

**THE EFFECTS OF SHIFTS IN RAINFALL PATTERN ON RAINFALL
CHARACTERISTICS IN TANZANIA**



BY

WIKEDZI FRANCIS LWIYISO

**A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN
AGRICULTURAL ENGINEERING OF SOKOINE UNIVERSITY OF
AGRICULTURE**

1999

ABSTRACT

This study was conducted with the aim of establishing the existence of significant shifts or departures in rainfall pattern and the effect this may have on some important rainfall characteristics in different parts of the country. A sample of 21 stations from six major agro-ecological zones in Tanzania was used in the study.

Start dates of the growing season in various parts of Tanzania are variable and to some extent symbolize rainfall variability. Hence in this study, shifts in rainfall pattern are assumed to be reflected in the departures of start dates of the growing season from the mean.

The start dates of the growing season for the various agro-ecological zones were determined using a calibrated rainfall-based criterion. Calibration of the rainfall-based criterion was achieved through use of a water balance simulation model which resulted in different sets of parameter values for each of the six agro-ecological zones. Other rainfall characteristics were derived using INSTAT statistical package.

Results show that all stations in the six agro-ecological zones experience shifts in the rainfall pattern. Significant negative correlations between start dates and length of the growing season exist in all the stations with uni-modal type of rains and those with bi-modal type but for the long rains only. In other words the earlier the rains start, the longer the growing season is expected to last and vice versa.

The amount of seasonal rainfall for uni-modal stations in the following zones, Coastal Forest and thicket (zone II), Acacia-Commiphora Thornbush (zone V) and Branchystegia-jubernadia Savanna (zone VI) was found to correlate negatively with start dates of the growing season. This means that the earlier the rains start, the more the amount of seasonal rainfall is to be expected and vice versa. In the same zones, the length of the growing season appeared to correlate positively with the amount of rainfall received. However start dates of the growing season for stations in the Moist Forest Mosaic (zone I), Montane Forest (zone III) and Acacia-Savanna and grasslands zones (zone IV) appeared to have no relationship with seasonal rainfall.

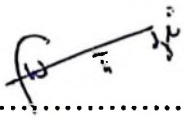
Stations in all the agro-ecological zones appeared to be more prone to dry spells when the growing season started early or late. A high proportion of dry days was observed in zones I and V when rainfall commenced early. A higher risk of dry spells was also noted for short rains during late start of the growing season. No association was observed to exist between the departures in start dates of growing season and the occurrence of ENSO and La-Nina events.

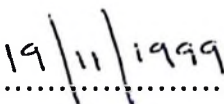
It can be concluded from this study that shifts on rainfall pattern have effects on important rainfall characteristics. It can further be concluded that a properly calibrated rainfall-based criterion may serve as a better alternative to a physically based soil water balance simulation model for the derivation of some important rainfall characteristics. Further analysis is however needed to characterize as many

stations within the agro-ecological zones as possible that can lead to the establishment of more realistic boundaries.

DECLARATION

I, WIKEDZI FRANCIS LWIYISO, do here by declare to the Senate of Sokoine University of Agriculture that this dissertation is my original work and that it has never been submitted for a degree in any other University.

Signature.....

Date.....

COPYRIGHT

No part of this dissertation may be produced, stored in any retrieval system, or transmitted in any means, electronic, mechanical, photocopying, recording or otherwise, without the prior written permission of the author or the University in that behalf.

ACKNOWLEDGEMENT

First and foremost I wish to give my deepest thanks to the Almighty God for his ever lasting love and guidance and most wonderful life he offers to me.

I register my sincere gratitude to my supervisors, Dr. N.I. Kihupi and Dr. H.O. Dihenga of the Department of Agricultural Engineering and Land Planning at Sokoine University of Agriculture (SUA) for their generous contribution of time, constructive and extensive comments throughout the course of this study.

I am grateful to SACCAR/GTZ for the financial support provided in the form of a scholarship. I am indebted to my employer Evangelical Lutheran Church in Tanzania - Southern Diocese (ELCT - SD) for offering me a study leave. Many thanks are conveyed to members of the Directorate of Meteorology, Dar es salaam particularly Mr. F. Tillya and Mr. Mbuma who facilitated data collection process.

I record my deepest thanks to my parents: Lwiyiso Chotompira, Se Msigwa, Se Lupenza and to my wife Restituta for their moral and spiritual support. Further appreciation to my wife who reserved her time to assist me on computer data entry. My joy and hope is in my wife who for about two and half years, put up with loneliness, negligence and inconvenience because of this study.

I would like also to extend my appreciation to Mr. Robert Kingamkono a PhD student for his tireless support especially on the use of the statistical package INSTAT. Life at SUA could have not been enjoyable without the company of the following fellow students Christian Mgina, Mulako Sitali, Stephen Nindi, Amin Bakari and Adam Njovu.

DEDICATION

This dissertation is dedicated to my wife Restituta Mdenye and to our beloved son Christopher through whom I see the meaning of everything I do in my life.

TABLE OF CONTENTS

ABSTRACT	ii
DECLARATION	v
COPYRIGHT	vi
ACKNOWLEDGEMENT	vii
DEDICATION	ix
TABLE OF CONTENTS	x
LIST OF FIGURES	xii
LIST OF TABLES	xiii
LIST OF APPENDICES	xv
ABBREVIATIONS AND SYMBOLS	xvi
1 INTRODUCTION	1
1.1 Background	1
1.2 Objectives	4
2 LITERATURE REVIEW	5
2.1 Rainfall variability and distribution	5
2.2 Rainfall analysis	9
2.3 Important agricultural rainfall characteristics	10
2.3.1 Start and end of rains	10
2.3.2 Start and end of growing season	12
2.3.3 Effective length of growing season	16
3 METHODOLOGY	19
3.1 Description of the Study area	19

3.2 Data collection	19
3.2.1 Climatological Data	19
3.2.2 Crop and Field data	22
3.3 Data analysis	25
3.3.1 Establishment of threshold values of start and end of rains	25
3.3.2 Calibration of rainfall criterion	26
3.3.3 Establishment of significant shifts in rainfall pattern.	27
3.3.4 Influence of shifts in rainfall pattern on important rainfall characteristics	28
4 RESULTS AND DISCUSSION	29
4.1 Establishment of threshold values of start and end of rains	29
4.2 Calibration of the rainfall criterion	34
4.3 Shifts in rainfall pattern	42
4.3.1 Effects of shifts in rainfall pattern on effective length of growing season	43
4.3.2 Effects of shifts in rainfall pattern on seasonal rainfall	50
4.3.3 Effects of shifts in rainfall pattern on dry spells within the growing season	54
4.3.4 Relationship between shifts in rainfall pattern and ENSO/La-Nina events	63
5 SUMMARY AND CONCLUSIONS	65
5.1 Summary	65
5.2 Conclusions and Recommendations	67
6 REFERENCES	69
7 APPENDICES	78

LIST OF FIGURES

FIGURE NO.		PAGE
3.1	Map of Tanzania showing major ecological zones and location of stations used in the study	20
4.1	Root zone depletion for 1993/1994 growing season for a maize crop in Mbeya	31
4.2	Shifts in rainfall pattern for seasonal rainfall in Sumbawanga	44
4.3	Shifts in rainfall pattern for long rains in Musoma	45
4.4	Relationship between length of growing season and seasonal rainfall for Njombe (zone VI)	52
4.5	Relationship between onset dates of growing season and seasonal rainfall for Tukuyu (zone III)	52
4.6	The probability of a 7-day and 10-day dry spell within 30 days following the date on the time axis for Tukuyu	55
4.7	The probability of a 7-day and 10-day dry spell within 30 days following the date on the time axis for Musoma	56

LIST OF TABLES

TABLE NO.		PAGE
3.1	Stations used in the study	21
3.2	Crop coefficients(k_c), p factor and rooting depths (z) for 125 and 180 days growing season of maize	23
3.3	Field capacity, wilting point and infiltration rate for different soils types	24
3.4	Initial soil moisture contents by volume (%) for representative soil in the respective stations	24
4.1	Water depletion (daily) in the root zone for maize crop	32
4.2	Start and end dates of growing season from water balance criterion for zone I-VI	33
4.3	Start dates of growing season for both water balance criterion and calibrated rainfall criterion for six agro-ecological zones	35
4.4	End dates of growing season for both water balance criterion and calibrated rainfall criterion for six agro-ecological zones	35
4.5	Parameters for rainfall criterion in six agro-ecological zones	36
4.6	Probable dates for which the growing season of maize crop can be expected to start and end at given percentage points (calibrated rainfall criterion)	38
4.7	Effective length (days) of growing season at three levels of probability (calibrated rainfall criterion)	41

- 4.8 Summary of results of t-test for early and late start of growing season for selected stations 46
- 4.9 Length of growing season (days) and total seasonal rainfall (mm) for years with significant shifts in start dates of growing season (zone I and II) 48
- 4.10 Correlation between shifts of start of growing season (S), length of the growing season (L) and seasonal rainfall (R) for uni-modal stations 49
- 4.11 First and last dates when probability of dry spells is below 0.5 for the years with no significant shifts in start dates of growing season for selected stations 59
- 4.12 First and last dates when probability of dry spells is below 0.5 for the years with the earliest start of growing season for selected stations 60
- 4.13 First and last dates when probability of dry spells is below 0.5 for the years with the latest start of growing season for selected stations 61
- 4.14 Proportions of dry days within the growing season when 7-day and 10-day dry spell probability is above 0.5 for years with shifts of onset dates of growing season 62
- 4.15 Proportions of ENSO and La-Nina events as captured by the years with shifts in start dates of growing season 64

LIST OF APPENDICES

APPENDIX	PAGE
A: Root zone depletion curves for representative stations	78
B: Shifts in rainfall pattern for studied stations	85
C: Curves of probability of 7-day and 10-day dry spells for various stations	100
D: Day numbers	105
E: Rainfall characteristics vis-à-vis shifts in rainfall pattern	106
F: Length of growing season (rainfall criterion) and seasonal rainfall for normal years	109
G: ENSO and La-Nina events	111

ABBREVIATIONS AND SYMBOLS

ENSO	Eli – Nino Southern Oscillation
FC	Field capacity
I	Infiltration rate
ITCZ	Inter – Tropical Convergence Zone
K _c	Crop coefficient
L	Length of growing season
MEA	Mean value
PWP	Permanent wilting point
R	Seasonal rainfall
RAW	Readily available water
S	Growing season
S _{de}	Standard deviationn
t	t-test values
TAW	Total available water
t _{cal}	Calculated t-test values
t _{tab}	Tabulated t-test values
WP	Wilting point
z	Rooting depth

1 INTRODUCTION

1.1 Background

The agricultural sector forms the basis of Tanzania's economy. The sector is estimated to employ most of the economically active population of the country. Most of the food and cash crops production in Tanzania is done by peasant farmers in rural areas under rainfed agriculture. Irrigation farming is not widely practised in this country. However, even in those areas where it is practised, it is done at a lesser extent (Lema, 1993). Therefore, rainfall remains the most significant factor in crop production in Tanzania and to a great extent governs the choice and the range of crops that can be grown and expected crop yields (Mavi, 1986).

Most parts of the country are subjected to temporal and spatial rainfall variability which is manifested in the start and end of the rainy season (Ngana, 1991) and hence the length of the growing season. The high variability of rainfall and its concentration during a relatively short season (Mhita, 1984) affects the water supply situation to crop growth. At certain times some areas in the country experience excessive rainfall causing floods in low lying areas. For instance in 1997/1998 season, floods and high peak of rainfall of 631.8 mm, 1084.2 mm and 1238.9 mm were reported to occur in Dar es salaam, Tanga and Zanzibar respectively (Directorate of Meteorology , personal communication, 1998). The situation was mainly caused by El - Nino/ Southern Oscillation (ENSO) event (Nyenzi, 1997) which is associated with the warming over the eastern equatorial Pacific ocean and the sea-saw pressure across

the Pacific ocean. On the other hand rainfall variability sometimes causes drought in semi-arid areas and other parts of the country due to the failure of the short rains in bi-modal areas and the seasonal rains in parts of the uni-modal areas. In 1995/96 growing season, there was a marked decline in crop production compared to 1994/95 season (ERB, 1997). The output of maize which is the main staple reached 2.11 million tons representing a 21% decline from 2.66 million tons of 1994/95. The decline of crop production was explained by the extended drought experienced in 1995/96 growing season. Good plans can be drawn through long term rainfall data analysis from which early indication of most probable nature of the forthcoming rainy season can be determined thus avoiding crisis management in responding to extreme weather events such as drought and floods.

Knowledge of the rainfall regime is an important prerequisite for agricultural planning. Most farmers are concerned with the start, end and length of the rainy season, knowledge which can assist them in planning agricultural activities. So far much work has been done (Mhita, 1984; Kassase, 1992; Kingamkono, 1994) using rainfall data to determine various important agricultural rainfall characteristics including establishment of criteria for the derivation of start, end and hence length of the growing season in some parts of Tanzania. Most of these criteria however were based solely on rainfall and did not consider other weather data, soil and crop parameters. Hence rainfall characteristics determined in this way may not be the best. Further, parameters for such criteria were global and never considered local climatic conditions which persist in most of the areas in the country (Nyenzi *et al.*, 1997).

Although rainfall criteria provide satisfactory results in determining the length of the growing season, a measure of water storage is needed to define the start and end of growing season more realistically (Mavi, 1986). Through water balance calculations, the soil moisture regime of an area can be known thus showing the frequency and amount of water deficit which enables the estimation of irrigation requirements and proper time for the most important agricultural operations (Nieuwolt, 1978).

Most parts of Tanzania experience shifts in rainfall pattern which are characterised by significant variation of the onset dates of rains (Nyenzi, 1997). However, little Work has been done to study the influence of shifts of rainfall pattern on different rainfall characteristics. Lack of knowledge on these influences of shifts has made precise decision making with regard to agricultural activities more difficult. For the country where more than 90% of the population derive their livelihood from agriculture, the importance of a proper evaluation of rainfall conditions cannot be over emphasised (Nieuwolt 1973).

This study looks at the influence of shifts in rainfall pattern on agriculturally important rainfall characteristics. Such information is useful in planning agricultural activities by the local communities and the agricultural industry as whole.

1.2 Objectives

The main objective of this study was to assess the influence of shifts in rainfall pattern on different rainfall characteristics for selected stations in Tanzania.

The specific objectives of this study were:

- (i) to establish threshold values for start and end of rains in each of the six agro-ecological zones using the water balance approach;
- (ii) to calibrate the rainfall based criterion using the established threshold values;
and
- (iii) to establish the existence or otherwise of significant shifts in rainfall pattern for a selected stations in Tanzania and their influence on important rainfall characteristics.

2 LITERATURE REVIEW

2.1 Rainfall variability and distribution

Different regions of the world experience rainfall variability which is manifested in the unpredictable start and end of the rainy season and rainfall distribution within a growing season (Jackson, 1982). Agriculture in many areas of Tanzania depends solely on rainfall. Therefore, in the absence of appropriate methods to estimate variability and reliability, the expected rainfall based decisions such as the type of crops to be grown and when to plant becomes difficult. Ngana (1992) reported a considerable variation of onset of rainfall as well as its distribution in many parts of Tanzania. The study observed that rains in the central semi-arid region may start as early as October to as late as December. The region also experienced a great deal of variation of monthly rainfall distribution from year to year where rains may concentrate in either the early season or in the late season.

The variable nature of rainfall in tropical areas has a direct impact on agricultural production. Berry *et al.* (1972) noted the effect of rainfall variability on crop selection and production in Dodoma region. In 1968, Dodoma was the major maize producer in Tanzania but the following year (1969) there was drought and almost no maize was produced (Berry *et al.*, 1972). Farmers were therefore advised to opt for drought tolerant traditional millet. Normally total rainfall at a location is computed on annual basis and a long term annual mean is used as an indicator of rains in a

respective location. The variation of the annual rainfall from year to year is a common feature which occurs frequently in various areas. For example, in Musoma the annual total rainfall has been reported to vary from 507 mm in 1976 to 1397 mm in 1961 (Kassase, 1992). This annual total rainfall variation has necessitated the use of long periods of record to estimate the annual mean values. Nieuwolt (1974) emphasized that knowledge of annual rainfall variability is of crucial importance in those parts of the tropics where rainfall is marginal or barely sufficient for normal agricultural use.

Various measures of variability have been employed in assessing the variability of rainfall, these include the use of coefficients of variation and probabilities like percentiles. Mzengeza (1994) considered a growing season rather than the calendar year in discussing the variability and reliability of rainfall in rice growing areas in Malawi. Coefficients of variation were observed to range from 19% to 39% at Chitipa and Makhanga Stations respectively. In Dodoma region, in Tanzania, the level of seasonal rainfall variability was shown by Ngana (1991) to have coefficients of variation ranging from 23% to 30% with regional average of 25%. The monthly variability of rainfall total during the main season varied from 52% in January/February to 71% in April. The study by Ngana (1991) further showed that the drier stations experienced higher variation. On the other hand percentile methods have been used by different workers to determine rainfall variability. Kingamkono (1994) determined 20, 50, 80 percentage points of annual rainfall for different stations in Tanzania. The marked variation of rainfall over the growing season

implies a high variability in crop yields. Therefore, since variability is one of the dominant characteristics of the tropical rainfall, more attention needs to be focused on the study of rainfall variability. This will be useful in forecasting and planning different agricultural activities.

Various studies have been made to analyse time series of rainfall data in an attempt to investigate past climatic conditions and to determine if there exists pronounced rainfall trends and distribution. Time series analysis of rainfall in East Africa was conducted by Thomson (1957) aiming at studying the trend of rainfall for the period between 1920 to 1947 from forty five, twenty five and fourteen stations in Kenya, Tanzania and Uganda respectively. Maps were produced to show the areas over which the average annual rainfall had been increasing or decreasing. But no cyclic trends were observed in the study. Lumb (1966) in a study along the Lake Victoria catchment, Lake Rukwa and Lindi-Kilwa Hinterland in Tanzania and over Aswa in Northern Uganda for the period 1899-1964, noted that there was a recurrence of wet and dry periods within the studied period with peak wet years ending in either five or six. These results are contrary to the recent findings by Nyenzi et al. (1997) who carried a study on occurrence of ENSO events in different parts of Tanzania for the period of 1963-1994. During the studied period, EL-Nino events occurred in 1963, 1965, 1969, 1972, 1976, 1977, 1982, 1983, 1987, and 1992. In the same area of victoria catchment, Riise (1971) analyzed rainfall data over the period 1922-1970 and found that the results of the study were rather free from long-term trends. Annual rainfall values of duration ranging from 44 to 83 years for 35 stations from Kenya,

Northern Tanzania and South Eastern Uganda were analyzed by Rodhe, *et al.* (1976) to determine trends, periodicities and variability. A definite trend over the period of record was noted in northern Kenya while the rest of the studied area experienced different series of fluctuations. These fluctuations have been attributed to sunspot activity and variations of the subtropical jet stream. More recently, however, these fluctuations may be attributed to the Quasibiennial Oscillation (QBO) and the El Nino and Southern Oscillation (ENSO) events.

Further studies on rainfall trends in East Africa were conducted by Ogallo (1980, 1981) who employed graphical and statistical methods to examine rainfall records for 86 stations from various regions of East Africa to detect rainfall trends in their annual, regional, seasonal, monthly and 5-day patterns during the period 1922-1975. Results of the study indicated that, nine out of eighty six stations studied, displayed statistically significant trends. However no statistically significant trends on regionally averaged rainfall series, monthly and dry season records were observed. Therefore no significant trends of rainfall in East Africa were observed during the studied period.

Studies by Kassase (1992) and Kingamkono (1994) in various parts of Tanzania have shown that there are no well defined significant trends of rainfall in most of the stations studied. Rather they found that there exists significant variability in seasonal rainfall in almost all stations. Ngana (1994) concluded that Pugu and Kazimzumbwi coastal forests had no persistent trend in any of the stations studied, although

fluctuations of rains from low to high from one period to another were noted. Therefore in general, a localized study with a long span of rainfall data to reveal repetitive and occurrence of shifts in rainfall patterns is required in order to reach a fairly good judgment on the rainfall trends of various parts of Tanzania.

2.2 Rainfall analysis

Results from the analysis of rainfall data can be used for the classification of areas according to the amount of rainfall received, to determine important agricultural rainfall characteristics and can also be used to develop crop weather models for monitoring or obtaining yields. The use of rainfall analysis on regional classification has been reported by da Mota (1980) in central and south America and Stewart (1988) in Mediterranean and Sudano - Sahelian zone. Where sufficient records are available, rainfall data can be analyzed statistically to predict rainfall characteristics. Weisner (1970) suggested that rainfall data of more than 30 years are sufficient for the statistical analyses. Estimations of length of growing season have been made by different workers through rainfall analysis studies. In Malawi rainfall analysis studies enabled Mzengeza (1994) and Majamanda (1998) to determine the effective length of growing season of various stations. Rainfall analysis has been done by various workers (Alusa and Mushi, 1974; Ngana, 1983; Mhita, 1984; Kassase, 1992 and Kingamkono, 1994) to estimate the growing season in various parts of Tanzania.

Different approaches have been used to conduct rainfall analysis. Rao *et al.* (1980) proposed the use of pentad, decadal or monthly periods of rainfall values in rainfall analysis. In the determination of the possible earliest dates for start and end of rains, Kassase (1992) used pentad values. However the use of grouped data in analysis causes loss of detail notably those on dry spells and the onset and end of rains (Stern *et al.*, 1982). The same argument was advanced by Kingamkono (1994) who concluded that the use of daily data was more advantageous than the use of grouped data.

2.3 Important agricultural rainfall characteristics

2.3.1 Start and end of rains

It has been difficult to define the commencement and withdrawal of rains in tropical climates because of the intermittent and variability nature of rainfall. Generally the onset of the rains is defined as the first date in the new rainfall season when rainfall is deemed sufficient to support crop growth (Stern *et al.*, 1982a). Many researchers have been involved in the investigation of the concept of start of rains. Virman (1975) defined the start of rains as being that week which had more than 20 mm of rain in one or two consecutive days provided that, the probability of at least 10 mm of rain in the subsequent week was greater than 0.7. The probability of occurrence of dry spells has also been used by different workers to define an earliest practical start and end of rains. Mhita (1984) used this approach to define starting dates for Ilonga, Dodoma, Morogoro and Moshi in Tanzania. Start of rains was defined as the first

date when 20 mm of rainfall over 5 consecutive days was realized and that no dry spell of 10 days or more occurred within the next 30 days. The threshold of 10 mm for 5 consecutive days and a dry spell of five days or more within 30 days were used to signify the end of rains. Ashok (1979) called the last rainy day of the season as the date of withdrawal of effective monsoon.

Stern *et al.* (1982) emphasized the efficient use of data where, short records can be used successfully for data analysis. The method involves modelling the seasonal pattern of daily rainfall and using this model to derive probabilities of rainfall events like start or end of rains. In East Africa, Alusa and Mushi (1974) used pentad value to derive the start and end of rains. The percent annual rainfall occurring in each pentad was derived and accumulated, then plotted against day numbers. Points of maximum positive and negative curvatures of the cumulative rainfall curve were taken as the mean onset and cessation dates respectively. A similar approach was adopted by Kassasse (1992) for determining the earliest possible start and end of the rains. Kingamkono (1994) modified this method by employing daily mean rainfall data instead of using grouped data. This approach gave more realistic results where mean onset and cessation dates were read directly on the graph and rainfall distribution was easily assessed by determining the slope of the cumulative rainfall distribution graph.

2.3.2 Start and end of growing season

A number of approaches have been proposed for analysing rainfall data towards determining the start and end of the growing season. These proposed approaches are based on the following criteria: rainfall, rainfall and evapotranspiration, soil water balance and modeling. The results of the analysis on derivation of start and end of the growing season varies with the criterion adopted. Kassase (1992) and Kingamkono (1994) concluded that rainfall criterion provided more realistic estimates at most stations studied than the rainfall and evapotranspiration criterion. Majamanda (1998) used the water balance method using a simulation model IRSIS (Raes, et al.,1987) which considers soil, climate and crop characteristics. The model displayed more realistic results which can be utilized by planners to help farmers in agricultural decision making.

In using a rainfall criterion, a threshold value below which a day is considered dry must first be defined. Mhita (1984) defines a dry day as one having less than 1 mm. This is because for purposes of start and end of growing rainfall season rainfall below 1 mm is considered not effective. Nieuwolt (1989) considered a day to be dry if it has less than 0.85 mm of recorded rainfall. Such an amount was often insignificant in terms of its contribution to crops as it is usually lost through evaporation in a matter of few hours. Kassase (1992) and Kingamkono (1994) used the same definition to define a dry day. Rao *et al.* (1980) defined a rainy day as a period of 24 hours in which 0.2 mm or more of rainfall is recorded. In the rainfall

criterion, the definition of the start and end of growing season is based solely on rainfall amount. The definition can be on monthly, decadal or pentad basis. However, Jackson (1989) had doubts on the use of monthly values in defining seasonal regimes, because normally the start and end of growing season does not coincide with calendar months and also that rainfall deficit during short time periods which is critical to agriculture can be overlooked. A number of researchers have used pentad approach to define the growing season. Torrance (1967) used pentads to examine the progress of the mean rainy season, occurrence of rainy and dry spells in the growing season and variations in the length of the dry season in central Africa. Ilesanmi (1972) and Ananthakrishnam *et al.* (1994) used pentad approach in growing season analysis in Nigeria and India respectively. Pentad approach was also used by Mzengeza (1994) in determining onset and end dates of rain season in Malawi. The onset day was defined to be the first occasion that the five day running total exceeded 40 mm and at least 3 of the days were rainy. The end of the rains was defined to be the first occasion of the occurrence of 15 consecutive dry days after the earliest possible end date.

