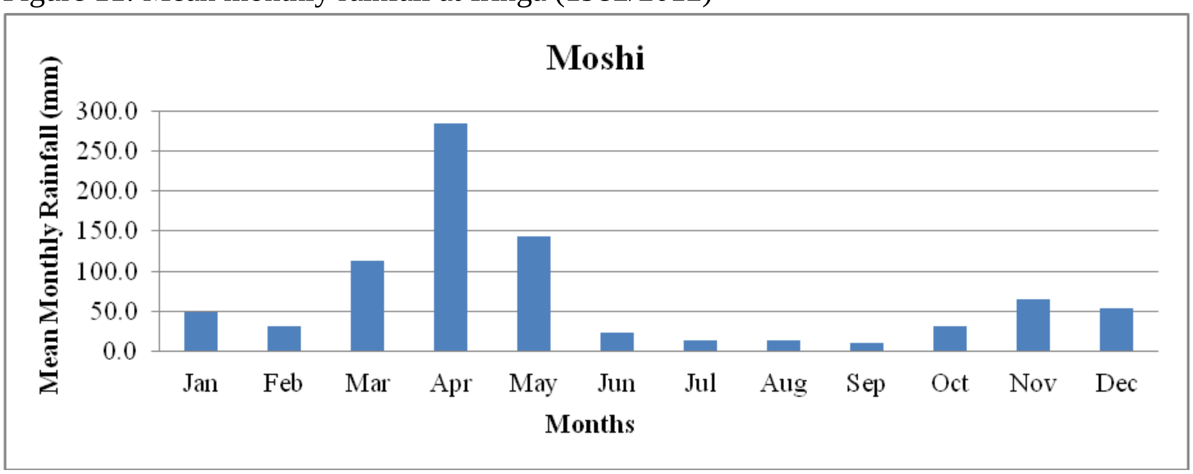

Figure 12; Mean monthly rainfall at Moshi (1982/2012)

4.3Results from Trend Analysis

In this study the trend analysis was determined through a graphical plot of the rainfall data series and statistical methods.

4.3.1 Graphical Method

The results of trends analysis from graphical method were categorized into two categories namely; increasing trends (positive) and decreasing trends (negative).The seasonal analysis of rainfall data for all stations showed that there are trends during MAM, OND and NA. Northern coast of Tanzania which comprised by Dar es salaam, Morogoro, Pemba, Kibaha, Tanga and Zanzibar rainfall data indicated a generally decreasing (negative) trend in both MAM and OND. Likewise in southern coast of Tanzania a representative station of Mtwara showed that there is the decreasing (negative) trend of rainfall during (November-April) NA as shown in appendix C. Also in Northeastern Highland of Tanzania i.e. Arusha, Moshi and Kilimanjaro showed negative (decreasing) trend in both MAM and OND. However stations around Lake Victoria basin like Bukoba, Mara and Mwanza depicted positive trends both in MAM and OND except in Mara where MAM showed negative trends. In the central western part of the country Dodoma depicted increasing trend while Kigoma depicted a negative trend. Furthermore south western highland i.e. Iringa and Mbeya showed negative trends while Rukwa positive trends. Also Southern region i.e. Songea depicted a negative or decreasing trends. In summary result from all graphical plots showed Negative trends except Mwanza, Bukoba, Dodoma and Sumbawanga. Figures 13-15 are examples of graphical plots showing rainfall trends, other stations are shown in Appendix C and Appendix D.

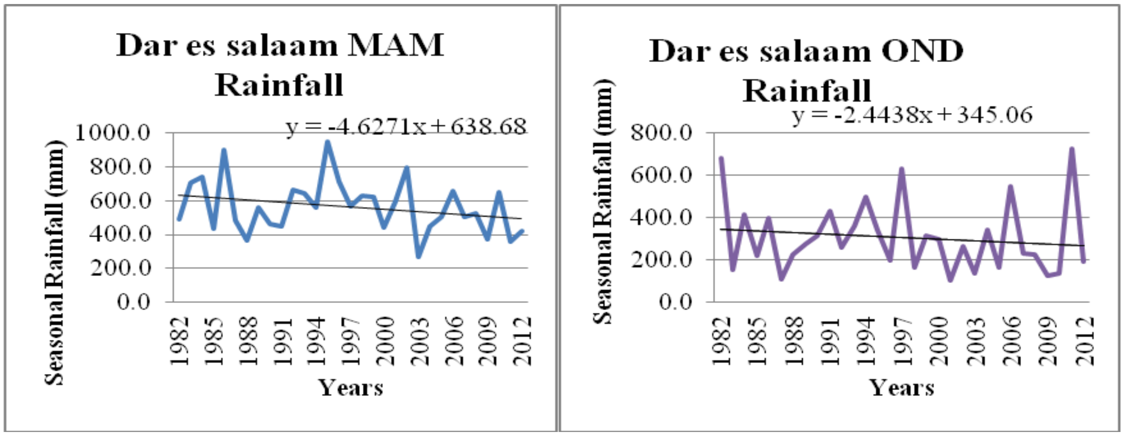

Figure 13; MAM and OND Rainfall for Dar es Salaam (1982-2012)

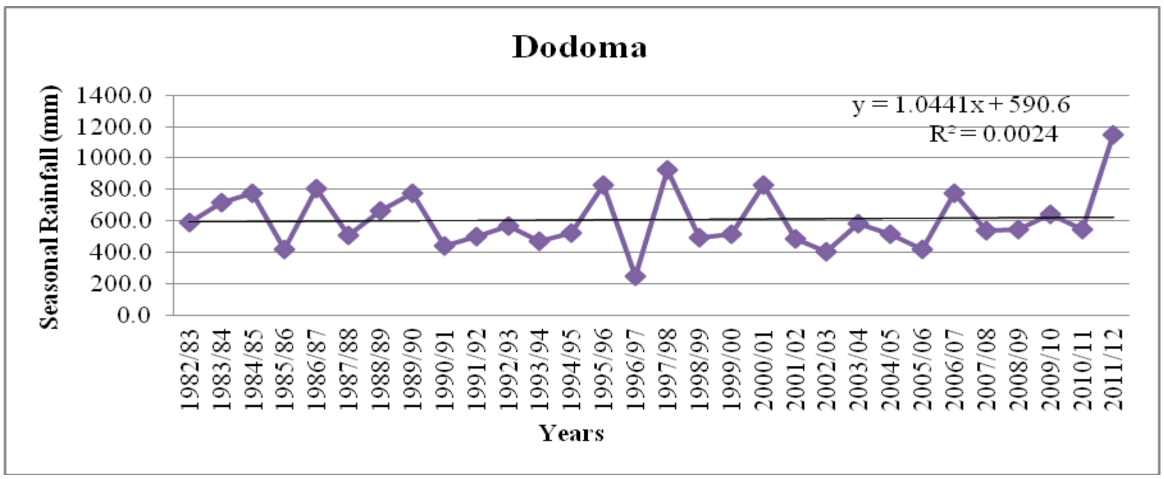

Figure 14; NA Rainfall for Dodoma (1982-2012)

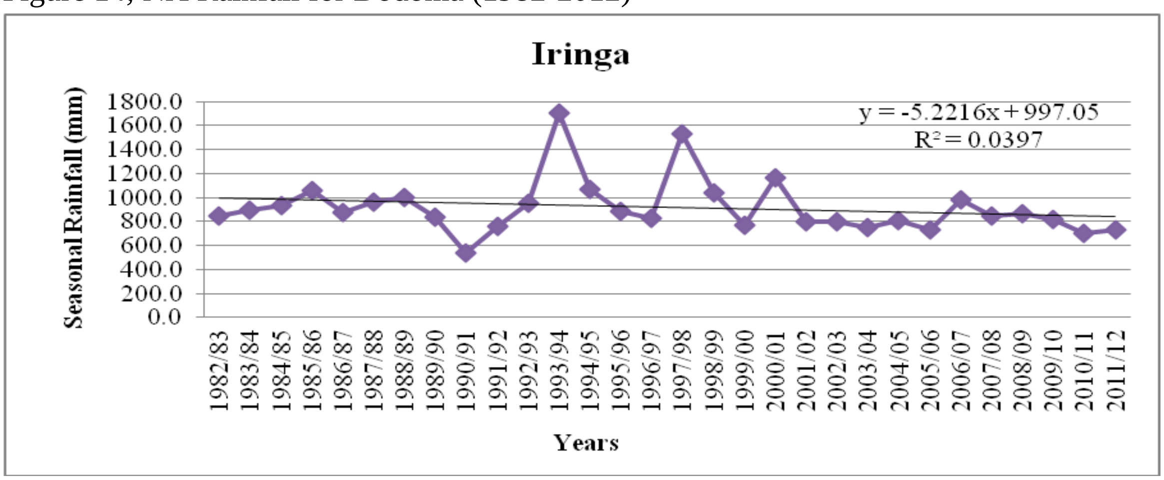

Figure 15; NA Rainfall for Iringa (1982-2012)

4.3.2 Results from Statistical Analysis of Trends

Statistical methods were used to test the significance of the trend. Results from statistical methods suggest that there were trends i.e. Means are different as shown in Table 2, this confirms that the population from which two means were computed is not the same and thus rainfall has changed. Furthermore result from statistical method showed that there are trends in all Rainfall stations, however at 95% confidence there is sufficient statistical evidence to conclude that trends in all rainfall stations are not significance except in Pemba and Tanga both coastal stations during MAM season. This is also portrayed in a time series plot shown in Appendix C and D. Table 2 show the results obtained from statistical analysis.

Table 2: Results of seasonal rainfall t-test statistic at 95 % confidence interval

Stations	**Seasons**	**Difference in means**	**Slopes**	**Trend**	**Significance of the trend**
Dar es salaam	MAM	85.3	-4.627	Negative	Not significance
	OND	37.7	-2.444	Negative	Not significance
Morogoro	MAM	11.2	-0.0058	Negative	Not significance
	OND	8.0	-2.0062	Negative	Not significance
Mwanza	MAM	29.1	1.6073	Positive	Not significance
	OND	52.4	2.2479	Positive	Not significance
Zanzibar	MAM	117.6	-7.7654	Negative	Not significance
	OND	21.8	-3.3002	Negative	Not significance
Pemba	MAM	220.1	-11.685	Negative	Significance
	OND	9.20	-1.2750	Negative	Not significance
Bukoba	MAM	11.4	8.279	Positive	Not significance
	OND	52.3	1.203	Positive	Not significance
Musoma	MAM	13.6	-0.3927	Negative	Not significance
	OND	28.5	0.5575	Positive	Not significance
Tanga	MAM	161.1	-11.207	Negative	Significance
	OND	4.7	-2.1659	Negative	Not significance
Moshi	MAM	54.6	-4.5056	Negative	Not significance
	OND	13.8	-1.516	Negative	Not significance
Kilimanjaro	MAM	26.0	-0.7979	Negative	Not significance
	OND	1.0	-1.5681	Negative	Not significance
Kibaha	MAM	70.2	-1.975	Negative	Not significance
	OND	23.5	-1.243	Negative	Not significance
Arusha	MAM	27.9	1.4752	Negative	Not significance
	OND	26.3	-2.723	Negative	Not significance
Kigoma	NA	13.7	-2.1139	Negative	Not significance
Tabora	NA	1.40	-1.8013	Negative	Not significance
Sumbawanga	NA	40.5	1.543	Positive	Not significance
Mbeya	NA	11.9	-2.9516	Negative	Not significance
Iringa	NA	54.6	-5.2216	Negative	Not significance
Ruvuma	NA	25.8	-3.378	Negative	Not significance
Singida	NA	19.0	-0.9914	Negative	Not significance
Dodoma	NA	35.8	1.0441	Positive	Not significance
Mtwara	NA	33.7	-5.5705	Negative	Not significance

4.4 Result from Analysis of Variability

In this study an attempt has been made to examine variability and reliability of seasonal as well as annual rainfall records using method of the coefficient of variation.

Results from seasonal coefficient of variation found that the largest value of variability was observed during OND at Kilimanjaro (Table 3). This implies that there is little rainfall in these regions during OND season; In addition high variability confirms that rainfall is less reliable. Furthermore lowest variability was found in unimodal areas such as Kigoma, Sumbawanga and Mbeya during November-April (NA) season which means that rainfall in these regions are most reliable. In bimodal regions comparison of MAM and OND seasons revealed that OND rainfall is more variable than MAM, this implies that MAM rainfall is more reliable in most parts of the country. Also analysis of MAM rainfall indicated that the highest value of variability was in Kilimanjaro i.e. 40.2%, while the lowest was at Bukoba 25.6% meaning that MAM rainfall are less reliable in Kilimanjaro and more reliable in Bukoba. Therefore the highest seasonal reliability was found in Kigoma followed by Sumbawanga, Mbeya, Ruvuma and Morogoro.