The rainfall and evapotranspiration criterion is based on water balance computation. It makes use of rainfall values and other climatic records namely temperature, relative humidity, radiation and wind speed to estimate the evapotranspiration values. Kowal and Knabe (1972) as cited by Stern *et al.* (1982a) used the rainfall and evapotranspiration criterion to define the start of the growing season as the first decade with more than 25 mm of rainfall provided that the next decade exceeded 0.5

of the potential evapotranspiration. Bernoit (1977) considered the start event as being the time when cumulative rainfall exceeded 0.5 of cumulative potential evapotranspiration provided that a dry spell of five days or more did not occur immediately after this onset. Kassase (1992) and Kingamkono (1994) considered the growing season starts when the first occasion of rainfall occur after an earliest possible start date on which a 10 day running total is greater than half the evapotranspiration. Likewise the end of growing season was defined as the first occasion after an earliest possible ending date on which a 10 day running total was less than half the evapotranspiration. In comparing this criterion with the rainfall criterion, no significant differences in start dates were observed while the end dates varied significantly. Stern *et al.* (1982a) observed that rainfall and evapotranspiration data alone were not sufficient to define and derive the end of the growing season realistically and that a measure of soil water storage was needed to define this event successfully.

The soil-water balance criterion takes into account the interaction of rainfall, evapotranspiration and the moisture holding characteristics of the soil. This criterion has shown realistic values (Majamanda, 1998) compared to the rainfall and rainfall and evapotranspiration criteria discussed previously. The soil is considered as a reservoir capable of holding a certain amount of water, the soil moisture holding capacity or the water holding capacity (WHC). The amount of available moisture is bounded at the upper limit by field capacity when the soil is saturated and extra water is lost to run off or deep percolation. The lower limit is the residual soil moisture

level when, under normal conditions, no more moisture can be extracted by plants or the permanent wilting point (PWP). Wallis (1963) examined the use of water balance methods to estimate soil - water deficit and crop water use in Kenya. The study assessed the impact of water deficit on yield and also related this to irrigation needs. Findings were used to classify different crops according to their probable water balance. Majamanda (1998) used the water balance criterion to estimate the effective growing season of Bvumbwe, Chileka, Chitedze and Makoka in Malawi. In this study it was noted that, knowledge of soil water balance provides information on the occurrence of the after-sowing or mid- season drought which can have an effect on farming practices as well as on the selection of suitable varieties. Slatyer (1968) emphasized that in order to get realistic values through water balance criterion, water supply must be the primary environmental factor in determining growing season characteristics. Through water balance studies the length of the growing season for different type of soils and crops can be estimated.

The Modeling criterion uses models to define rainfall events relevant to agriculture. The criterion uses daily rainfall measurements. In Nigeria Stern *et al.* (1981) outlined a probabilistic model of daily rainfall to derive the length of growing season and risk of dry spells. The model described the probability of rain throughout the year by fitting curves to observed proportions of rain days. The model also described the frequency of daily rainfall amounts on rain days using gamma distributions. In arid West Africa Dennet *et al.* (1983) used probabilistic models to examine the independency of rainfalls through the rainy season. Weak relationships between

monthly rainfall totals and the rain days were observed. The start and end of the rains were found to be independent. Stern *et al.* (1982b) pointed that, the modeling approaches provided more precise estimates and are smoothly plotted and periods shorter than the standard 30 years can be used to achieve reasonable results.

2.3.3 Effective length of growing season

Effective length of growing season is normally defined as the duration between the start and end of the growing season. In order to answer conditional questions about the length of the season, Stern *et al.*(1982) suggested that there is a need to assess whether there is any correlation between the dates of the start and end of growing season. Mhita (1984) observed that the start and end of rains were independent while correlation existed between the length and the start of the growing season. Similar results have been reported by Dennett *et al.* (1983) in seasonally arid areas of West Africa, Majamanda (1998) in Malawi and Kassase (1992) and Kingamkono (1994) in Tanzania. In Niamey Niger Stewart (1988) found that length of growing season was negatively correlated with the date of onset of growing season. In East Africa, Alusa and Mushi (1974) conducted an analysis on start and end of rains of bi-modal and uni-modal stations in Tanzania. Results of the analysis showed that, for the stations which are located in the same zone the total average length of the growing season of short and long rains of bi-modal stations were the same as the average length of the growing season of uni-modal stations. Various studies (Alusa and Mushi, 1974; Kassase, 1992; and Kingamkono, 1994) have shown that, length of growing season is

influenced by the shifts of rainfall pattern which is manifested in the date of onset of growing season.

2.3.4 Dry spell analysis

Analysis of dry spells is important in crop production because dry periods are expected within the growing season. Normally a single dry day does not have a significant impact on moisture stress of a plant. Therefore it is rather important to know the occurrence of consecutive dry periods during the growing season. The impact of these dry spells differs from crop to crop, type of soil and the crop development stages. A short period of dry spell in sandy soils has more effect to plants than in clay soils since the rate of water depletion is high in the former soil. Ngana (1983) used probability of occurrence to analyse dry spells for January-February in Dodoma using a 32-year data set (1950-1982). Analysis from individual months indicated that the probability of experiencing 3 weeks of continuous drought in January was 9.1%. In Singapore Jackson, (1972) observed that, dry spells of more than 6 days, each with less than 0.25mm rain occurred in every month except November over the period 1962-1966 with the longest dry spell lasting 20 days.

In dry spell analysis, Kingamkono (1994) found that stations which appeared to have a longer growing season were not necessarily the recipients of larger amounts of rainfall. Rather they experienced poor rainfall distribution with very high probabilities of dry spells within the growing season. Where growing seasons are

prone to high risk of dry spells, cultivation of certain crops can be a daunting task especially when dry periods coincide with sensitive phenological stages. For example, during the stages of silking and tasseling, moisture stress may have serious consequences on maize production. Fertilisation of the seed may be incomplete and even if this stage will be followed with adequate moisture, the harvested cobs will have few developed kernels and many undeveloped kernels (Berry, 1972). Inadequate amount of water during ripening stage may reduce the size of the kernel. Although all seeds may have been fertilised, the final weight of the grain is likely to be reduced (Berry, 1972). Doorrenbos and Kassam (1979) noted that, when water stress is imposed to the pollination and grain filling stages of maize, high reduction of crop yield is realised. Therefore assessing the risk of sowing on any particular date is recommended (Neuwolt, 1989). For good crop development, consideration of dry periods within the growing season is important and determination of probability of dry spells is more valuable especially when planning agricultural activities.

3 METHODOLOGY

3.1 Description of the Study area

Twenty one stations from six agro-ecological zones in Tanzania (Figure 3.1) were used in this study. Nieuwolt (1978) defined agro-ecological zones as natural physical regions which are sufficiently large to be mapped at scale of 1:2,000,000 and are sufficiently uniform in climate, physiography and soil patterns for generalized descriptions and evaluation of the agricultural potential and constraints to be meaningful. Table 3.1 gives the details of the studied stations. Selection of the stations was based on the availability of sufficient weather data and to ensure that all the six agro-ecological zones in Tanzania are represented.

3.2 Data collection

3.2.1 Climatological Data

Daily historical rainfall data for twenty one stations were collected from the Directorate of Meteorology in Dar es Salaam. Few data were found in CLICOM files while the rest were manually copied from the archives of the Directorate and subsequently entered into respective computer packages. The record length of the collected rainfall data for each station

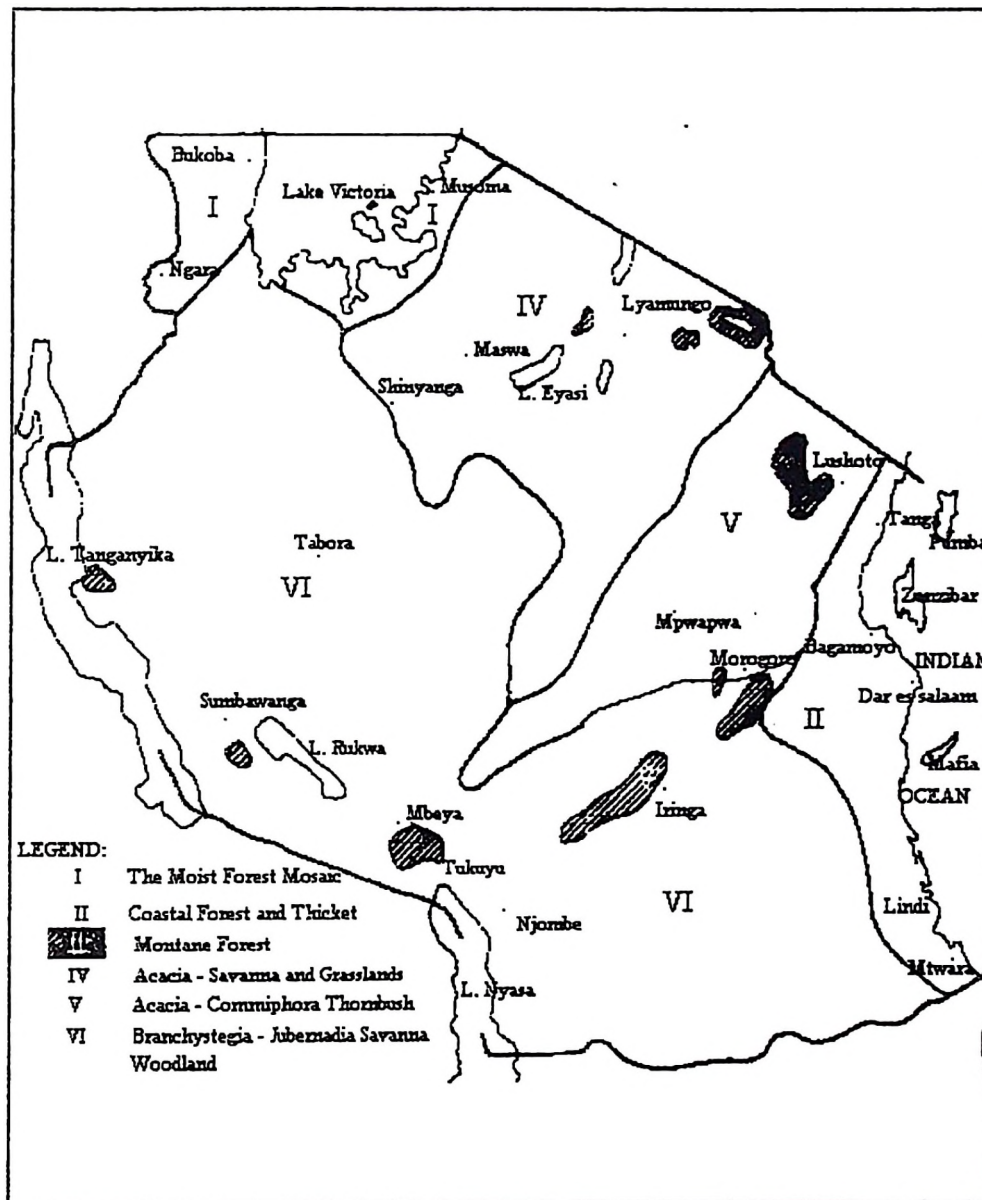


Fig. 3.1: Map of Tanzania showing major ecological zones of Tanzania and location of stations used in the study. Source: Stuart et al. (1990)

Table 3.1: Stations used in the study

Station	Agro ecological zone	Duration of rainfall data	Altitude (m)	Location	Mean annual rainfall (mm)
Bukoba*	I	1960-1997	1143	1° 2' S 31° 49' E	2101
Ngara	I	1961-1997	1798	2° 28' S 30° 38' E	1024
Musoma	I	1960-1997	1147	1° 30' S 33° 48' E	897
Dar es salaam	I	1960-1997	53	6° 52' S 39° 12' E	1266
Zanzibar	II	1961-1997	21	6° 13' S 39° 13' E	1694
Lindi	II	1960-1997	41	10° 05' S 39° 42' E	766
Bagamoyo	II	1961-1997	9	6° 25' S 38° 55' E	1079
Tanga*	II	1960-1997	49	5° s 39° 04' E	1331
Mtwara	II	1960-1997	113	10° 21' S 40° 11' E	1123
Mbeya*	III	1961-1997	1704	8° 56' S 33° 28' E	964
Tukuyu	III	1961-1997	1615	9° 15' S 33° 38' 38' E	2385
Lushoto	III	1961-1997	1396	4° 47' S 38° 17' E	1089
Shinyanga*	IV	1961-1997	1143	3° 39' S 33° 24' E	843
Lyamungo	IV	1961-1997	1250	3° 14' S 37° 15' E	1550
Maswa	IV	1961-1997	1341	3° 10' S 33° 46' E	693
Mpwapwa	V	1961-1997	1036	6° 2' S 36° 30' E	765
Morogoro*	V	1960-1997	526	5° S 38° E	886
Njombe	VI	1961-1997	1890	9° 25' S 34° 45' E	1155
Sumbawanga	VI	1961-1997	1722	7° 57' S 31° 36' E	887
Tabora*	VI	1960-1997	1182	5° 5' S 32° 5' E	1041
Iringa	VI	1960-1997	1428	7° 38' S 35° 46' E	618

* Stations used as representatives for respective agro-ecological zones

ranged from 37 to 38 years. Daily weather data for the period 1990-1994 which included temperature, wind speed, sunshine hours and relative humidity of the representative stations (Shinyanga, Mbeya, Tanga, Bukoba, Morogoro and Tabora) were also collected from the Directorate of Meteorology for establishment of threshold values of start of growing season using the water balance approach. Short period of daily weather data was taken because the annual variation of these elements is less than 12% while that of rainfalls is more than 30% (Mhita 1984).

3.2.2 Crop and Field data

The water balance simulation package IRSIS uses field and crop data (type of soil, wilting point, field capacity, basic infiltration rate, crop coefficients k_c , p factor and rooting depth) to simulate actual water content of the root zone throughout the growing season. The display of root zone depletion curves indicates the probable dates of start and end of growing season. The potential start and end dates of rains were derived from the corresponding tabulated information.

Maize crop was selected in this study because it is grown in all zones studied. Length of the growth period of maize was taken as 125 and 180 days for bi-modal and uni-modal stations respectively. Table 3.2 summarizes the assumed values of p factor, crop coefficients k_c and rooting depths z as recommended by Doorenbos and Pruitt, (1997).

Table 3.2: Crop coefficients (k_c), p factor and rooting depths (z) for 125 and 180 days growing season of maize.

	125 days growing season				180 days growing season			
	stage 1*	stage 2	Stage 3	stage 4	Stage 1	stage 2	stage 3	stage 4
Days	30	50	60	40	30	15	45	35
Kc	0.4	0.55	1.15	0.5	0.4	0.5	0.55-1.15	0.5
z (m)	0.2-0.35	0.4-0.8	0.8	0.9	0.25-0.35	0.4-0.55	0.8	0.9
P	0.5-0.55	0.55	0.5-0.45	0.4	0.5-0.55	0.55-0.5	0.5-0.45	0.4

*Note: Stage 1 is the vegetative stage, stage 2 is the flowering stage, stage 3 is the yield formation stage and stage 4 is the ripening stage

Heterogeneous soils exist in various parts of Tanzania and different ways have been used to classify soils. In this study the following dominant soil types were used in the analysis: loam soil for Mbeya, sand loamy for Morogoro, Tabora and Bukoba, silty clay loam for Shinyanga, fine sandy loam for Tanga (Hathout, 1973). Table 3.3 and Table 3.4 present respectively the properties of the selected soils as recommended by Doorenbos and Pruitt, (1997) and the assumed initial soil moisture contents at the corresponding soil depth for each representative station. Assumptions of these values were based on the fact that simulation of the model started just after the start of rainfall where soil moisture content within the root zone was below field capacity and was increasing with the depth of soil.

Table 3.3: Field capacity, wilting point and infiltration rate for different soil types in the study area.

Soil type	Field capacity (FC) % by volume	Wilting point (WP) % by volume	Infiltration rate (I) mm/day
Loam	29.3	9.8	50
Sandy loam	19.5	6.1	165
Loamy sand	27.3	8.7	120
Fine sandy loam	27.3	8.7	120
Silty clay loam	34.5	18.5	15

Table. 3.4: Initial soil moisture contents by volume (%) for representative soils in the respective stations

Soil depth (m)	Initial moisture content (% by volume)					
	Tanga	Morogoro	Bukoba	Mbeya	Tabora	Shinyanga
0.0 - 0.4	16	12	15	16	12	14
0.4 - 1.0	20	16	17	20	16	21
1.0 – 1.5	25	18	20	28	20	26

3.3 Data analysis

3.3.1 Establishment of threshold values of start and end of rains

The approach used by Majamanda (1998) in determining threshold values for start and end of growing season using water balance criterion was adopted in this study. The respective field, climatological and crop data were entered in a water balance simulation model (IRSIS) to establish threshold values for start and end of growing season for the following stations: Tanga, Tabora, Bukoba, Mbeya, Morogoro and Shinyanga which represent the six agro-ecological zones in Tanzania.

In the simulation of the soil water balance, the potential start of a growing season was considered to be the first day on which the running soil water balance equaled or exceeded the difference between the total available water (TAW) and the readily available water (RAW) with no intervening lapses of 10 days or more in the subsequent 30 days. On the other hand, the end of the growing season was taken as the first day when the running soil water balance was less than the difference between TAW and RAW with the situation remaining consistently so in the subsequent 10 or more days. The established threshold values were then used to fine tune the rainfall criterion using INSTAT statistical package for further agroclimatological analysis.

3.3.2 Calibration of rainfall criterion

The established threshold values of start and end of growing season from four crop seasons for each zone were used to calibrate the rainfall criterion with INSTAT. Definitions of different parameters as used in the rainfall criterion by Stern et al.(1982a) were adopted in this study where:-

- (a) The event marking the start of the growing season is not considered until after a stated earliest possible start date, D.
- (b) An event E, then indicates a potential start date, defined as the first occurrence of at least “ X ” mm totaled over ‘ t ’ consecutive days for which ‘ r ’ days are wet.
- (c) The potential start could be a false start if an event F, occurs afterwards where F is defined as a dry spell of ‘ n ’ or more days in the next ‘ m ’ days.
- (d) The event marking the end of the growing season is not considered until after a stated earliest end date, G.
- (e) An event H, then indicates a potential end date, which is defined as the running total of ‘ Y ’ mm reached and followed by a dry spell of at least ‘ s ’ days.

For each growing season a manual search procedure for the determination of optimal values of the different parameters within the rainfall criterion was applied. The Chi square (χ^2) test was carried out on two data sets of threshold values generated from water balance simulation model versus calibrated values to test the goodness of fit. The optimized parameters for the rainfall criterion for start and end of the growing

season for each of the six agro-ecological zones were established. Important rainfall characteristics determined using the calibrated rainfall criterion were compared with those obtained in previous studies (Kassase, 1992 and Kingamkono, 1994) who used one set of parameters in the rainfall criterion for all stations studied.

3.3.3 Establishment of significant shifts in rainfall pattern.

In this study a significant shift in rainfall pattern was defined as one standard deviation of the onset dates of growing season for the span of years studied. From each station and each rainy season the mean and standard deviation values were calculated from the derived start dates of growing season. The upper and lower boundaries of the shifts were marked by mean plus standard deviation ($Mea+Sde$) and mean minus standard deviation ($Mea-Sde$) respectively. The calculated values were then plotted against years for the duration studied. Years whose corresponding values in a graph were above or below the upper and lower boundaries were taken as the years with significant shifts in rainfall pattern. The t-test was conducted to see whether early and late start dates of growing season are significantly different from the start dates of growing season during normal years.

3.3.4 Influence of shifts in rainfall pattern on important rainfall characteristics.

Important agricultural rainfall characteristics i.e. start, end and length of growing season, total seasonal rainfall, and occurrence of dry spells within the growing season were determined in normal and those years which experienced significant shifts in order to observe the effects of shifts in rainfall pattern on rainfall characteristics. The start and end dates of growing season in each zone were derived from the calibrated rainfall criterion and used to calculate the length of the growing season. The effective length of the growing season was taken as the duration between the start and end dates of the effective growing season. A regression analysis was conducted between the effective length of growing season and the start dates of the growing season.

Daily rainfall amount within the effective growing season of each year which experienced significant shifts was summed up. Regression analysis was performed to study the effect of shifts of start dates of growing season on seasonal rainfall. Daily rainfall data were used to analyze the occurrence and risk of dry spell within the growing season. The analysis was performed on 30 days period overlapping at 5-day intervals. The proportions of years with spell length of at least 7 or 10 days was determined. Correlation between the proportions of dry days and start dates of growing season was also conducted.

4 RESULTS AND DISCUSSION

4.1 Establishment of threshold values of start and end of rains

The water balance simulation model IRSIS was used to provide threshold values for the establishment of the start and end dates of each of the four growing season of the following representative stations: Bukoba, Mbeya, Mpwapwa, Shinyanga, Tabora, Morogoro and Tanga.

The water balance criterion makes use of soil, crop and climatological data to provide a realistic soil moisture regime in the soil profile. The criterion based on accurate field and crop data provides more accurate values of dates of start and end of growing season and precise information on the occurrence of an after-sowing or seasonal drought. Figure 4.1 shows the root zone depletion for Mbeya during 1993/1994 growing season for which dates of onset and end of growing season were derived from the corresponding tabulated information (Table 4.1). It can be observed that, the 1993/1994 growing season started on 4th January and ended on 14th April with adequate soil moisture to support growth of a maize crop. Root zone depletion curves for other stations are given in appendix A. Except for Bukoba, short seasons of bi-modal stations experience insufficient rainfall for maize growth. Table 4.2 summarises the values of start and end dates of growing season from water balance criterion for the representative stations. It can be observed that most of the stations

experienced short duration of short rains and in some years failure of short rains. This is because short rains are highly variable in space and time.

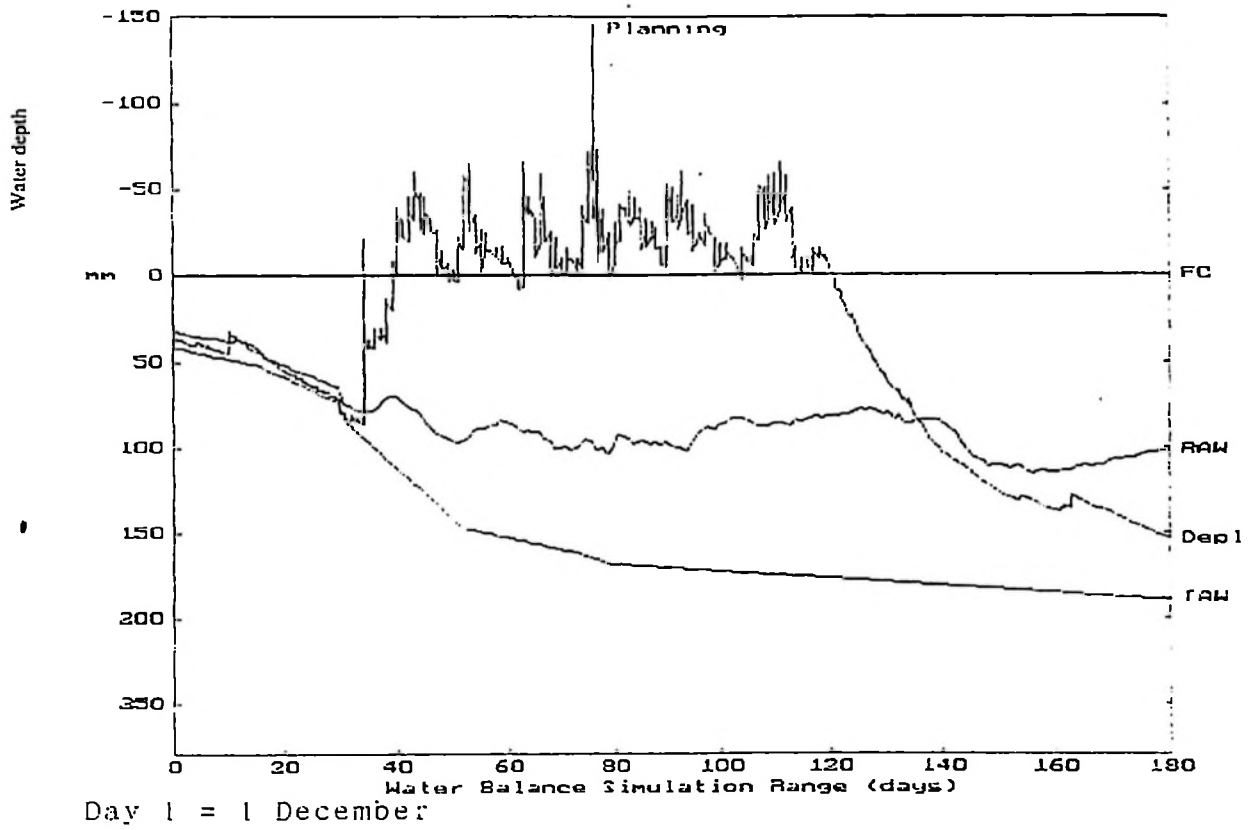


Fig. 4.1: Root zone depletion for 1993/1994 growing season for a maize crop in Mbeya.

Table 4.1: Water depletion (daily) in the root zone for maize crop

Dates	Rainfall (mm)	TAW (mm)	RAW (mm)	D begin (mm)	D end (mm)	RAW - D end (mm)
*						
26/12/93	0	67.5	59.3	64.5	64.9	-5.6
27/12/93	0	69	60.6	66.2	66.5	-5.9
28/12/93	0	70.5	61.8	67.8	68.1	-6.3
29/12/93	0	72	63.1	69.4	69.7	-6.6
30/12/93	0	73.5	64.4	71	71.3	-6.9
31/12/93	0	84	74.6	80.2	80.3	-5.7
1/1/94	0	87	75.5	82.7	83.6	-8.1
2/1/94	2.8	90	77.9	83.2	83.9	-6
3/1/94	1.2	93	79	85.1	86.4	-7.4
4/1/94	108.1	96	78.4	38.8	42.5	35.9
5/1/94	5.3	99	78.9	39.6	42.4	36.5
6/1/94	11.9	102	75.9	32.9	37.4	38.5
7/1/94	7	105	73.1	32.8	39.2	33.9
8/1/94	26.8	108	70.2	14.8	19.8	50.4
9/1/94	28.4	111	69.5	-6.2	-1.7	71.2
10/1/94	38.2	114	73.1	-35.9	-32.8	105.9
11/1/94	0	117	76.3	-22.8	-20.1	96.4
12/1/94	26.4	120	76.6	-37.4	-33.3	109.9
13/1/94	27.2	123	78.5	-49.1	-44.5	123
14/1/94	3.7	126	82.6	-27.5	-22.7	105.3
15/1/94	23.9	129	87.5	-37.2	-34.3	121.8
8/4/94	0	178.3	79	49.6	54.9	24.1
9/4/94	0	178.5	80.6	54.9	59.1	21.5
10/4/94	0	178.7	80	59.1	64.1	15.9
11/4/94	0	178.9	83.7	64.2	67.8	15.9
12/4/94	1.4	179.1	81.5	66.3	72.5	9
13/4/94	0.8	179.3	86.1	71.7	75.7	10.4
14/4/94	3.2	179.5	86.4	72.5	79.6	6.8
15/4/94	0	179.8	84.2	79.6	85.4	-1.2
16/4/94	0	180	84	85.4	91.3	-7.3
17/4/94	0	180.2	83.5	91.3	96.4	-12.9
18/4/94	0	180.4	83.8	96.4	99.6	-15.8
19/4/94	0	180.6	84.3	99.6	103.4	-19.1
20/4/94	0	180.8	86.8	103.4	104.7	-17.9
21/4/94	0	181	90.2	104.7	107.4	-17.2
**						

* Data for (01/12-25/12/1993) and ** Data for (22/04 -29/05/1994) are omitted for brevity in text

D = Depths of water
 RAW = Readily Available Water
 TAW = Total Available Water

Table 4.2 Start and end dates of growing season from water balance criterion
for zone I-VI

Station	zone	growing season	short rains		long rains	
			start	end	start	end
Bukoba	I	1990	10/10/1990	31/12/1990	20/01/1990	16/06/1990
		1991	10/09/1991	27/12/1991	13/01/1991	17/07/1991
		1992	22/10/1992	29/12/1992	20/02/1992	02/08/1992
		1993	13/08/1993	15/10/1993	02/02/1993	12/05/1993
Tanga	II	1972	-	-	04/04/1972	25/06/1972
		1979	-	-	04/02/1979	03/07/1979
		1985	12/11/1985	31/12/1985	02/04/1985	09/07/1985
		1991	-	-	26/03/1991	03/07/1991
Mbeya	III	1967/1968			19/11/1967	03/03/1968
		1978/1979			13/11/1978	02/04/1979
		1985/1986			20/11/1985	16/04/1986
		1993/1994			04/01/1994	14/04/1994
Shinyanga	IV	1965/1966			04/11/1965	20/02/1966
		1984/1985			03/12/1984	08/01/1985
		1992/1993			12/12/1992	24/02/1970
Morogoro	V	1972	-	-	23/02/1972	07/06/1972
		1979	-	-	16/02/1979	28/05/1979
		1987	18/12/1987	28/12/1987	31/03/1987	09/06/1987
		1993	16/09/1993	07/10/1993	17/03/1993	29/06/1993
		1995	-	-	07/03/1995	01/06/1995
Tabora	VI	1969/1970			09/11/1969	24/02/1970
		1977/1978			02/11/1977	18/02/1978
		1980/1981			15/11/1980	05/03/1981
		1993/1994			11/12/1993	25/03/1994

4.2 Calibration of the rainfall criterion

Values of start and end of growing season obtained from the water balance approach under section 4.1 were used to calibrate the rainfall criterion using INSTAT for four crop seasons in the respective zones. A combination of different values for the parameters were tried in order to derive optimal values for defining start and end of growing season for each cropping season. Derived values and those from water balance criterion were tested for goodness of fit using Chi-square (χ^2) test as shown in Table 4.3 and Table 4.4. In the analysis of the differences between calibrated and water balance derived criteria, it was observed that at 95% level of significance the computed χ^2 were less than the tabulated χ^2 values. Therefore calibrated values are significantly not different with those from water balance criterion. The mean values of calibrated start and end of growing season from the four cropping seasons were determined and used to establish the rainfall criterion for start and end of growing season for each respective zone.

Table 4.3: Start dates of growing season for both water balance criterion and calibrated rainfall criterion for six agro-ecological zones

Zone	Station	Rainfall modal	water balance criterion	calibrated rainfall criterion	χ^2 cal	χ^2 tab
I	Bukoba	Long rains	31 January	27 January	0.048	7.815
II	Tanga	Long rains	17 March	24 March	0.353	9.488
III	Mbeya	Seasonal rains	25 November	24 November	0.417	7.815
IV	Shinyanga	Seasonal rains	26 November	19 November	0.077	5.991
V	Morogoro	Long rains	07 March	18 March	4.928	9.488
VI	Tabora	Seasonal rains	17 November	16 November	0.955	5.991

Table 4.4: End dates of growing season for both water balance criterion and calibrated rainfall criterion for six agro-ecological zones

Zone	Station	Rainfall modal	water balance criterion	calibrated rainfall criterion	χ^2 cal	χ^2 tab
I	Bukoba	Long rains	27 June	12 June	4.626	7.815
II	Tanga	Long rains	28 June	24 June	4.436	9.488
III	Mbeya	Seasonal rains	1 April	29 March	0.237	7.815
IV	Shinyanga	Seasonal rains	29 March	3 March	4.346	5.991
V	Morogoro	Long rains	3 June	1 June	3.203	9.488
VI	Tabora	Seasonal rains	8 March	23 February	3.407	5.991

Table 4.5 summarises different parameters of the rainfall criterion for start and end of growing season for the respective agro-ecological zones. Definitions of the parameters are given below the table.

Table 4.5: Parameters for rainfall criterion in six agro-ecological zones

zone	start of growing season					end of growing season	
	X (mm)	t (days)	r (days)	n day(s)	m (days)	Y(mm)	S (days)
I	21	2	1	10	30	9	10
II	30	4	3	10	30	7	10
III	42	4	1	10	30	4	10
IV	45	5	4	10	30	9	10
V	16	5	2	10	30	7	10
VI	30	5	4	10	30	10	10

Note: X - running total of rainfall in mm, t - consecutive days for which running total of rainfall 'X' is reached, r - wet days within the consecutive days, n - days which consist of dry spells and m - days after growing season, Y - running total of rainfall in mm reached after the earliest end of growing season and s - days of dry spells after the earliest end of the growing season.

In other words the first date of growing season occurs when a running total of 'X' mm of rainfall is reached after the earliest start date in 't' days for which 'r' days are wet provided that there is no dry spell of 'n' days or more in the next 'm' days. End of the growing season is defined as the running total of 'Y' mm reached after the earliest end and followed by a dry spell of at least 's' days.

Table 4.6 presents the probable dates of start and end of growing season for all stations studied in respective zones using the calibrated rainfall criterion. From the table it can generally be noted that, variation in start and end dates of growing season exist in all stations in the six agro-ecological zones. Except for zone I, short rains exhibit higher variability in start dates of growing season than it is in the respective long rains. This is probably due to the fact that, short rains are poorly distributed and highly variable both in space and time (Nyenzi, 1992). On end dates, short rains are more stable compared to end dates of long rains. Long rains of all stations in the six agro-ecological zones except Maswa experience high variability on start dates compared to the end dates. This indicates that, end dates of growing season in these stations can be predicted more accurately than start dates.

Except Tukuyu, uni-modal stations which are located in zone III and VI experience late start of growing season compared to the uni-modal stations in zone I and IV that are located in the northern part of Tanzania between Lake Tanganyika and Victoria. The early start dates of these stations can be due to convective activities which are associated with the movement of the sun which at this time is moving from the equator southwards towards the tropic of Capricorn and their nearness to the water mass (Alusa and Mushi, 1974). Similar observations were reported by Kingamkono (1994) who noted that, the uni-modal stations that are located north of latitude 6° show early start dates than those to the South. The exception of Tukuyu is probably due to the fact that it is nearer to Lake Nyasa on the windward side. From Table 4.6 it can further be noted that, in one out of two years, long rains of most of the bi-modal stations start in March.

Table 4.6: Probable dates for which the growing season of maize crop can be expected to start and end at given percentage points (calibrated rainfall criterion)

Station	zone	season	start date				end dates			
			20%	50%	80%	s.d	20%	50%	80%	s.d
Bukoba	I	Long	11Jan	22 Jan	28 Feb	26.1	27 May	14 Jun	27 June	21.3
		Short	12 Sept	22 Sept	11 Oct	14.6	09 Dec	24 Dec	08 Jan	16.3
Musoma	I	Long	08 Feb	23 Feb	20 Mar	23.6	02 May	30 May	11 June	25.1
		Short	16 Sept	10 Oct	03 Nov	23.3	03 Dec	09 Dec	22 Dec	10.5
Ngara	I	Seasonal	08 Sept	24 Sept	20 Oct	27.3	06 May	11 May	20 May	7.3
Dares salaam	II	Long	11 Mar	20 Mar	03 Apr	13.1	3 May	20 May	08 June	23.8
		Short	11 Oct	29 Oct	12 Nov	22.7	01 Dec	28 Dec	20 Jan	21.5
Zanzibar	II	Long	5 Mar	17 Mar	31 Mar	13.4	08 May	22 May	04 June	13.1
		Short	26 Sept	26 Oct	11 Nov	23.2	05 Dec	26 Dec	08 Jan	17.7
Bagamoyo	II	Long	17 Mar	06 Apr	14 Apr	15.2	14 May	22 May	09 June	15.5
		Short	21 Oct	08 Nov	22 Nov	19.4	01 Dec	28 Dec	22 Jan	23.3
Tanga	II	Long	19 Mar	30 Mar	13 Apr	14.8	04 May	25 May	05 June	21.1
		Short	13 Sept	08 Oct	04 Nov	24.4	06 Dec	18 Dec	01 Jan	15.4
Lindi	II	Seasonal	26 Nov	14 Dec	03 Jan	27.3	01 June	02 June	09 June	6.36
Mtwara	II	Seasonal	21 Nov	10 Dec	07 Jan	25.6	01 June	01 June	06 June	5.2
Mbeya	III	Seasonal	24 Nov	06 Dec	19 Dec	17.7	27 Apr	08 May	19 May	12.3
Tukuyu	III	Seasonal	14 Sept	10 Nov	30 Nov	34.6	23 May	10 June	03 July	27.4
Lushoto	III	Long	08 Mar	20 Mar	10 Apr	14.5	2 Apr	15 Apr	05 May	17.5
		Short	07 Oct	08 Nov	03 Dec	27.1	01 Dec	06 Dec	17 Dec	9.6.6
Shinyanga	IV	Seasonal	18 Oct	04 Nov	18Nov	24.9	10 Apr	25 Apr	10 May	14.8
Lyamungo	IV	Long	08 Mar	24 Mar	04 Apr	13.8	08 June	20 June	20 July	24.4
		Short	24 Sept	27 Oct	21 Nov	28.9	03 Dec	14 Dec	05 Jan	18.7
Maswa	IV	Seasonal	25 Oct	24 Nov	29 Nov	16.2	06 May	18 May	24 June	23.1
Mpwapwa	V	Seasonal	26 Nov	08 Dec	22 Dec	17.7	06 May	01 June	13 June	19.6
Morogoro	V	Long	26 Feb	13Mar	23 Mar	11.8	13 Apr	12 May	01 June	23.5
		Short	21 Oct	05 Nov	21 Nov	21.9	01 Dec	07 Dec	31 Dec	16.4
Njombe	VI	Seasonal	21 Nov	09 Dec	30 Dec	17.8	28 Apr	10 May	18 May	16.3
Sumbawanga	VI	Seasonal	19 Nov	04 Dec	20 Dec	16.6	17 Apr	28 Apr	10 May	15.3
Tabora	VI	Seasonal	04 Nov	19 Nov	10 Dec	19.7	12 Apr	06 May	17 May	17.3
Iringa	VI	Seasonal	09 Dec	22 Dec	04 Jan	17.3	10 Apr	29 Apr	11 May	16.3

In this study the effective length of the growing season was taken as the duration between start and end dates of the growing season. Table 4.7 shows the effective length in days of the growing season at three levels of probability. All studied stations in the six agro-ecological zones, experience high variability of length of growing season. Tukuyu (seasonal rains) exhibits higher variability while Sumbawanga (seasonal rains) exhibits the lowest variability of the growing season. Ngara has the longest growing season with 202 days or more in 4 out of 5 years, 234 days or more in 1 out of 2 years and 247 days or more in 1 out of 5 years. Mpwapwa has the shortest growing season for uni-modal stations with growing season of 167 days or more in 1 out of 5 years, 147 days or more in 1 out of 2 years and 124 days or more in 4 out of 5 days. In bi-modal stations, Bukoba (long rains) has the longest growing season of 142 days or more in 1 out of 2 years while Morogoro (short rains) has the shortest length of growing season with 37 days or more in 1 out of 2 years.

Some of the results from previous studies on similar stations (Kassase, 1992; Kingamkono,1994) using blanket values of parameters in the rainfall criterion agree with those observed in this study this means that, such rain characteristics can be determined to the similar level of accuracy using either of these approaches. For example from both previous and this study it was observed that variability in start, end and length of growing season exists in all stations and that variability of start dates for most of bi-modal stations is high for short rains than it is for long rains. On end dates of growing season, long rains of most of the bi-modal stations exhibit high variability than for short rains this may perhaps be attributed to the fact that there are

few and therefore more consistent end dates of short rainy season because of high failure

Table 4.7: Effective length (days) of growing season at three levels of probability
(calibrated rainfall criterion)

station	zone	season	Effective length of growing season (days) equal or greater than			sd
			80%	50%	20%	
Bukoba	I	Long	93	142	154	33.9
		Short	72	91	108	20.7
Musoma	I	Long	58	83	107	29.1
		Short	41	68	89	23.8
Ngara	I	Seasonal	202	234	247	29.1
Dar es salaam	II	Long	35	61	74	25.2
		Short	34	54	98	31.5
Zanzibar	II	Long	53	77	102	21.6
		Short	40	62	81	26.9
Bagamoyo	II	Long	32	48	90	29.4
		Short	21	43	81	28.5
Tanga	II	Long	40	70	86	24.2
		Short	37	56	86	31.2
Lindi	II	Seasonal	152	172	198	28.5
Mtwara	II	Seasonal	116	151	171	35.3
Mbeya	III	Seasonal	135	154	175	24.1
Tukuyu	III	Seasonal	185	228	263	43.4
Lushoto	III	Long	62	94	123	34.6
		Short	38	84	103	31.6
Shinyanga	IV	Seasonal	154	174	192	28.9
Lyamungo	IV	Long	68	98	119	28.5
		Short	30	57	83	28.8
Maswa	IV	Seasonal	80	153	154	22.9
Mpwapwa	V	Seasonal	124	147	167	28.7
Morogoro	V	Long	32	65	87	28.5
		short	16	37	51	29.2
Njombe	VI	Seasonal	129	148	177	27.4
Sumbawanga	VI	Seasonal	138	149	175	19.9
Tabora	VI	Seasonal	133	163	183	26.7
Iringa	VI	Seasonal	103	130	149	24.3

of short rains. Long rains in almost all bi-modal stations start in March. Ngara exhibits the longest growing season. A similar observation was noted on the early start dates of growing season in stations located in northern part of Tanzania. Table E1 in appendix E shows the probable dates of start of rains and the effective length of the growing season which were determined in previous studies (Kassase, 1992 and Kingamkono, 1994) using a set of parameters. With reference to Table 4.6 and Table 4.7 the calibrated rainfall criterion gives later start of rains and shorter growing season for uni-modal stations compared to the findings from the previous studies where the rainfall criterion was adopted (Kassase, 1992 and Kingamkono, 1994).

4.3 Shifts in rainfall pattern

The calibrated rainfall criterion for each zone was used to determine the start dates of growing season for all years of record for the stations studied from respective zones. In order to establish shifts in rainfall pattern, the deviations from the mean start dates equal to one standard deviation were used to mark the upper and lower boundaries of shifts in each station. A t - test was performed for early, late and normal dates of start of growing season where it was hypothesised that the means of start dates of growing season above the upper boundary and below the lower boundary were equal to the mean of normal dates of start of growing season in each station. Table 4.8 shows that, the computed t (t cal) values are larger than the tabulated values (t table). Therefore the statistical hypothesis was rejected. This means that, at $P \leq 0.05$, the early and late start dates of growing season are significantly different from start dates

of growing season during normal years. Hence all stations experience significant shifts in rainfall pattern.

Figure 4.2 shows the shifts in start dates of seasonal rains in Sumbawanga. Like other uni-modal stations in zone II, III, IV, V and VI, Sumbawanga was observed to experience early and late start of rains. For example, in 1986 seasonal rains started on 30th October while in 1987 and 1991 rainfall started on 4th January and 5th January respectively. In zone I, years with late start of growing season showed higher deviations on start dates of rains than those with early start of rains as depicted in Figure 4.3 for Musoma (long season). Similar graphs for other stations are presented in Appendix B.

4.3.1 Effects of shifts in rainfall pattern on effective length of growing season

Effects of shifts in start dates of rains on length of the growing season were assessed for two stations from each zone. Table 4.9 presents the length of the growing season and seasonal rainfall (zone I and II) for years which have significant shifts in start dates of rains. Table E1 in appendix E shows the length of the growing season and seasonal rainfall for zone III-VI. Length of growing season appears to be influenced by the shifts in rainfall pattern which is characterised by the start dates of rains.

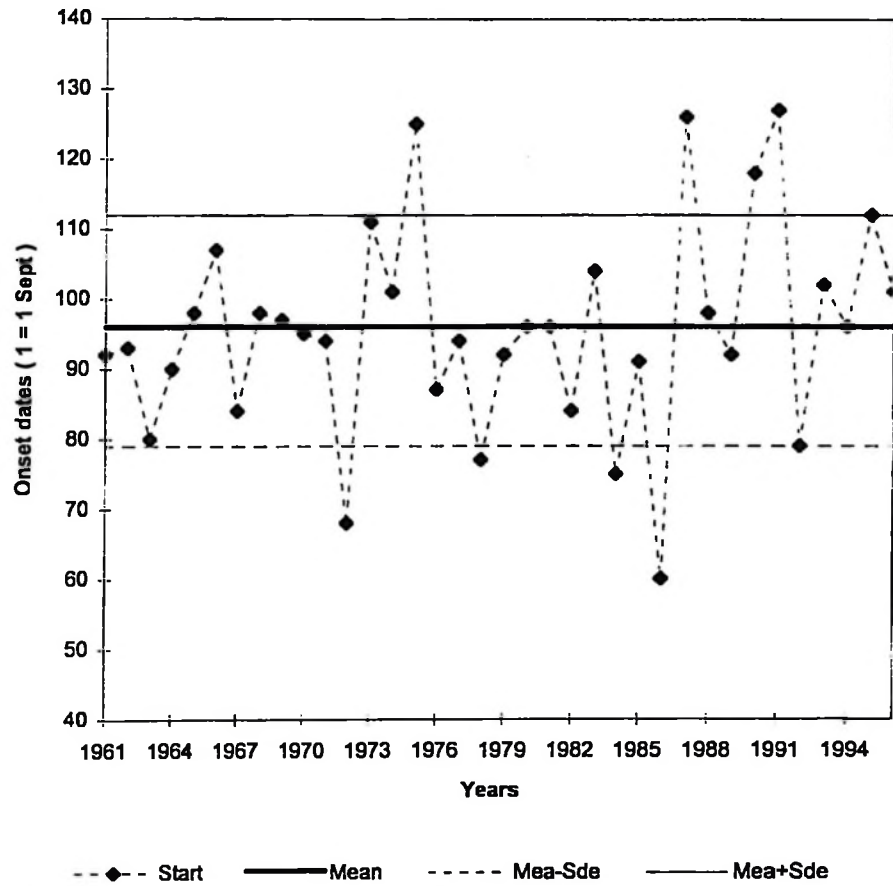


Fig.4.2: Shifts in rainfall pattern for seasonal rainfall in Sumbawanga

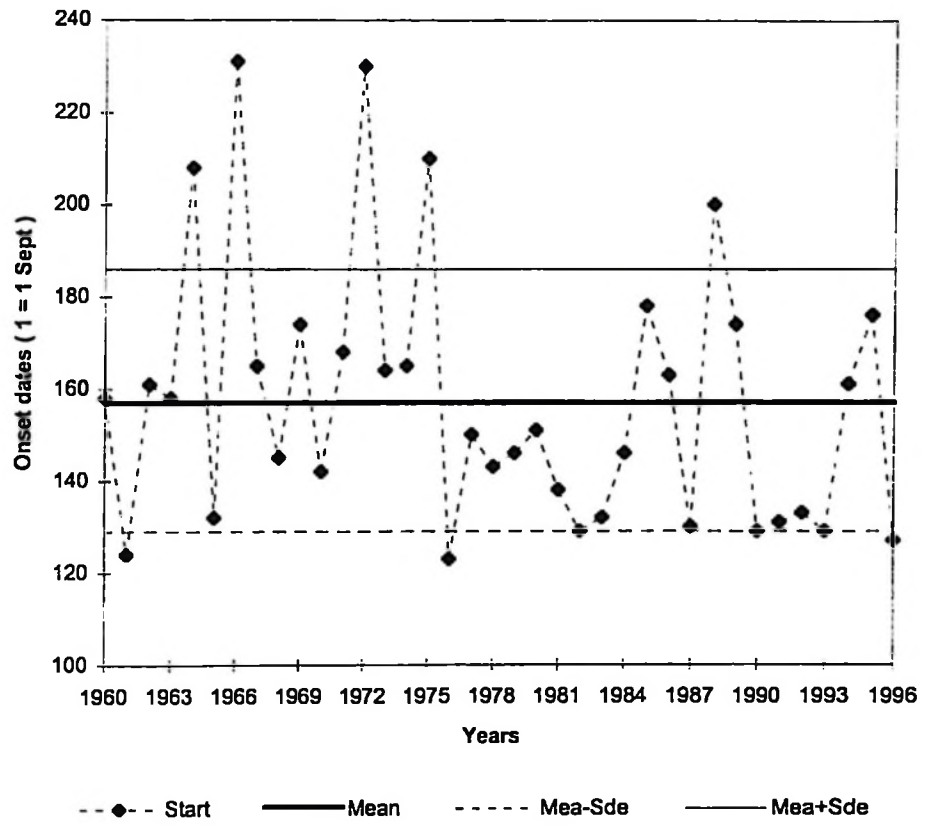


Fig.4.3: Shifts in rainfall pattern for long rains in Musoma

Table 4.8: Summary of results of t - test for early and late start of growing season for selected stations.

season		Early start of growing season			Late start of growing	
Zone	Station	Rain Season	t cal	t table	t cal	t table
I	Ngara	Seasona	3.162	2.045	6.279	2.042
	Musoma	Long	2.731	2.042	8.390	2.043
		Short	5.490	2.042	6.110	2.042
II	Lindi	Seasona	6.626	2.048	6.478	2.048
	Tanga	Long	2.953	2.056	8.569	2.042
		Short	5.857	2.048	4.431	2.039
III	Tukuyu	Seasona	8.299	2.045	3.910	2.056
	Lushoto	Long	4.304	2.056	5.627	2.052
		Short	8.897	2.037	8.406	2.045
IV	Shinyanga	Seasona	4.259	2.039	7.083	2.042
	Lyamungo	Long	7.183	2.048	3.759	2.059
		Short	5.253	2.059	9.470	2.052
V	Mpwapwa	Seasona	6.192	2.042	4.735	2.042
	Morogoro	Long	7.033	2.042	4.299	2.048
		Short	2.475	2.036	8.772	2.042
VI	Njombe	Seasona	5.734	2.056	7.574	2.052
	Sumbawanga	Seasona	5.814	2.042	6.902	2.042

From Table 4.10 it can be observed that, a negative correlation exists between the shifts of start dates of rains and the length of the growing season in all zones studied. For example in 1962 rains in Ngara (zone I) started 96 days after the normal dates with 145 days of growing season while in 1989 rains started 31 days earlier with a corresponding length of 286 days. Normally Ngara has an effective length of growing season of 241 days in 1 out of 2 days (Table 4.5). Similar observations were made for uni-modal stations in zones II, III, IV, V, and VI where, all years with early start of rains experience long length of growing season while late start of rains imply short length of a growing season.

Start dates of long rains of bi-modal stations in zone I and III vary negatively with the corresponding length of growing season (Table E2 in appendix E). It was further observed that, variation in start dates of most of the short rains has no defined relationship with the respective length of growing season. The length of growing season was noted to correlate positively with amount of rainfall received during short seasons. Some years in bi-modal stations insufficient short rains were received to support the growth of maize crop. In fact in some years there were no short rains at all for some stations, for example, in Lyamungo, Musoma and Lushoto in 1976, Tanga in 1971, 1983 and 1996 and Morogoro experienced no short rains in 1986 and 1996.