Results from annual coefficient of variation showed that the largest value of variability was observed at Kilimanjaro 33.3% followed by Moshi, Dodoma and Iringa. Kilimanjaro depicted the largest value both in seasonal and annual rainfall analysis; this proves that rainfall in Kilimanjaro is least reliable. In addition the comparison of annual and seasonal results showed that there is higher seasonal variation than annual variation, which also means that annual rainfall is higher and more reliable than seasonal rainfall. On the other hand lowest variability was found in Kigoma followed by Bukoba and Mbeya, these findings is similar with what observed in seasonal analysis. Therefore Kigoma, Sumbawanga, Bukoba and Mbeya observed to be the regions where rainfall is very reliable over Tanzania. Table 3 shows the results of coefficient of variation.

Table 3: Results of Seasonal and Annual variability and reliability

Stations	Seasons	Seasonal variability	Seasonal Reliability	Annual variability	Annual Reliability
Dar es salaam	MAM	28	72	23.6	76.4
	OND	55.1	44.9		
Morogoro	MAM	21.1	78.9	21.4	78.6
	OND	58.8	41.2		
Mwanza	MAM	28	72	19.1	80.9
	OND	29	71		
Zanzibar	MAM	29	71	23.1	76.9
	OND	45.5	54.5		
Pemba	MAM	32.5	67.5	26.7	73.3
	OND	71.6	28.4		
Bukoba	MAM	25.6	74.4	17.8	82.2
	OND	30.7	69.3		
Musoma	MAM	27.4	72.6	19.0	81.0
	OND	46.3	53.7		
Tanga	MAM	32.5	67.5	25.2	74.6
	OND	63.9	36.1		
Moshi	MAM	36.6	63.4	29.5	70.5
	OND	62.8	37.2		
Kilimanjaro	MAM	40.2	59.8	33.3	66.7
	OND	85.6	14.4		
Kibaha	MAM	30.6	69.4	26.3	73.7
	OND	57.8	42.2		
Arusha	MAM	32.8	67.2	27.8	72.2
	OND	63.9	36.1		
Kigoma	NA	15.6	84.4	13.8	86.2
Tabora	NA	20.5	79.5	19.0	81.0
Sumbawanga	NA	17.3	82.7	19.8	80.2
Mbeya	NA	17.5	82.5	18.7	81.3
Iringa	NA	25.2	74.8	28.2	71.8
Ruvuma	NA	20.0	80.0	18.9	81.1
Singida	NA	24.7	75.3	19.3	80.7
Dodoma	NA	30.6	69.4	28.0	72.0
Mtwara	NA	21.6	78.4	26.3	73.7

Results from spatial plot of annual coefficient of variation showed that the highest year to year rainfall variability occurred in the north east part of Tanzania i.e. it was observed at Kilimanjaro followed by Moshi. This is consistent with the observation of a dry zone (Okoola, 1998), also central and southern part of the country i.e. Dodoma and Iringa depicted largest variation. In contrast the lowest variability was found in western Tanzania specifically Kigoma. Therefore Kigoma, Sumbawanga, Bukoba and Mbeya observed to be the regions where rainfall is very reliable over Tanzania. Figure16 shows the spatial pattern of coefficient of variation (%) for annual rainfall.

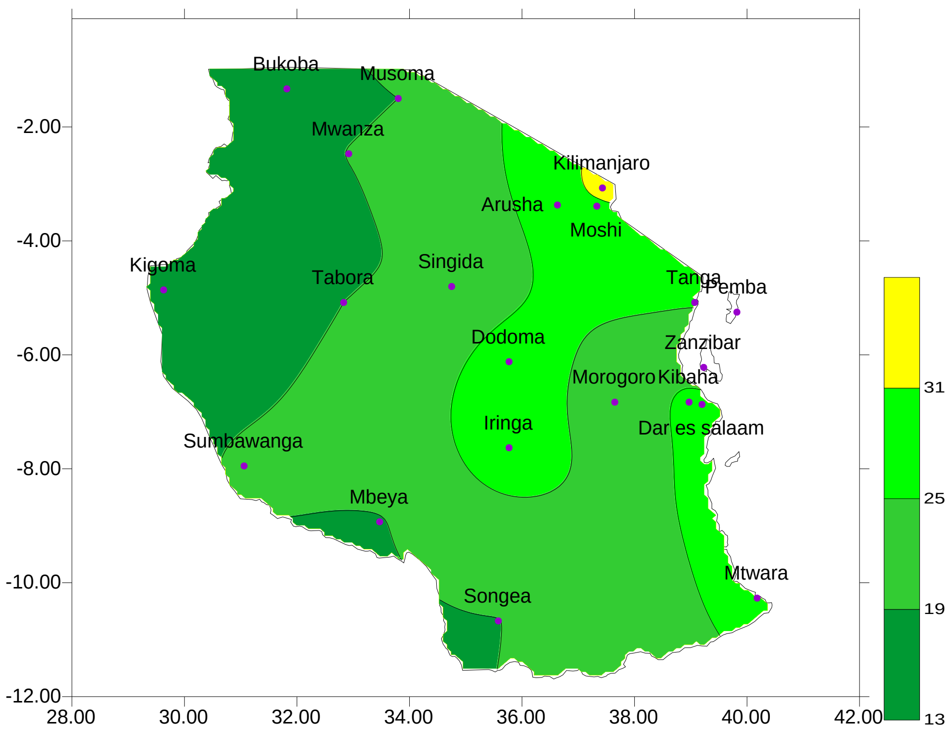

Figure 16. The spatial pattern of coefficient of variation (%) for the annual rainfall

4.5 Result from Spatial Analysis

Mean annual rainfall for 31 years indicated that Bukoba region had the highest rainfall followed by Zanzibar and Pemba. For the case of Bukoba this is possibly due to presence of enough moisture around Lake Victoria basin and closeness to equator where there is surplus of solar energy. Also L.Victoria tends to be shallow to west leading to enhanced evaporation (Datta, 1981). In case of Zanzibar and Pemba the regions is an islands surrounded by Indian Ocean, therefore highest rainfall is probably due to presence of enough moisture. Furthermore results from spatial analysis showed that highest mean annual rainfall was in bimodal rainfall regime. Mwanza, Tanga, Dar es Salaam, Mtwara, Songea depicted more than 1000mm of mean annual rainfall. Moreover the rest of the regions have mean annual rainfall less than 1000mm. The lowest mean annual rainfall was at Kilimanjaro, which confirms that Kilimanjaro received smallest amount of rainfall. In fact this is also supported with the result obtained from the coefficient of variability. Figure 17 and 18 portrays the spatial distribution of mean annual rainfall.

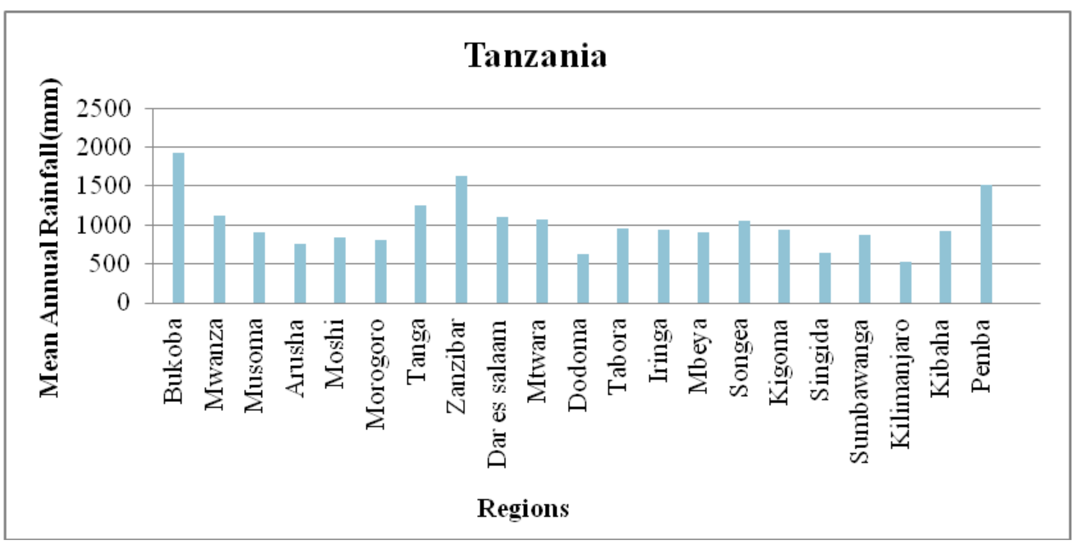

Figure 17. The spatial distribution of mean annual rainfall from 1982-2012

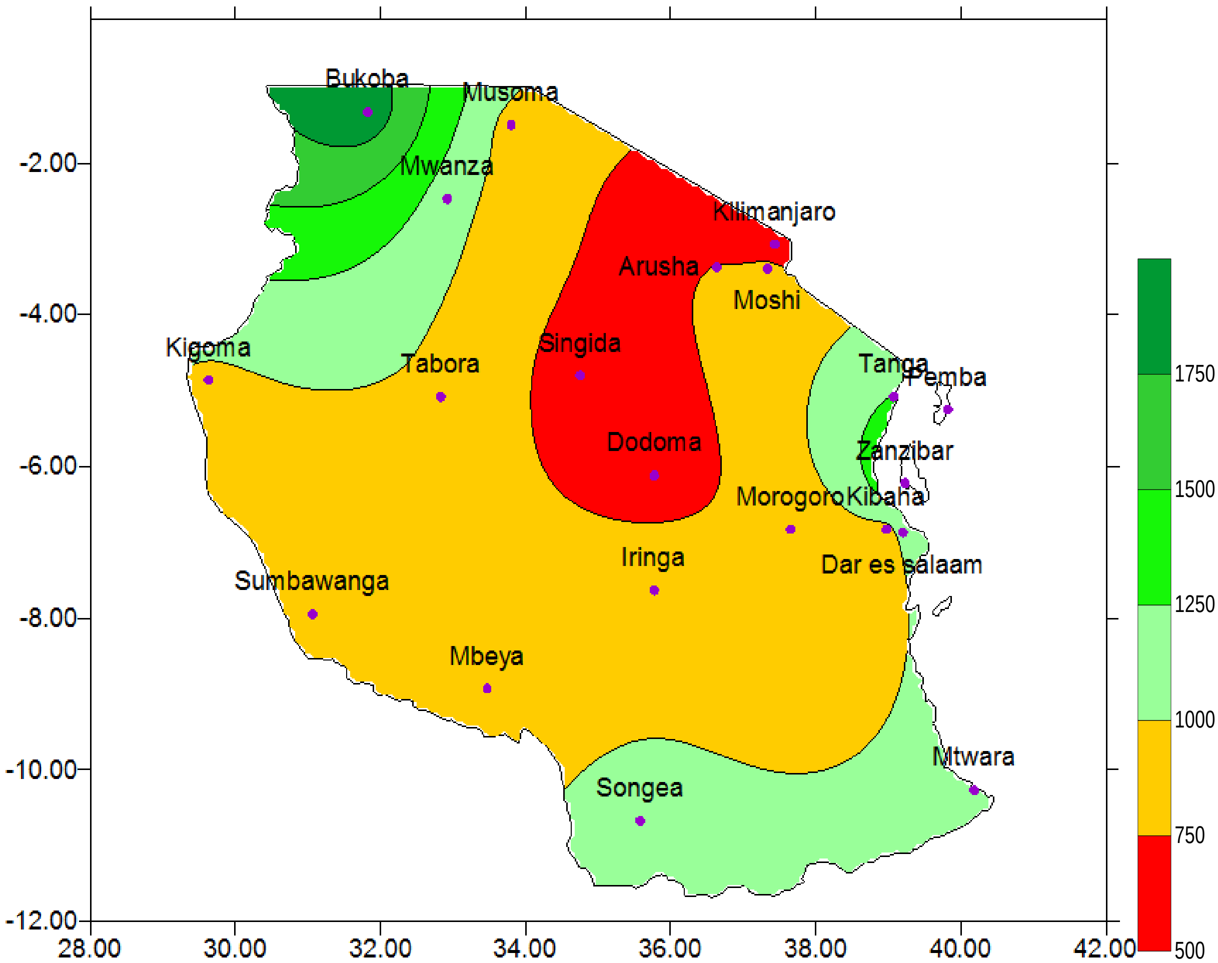

Figure 18. The spatial distribution of mean annual rainfall from 1982-2012

Results from spatial plot of annual reliability showed that the lowest year to year rainfall reliability occurred in the north east part of Tanzania i.e. it was observed at Kilimanjaro followed by Moshi. Also central and southern part of the country i.e. Dodoma and Iringa depicted lowest reliability value. In contrast the largest reliability was found in western parts of Tanzania specifically Kigoma. Therefore Kigoma, Sumbawanga, Bukoba and Mbeya observed to be the regions where rainfall is very reliable over Tanzania. Figure19 shows the spatial pattern of reliability of annual rainfall.