Table 4.9: Length of growing season (days) and total seasonal rainfall (mm) for years with significant shifts in start dates of growing season (Zone I and II).

station	zone	Rain season	shifted year	shifts (days)	growing season start	growing season end	growing season length	seasonal rainfall (mm)
Ngara	I	Seasonal	1962+	96	05 Jan	29 May	145	952
			1979+	41	11 Nov	15 June	217	759
			1983-	29	04 Sept	02 June	272	711
			1986+	29	30 Oct	16 June	230	831
			1989-	31	01 Sept	13 June	286	1148
			1991+	29	30 Oct	31 May	214	724
			1992-	29	03 Sept	11 June	282	1052
			1993+	48	18 Nov	30 May	194	1283
Musoma	I	Long	1964+	51	26 Mar	16 June	82	296
			1966+	74	18 Apr	04 July	77	210
			1972+	73	17 Apr	10 July	84	263
			1975+	53	28 Mar	06 July	100	274
			1988+	43	18 Mar	01 July	105	254
		Short	1961-	42	03 Sept	01 June	272	1546
			1967-	93	06 Sept	09 Jan	125	256
			1974-	36	09 Sept	04 Feb	148	175
			1995-	41	04 Sept	15 Dec	102	171
			1996-	43	02 Sept	17 Dec	106	152
Lindi	II	Seasonal	1968-	34	09 Nov	04 May	177	869
			1987+	30	12 Jan	01 Mar	49	127
			1973+	42	24 Jan	13 May	110	491
			1976+	38	20 Jan	10 June	142	450
			1982-	51	23 Oct	14 June	235	846
Tanga	II	Long	1961-	72	05 Jan	30 May	146	262
			1968+	40	27 Apr	22 June	56	135
			1971-	71	03 Jan	02 Apr	90	109
			1978-	70	07 Jan	22 June	167	1129
			1980+	48	14 Dec	29 Dec	15	15
			1990-	55	22 Jan	05 June	135	609

Note: + Years with late start of rains - Years with early start of rains

Table 4.10: Correlation between shifts of start of growing season (S), length of the growing season (L) and seasonal rainfall (R) for uni-modal stations.

Zone	Regression equation	Correlation coefficient
I	$S = 237.9 - 0.948L$	-0.961
	$S = 17.4 - 0.009R$	-0.004
	$L = 235.7 + 0.007R$	0.002
II	$S = 78.6 - 0.516L$	-0.672
	$S = 70.7 - 0.118R$	-0.688
	$L = 26.1 + 0.209R$	0.856
III	$S = 116.3 - 0.841L$	-0.762
	$S = 22.7 - 0.033R$	-0.184
	$L = 105.9 + 0.044R$	0.297
IV	$S = 151.7 - 1.107L$	-0.562
	$S = 96.4 - 0.238R$	-0.439
	$L = 62.4 + 0.189R$	0.015
V	$S = 123.9 - 0.882L$	-0.833
	$S = 98.8 - 0.137R$	-0.795
	$L = 55.7 + 0.131R$	0.609
VI	$S = 133.1 - 0.882L$	-0.916
	$S = 65.3 - 0.069R$	-0.447
	$L = 64.8 + 0.093R$	0.627

4.3.2 Effects of shifts in rainfall pattern on seasonal rainfall

Rainfall is the most important climatic element in all agricultural regions of Tanzania. The amount, intensity and distribution of the rain within the growing season are of decisive importance for crop production. In this study interest was on the effect of shifts in rainfall pattern on seasonal rainfall rather than annual rainfall. Table F2 in appendix F summarises the total seasonal rainfall at given probability of exceedance for selected stations in six agro-ecological zones. Variations of seasonal rainfall have been observed among different zones. Out of the uni-modal stations, Tukuyu from zone III receives the highest seasonal rainfall of 1634 mm in 1 out of 2 years while the lowest value of 689 mm was received by Mpwapwa in zone V at the same probability level. In bi-modal stations, Bukoba (short rains) from zone I experienced the highest seasonal rainfall of 720 mm in 1 out of 2 years and Lyamungo (short rains) from zone III exhibits the lowest seasonal rainfall of 51 mm in 1 out of 2 years.

Variation in the start dates of rains influence the seasonal rainfall received in different zones studied. From Table 4.9 and Table E2 in Appendix E, it can be observed that, the amount of seasonal rainfall received by uni-modal stations which are located in zone II, V and VI varies with the shifts in start of rains. The seasonal rainfall correlates negatively with the onset dates of rains with the coefficients of correlation ranging from 0.447 to 0.795. This means that the early start of rains leads to high total seasonal rainfall while a small amount of rainfall is received when these

stations experience late start of rains. The uni-modal stations in these zones also exhibit positive correlation between the length of the growing season and amount of rainfall received. Figure 4.4 shows how length of growing season in Njombe (zone VI) relates with received seasonal rainfall. Growing season of more than 142 days receive a fairly constant amount of seasonal rainfall of around 1200 mm. Knowledge of length of growing season in this zone (VI) can therefore be used to predict the expected rainfall. During normal years (in 1 out of 2 years) Mpwapwa (zone V) realises a total seasonal rainfall of 689 mm but in 1962 and 1986 when significant early start of rains was recorded, the seasonal rainfall was respectively 913 mm and 1112 mm. On the other hand in 1972 and 1993 Mpwapwa experienced late start of rains where rains started on 3 January and 6 January respectively. During the same period the seasonal rainfall received was only 537 mm and 560 mm respectively.

Uni-modal stations in zone I, III and IV and bi-modal stations exhibit no well defined relationship between shifts of onset dates of rains and seasonal rainfall. Most of the uni-modal stations in these zones and long rains of bi-modal stations, have specific range of time for which commencement of rains results in high seasonal rainfall. Figure 4.5 shows the relationship between the onset dates of rains and corresponding amount of seasonal rainfall received in Tukuyu (zone III). From the figure it can be deduced that, Tukuyu attains its mean annual rainfall of 2380 mm when rains commence between mid September and first week of December. The characteristics of the seasonal rainfall in different agro-ecological zones studied can be described by local rainfall patterns which are influenced by factors such as

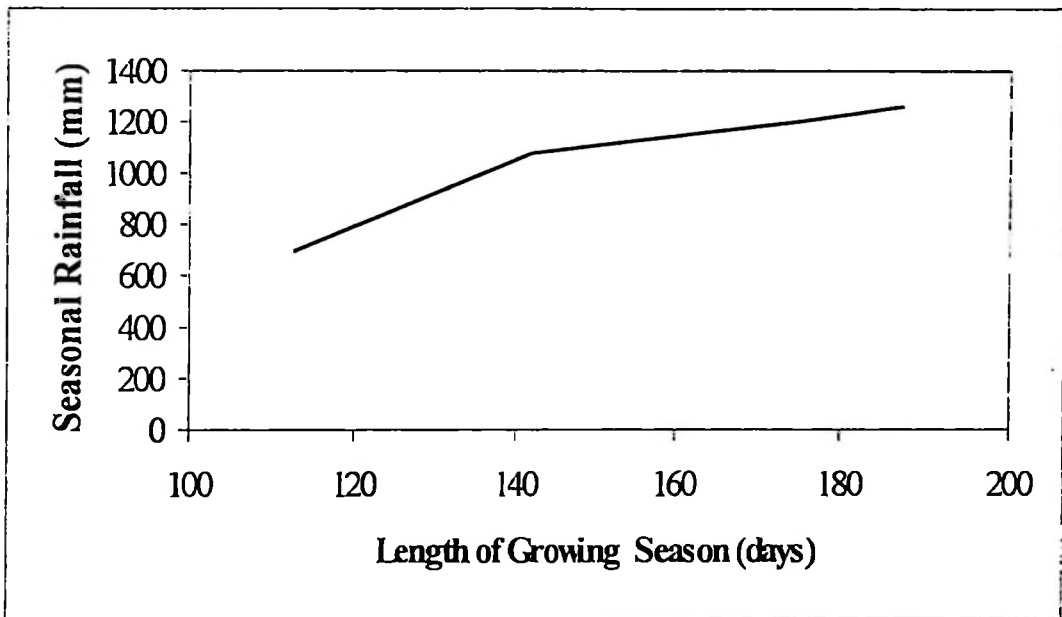


Figure 4.4: Relationship between length of growing season and seasonal rainfall for Njombe (Zone VI)

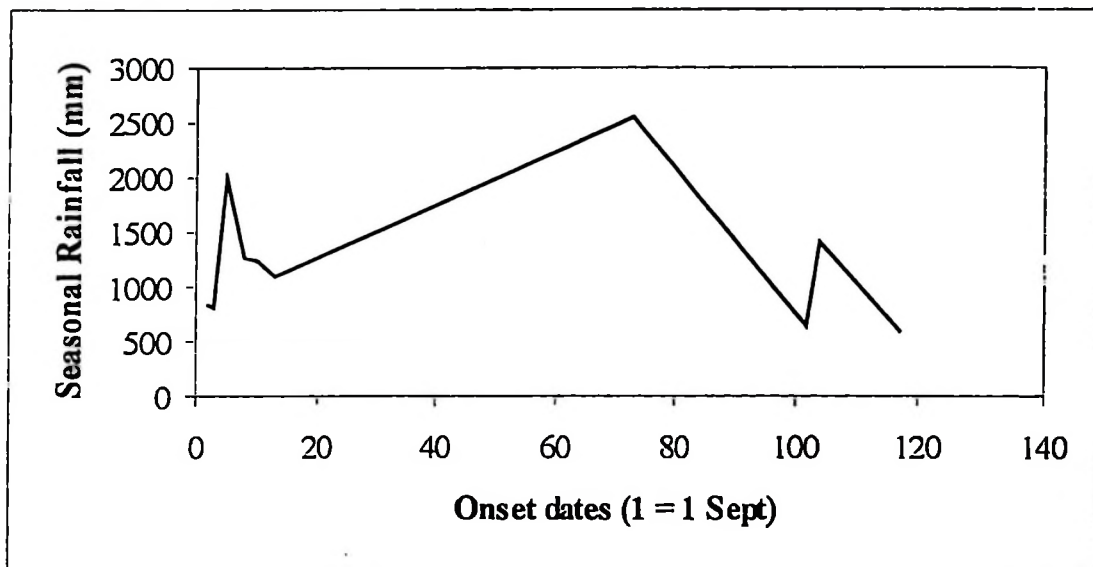


Figure 4.5: Relationship between onset data of growing season and seasonal rainfall for Tukuyu (Zone III)

geographical location, altitude and presence of large water masses. Zone I is located around the shore of Lake Victoria where the seasonal rainfall to a large extent is influenced by the water mass through Lake Victoria circulation. Zone II covers the eastern part of Tanzania along the shore of Indian ocean. This coastal area experiences land-sea breeze which influence the seasonal rainfall over the area. Zones III-V extend from north-eastern part of Tanzania to the central region. The highland surface temperature during the period of December to March give rise to a large low pressure area in the southern parts. This situation give rise to north easterly dry air stream over the northern parts of the country bringing little rainfall in that area (Lema,1986). The seasonal rainfall in north-eastern parts is also probably influenced by the orographic effect especially in the region over mount Kilimanjaro. The tight rainfall gradients over this area between the high ground and adjacent low lands cause high variability of rainfall. Zone VI covers a large part of the country. It extend from south, south - western to north - western. In this zone, among other geographical features, it covers southern highlands, Lake Nyasa and Lake Tanganyika. High altitude and large water masses have substantial effects on seasonal rainfall over the region. The large amount of rainfall in southern Tanzania during January, February and March are related to the nearness of the Inter-Tropical Convergence Zone. The seasonal rainfall over South - western and western parts of the country is also likely to be influenced by the intrusion of moist westerly air stream over western Tanzania from the Congo basin during southern summer (Nyenzi, 1997) also by the meridional arm of the Intertropical Convergence Zone (ITCZ).

4.3.3 Effects of shifts in rainfall pattern on dry spells within the growing season.

The element of risk of a dry spell is of great importance to tropical agriculture. Most of the areas in the country are prone to high seasonal rainfall variations, a situation that can result in long dry spells which may cause water deficit to crop.

Figure 4.6 and Figure 4.7 show the distributions of probability of dry spells in 30-day periods estimated as the observed proportion of years in which a dry spell of at least 7 or 10 days occur in Tukuyu and Musoma respectively. Similar distributions for selected stations are given in Appendix C. As expected the probability of dry spell is low during the rainy season and high during the dry season. Musoma which is a typical bi-modal station has two periods of lowest probability. These periods coincide with the short and long rains seasons.

A day was termed dry if the probability of dry spell is greater than 0.5. Uni-modal stations in Zone V and VI experience wet periods which coincide with the growing season that extends from November to April during normal years (Table 4.11).

The short seasons indicate that both 7-day and 10-day dry spells do not reach the zero probability. Therefore it is more risky to crop during short rains where there is a high risk of dry spells.

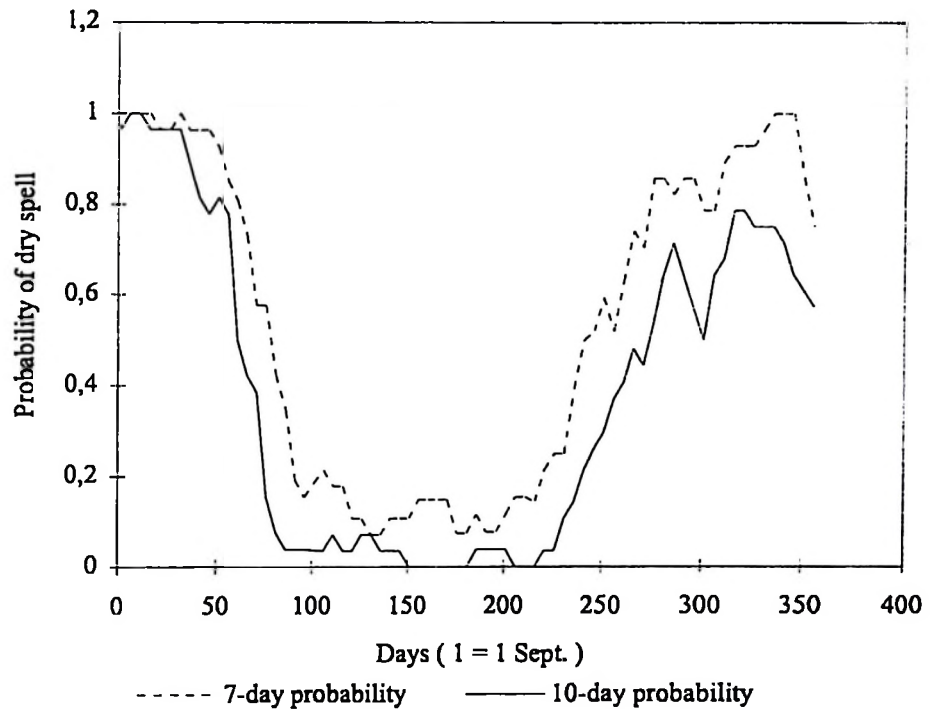


Figure 4.6: The probability of a 7-day and 10-day dry spell within 30 days following the date on the time axis for Tukuy

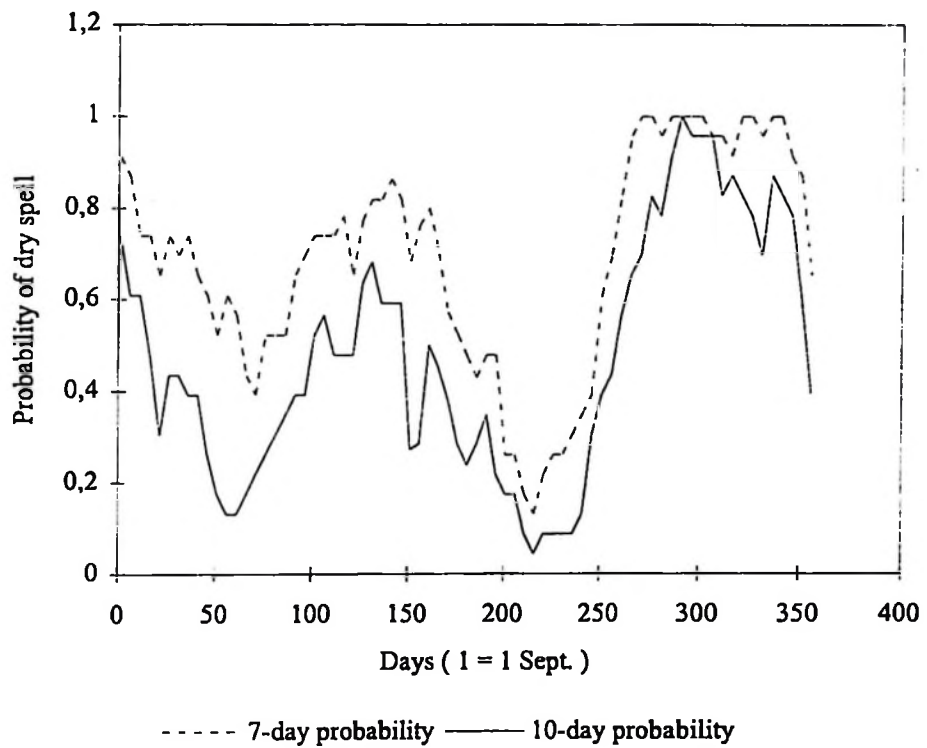


Figure 4.7: The probability of a 7-day and 10-day dry spell within 30 days following the date on the time axis for Muso

Occurrence of dry spells within the growing season in years which experience extreme shifts in start dates of growing season was assessed by finding the distributions of 7-day and 10-day dry spell probability in 30-day periods at 5 days interval for each year. Tables 4.12 and 4.13 show the first and last dates when probability of long dry spell is below 0.5 for the years with the earliest and latest start of growing season respectively for selected stations in six agro-ecological zones. During early and late start of rains it was generally observed that, stations in all zones are prone to risk of dry spells within the growing season. High risk was noted for short rains during late start of rains.

Table 4.14 presents the proportions of dry days within the growing season when 7-day and 10-day dry spell probability is above 0.5 for years with shifts in start dates of rains. High proportions of dry days can be observed in zone I-V when rainfall commences early. In zone I for example, when rains start 43 days earlier than normal, 80% of the growing season is covered by dry days. It was further observed that, stations in zone I, III and IV have no linear relationship between the onset dates of rains and amount of rainfall received. Findings from this study have shown that, in zone I-IV the 7-day dry spell probability of occurrence are negatively correlated with the onset dates of rains. This means that in these zones, the earlier the rains commence the larger the number of dry days within the growing season.

From this study it can be concluded that, short seasons of bi-modal stations are associated with long dry spells which affect crop growth. Years with significant

shifts in start dates of growing season are prone to risk of dry spells in stations located in zone I-V. Therefore due to the occurrence of dry spell in early and late start of growing season, cultivation of short duration maize (75-90 days maturity) can be adopted with the use of supplemental irrigation or other moisture retention techniques as a solution to sustainable crop production. To be sure of crop harvest, drought resistant crops like sorghum, millet, beans and cassava should be considered. Since maize is a one of the staple food in Tanzania, early maturity maize varieties like Katumani should be preferred.

Table 4.11: First and last dates when probability of dry spells is below 0.5 for the years with no significant shifts in start dates of growing season for selected stations

station	zone	season	7-day dry spell		10-day dry spell	
			start	end	start	end
Ngara	I	Long	06 Oct	20 Dec	*	*
			23 Feb	23 Apr	06 Sept	28 Apr
Musoma	I	Long	28 Feb	03 May	14 Jan	13 May
		Short	31 Oct	20 Nov	21 Sept	04 Jan
Lindi	II	Long	13 Feb	03 Apr	20 Nov	18 Apr
Tanga	II	Long	09 Mar	08 May	04 Mar	18 Apr
		Short	*	*	01 Sept	25 Nov
Tukuyu	III	Long	20 Nov	28 Apr	05 Nov	28 May
Lushoto	III	Long	28 Feb	03 May	13 Feb	12 July
Shinyanga	IV	Long	15 Nov	03 Apr	26 Oct	18 Apr
Lyamungo	IV	Long	19 Mar	02 July	04 Mar	27 July
		Short	*	*	21 Oct	10 Dec
Mpwapwa	V	Long	25 Nov	08 Feb	*	*
			28 Feb	03 Apr	15 Nov	23 Apr
Morogoro	V	Long	09 Mar	23 Apr	23 Feb	13 May
		Short	*	*	17 Nov	25 Dec
Njombe	VI	Long	30 Nov	29 Mar	25 Nov	08 Apr
Sumbawanga	VI	Long	15 Nov	24 Mar	31 Oct	03 Apr

* No period within the growing season with probability of 7-day dry spell below 0.5

Table 4.12: First and last dates when probability of dry spell is below 0.5 for the year with the earliest start of growing season for selected stations

station	zone	season	Year	7- day dry spell		10-day dry spell	
				start	end	start	end
Ngara	I	Long	1989	07 Sept	05 Dec	01 Sept	23 Apr
Musoma	I	Short	1996	*	*	31 Oct	30 Dec
Lindi	II	Long	1982	20 Nov	20 Dec	31 Oct	20 Dec
				08 Feb	18 Apr	03 Feb	23 May
Tanga	II	Long	1971	29 Mar	03 May	29 Mar	23 May
Tukuyu	III	Long	1986	31 Oct	29 Jan		
				23 Feb	18 May	31 Oct	18 May
Lushoto	III	Long	1986	13 Feb	03 May	13 Feb	08 May
		Short	1967	16 Oct	15 Nov	11 Oct	05 Dec
Shinyanga	IV	Long	1975	30 Nov	09 Jan	21 Oct	08 Feb
				14 Mar	03 Apr	09 Mar	28 Apr
Lyamungo	IV	Long	1964	19 Jan	08 Feb	10 Dec	08 Feb
				14 Mar	08 May	14 Mar	23 May
		Short	1975	25 Nov	20 Dec	10 Nov	30 Dec
Mpwapwa	V	Long	1962	20 Nov	13 Apr	15 Nov	18 Apr
Morogoro	V	Short	1997	01 Sept	11 Oct	01 Sept	16 Oct
Njombe	VI	Long	1985	31 Oct	08 Apr	31 Oct	08 Apr
Sumbawanga	VI	Long	1986	15 Nov	13 Feb	15 Nov	19 Mar

* No period within the growing season with probability of 7-day dry spell below 0.5

Table 4.13: First and last dates when probability of dry spell is below 0.5 for the year with the latest start of growing season for selected stations

station	zone	season	Year	7- day dry spell		10-day dry	
				start	end	start	end
Ngara	I	long	1962	05 Jan	08 May	05 Jan	13 May
Musoma	I	long	1966	18 Apr	08 May	20 Dec	28 May
		short	1981	*	*	**	**
Lindi	II	long	1973	13 Feb	18 Apr	20 Nov	05 Dec
						13 Feb	23 Apr
Tanga	II	long	1963	14 Mar	03 Apr	14 Mar	03 Apr
				03 May	28 May	03 May	02 June
		short	1996	11 Oct	10 Nov	01 Sep	15 Nov
Tukuyu	III	long	1975	26 Dec	03 May	05 Nov	03 May
Lushoto	III	long	1968	09 Mar	13 May	04 Mar	13 May
		short	1968	*	*	11 Oct	15 Nov
Shinyanga	IV	long	1981	21 Oct	09 Jan		
				08 Feb	13 Apr	16 Oct	18 Apr
Lyamungo	IV	long	1993	08 Feb	12 June	03 Feb	17 June
		short	1983	*	*	**	**
Mpwapwa	V	long	1993	06 Jan	08 Feb	26 Dec	04 Mar
						13 Apr	28 Apr
Morogoro	V	long	1965	29 Mar	13 May	19 Mar	13 May
		short	1996	*	*	**	**
Njombe	VI	long	1992	13 Jan	18 Apr	30 Dec	18 Apr
Sumbawanga	VI	long	1991	05 Jan	13 Feb	26 Sept	24 Mar

* No period within the growing season with probability of 7-day dry spell below 0.5

** No period within the growing season with probability of 10-day dry spell below 0.5

Table 4.14: Proportions of dry days within the growing season when 7-day and 10-day dry spell probability is above 0.5 for years with shifts of onset dates of growing season.

Zone	Shifts (days)	7-day dry spell proportions	Correlation coefficients	10-day dry spell proportions	Correlation coefficients
I	-43	0.8		0.2	
	-31	0.7		0.2	
	43	0.6	0.514	0.3	0.051
	74	0.7		0.5	
	96	0.1		0.1	
II	-74	0.6		0.4	
	-51	0.6	0.965	0.3	0.108
	42	0.4		0.4	
III	-79	0.7		0.4	
	-57	0.1	0.503	0.1	0.612
	75	0		0	
IV	-100	0.7		0.4	
	-57	0.5	0.9	0.4	0.816
	-57	0.5		0.2	
	53	0		0	
V	-63	0.7		0.6	
	-54	0.3	0.166	0.2	0.006
	20	0.6		0.5	
	30	0.7		0.4	
VI	-35	0.4		0.3	
	-29	0.1	0.332	0.1	0.015
	31	0.6		0.3	
	35	0.2		0.2	

Note: - sign signify early start of rains

4.3.4 Relationship between shifts in rainfall pattern and ENSO/La-Nina events

Several studies have shown that, rainfall variability in the tropics links with the ENSO activities (Nyenzi et al.,1997). In Tanzania a recent El-Nino event occurred in 1997/1998 season causing very excessive rains in many parts of the country. During this event the agricultural sector was severely affected as most farmers were unable to cultivate their farms due to floods and cultivated farms were swept away. Other economic activities were also affected following the collapse of the country `s transport infrastructure.

In this study, an assessment of association between shifts in rainfall pattern and the occurrence of El-Nino and La Nina events in six agro-ecological zones was made. Table G1 in Appendix G presents the occurrence of El-Nino and La-Nina events in Tanzania during 1900-1997 period. Table 4.15 shows the proportions of ENSO and La-Nina events which have been captured by the years with both early and late start of growing season. During early start of growing season, ENSO events occurred in all zones except in zone V while La-Nina did not occur in zone VI. These events were observed to occur frequently in zone IV. During late start of growing season both events occurred almost in all zones except in zone IV for ENSO and zone IV and VI for La-Nina events.

Although EL-Nino and La-Nina events coincide with some of the years that experience shifts in start dates of growing season, these events were random with no connection with either early or late start of growing season. Therefore it can be concluded that, shifts of start dates of growing season are not indicative of occurrences of ENSO and La-Nina events but occurrences of ENSO and La Nina events can influence variabilities of start dates of growing seasons.

Table 4.15: Proportions of ENSO and La-Nina events as captured by the years with shifts in start dates of growing season.

Zone	Description	Early start		late start	
		ENSO	La-Nina	ENSO	La-Nina
I	moist forest mosaic	0.20	0.25	0.10	0.38
II	Coastal forest and thicket	0.10	0.13	0.20	0.13
III	Montane forest	0.30	0.25	0.20	0.25
IV	acacia savanna & grasslands	0.40	0.50	-	-
V	Acacia commiphora thornbush	-	0.13	0.30	0.13
VI	Savanna woodland	0.10	-	0.20	-

5 SUMMARY AND CONCLUSIONS

5.1 Summary

The main objective of this study was to assess the influence of shifts in rainfall pattern on important rainfall characteristics in different parts of Tanzania. Twenty one stations located in six agro-ecological zones were selected for the study. For each station, rainfall data of duration ranging from 36 to 37 years were used. The study used also other climatological data of 5 years span i.e. temperature, relative humidity, radiation and wind speed to calculate the evapotranspiration. Since evaporation is fairly stable over time, the short span of data have no significant effect on the accuracy of results of analysis carried out (Ngana, 1983 and Niewolt, 1989). Maize crop was selected in this study as it is grown in all zones. Field and crop data for water balance calculations were assumed as recommended by Doorenbos and Pruitt (1997).

Although previous studies have shown water balance approach to be more precise in determining the various rainfall characteristics than the other criteria (Majamanda, 1998) the method requires excessive input data which may not be readily available in many locations. However, a well calibrated rainfall criterion can be just as precise and can be applied for different places by simply using the appropriate parameters typical of an area.

In this study, calibration was done using a water balance (IRSIS) model which makes use of field, climatological and crop data. The output of the calibration was in terms of the values of parameters used in the rainfall criterion. Results of the validation of the criterion for the different zones were in agreement with those of the water balance model simulation.

All stations in the six agro-ecological zones experience some shifts in the rainfall pattern, with uni-modal stations in zone I having late start of the growing season in those years with significant departures. However stations in the other zones exhibit both early and late start of the growing season. Nevertheless in all zones there were no well defined trends of shifts or departures of start dates of the growing season.

Shifts in rainfall pattern have shown to have influence on the length of growing season, seasonal rainfall and risk of dry spell within the growing season in all zones. Negative correlation ranging from 0.562 to 0.961 existed between the shifts of start dates of growing season and the length of the growing season in uni-modal and long rains of bi-modal stations in all zones studied. This means that, stations experience short growing season with late start of growing season. The converse is true for early start of growing season where stations exhibit long growing seasons.

The amount of seasonal rainfall received in uni-modal stations (zone II, V and VI) was found to correlate negatively with the onset of growing season. The amount of

seasonal rainfall in these zones was also noted to correlate positively with the length of the growing season.

All stations studied appeared to be prone to dry spells for the years with early or late start of the growing season. High proportions of dry days within the growing season were observed to occur in zone I and V when rainfall commences early. It was further noted that, during late start of rains, short rains of bi-modal stations are prone to high risk of dry spells. The dry days within the growing season in zone I-IV were found to correlate negatively with the start dates of the growing season.

Although some years which experience shifts in start dates of growing season coincided with EL-Nino/La-Nina years, generally no association was found to exist between the onset dates of growing season and the occurrence of El-Nino and La-Nina events. However there is no doubt that El Nino and La Nina have influence on amount of rainfall and the growing season.

5.2 Conclusions and Recommendations

The following conclusions can be made from this study:

- (i) Calibrated rainfall based criterion appears to give better estimates of start, end and length of growing season compared to the uncalibrated criterion.
- (ii) Shifts in rainfall pattern exist in different parts of Tanzania where stations in different zones experience early and late start of growing season.

- (iii) Shifts in start dates have influence on the length of the growing season
- (iv) Most of the stations are prone to high risk of dry spells. The dry days within the growing season in zone I-IV correlate negatively with the onset of growing season while no relationship was observed for zones V and VI.
- (v) The amount of seasonal rainfall received in zones II, V and VI correlates negatively with the onset of the growing season. However no defined relationship was found for stations located in other zones.

From the results of this study, it is recommended that:

- . Although the calibrated rainfall criterion appeared to give realistic values of start and end dates of growing season, further work should be conducted to validate these values with actual data (start, end and length of growing season) in respective stations.
- . During the calibration process a search to determine optimal parameters of the rainfall criterion was done manually which is tedious and time consuming. Therefore the use of appropriate computer based search procedure is recommended for determining the optimal values of different rainfall criterion parameters.
- . Calibration was based on one representative station from each zone. Therefore the use of location specific information/data to represent the entire agro-ecological zone should be made with caution.

6 REFERENCES

- Alusa, A.L. and Mushi, M.T. (1974) A study of the onset, duration and cessation of the rains in East Africa. Pre-prints Int. Trop. *Meteorology meeting, Nairobi, Kenya.* pp 133 - 40
- Ananthkrishnan, R. and Rajagopalachari, P.J. (1964) *Pattern of monsoon rainfall distribution over India and neighbourhood.* Proceedings of the symposium on tropical Meteorology. Rotorua, New Zealand. pp 192
- Ashok Raj, P.C. (1979) *Onset of effective monsoon and critical dry spells.* IARI Resources Bulletin. No,11 (New series). pp 25
- Bernoit, P. (1977) The start of growing season in Northern Nigeria. *Agricultural Meteorology* 18, 91-99
- Berry, L., Hankins, T. and Kates, R.W. (1972) *Natural hazard Research Human Adjustment to agricultural drought in Tanzania.* Pilot investigation. BRALUP Research paper No. 13, University of Dar es salaam. pp 62
- Blend, R. and Marriage, Z. (1998) *Climatic uncertainty and natural resource policy: What should the role of Government be?* ODI Natural resource perspectives No.31 April 1998. pp 2

- Da Mota, F.S. and Da Silva, J.O. (1980) A water technology model for rice in southern Brazil. In: *Proceedings of a symposium on the Agrometeorology of the rice crop*. IRRI, Los Banos. pp 235-238
- Dennett, M. D., Rodgers, J.A. and Stern, R.D. (1983) Independence of rainfalls through the rainy season and the implications for the estimation of rainfall probabilities. *Journal of climatology* 3,375-384
- Doorenbos, J. and Kassam, A.H. (1979) *Yield response to water*. FAO Irrigation and Drainage paper No. 33, FAO, Rome. pp144
- Doorenbos, J. and Pruitt, W.O. (1997) *Crop water requirements*. FAO Irrigation and Drainage paper No. 24, FAO, Rome. pp 156
- ERB (1997) *Economic bulletin for the quarter ended June 1997* Vol. XXVII No.2 1,10-15
- Halthout, S. (1973) *A new approach to soil mapping in Tanzania*. Bureau of Resource Assessment and Land Use Planning, University of Dar es Salaam. pp 37
- Ilesanmi, O.O. (1972) An empirical formulation of the onset, advance and retreat of rainfall in Nigeria. *Journal of Tropical Geography* 34,17-24

Jackson, I.J. (1982) *Climate, water and Agriculture in the tropics*. John Wiley and Sons, New York. pp 248

Jackson, I. J. (1989) *Climate, water and agriculture in the tropics*. Second edition. Longman, Scie. Techn. U.S. John Wiley Sons, N.Y. pp 377

Kassase, C.I. (1992) *Determination of effective length of growing season in Tanzania*. M.Sc. Dissertation, Sokoine University of Agriculture, Morogoro, Tanzania. pp 104

Kingamkono, R.M.L. (1994) *The effective length of growing season in Tanzania*. M.Sc. Dissertation, Sokoine University of Agriculture, Morogoro, Tanzania. pp 100

Kowal and Knabe, D.T. (1972) *An Agronoclimatological Atlas of the Northern state of Nigeria*. Ahamadu Bello University press, Zaria Nigeria. pp 23

Lema, A. J. (1986) *An inquiry into climatic change in East Africa*. Institute of Resources Assessment. Research report No. 68 (new series), University of Dar es salaam. pp 49

- Lema, A.J. (1993) *Lake Victoria waters in the context of irrigations development in Tanzania*. Institute of Resources assessment research paper No 31, University of Dar es salaam. pp 31
- Lumb, F. (1966) *Cycles and Trends of rainfall over East Africa*. In Proceedings of the third specialist meeting on applied Meteorology. Muguga, Kenya. pp 52
- Majamanda, I.I. (1998) *Evaluation of the water Budget Technique for the determination of the effective length of the growing season under different climatic conditions in Malawi*. M.Sc. Dissertation, Sokoine University of Agriculture. pp 107
- Mzengeza, T.R. (1994) *Determination of onset, end, duration and variability of rainfall in rice growing areas of Malawi*. M Sc. Dissertation, Sokoine University of Agriculture. pp 87
- Mavi, H.S. (1986) *Introduction to Agrometeorology*. Oxford & IBH Publishing Co. New Delhi. pp 237
- Mhita, M.S. (1984) *The use of water balance models in the optimisation of cereal yields in seasonally - arid tropical Regions*. PhD thesis University of Reading. pp 266

- Ngana, J.O. (1983) *Rainfall and agriculture droughts and famine in Dodoma District*. Institute of Resource Assessment Res. report No. 60 (new series), University of Dar es Salaam. pp 27
- Ngana, J.O. (1990) *Modelling for periodic features in seasonal rainfall and its implications to water resources and agricultural planning*. Institute of Resource Assessment Res. report No. 27, University of Dar es Salaam. pp 23
- Ngana, J.O. (1991) *Selection of probability distribution of estimating reliably seasonal rainfall in semi - arid Central Tanzania*. Institute of Resource Assessment Res. report No 79, University of Dar es Salaam. pp 23
- Ngana, J.O. (1992) *Climatic assessment of Kondoa eroded area*. Institute of Resource Assessment Res. report No. 80 (new series), University of Dar es Salaam. pp 35
- Ngana, J.O. (1994) *The climatology and Hydrology of Pugu and Kazimzumbwi coastal forests*. Institute of Resource Assessment Res. report No. 94 (new series), University of Dar es Salaam. pp28
- Nieuwolt, S. (1973) *Rainfall and evaporation in Tanzania*. BRALUP Research paper No. 24, University of Dar es Salaam. pp 46

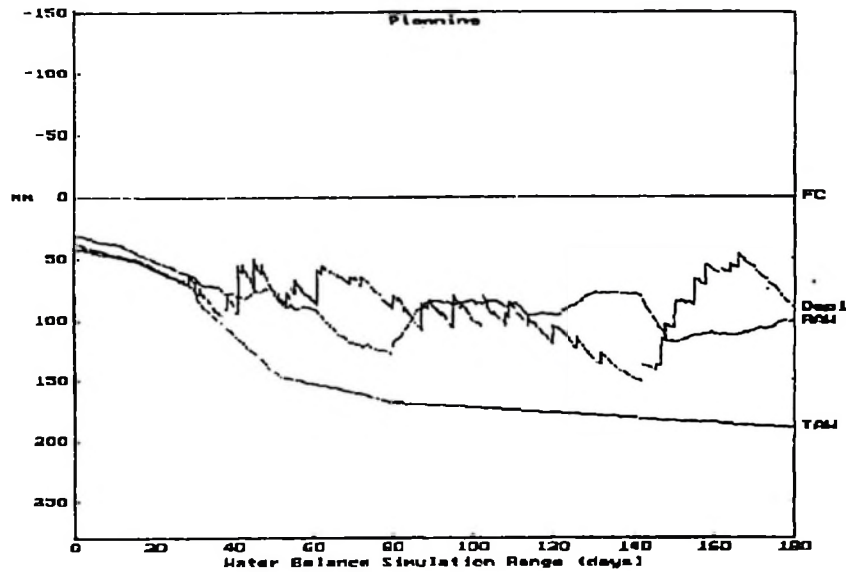
- Nieuwolt, S. (1974) The influence of Aspect and Elevation on daily rainfall: some examples from Tanzania. *In Agrometeorology of the highlands of eastern Africa*. WMO. No.389, Geneva.
- Nieuwolt, S. (1978) *Tropical climatology-An introduction to the climate of low latitudes*. John Wiley and sons, Chichester. New York, Brisbane, Toronto. pp109
- Nieuwolt, S. (1989) Estimating the agricultural risks of tropical rainfall. *Agricultural and Forestry Meteorology* 45, 251-263
- Nyenzi, B.S. (1992) El-Nino/Southern Oscillation (ENSO) Fluctuations and its influence to Southern Africa climate. *Proceedings of the first SADC conference on climate change*. Windhoek, Namibia, 2-6 March, 1992, SADC-ELMS Co-ordination Unit, Maseru 1995.
- Nyenzi, B.S., Kavishe, M.M., Tibaijuka, P.F., Kululetera, V., Nassib, I.R. and Tilya F.F. (1997) Drought analysis in Tanzania. *A study on long range weather forecasting in Tanzania*. Research report No. 1/97, 1-51
- Ogallo, L. (1980) *Time series analysis of rainfall in East Africa*. PhD. Thesis University of Nairobi. pp 236

- Ogallo, L. (1981) Trends of rainfall in East Africa, Kenya. *Journal of science and Technology*. A:83-90
- Raes, D.H. Lemmens, P. Van Aelst, M. Vandenbulcke, and Simith, M. (1987) *IRISIS - Irrigation Scheduling Information system*, Vol. 1, Ref. Manual No. 3, Laboratory of Land Management, K.U. Leuven, Belgium. pp 119
- Rao, G.R.; Kadama, D.M.; Shinde, J.S. and Varade, S.B. (1980) Extreme probability analysis of rainfall at Parbhani, Maharashtra. *Rice abstracts* 3(5), 95
- Riise, U. (1971) *Rainfall variation in Tanzania*. BRALUP Research report No. 45/1 University of Dar es Salaam. pp 28
- Rodhe H. and Virji, H. (1976) Trends and periodicities in East African rainfall data. *Monthly weather review* 104,307-315
- Slatyer, R.D. (1968) The use of soil water balance relationships in Agroclimatology. In: *UNESCO Agroclimatological Methods. Natural resources research*. VI, 73-87
- Stern, R.D.; Dennett, M.D. and Garbutt D.J. (1981) The start of rains in west Africa. *Journal of climatology* 1,59 - 68

- Stern, R.D. and Coe, R. (1982) The use of rainfall models in agricultural planning. *Agricultural Meteorology* 26,33-50
- Stern, R.D.; Dennett, M.D. and Dale, I.C. (1982a) Analysis of daily rainfall measurements to give agronomically useful results. *I. Direct methods* *Experimental Agriculture* 18,223-36
- Stern, R.D ; Dennett, M.D and Dale, I.C. (1982b) Analysis of daily rainfall measurements to give agronomically useful results. *II. A modelling approach.* *Experimental Agriculture* 18,237-253
- Stewart, J.I. (1988) *Response farming in rainfed agriculture.* The Whart Foundation press, Dacis, California. pp 11-45
- Stuart, S.N.; Adams, R.J. and Jenkins, M.D. (1990) *Biodiversity in Sub-Saharan Africa and its Islands: Conservation, management and sustainable use.* A contribution to the Biodiversity conservation strategy programme. Occasional papers of the IUCN series survival commission No.6, IUCN, Glant. pp 43
- Thomson, B.W. (1957) Some reflections on equatorial and tropical forecasting. East African Meteorological Department, *Technical Memorandum* No. 7.

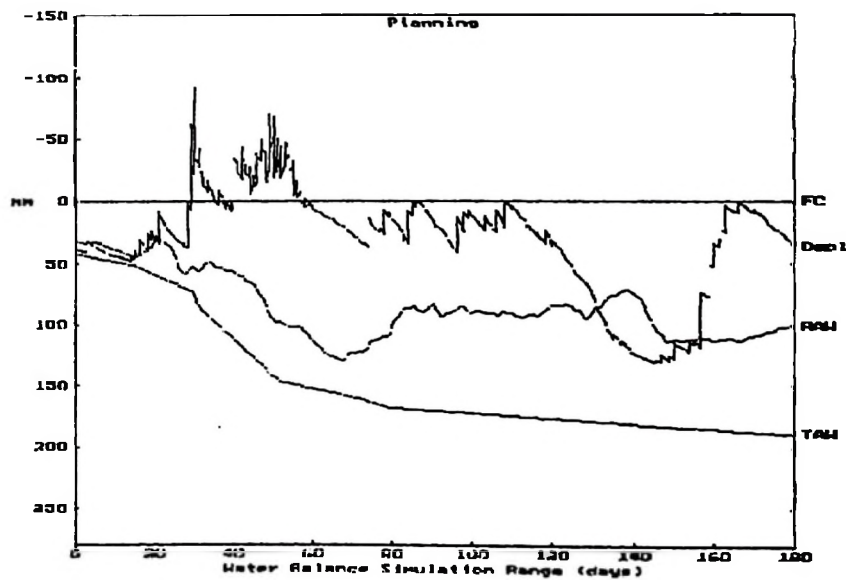
- Torrance, J.D (1967) The nature of the rainy season in central Africa. *First Rhodesia scientific congress. Association of scientific societies in Rhodesia, Salisbury.*
13-14
- Virman, S.M. (1975) The Agricultural climate of the Hyderabad region in relation to crop planning. *International Report Farm, System Program.* ICRSAT
Hyderabad, India. pp 14
- Wallis, J.A.N. (1963) Water use by irrigated Arabic coffee in Kenya. *Journal of Agricultural science* 60, 381-388
- Walter, M.W. (1967) Length of the rainy season in Nigeria. *Nigerian geographical journal.* pp 32
- Weisner, C.J. (1970) *Hydrometeorology.* Champamanad Hall, London. pp 232.