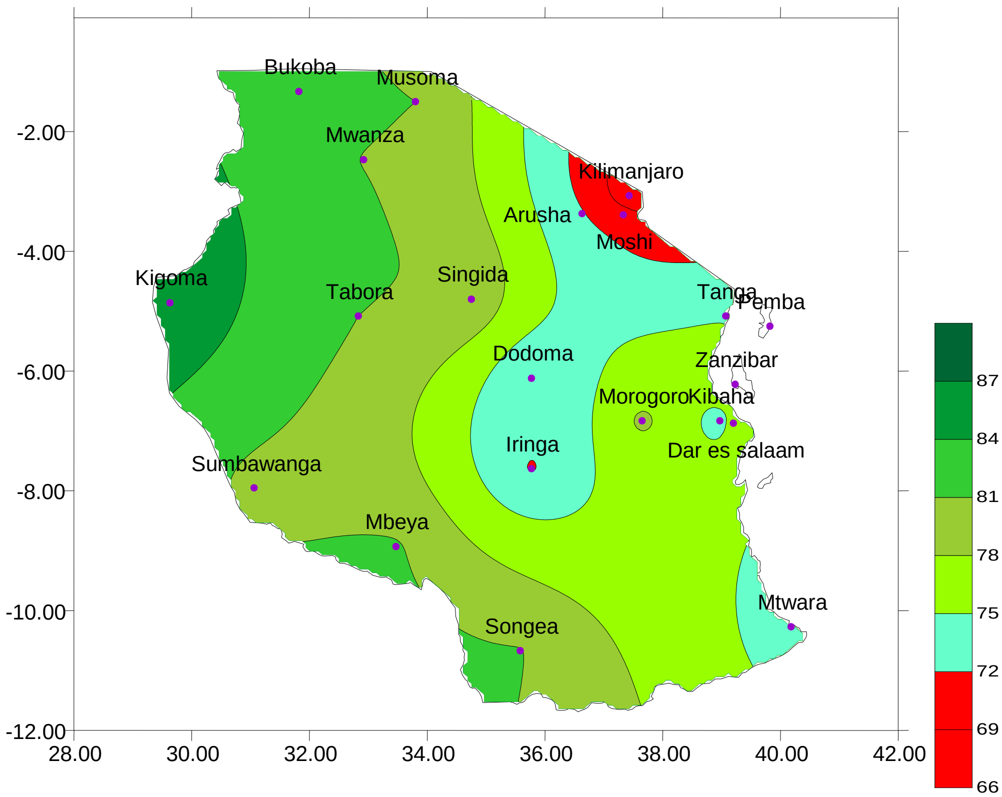

Figure 19. The spatial pattern of reliability for the annual rainfall

CHAPTER FIVE

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY

The study of rainfall variability over Tanzania was conducted based on two aspects; temporal and spatial variability. The rainfall data used in the study was found to be homogenous and consistent. Temporal analysis of mean monthly rainfall distribution by graphical method showed that there are two rainfall regimes over Tanzania i.e. unimodal and bimodal. In spatial analysis both graphical and contouring methods were used to show variation of rainfall from one place to another. Results from spatial analysis suggest that rainfall is much higher in the regions close to water bodies than where there are no water bodies. Furthermore trends were investigated using graphical methods as well as statistical methods such as difference of two means and student t - test in order to test significance of the trends. The results from trend analysis indicate that there was a trend for most of the stations; however it was downward trend for all station except in Mwanza, Bukoba, Dodoma and Sumbawanga.

5.2 CONCLUSIONS

In this study various objectives have been achieved, where by temporal and spatial variability of rainfall was determined. Result from the temporal characteristic of Tanzania rainfall classified into unimoda and bimodal. Moreover results from trend analysis have shown that there were decreasing trends for all stations except in Mwanza, Sumbawanga, and Dodoma, but trends are not statistically significant except in two stations i.e. Pemba and Tanga. Result from analysis of variability showed that Kilimanjaro rainfall has largest variability value which in turn implied that Kilimanjaro rainfall is least reliable; this is probably due to the rain shadow effect while rainfall in Kigoma, Mbeya, Sumbawanga, Bukoba is most reliable. Furthermore Results from spatial analysis indicate that rainfall is much higher in the regions close to water bodies particularly area around Lake Victoria basin and Indian Ocean, this is possible due to the fact that closeness to water bodies as well as closeness to equator that contribute a lot of moisture in these regions. Also rain formation depends on source of moisture.

5.3 RECOMMENDATIONS

The study has displayed the existence of trends in seasonal rainfall, however in most parts of the country there is decreasing trend. A reduction of precipitation if accompanied by high inter annual variability could disrupt various water dependent activities such as agriculture, hydroelectric power generation among others. Therefore there is the need for further research using daily, monthly and annual data for longer period than what used in this study especially for those regions that showed significant trends. The study also revealed the existence of much higher rainfall in the regions close to water bodies, for that reason more research should be carried out in order to understand the physical processes that lead to frequent increase and decrease of rainfall trends in most part of the country. Result from analysis of variability revealed that Kilimanjaro rainfall has largest variability value and less reliable. Also spatial analysis showed that Kilimanjaro has smallest amount of rainfall, therefore more research should be done in order understand the reasons behind such variability and little rainfall. This study will be of assistance to better inform farmers as well as agricultural decision makers, also study of temporal variability and trends of rainfall may be used to characterize climatology of the country.

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Appendix A; Single Mass curves

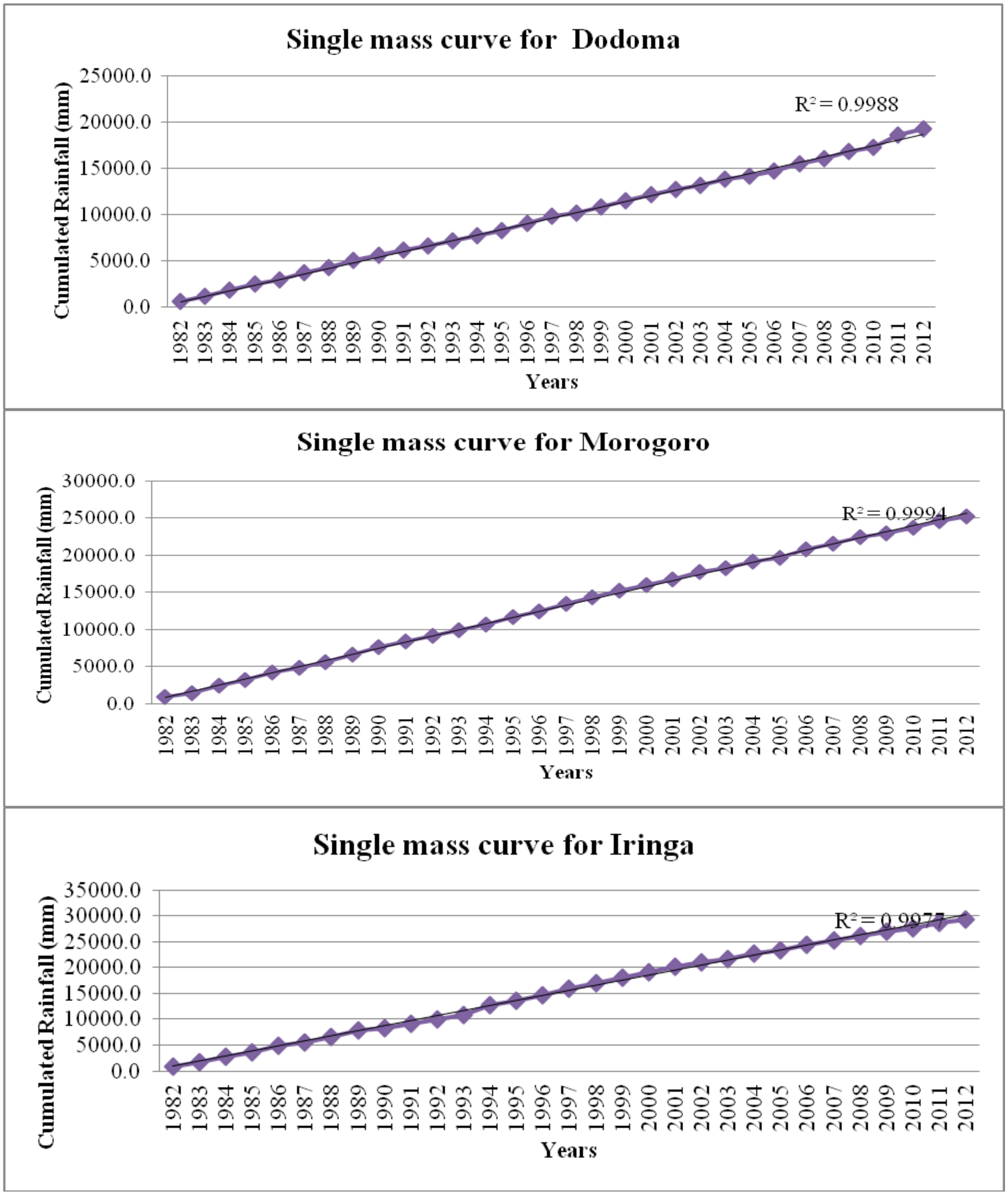

Figure 20. Single mass curve for Dodoma, Morogoro and Iringa

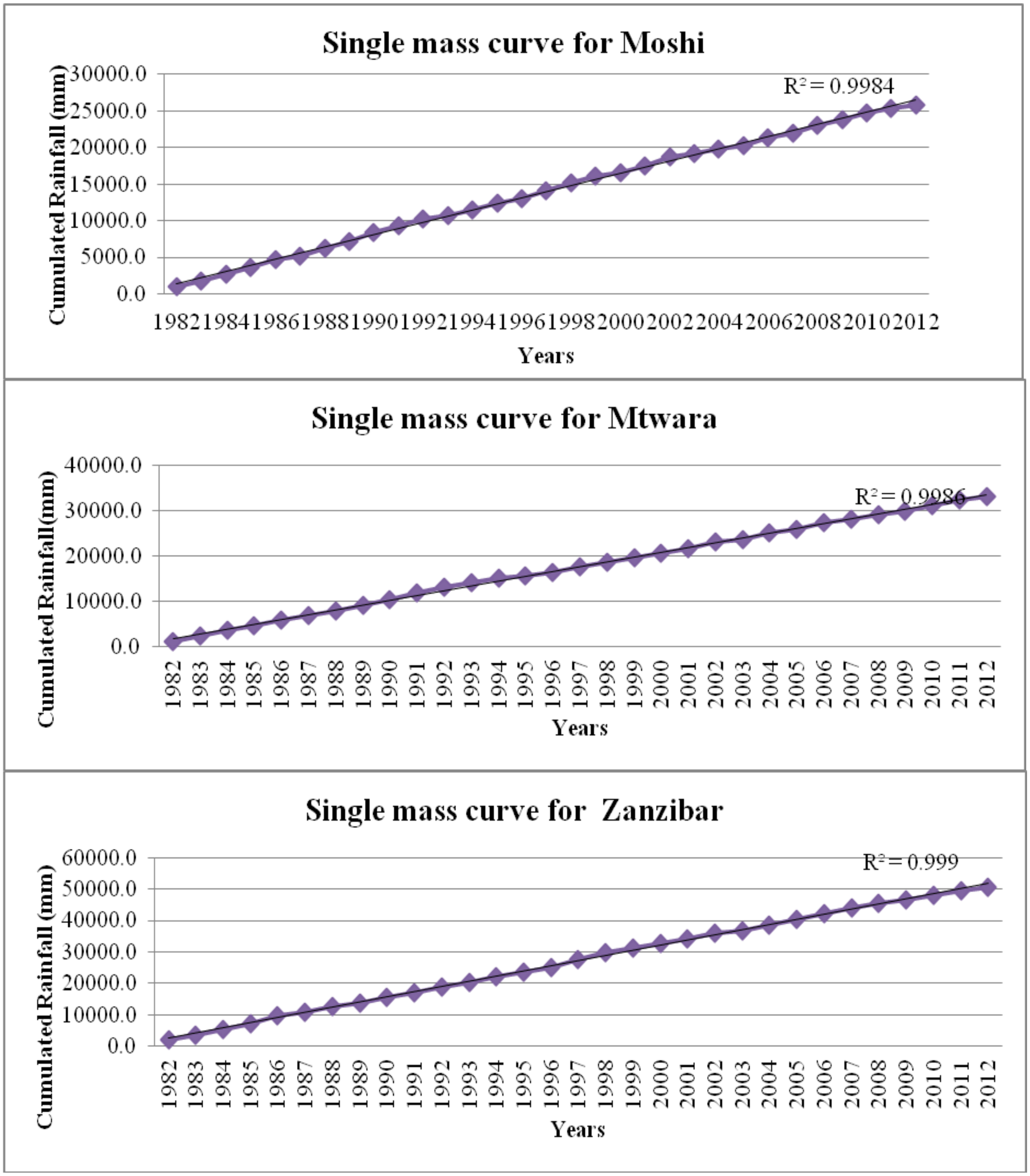

Figure 21. Single mass curve for Zanzibar, Mtwara and Moshi

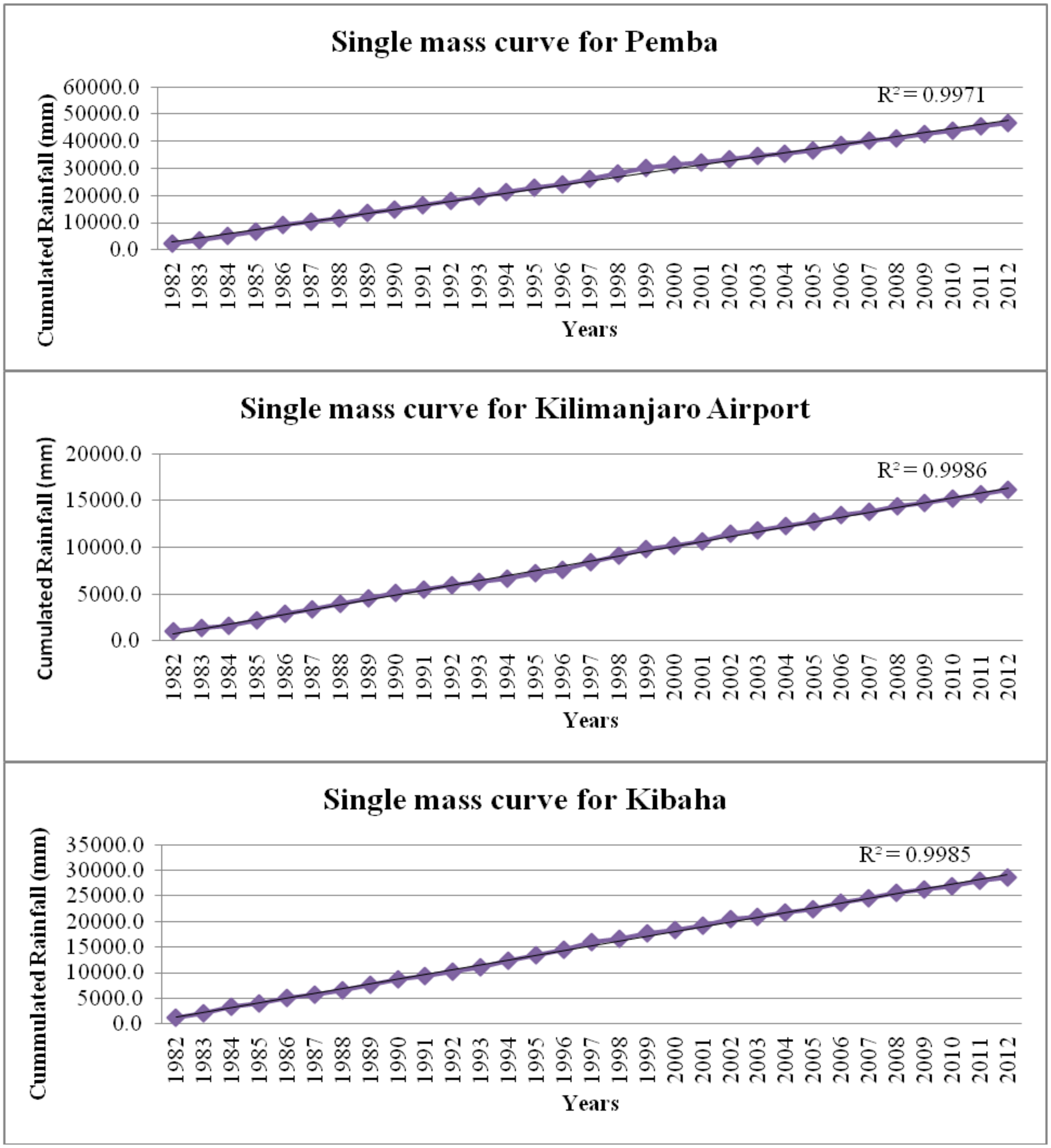

Figure 22. Single mass curve for Kibaha, Pemba and Kilimanjaro

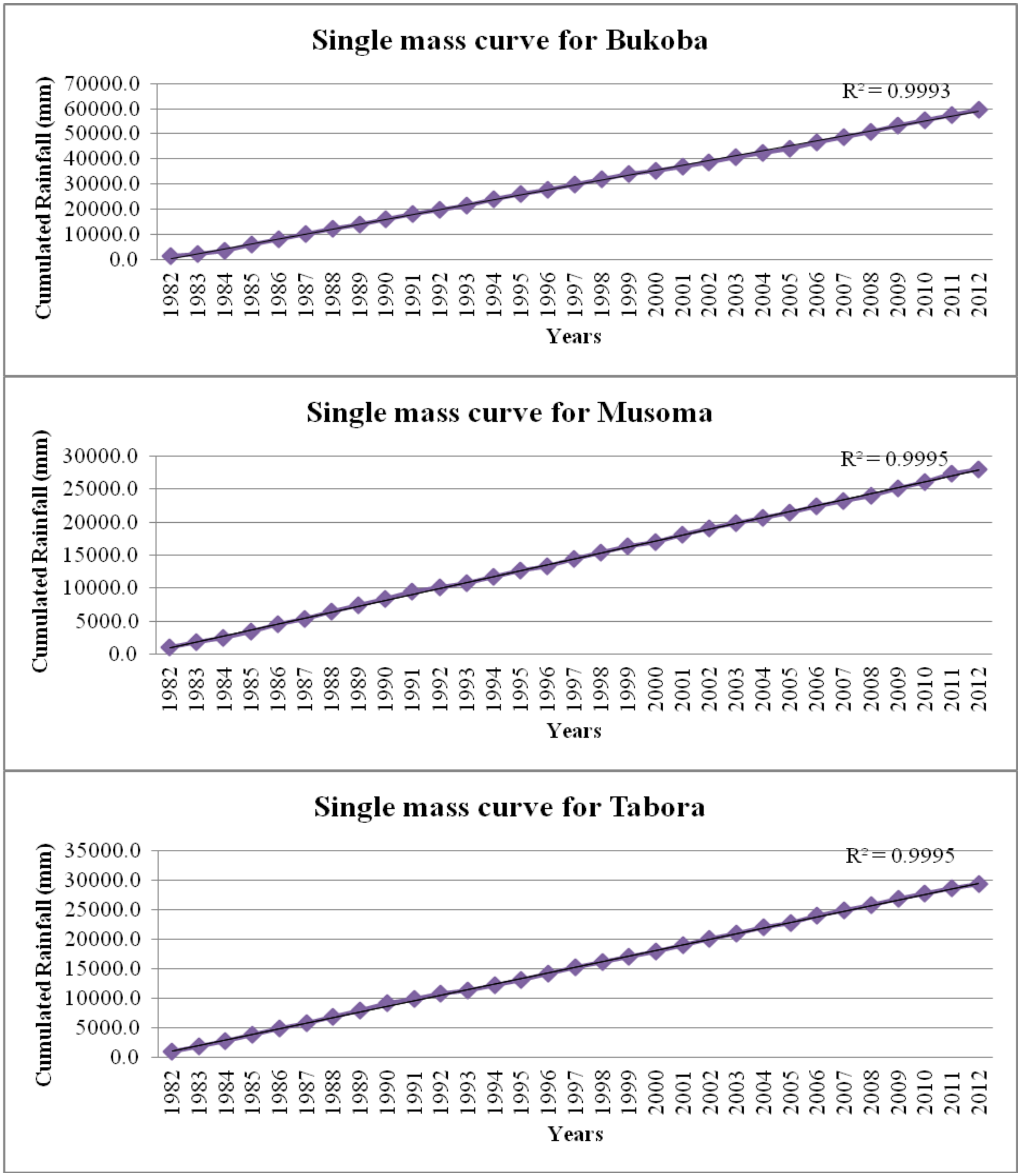

Figure 23. Single mass curve for Tabora, Musoma and Bukoba