APPENDIX A : Root zone depletion curves for representative stations



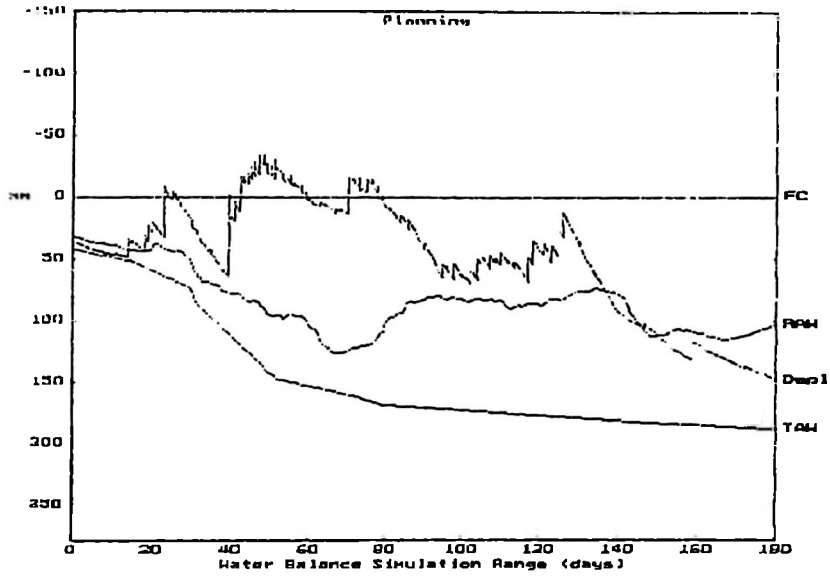
Day 1 = 1 November

Fig. A1: Mbeya rootzone depletion for 1967/1968 growing season
- maize crop



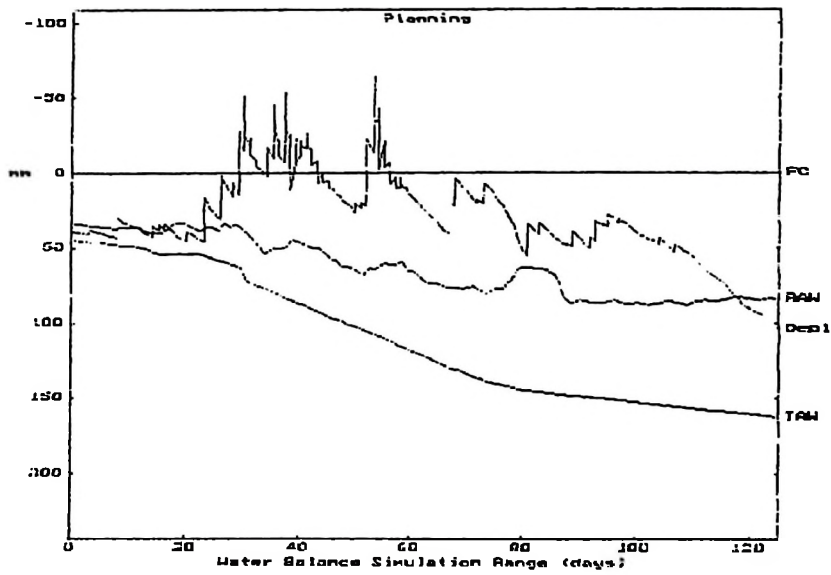
Day 1 = 1 November

Fig. A2: Mbeya rootzone depletion for 1985/1986 growing season
- maize crop



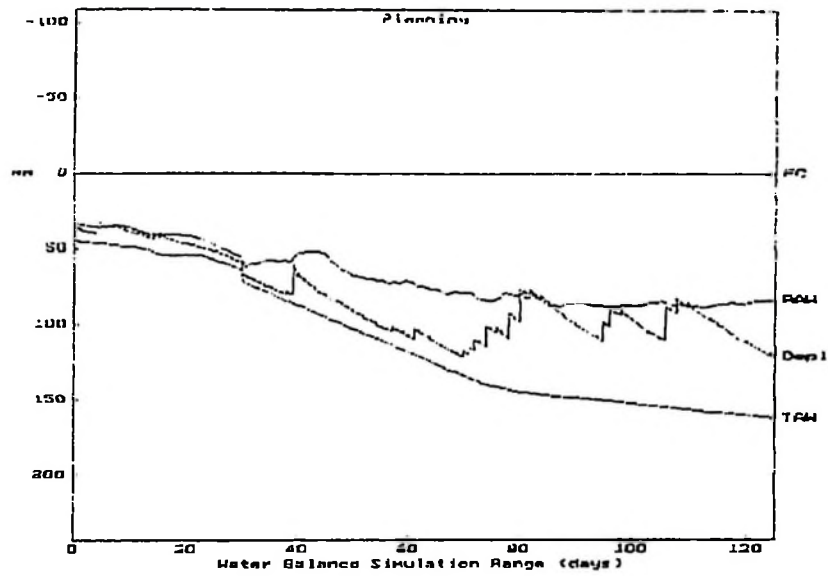
Day 1 = 1 November

Fig. A3: Mbeya rootzone depletion for 1992/1993 growing season - maize crop



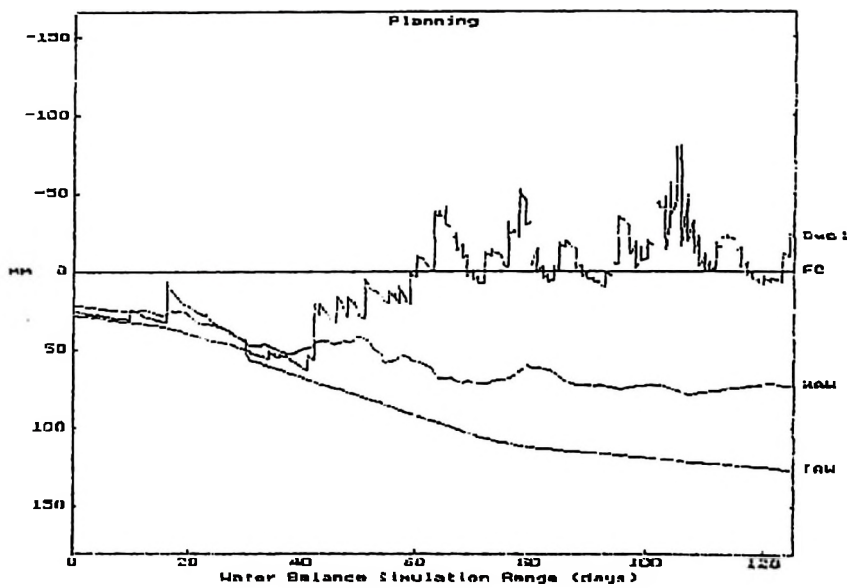
Day 1 = 1 March

Fig. A4: Tanga rootzone for 1972 long growing season - maize crop



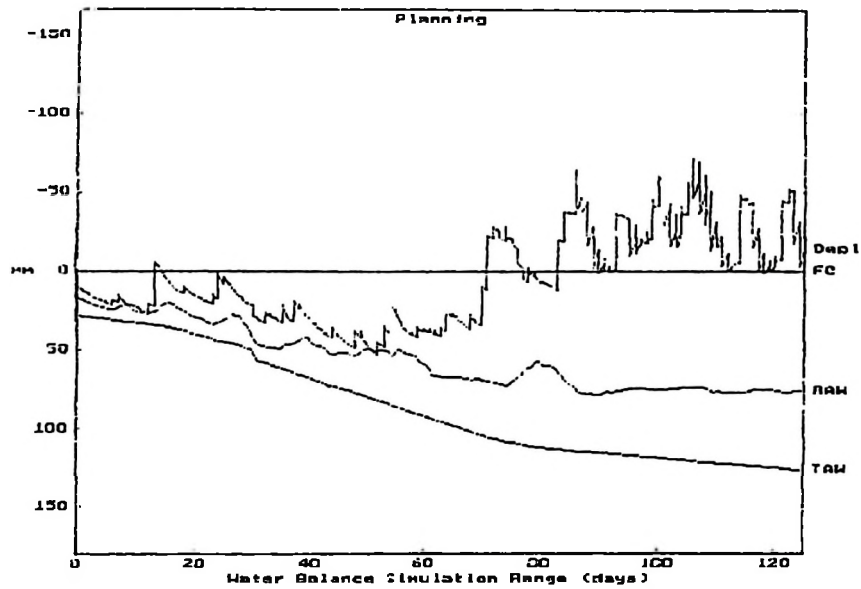
Day 1 = 1 September

Fig. A5: Tanga rootzone depletion for 1972 short growing season - maize crop



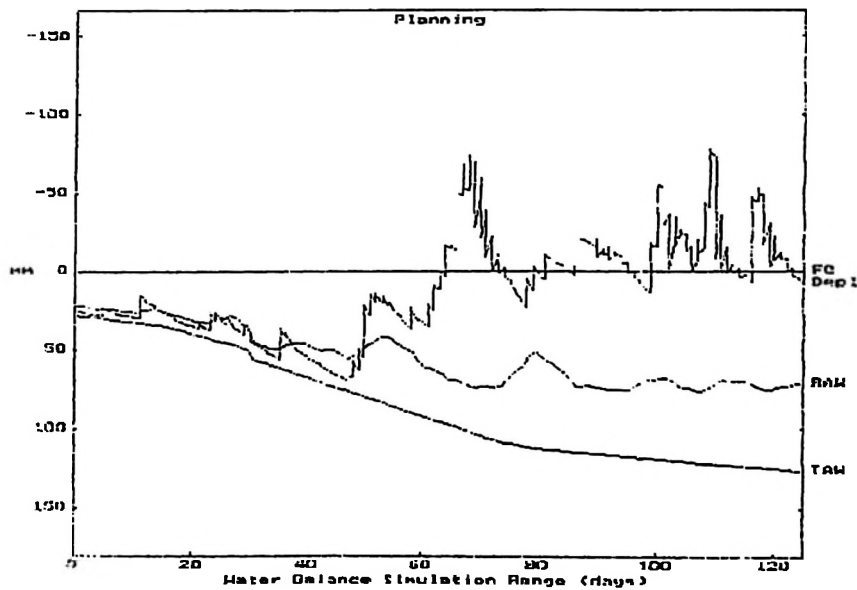
Day 1 = 1 September

Fig. A6: Bukoba rootzone depletion for 1990 short growing season - maize crop



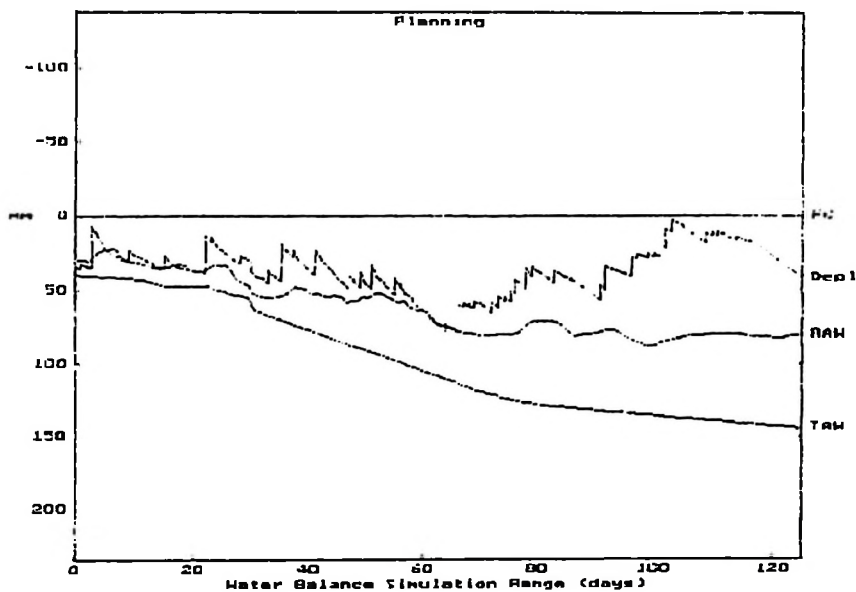
Day 1 = 1 February

Fig. A7: Bukoba rootzone depletion for 1991 long growing season
- maize crop



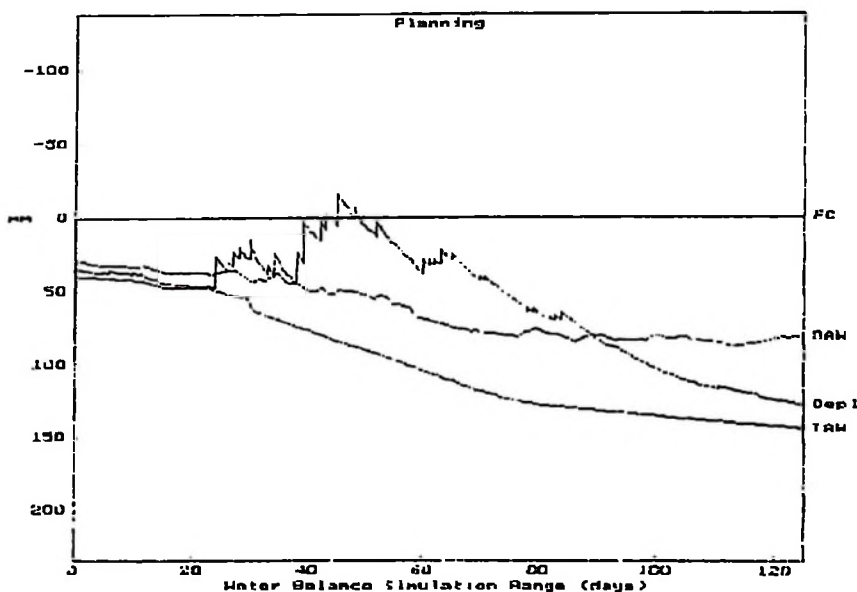
Day 1 = 1 January

Fig. A8: Bukoba rootzone depletion for 1992 long growing season
- maize crop



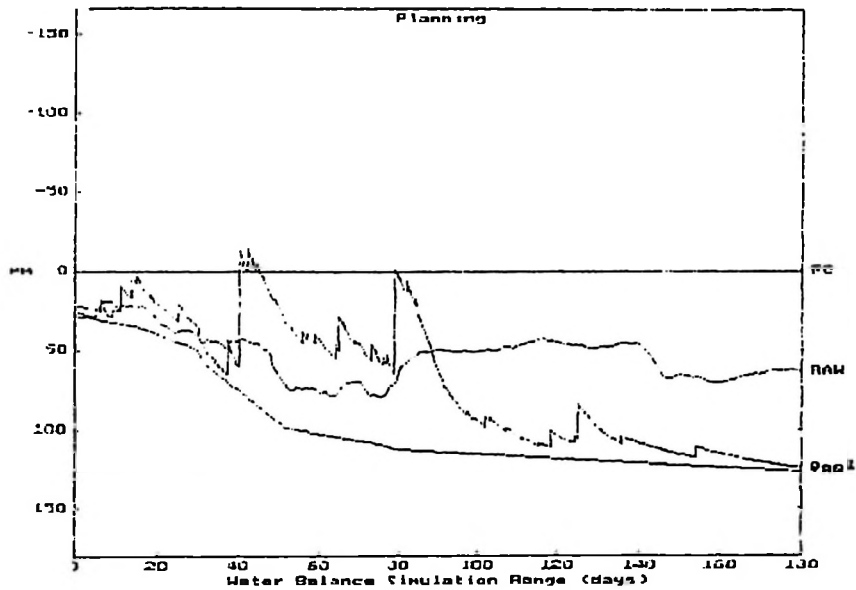
Day 1 = 1 February

Fig. A9: Morogoro rootzone depletion for 1990 long growing season - maize crop



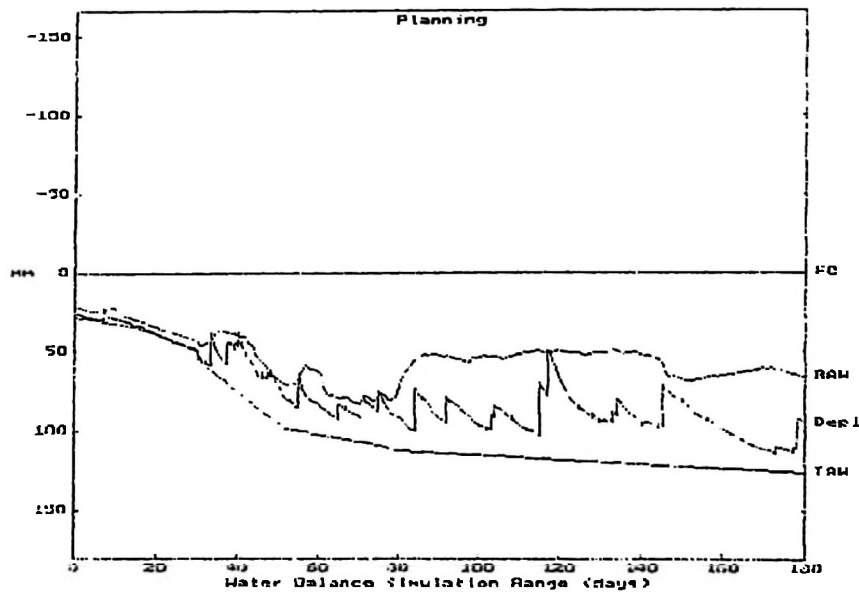
Day 1 = 1 September

Fig. A10: Morogoro rootzone depletion for 1972 short growing season - maize crop



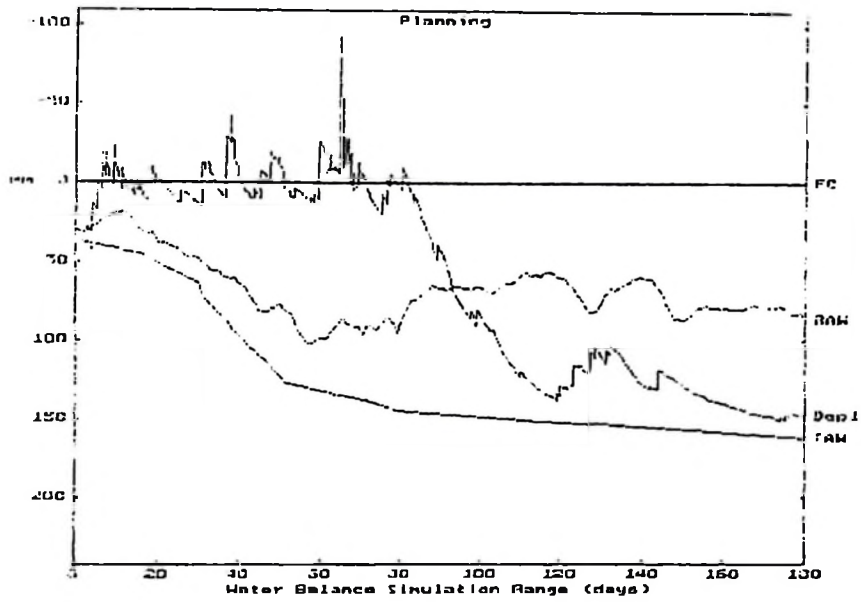
Day 1 = 1 December

Fig. A11: Shinyanga rootzone depletion for 1992/1993 growing season - maize crop



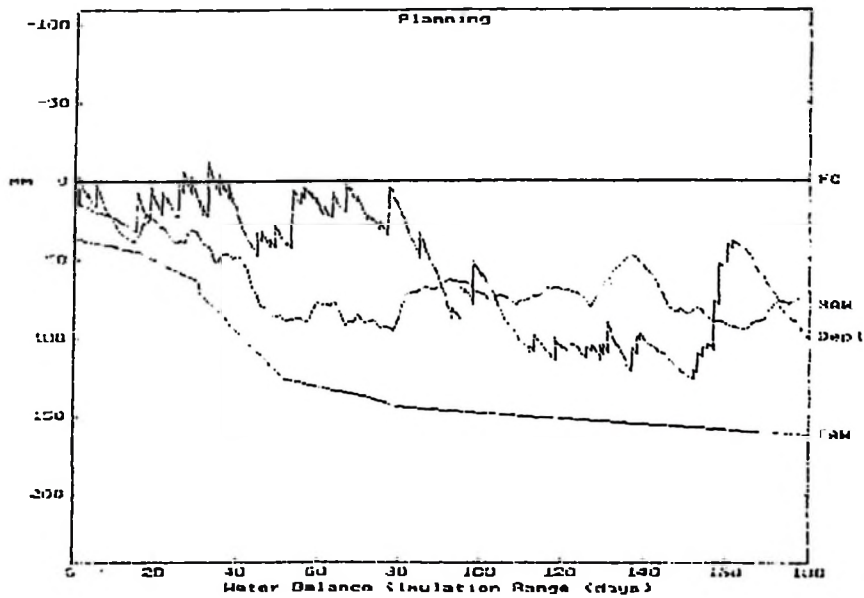
Day 1 = 1 November

Fig. A12: Shinyanga rootzone depletion for 1974/1975 growing season - maize crop



Day 1 = 1 November

Fig. A13: Tabora rootzone depletion for 1969/1970 growing season
- maize crop



Day 1 = 1 November

Fig. A14: Tabora rootzone depletion for 1977/1978 growing season