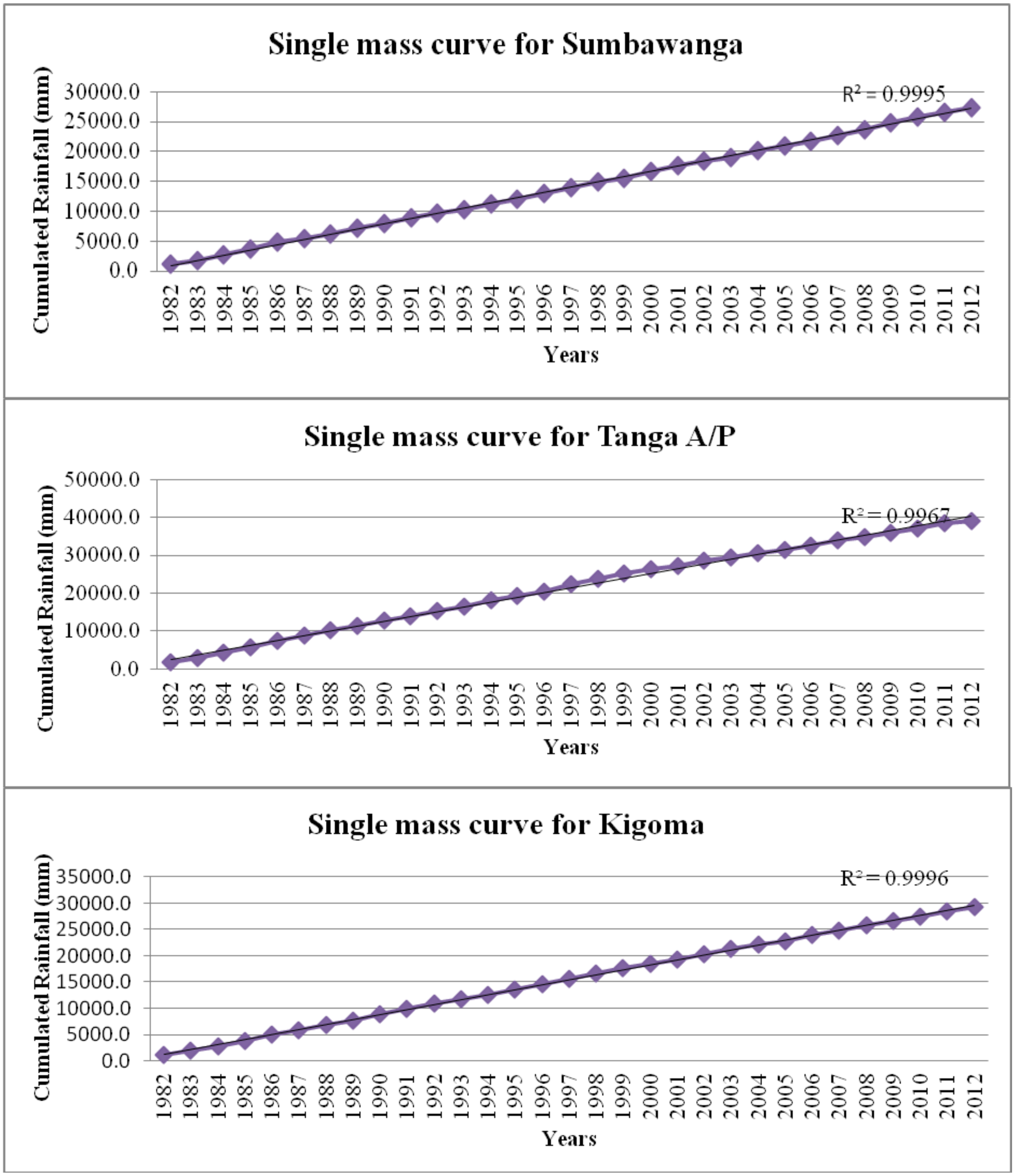

Figure 24. Single mass curve for Kigoma, Tanga and Sumbawanga

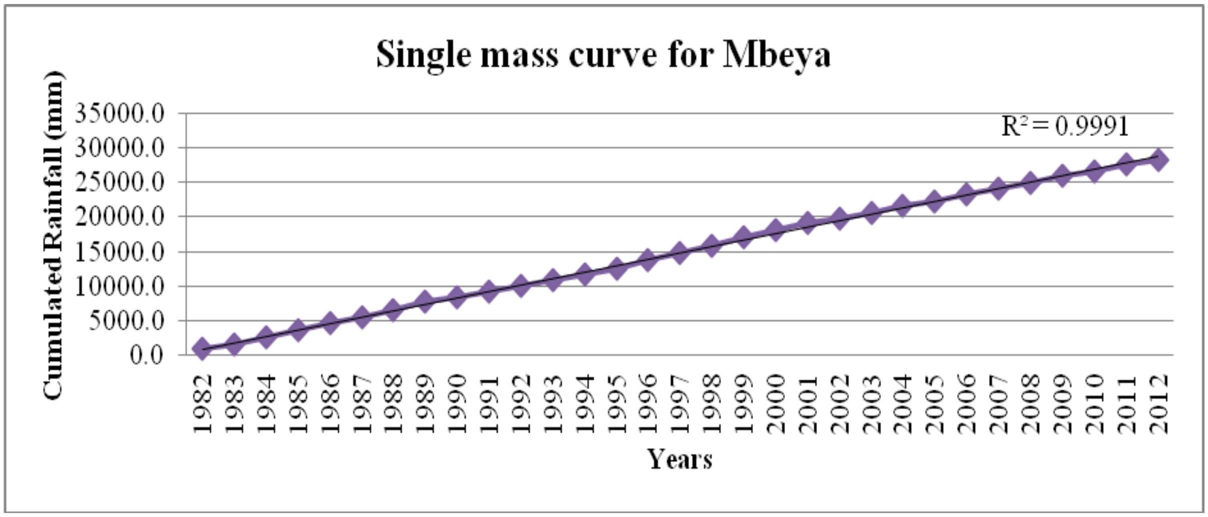

Figure 25. Single mass curve for Mbeya

Appendix B; Mean Monthly Rainfall

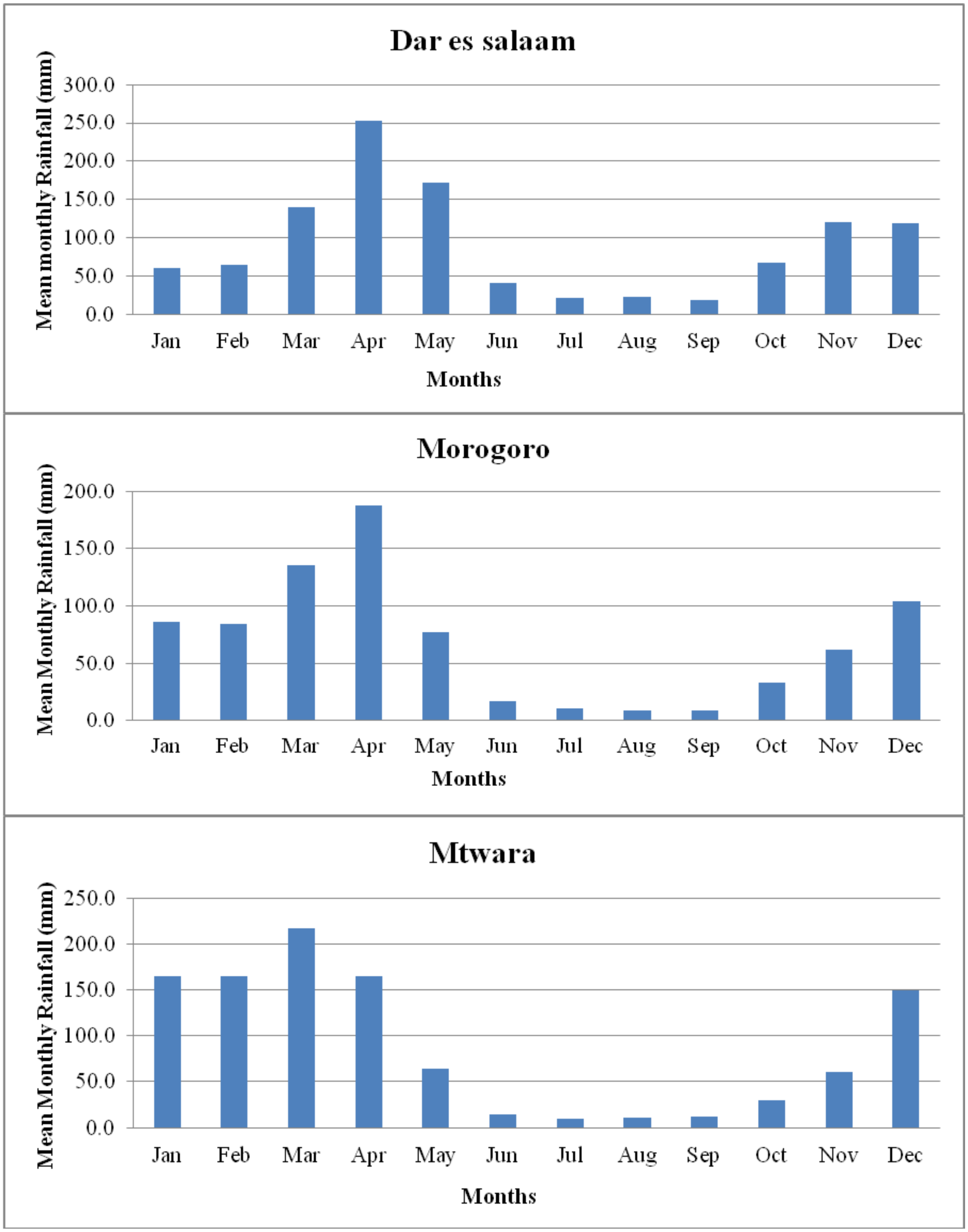

Figure 26. Mean Monthly Rainfall for Dar es Salaam, Mtwara and Morogoro

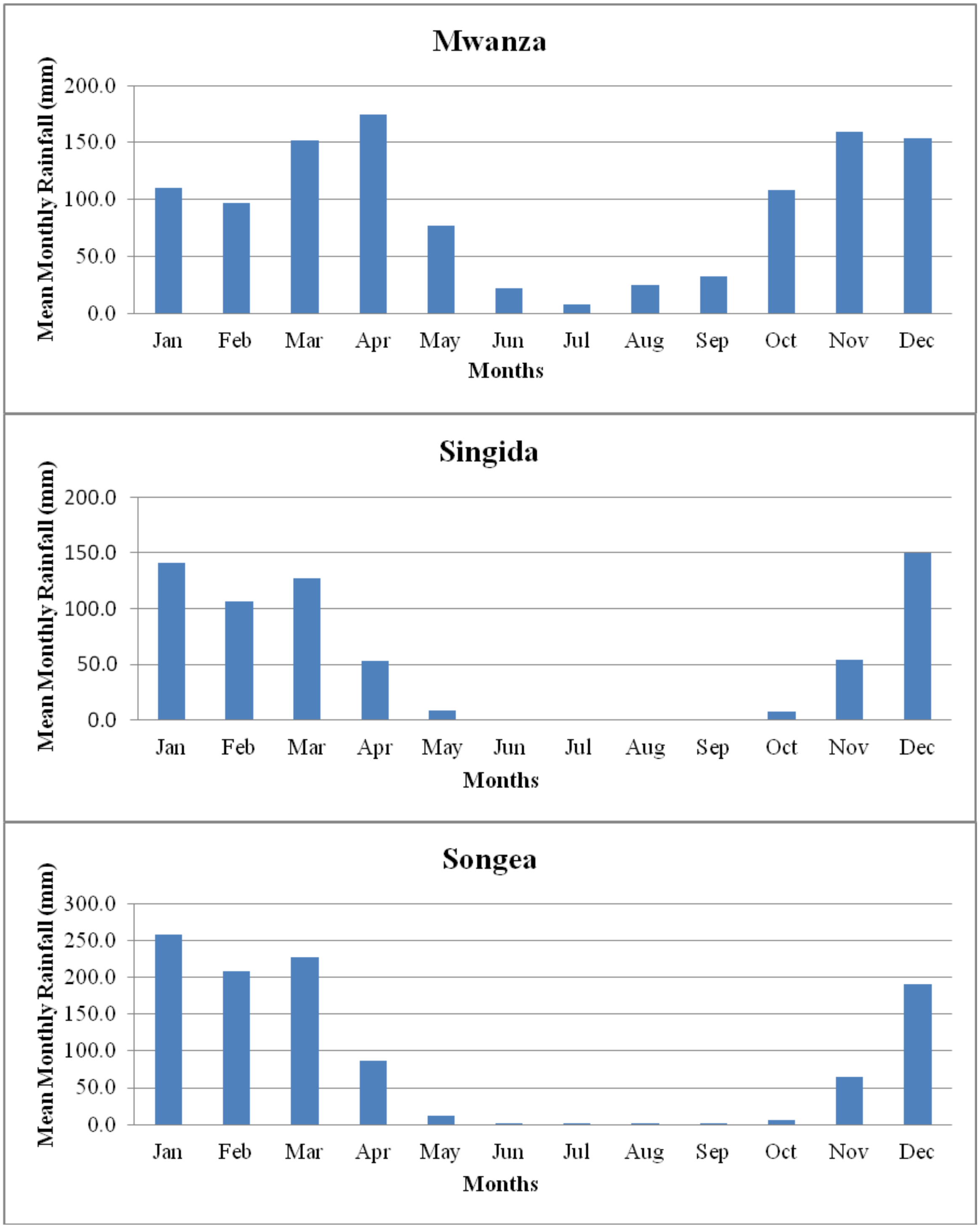

Figure 27. Mean Monthly Rainfall for Songea, Singida and Mwanza