- maize crop

APPENDIX B : Shifts in rainfall pattern for studied stations

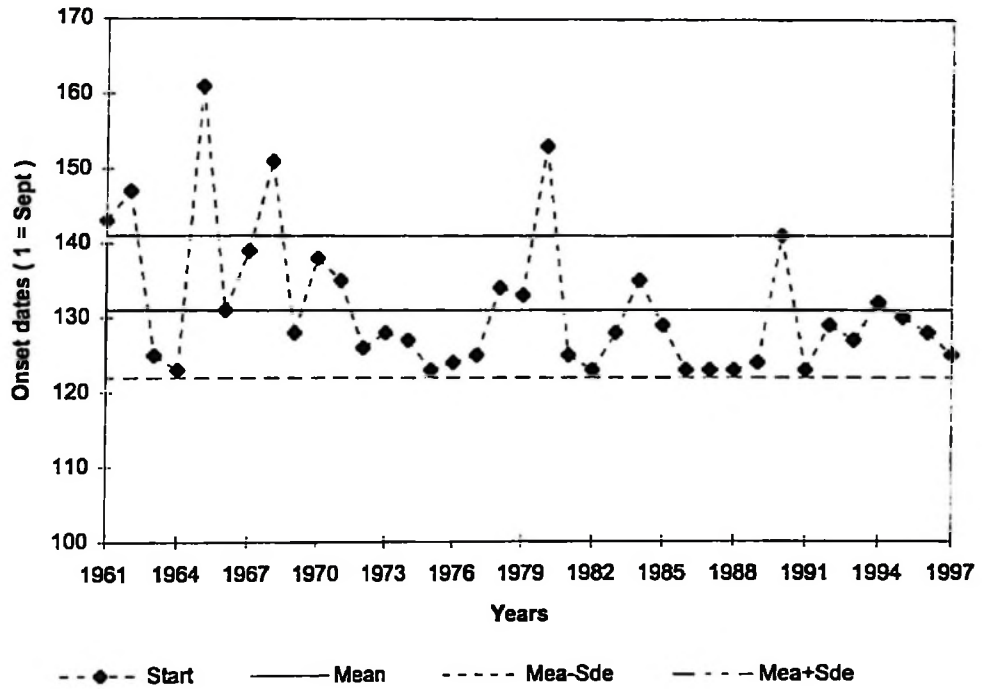


Fig.B1: Shifts in rainfall pattern for long rains Bukoba

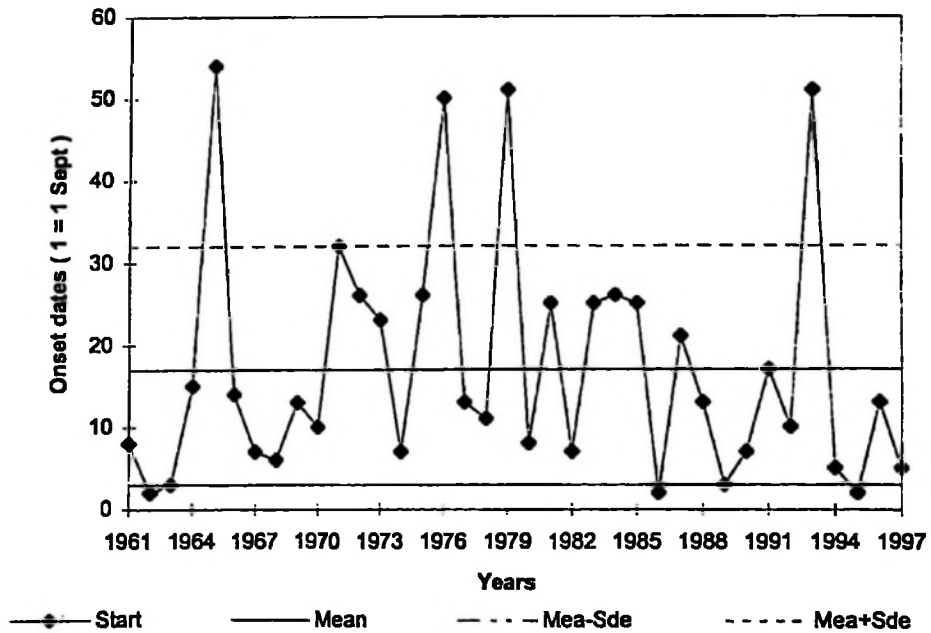


Fig.B2: Shifts in rainfall pattern for short rains in Bukoba

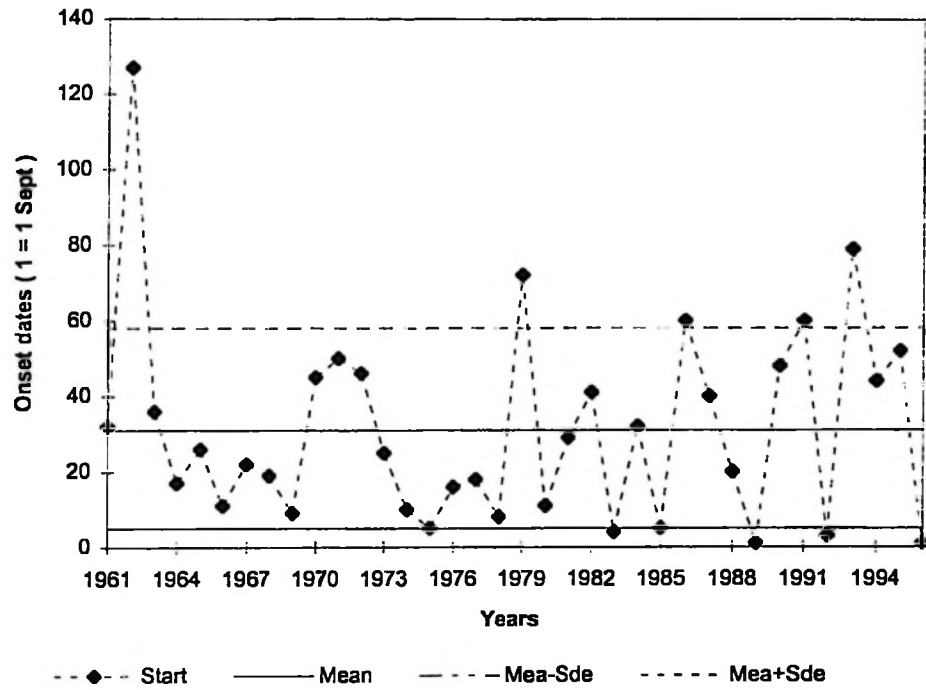


Fig.B3: Shifts in rainfall pattern for seasonal rainfall in Ngara

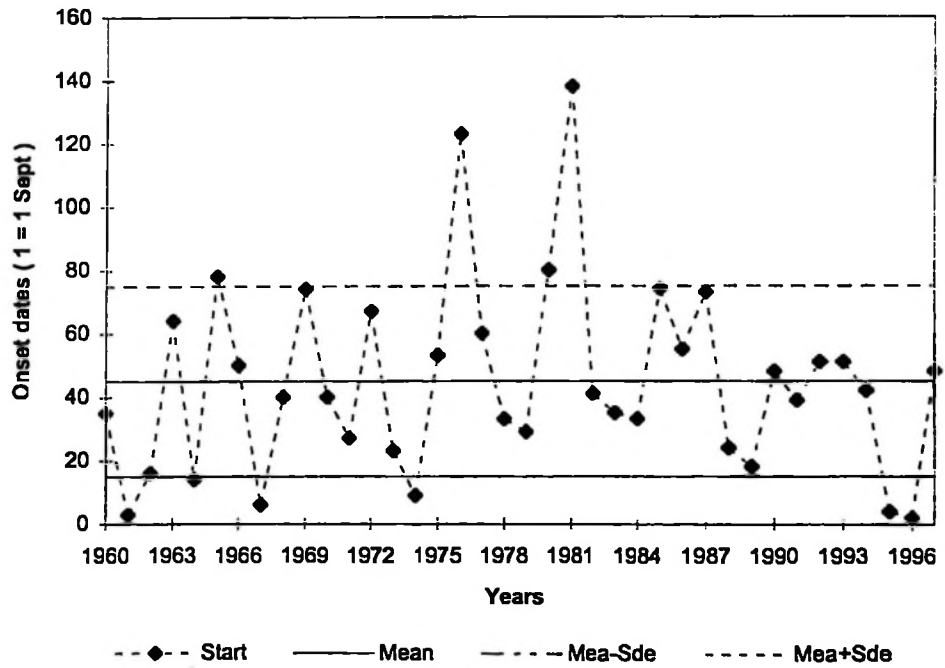


Fig.B4: Shifts in rainfall pattern for short rains in Musoma

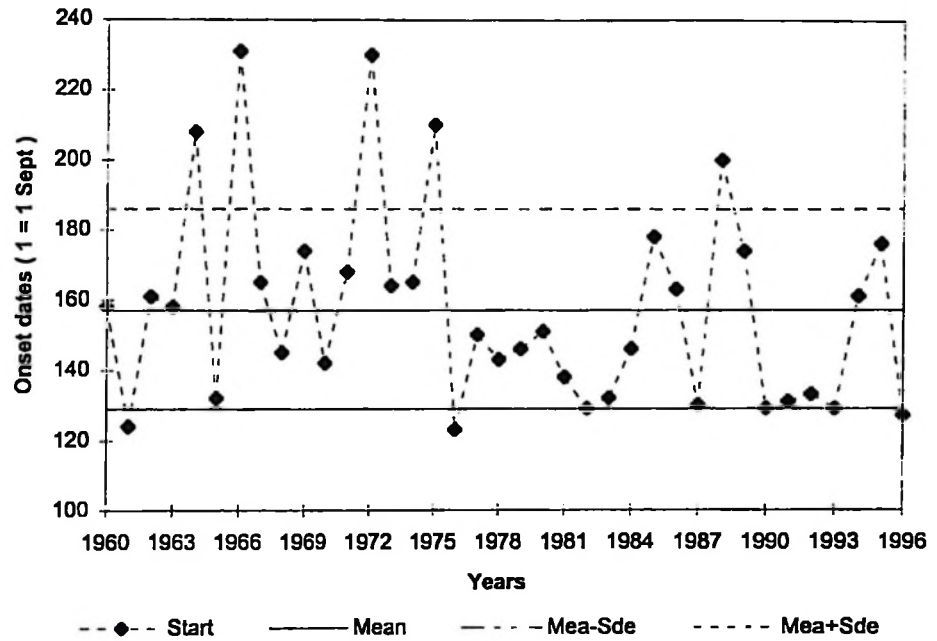


Fig.B5: Shifts in rainfall pattern for long rains in Musoma

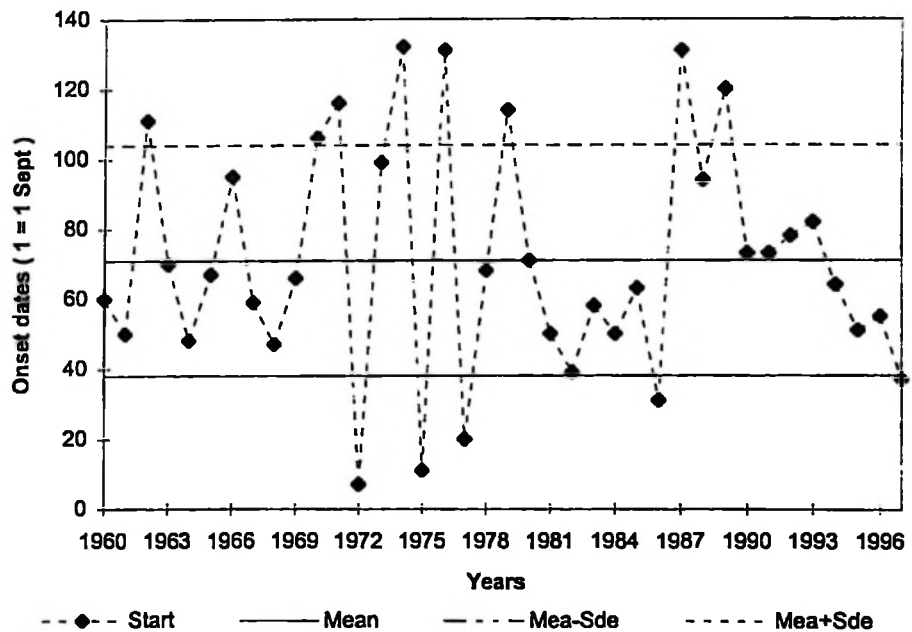


Fig.B6: Shifts in rainfall pattern for short rains in Dar es salaam

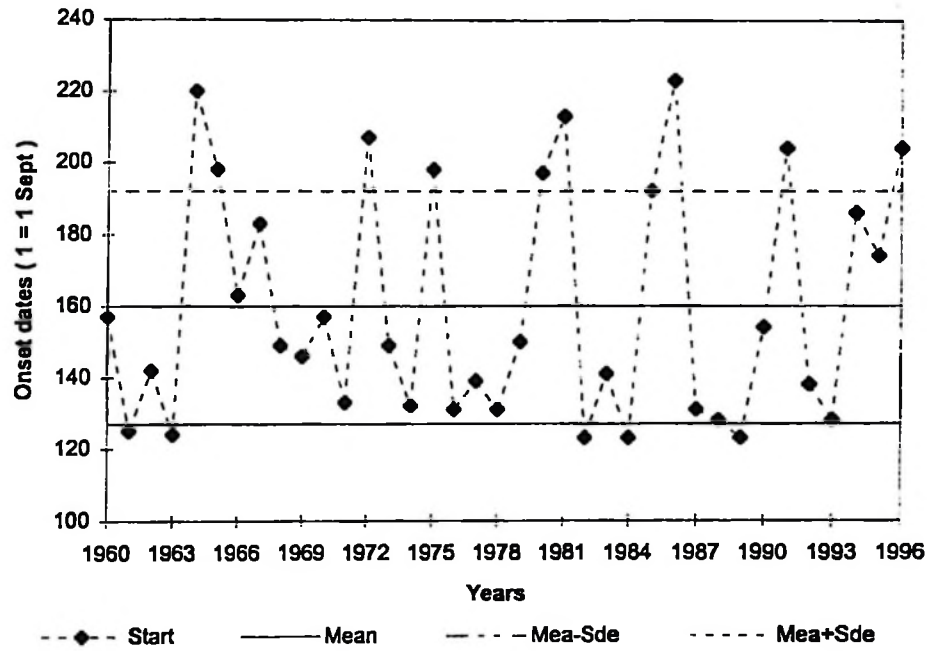


Fig.B7: Shifts in rainfall pattern for long rains in Dar es salaam

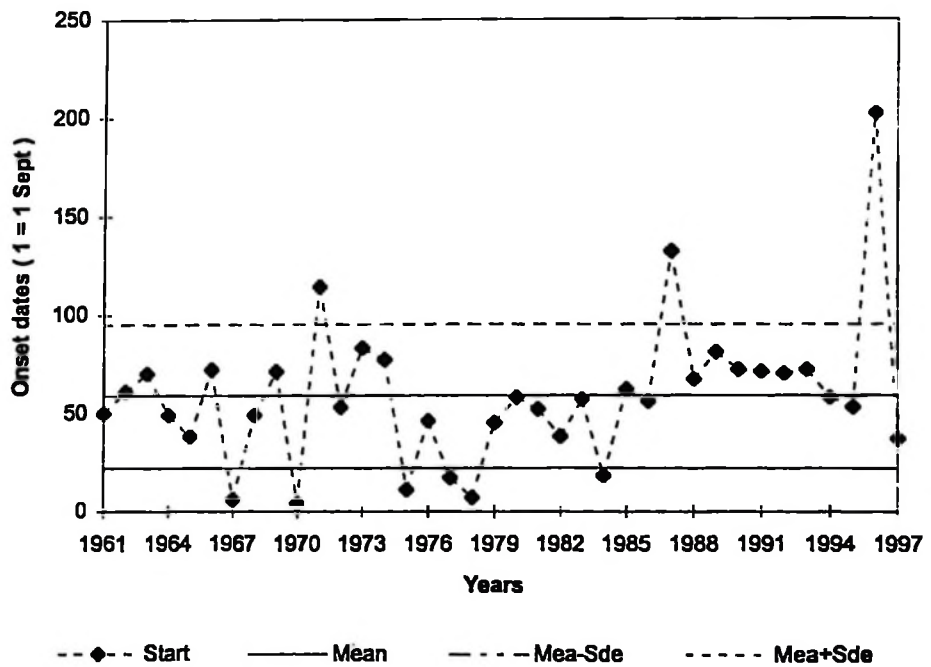


Fig.B8: Shifts in rainfall pattern for short rains in Zanzibar

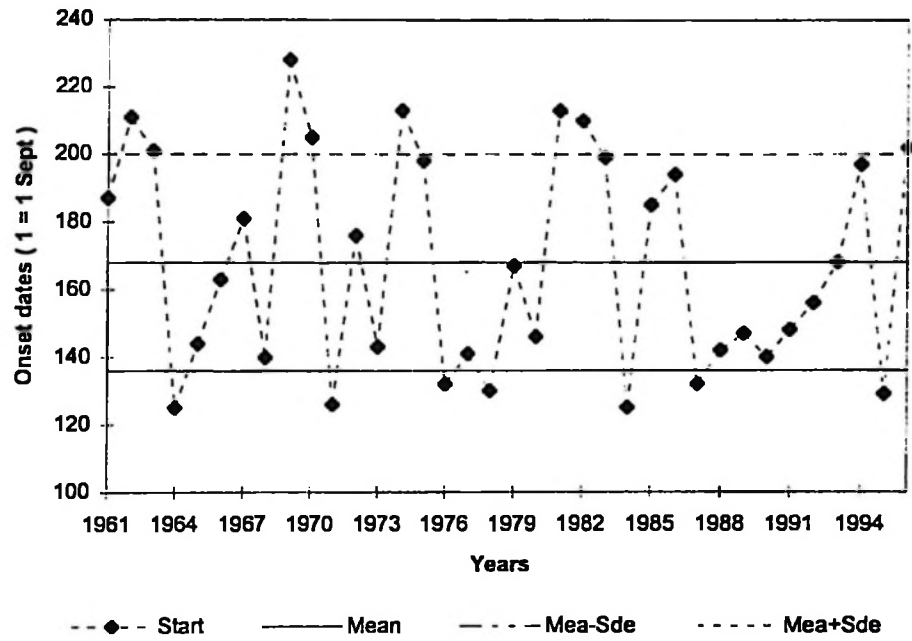


Fig.B9: Shifts in rainfall pattern for long rains in Zanzibar

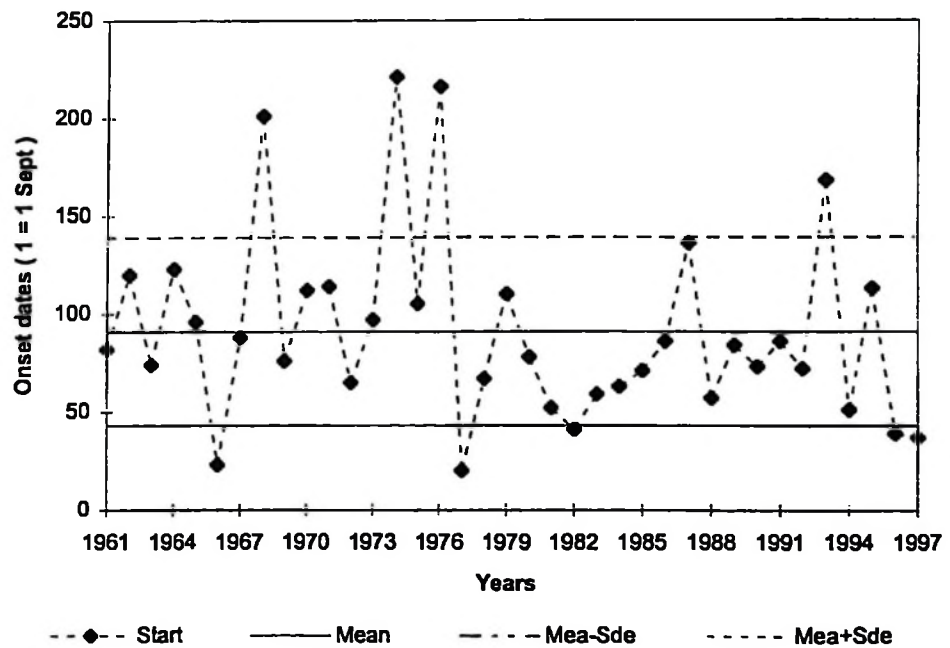


Fig.B10: Shifts in rainfall pattern for short rains in Bagamoyo

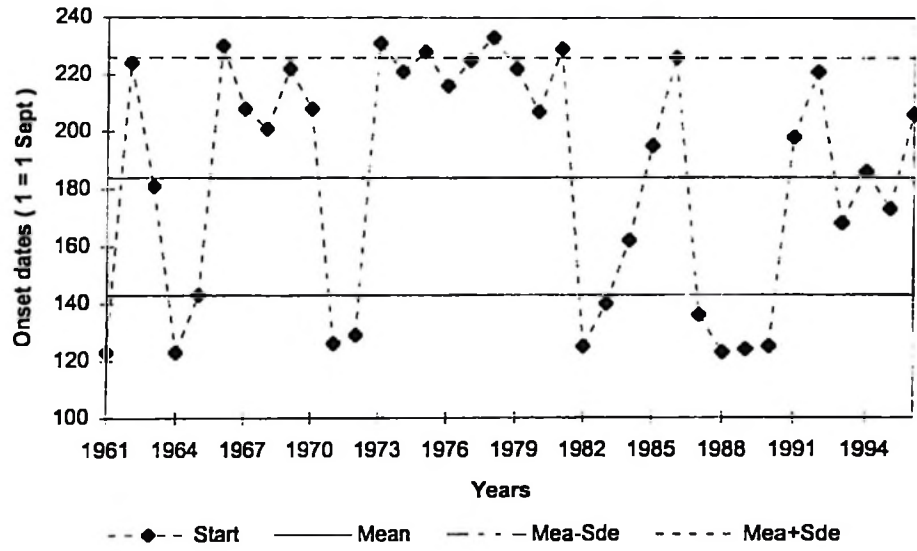


Fig.B11: Shifts in rainfall pattern for long rains in Bagamoyo

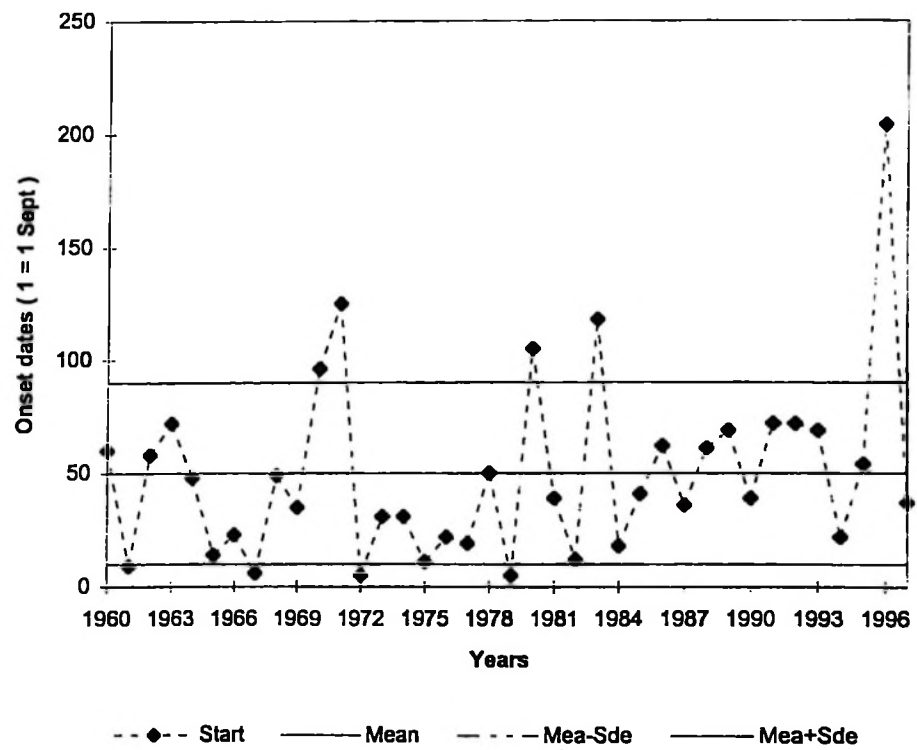


Fig.B12: Shifts in rainfall pattern for short rains in Tanga

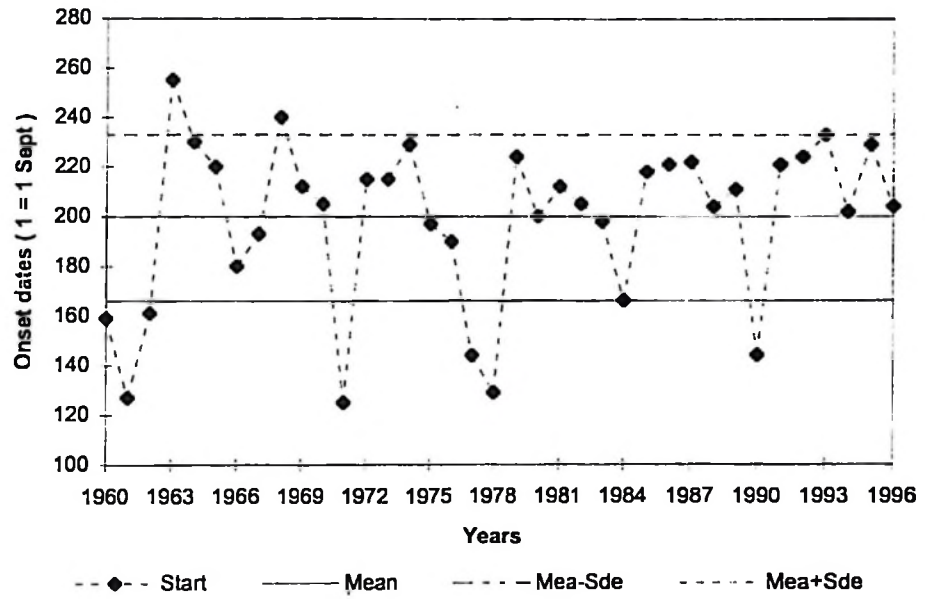


Fig.B13: Shifts in rainfall pattern for long rains in Tanga

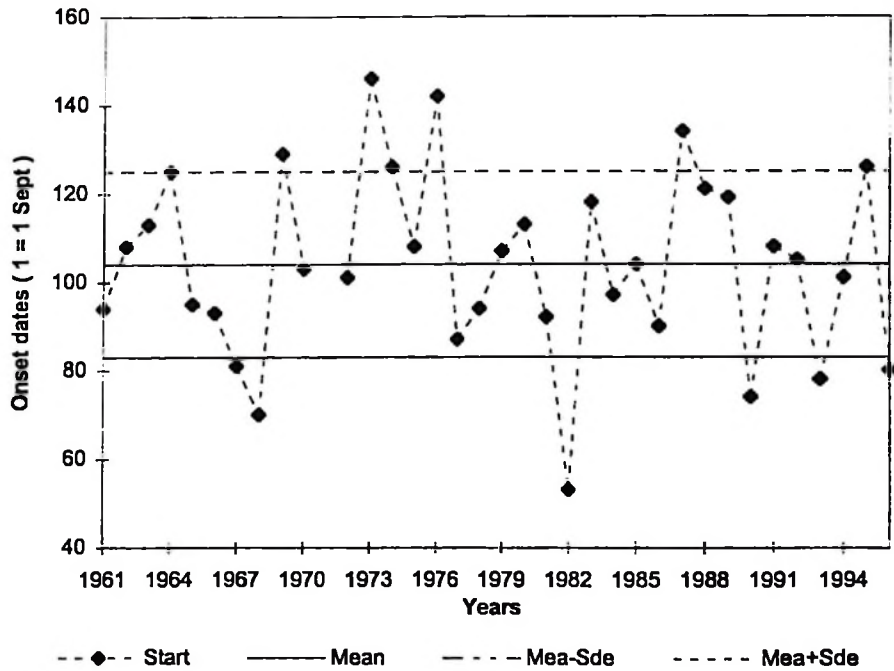


Fig B14: Shifts in rainfall pattern for seasonal rainfall in Lindi

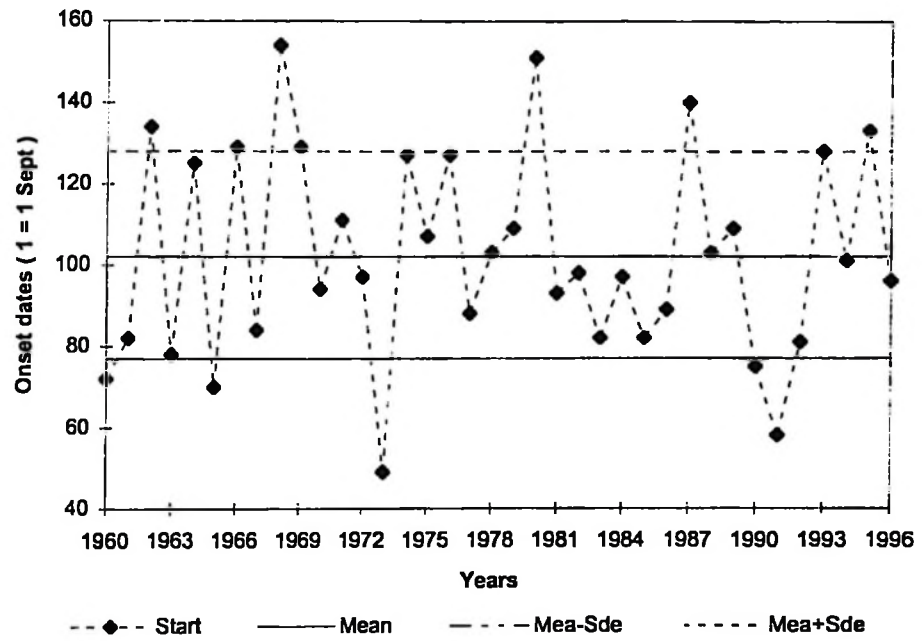


Fig.B15: Shifts in rainfall pattern for seasonal rainfall in Mtwara

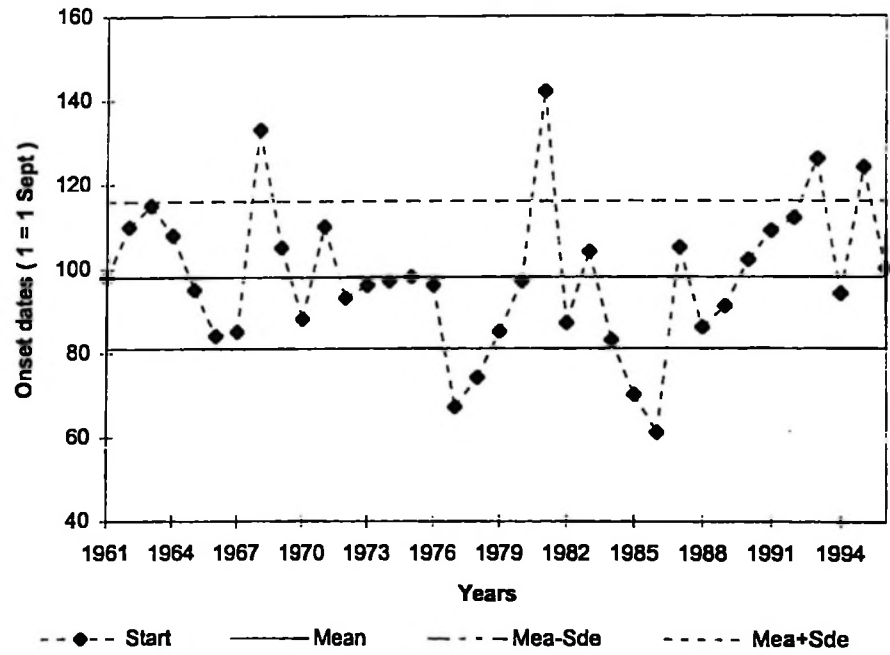


Fig.B16: Shifts in rainfall pattern for seasonal rainfall in Mbeya

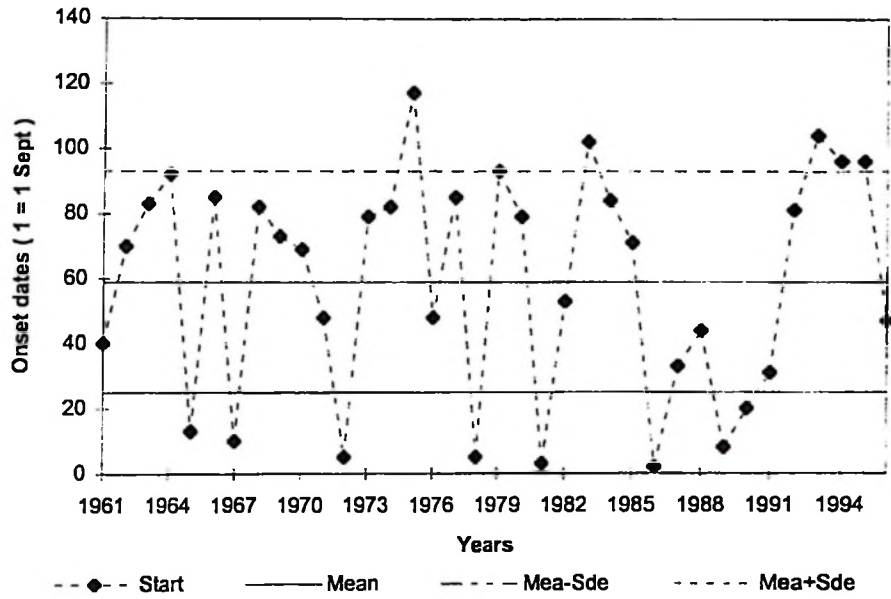


Fig.B17: Shifts in rainfall pattern for seasonal rainfall in Tukuyu