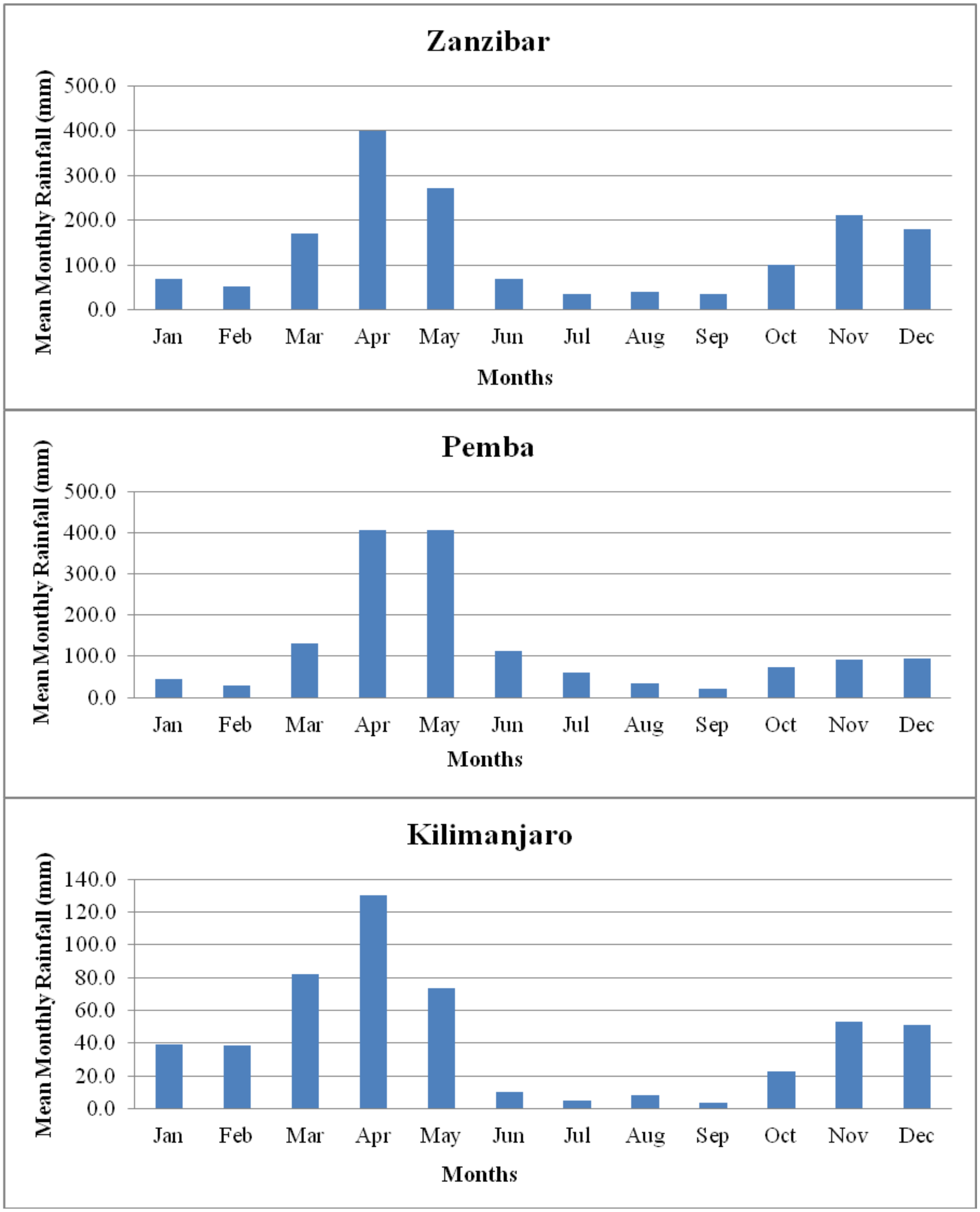

Figure 28. Mean Monthly Rainfall for Kilimanjaro, Pemba and Zanzibar

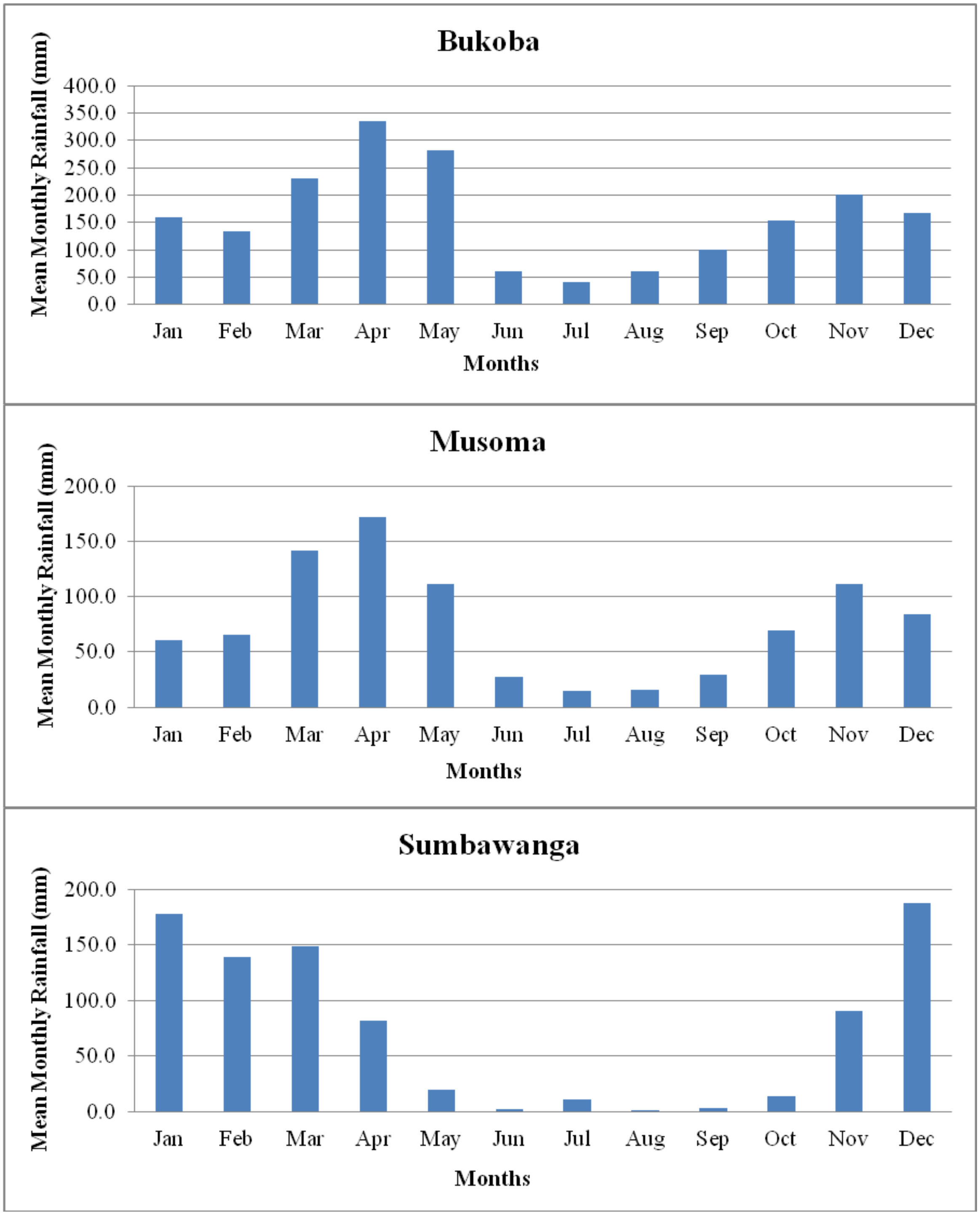

Figure 29. Mean Monthly Rainfall for Bukoba, Musoma and Sumbawanga

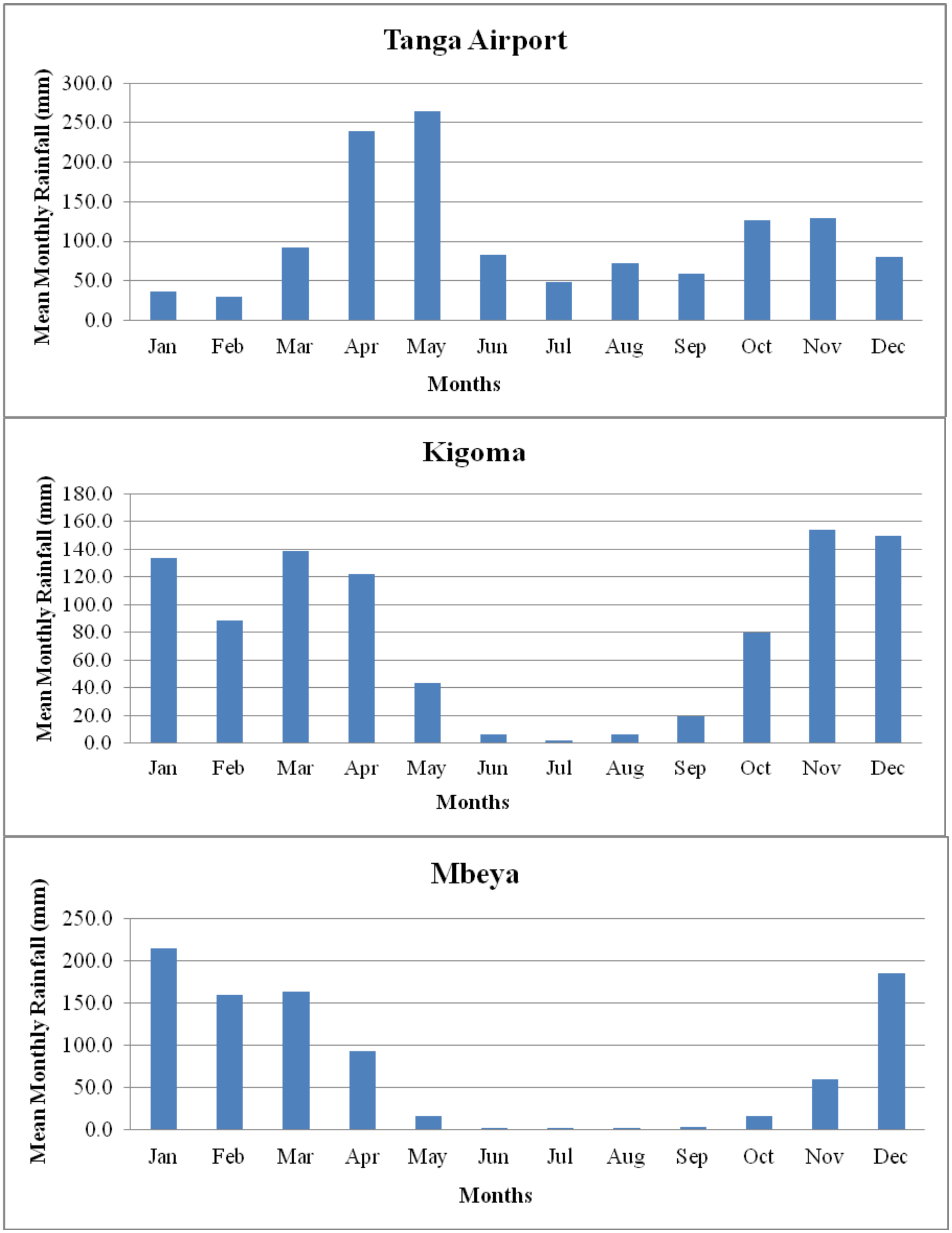

Figure 30. Mean Monthly Rainfall for Tanga, Kigoma and Mbeya

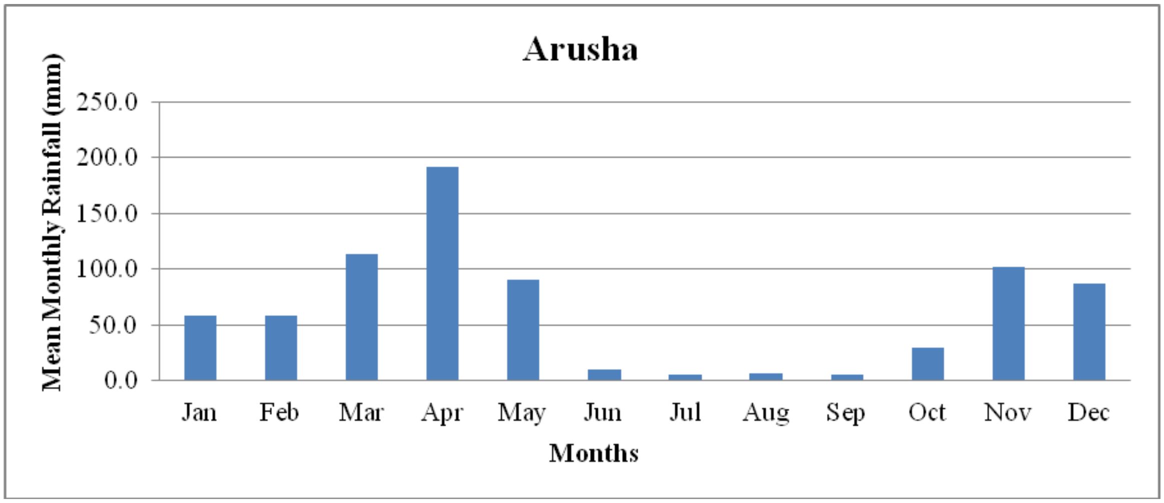

Figure 31. Mean Monthly Rainfall for Arusha

Appendix C; Result from Trend Analysis Unimodal Regions

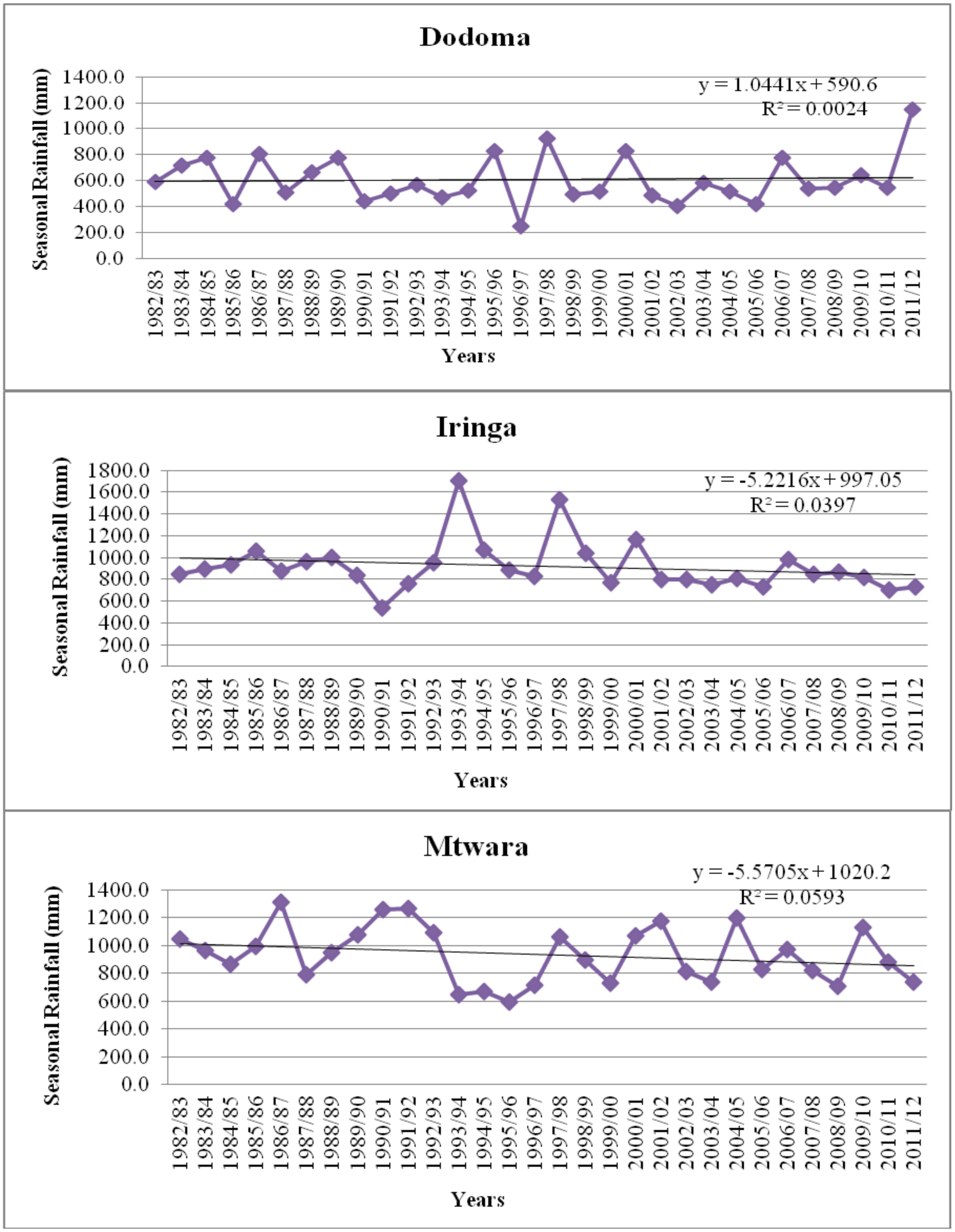

Figure 32. NA Rainfall for Dodoma, Iringa and Mtwara

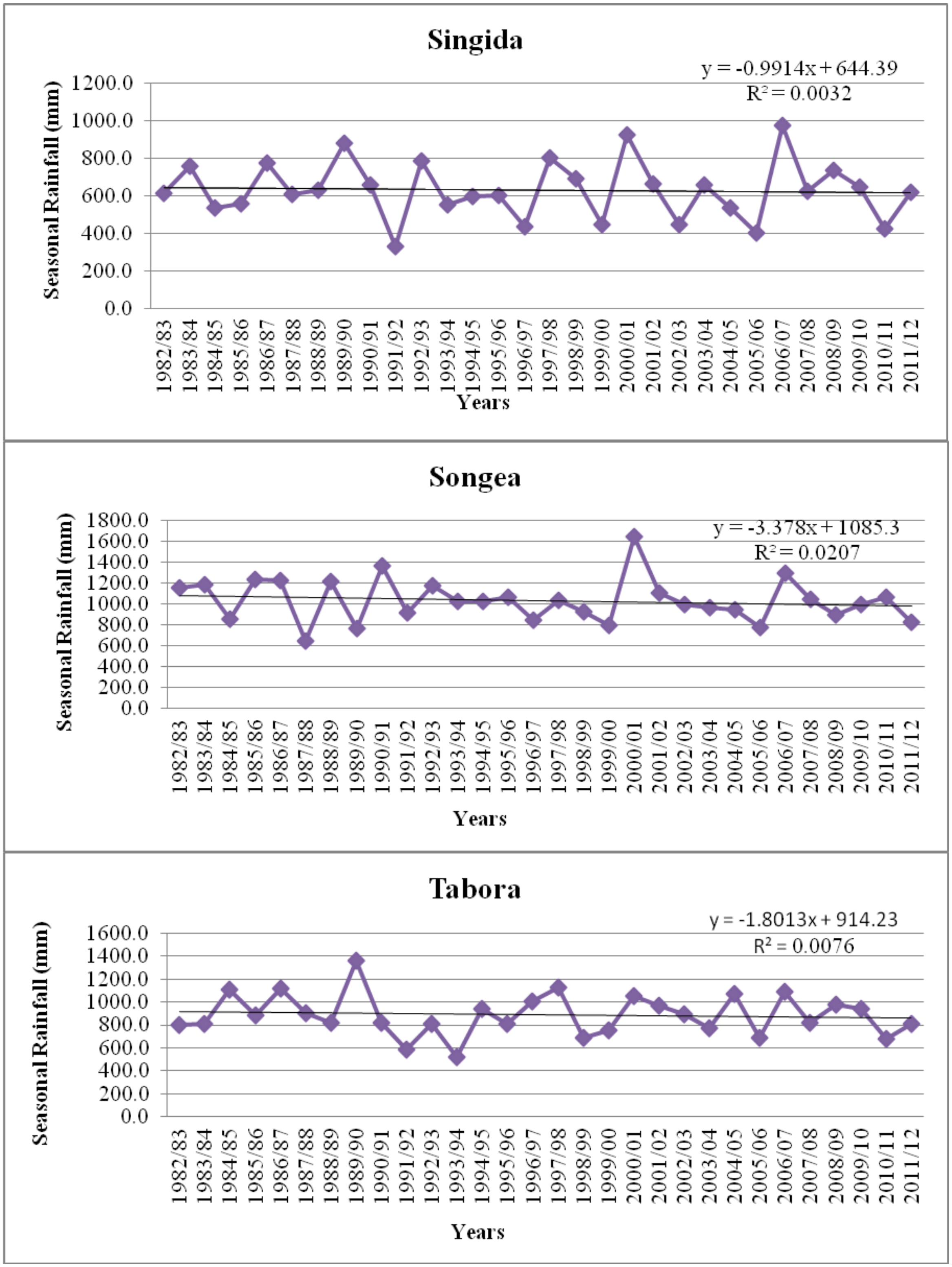

Figure 33. NA Rainfall for Singida, Songea and Tabora

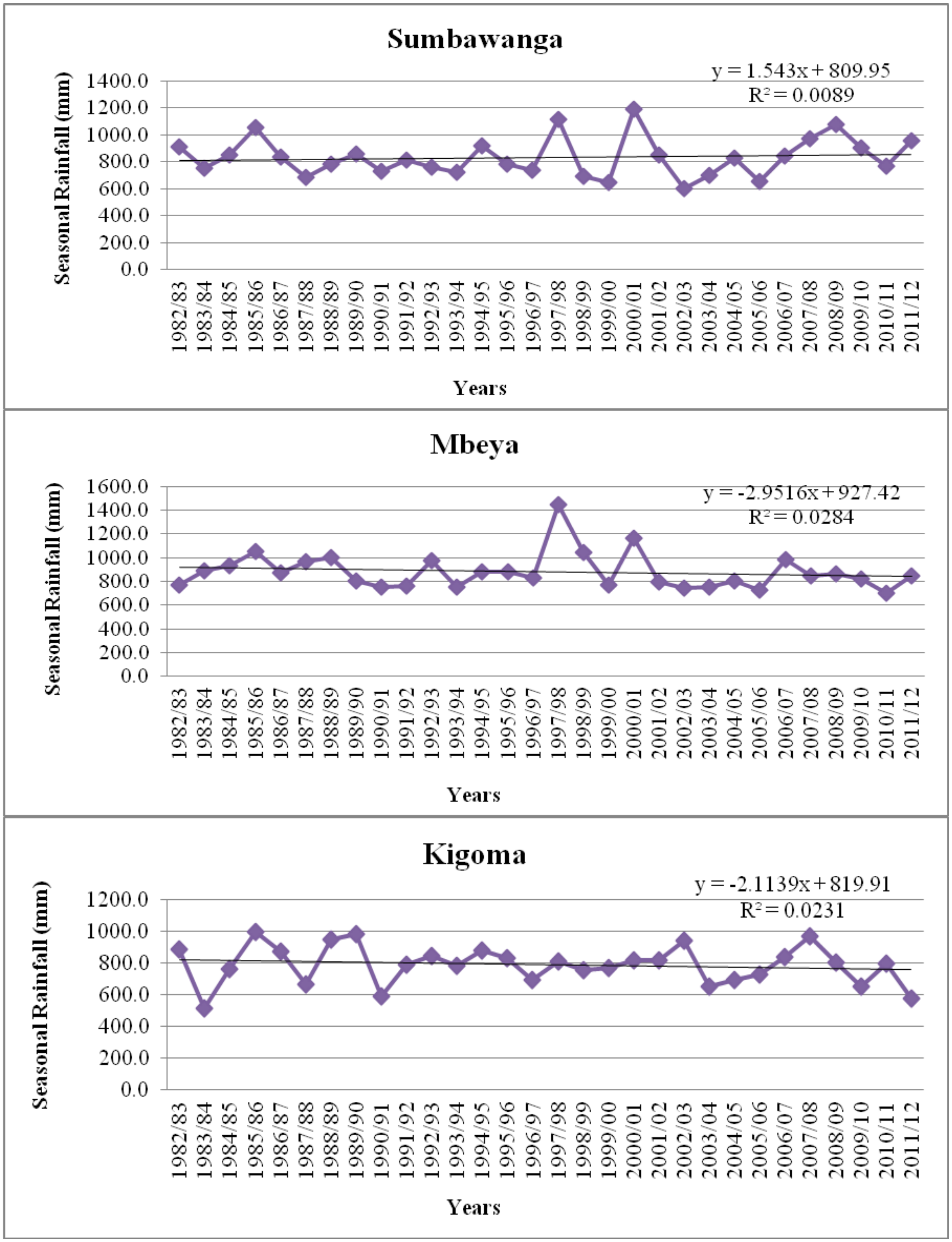

Figure 34. NA Rainfall for Sumbawanga, Mbeya and Kigoma

Appendix D: Temporal variation of seasonal rainfall for MAM and OND

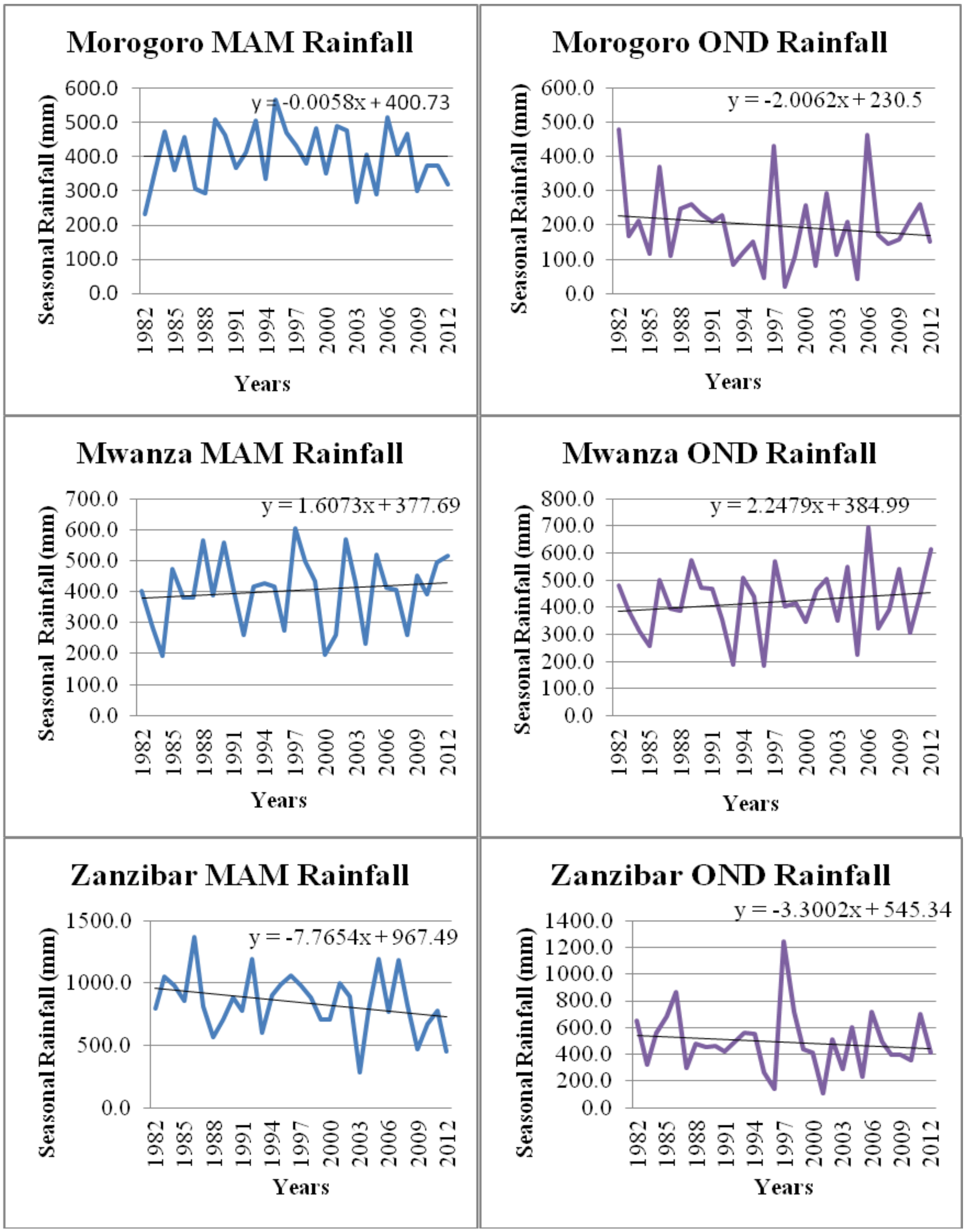

Figure 35. MAM and OND Rainfall for Morogoro, Mwanza and Zanzibar

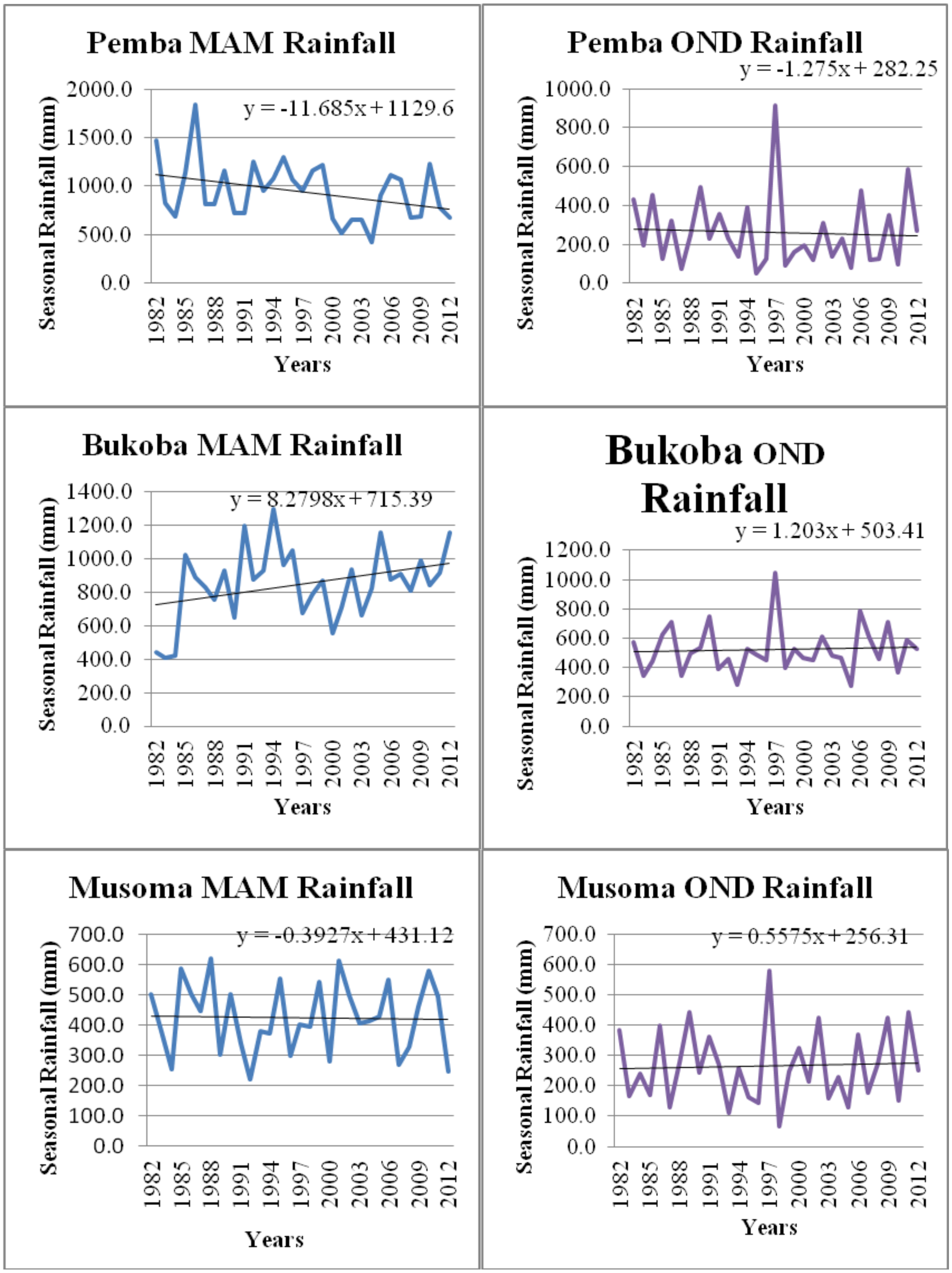

Figure 36. MAM and OND Rainfall for Pemba, Bukoba and Musoma

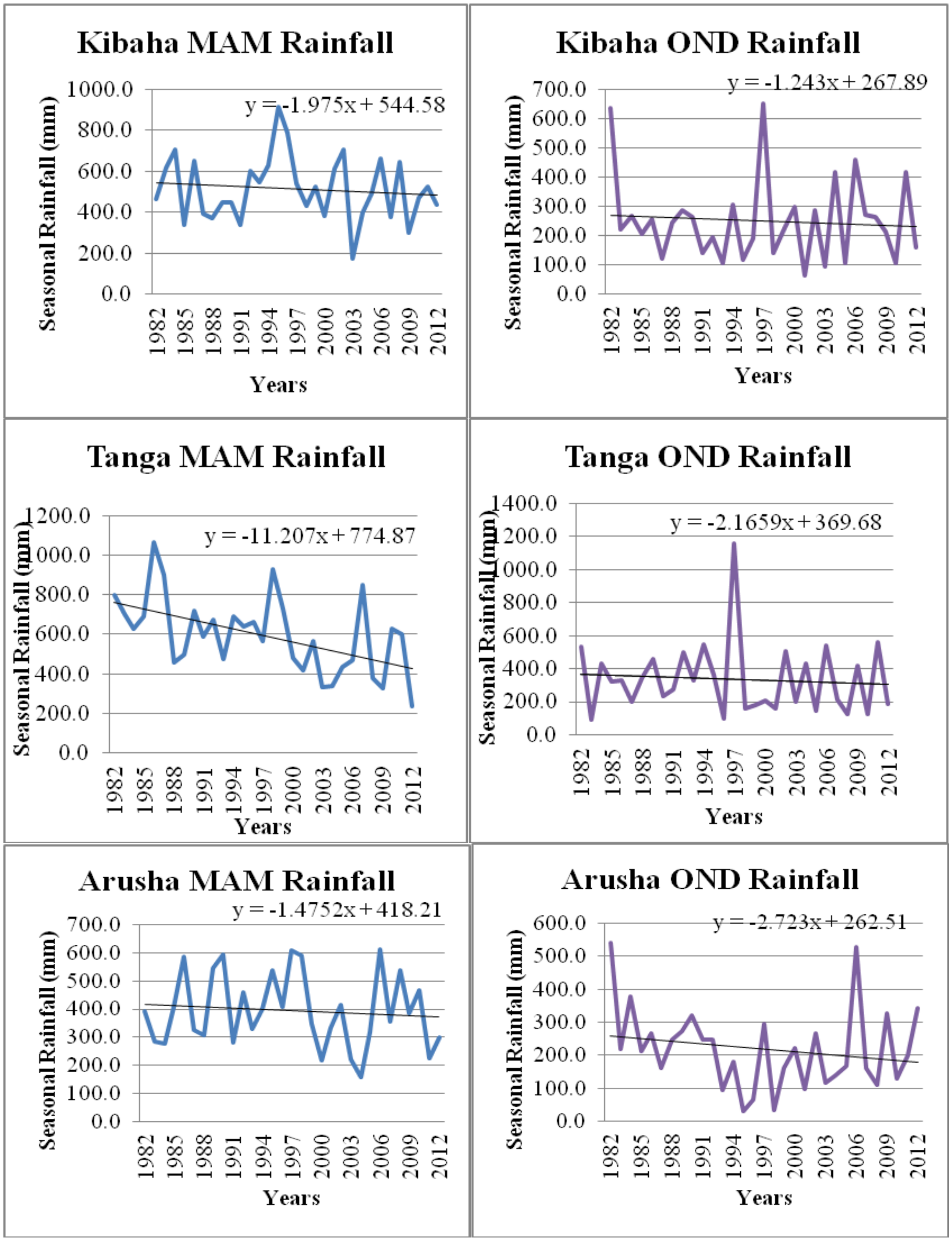

Figure 37. MAM and OND Rainfall for Kibaha, Tanga and Arusha

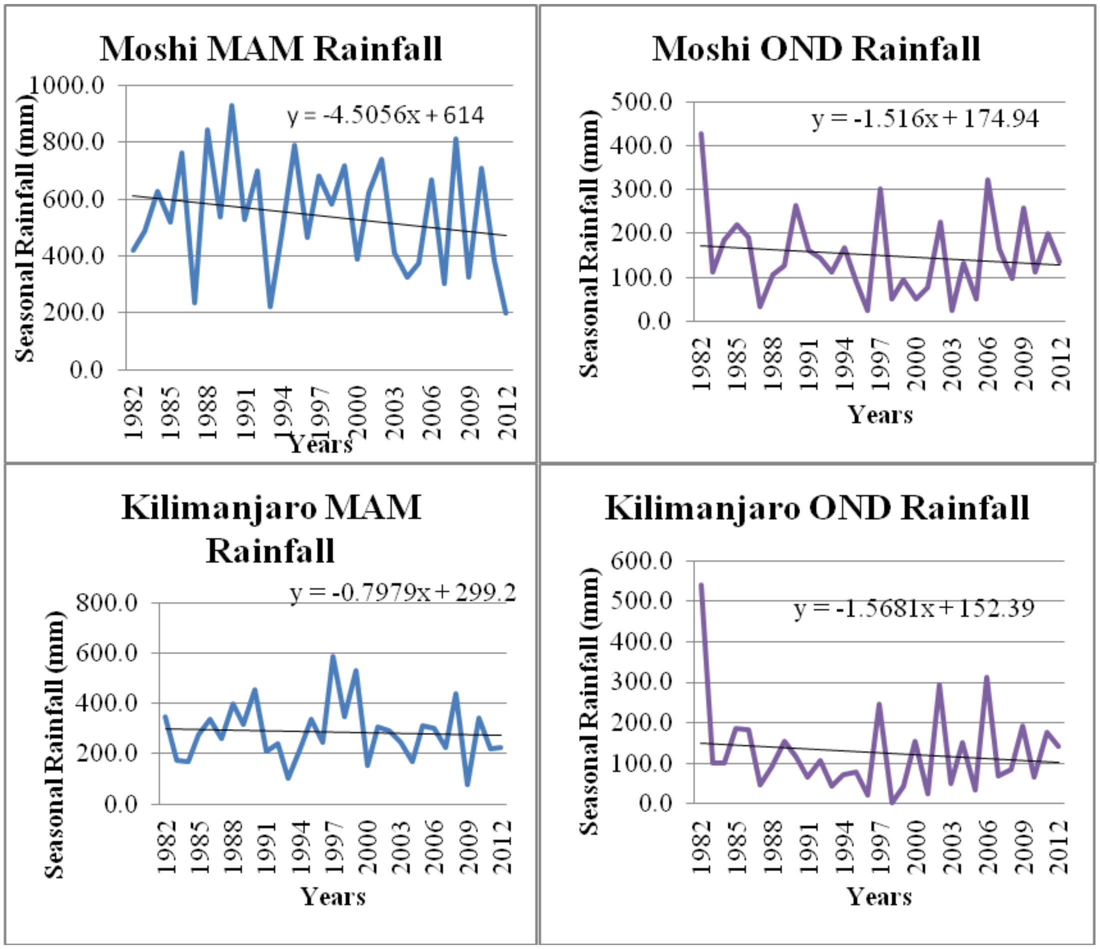

Figure 38. MAM and OND Rainfall for Moshi and Kilimanjaro