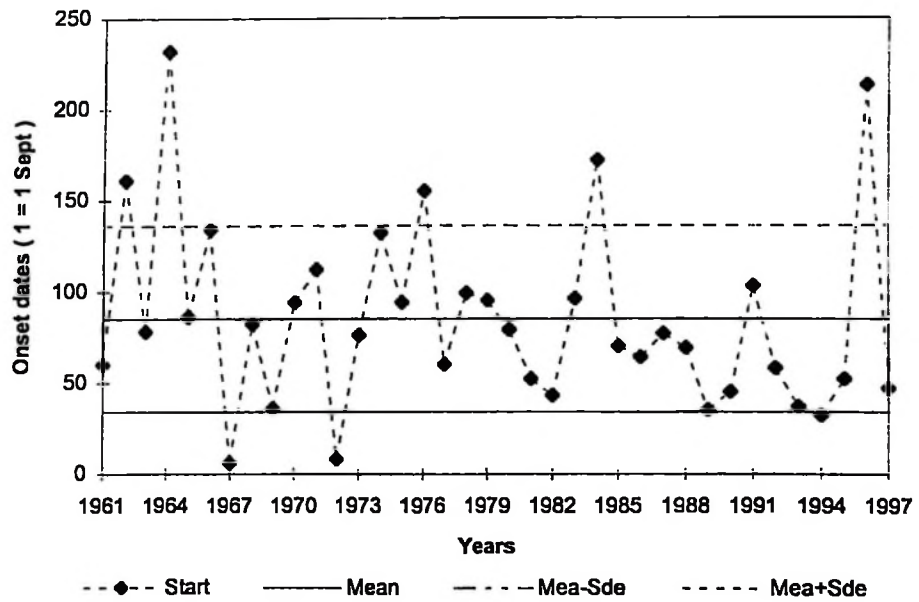


Fig.B18: Shifts in rainfall pattern for short rains in Lushoto

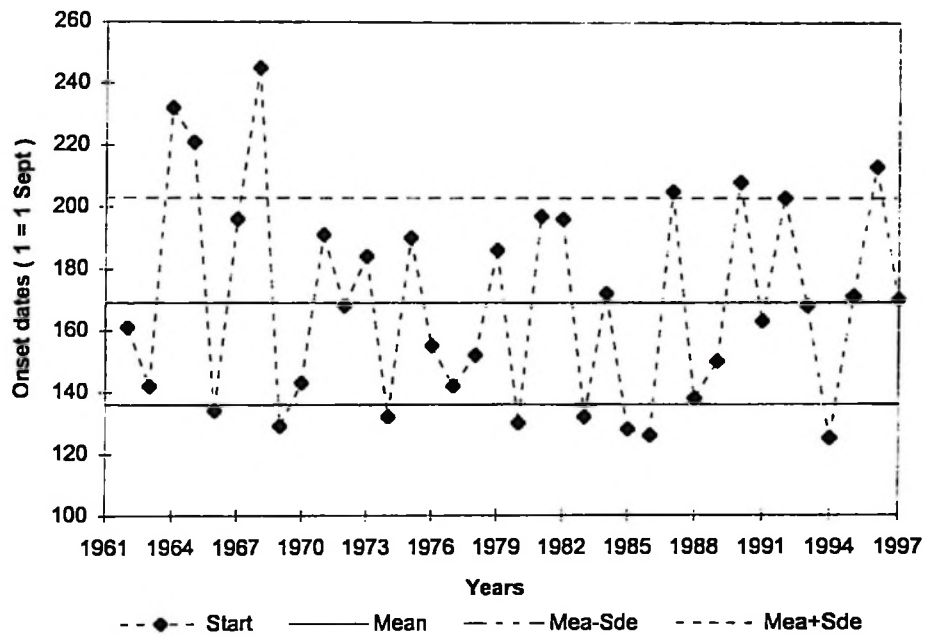


Fig.B19: Shifts in rainfall pattern for long rains in Lushoto

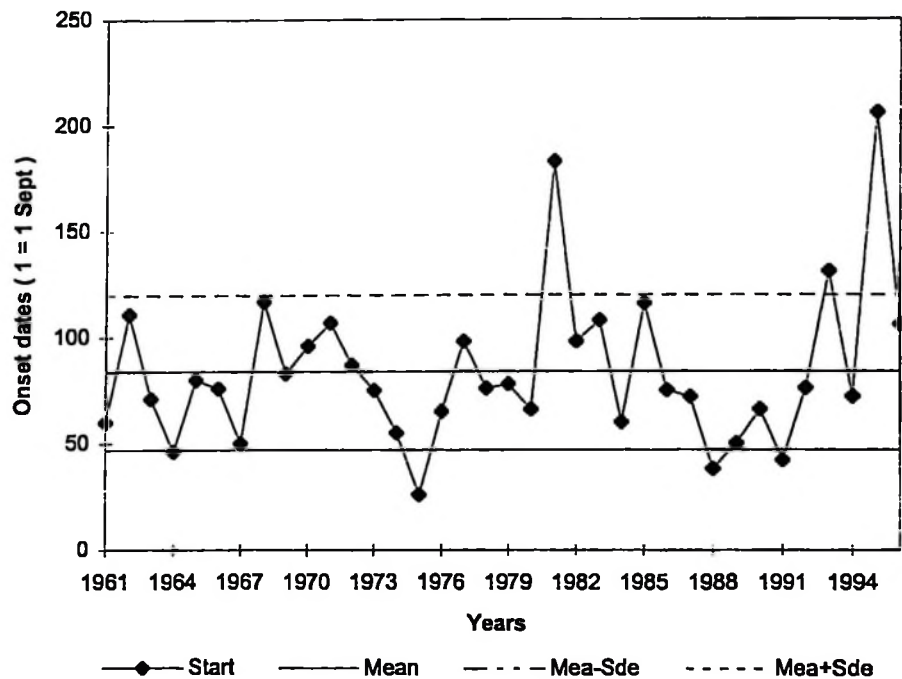


Fig.B20: Shifts in rainfall pattern for seasonal rainfall in Shinyanga

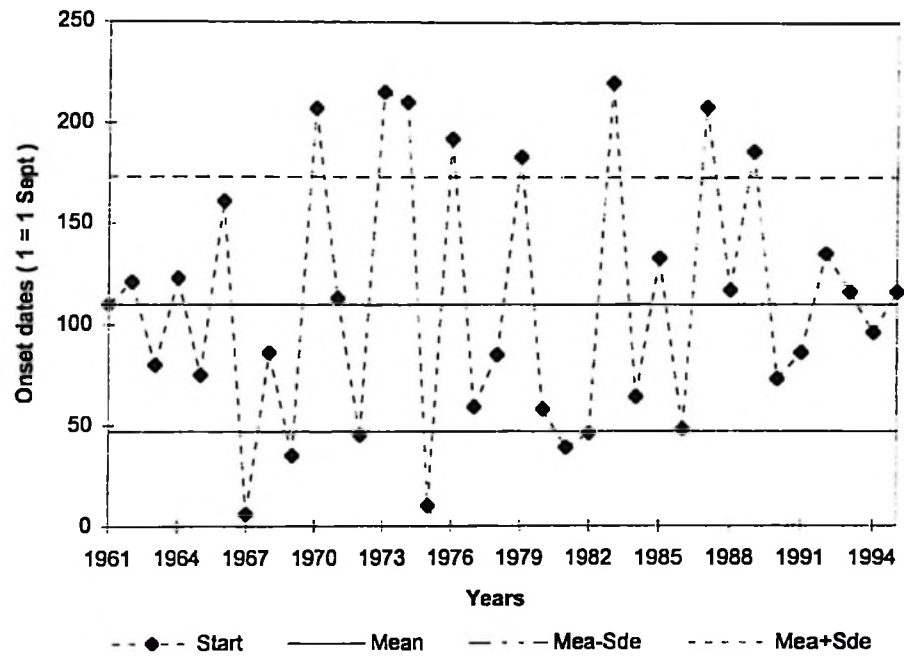


Fig.B21: Shifts in rainfall pattern for short rains in Lyamungo

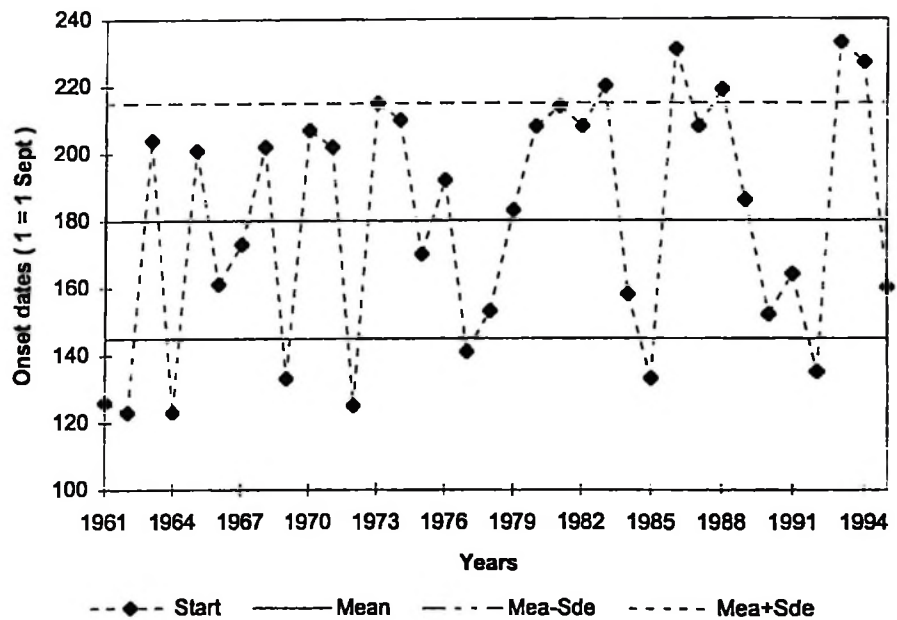


Fig.B22: Shifts in rainfall pattern for long rains in Lyamungo

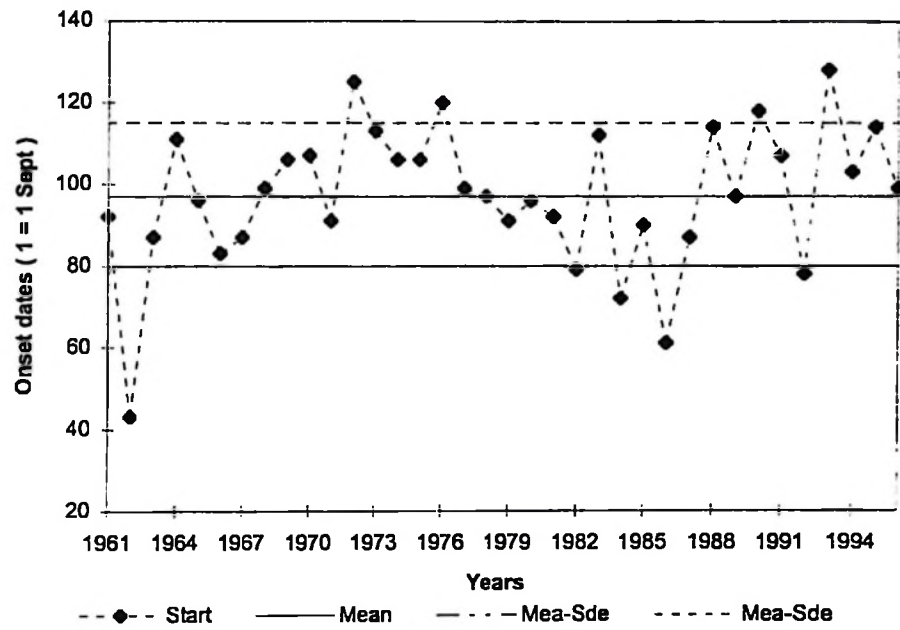


Fig.B23: Shifts in rainfall pattern for seasonal rainfall in Mpwapwa

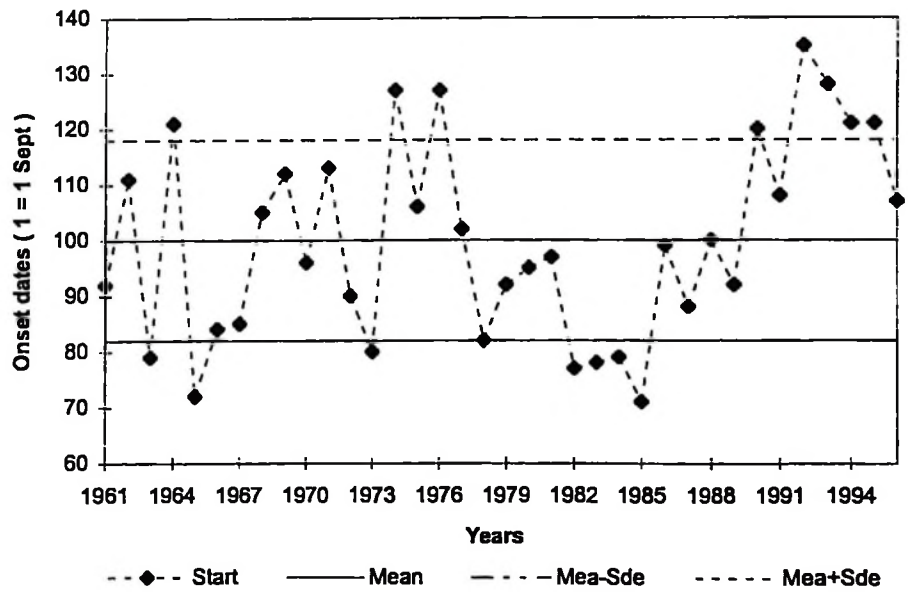


Fig.B24: Shifts in rainfall pattern for seasonal rainfall in Njombe

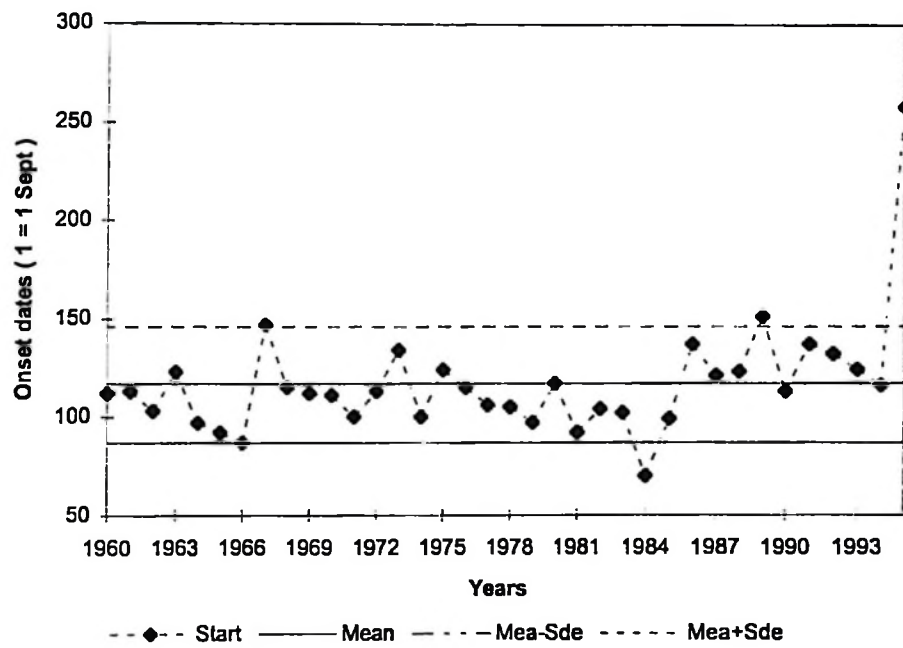


Fig.B25: Shifts in rainfall pattern for seasonal rainfall in Iringa

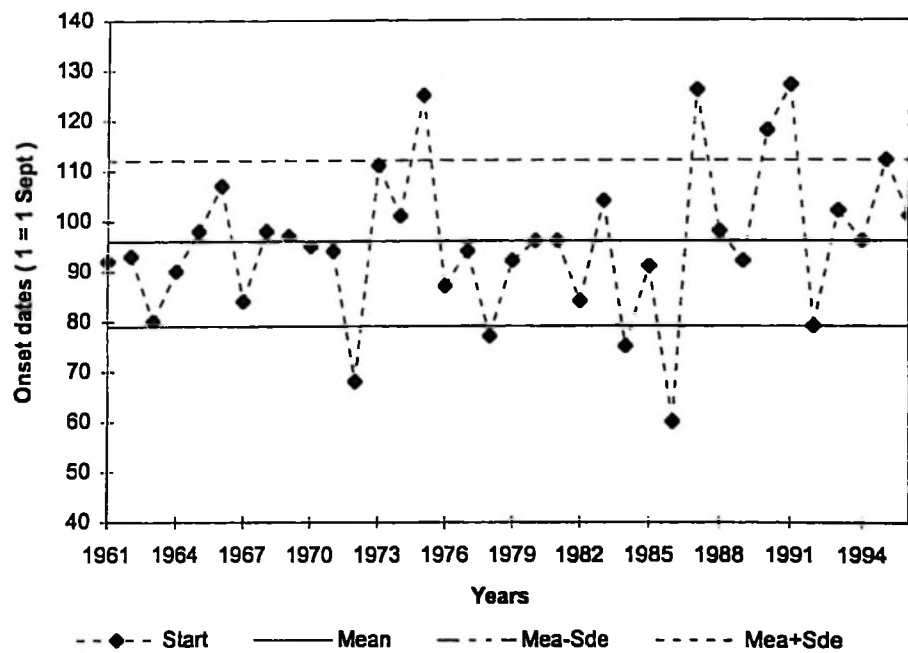


Fig.B26: Shifts in rainfall pattern for seasonal rainfall in Sumbawanga

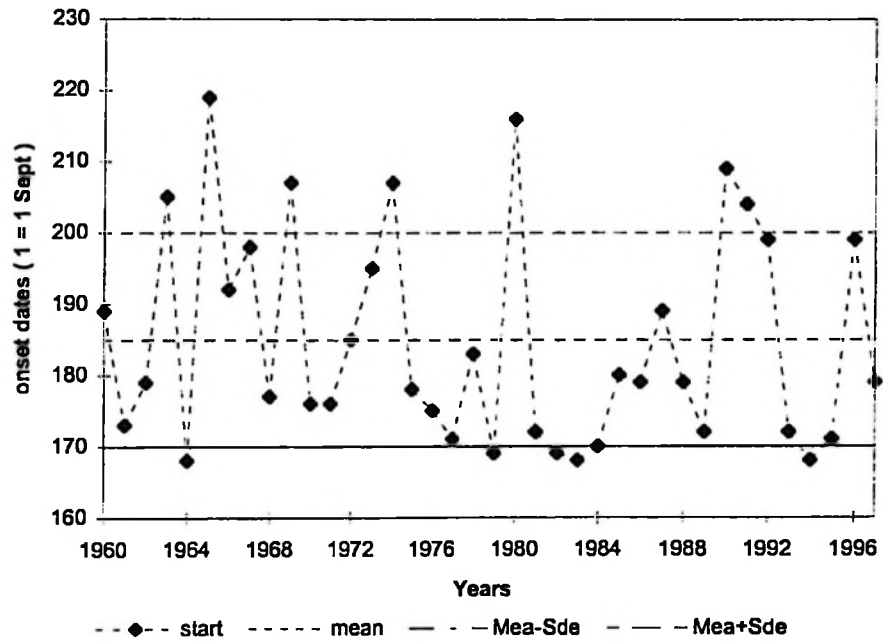


Fig.B27: Shifts in rainfall pattern for long season in Morogoro

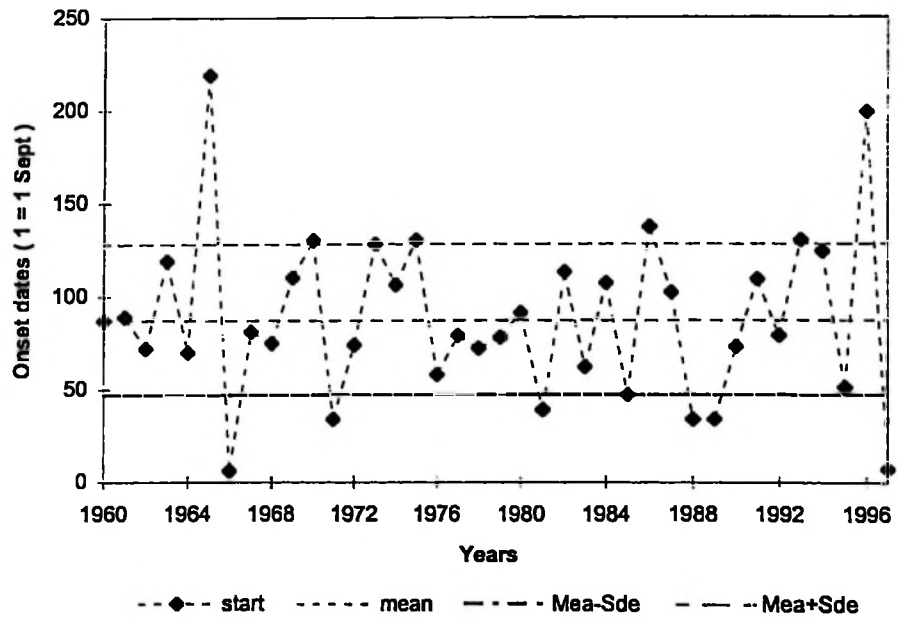


Fig.B28: Shifts in rainfall pattern for short rains in Morogoro

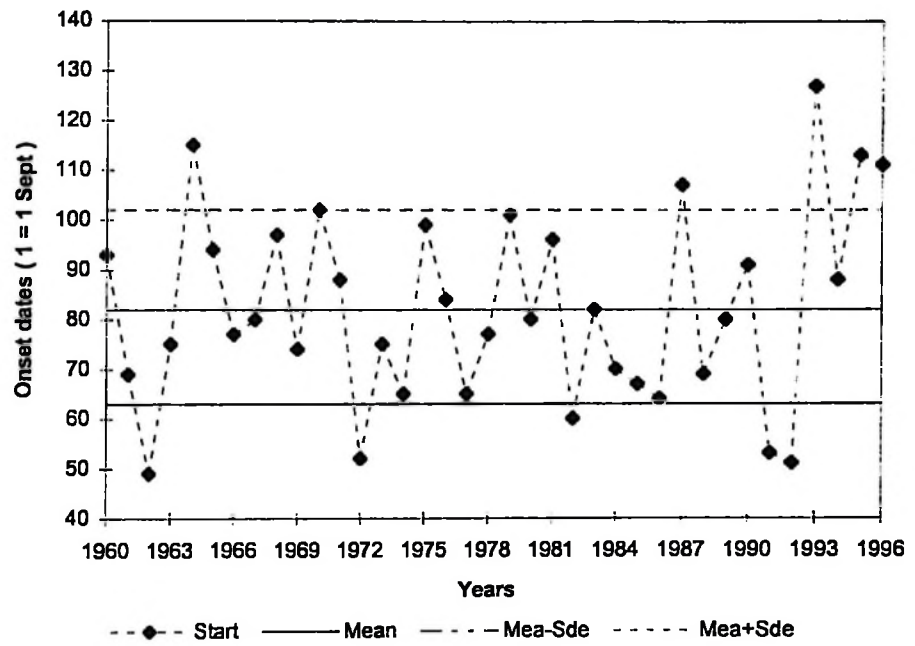


Fig.B29: Shifts in rainfall pattern for seasonal rainfall in Tabora

APPENDIX C : Curves of probability of 7-day and 10-day dry spells for various stations

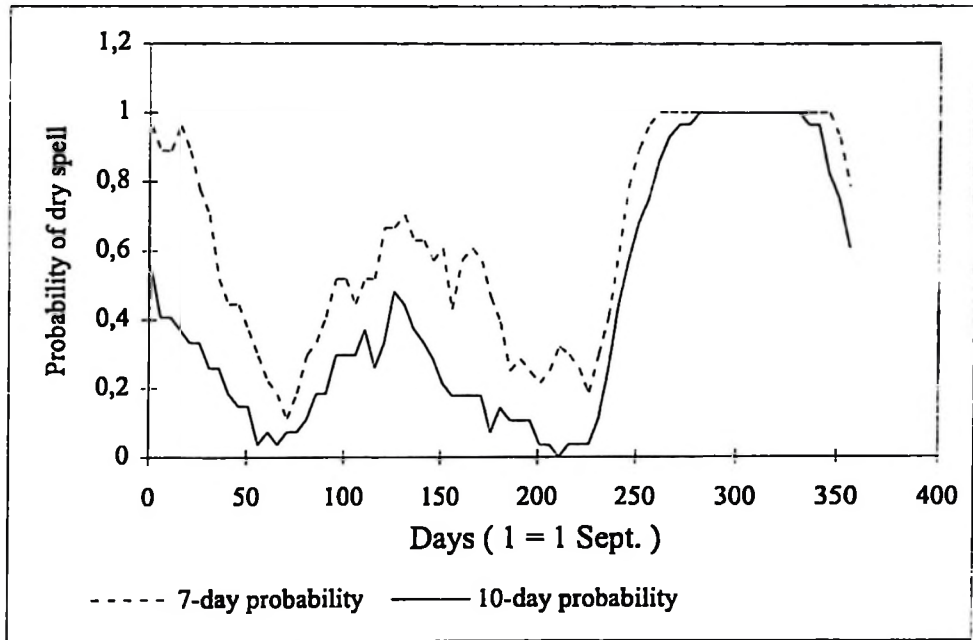


Figure C1: The probability of a 7-day and 10-day dry spell within 30 days following the date on the time axis for Ngara

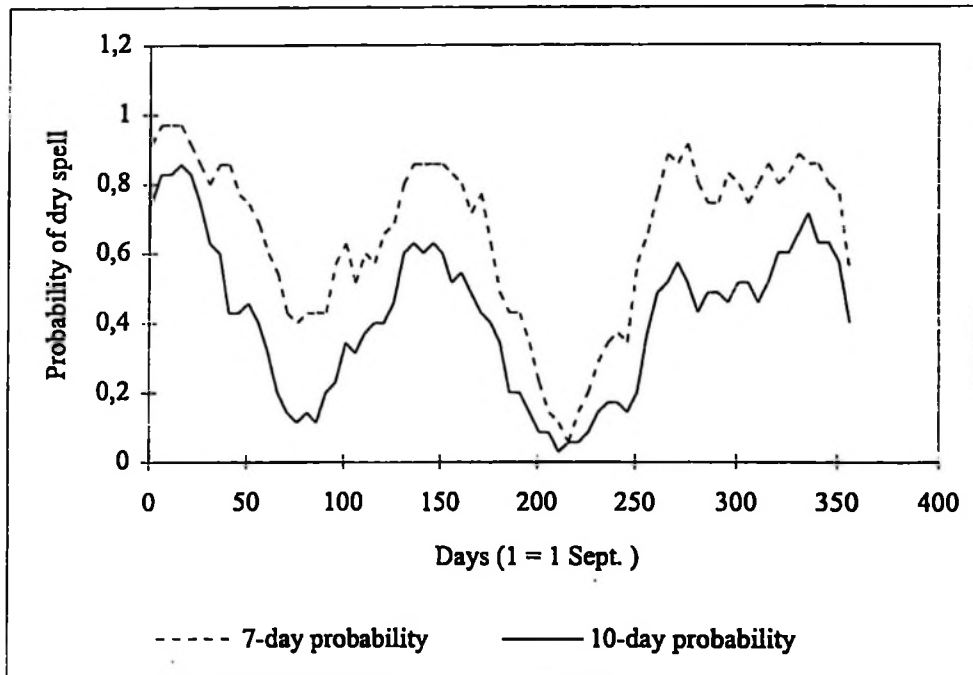


Figure C2: The probability of a 7-day and 10-day dry spell within 30 days following the date on the time axis for Lushoto

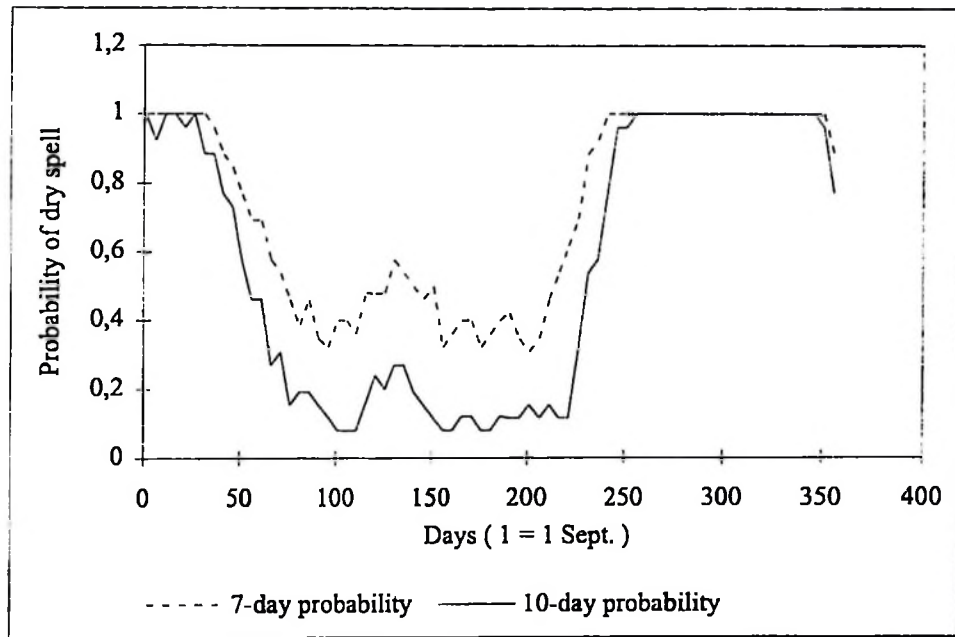


Figure C3: The probability of a 7-day and 10-day dry spell within 30 days following the date on the time axis for Shinyanga

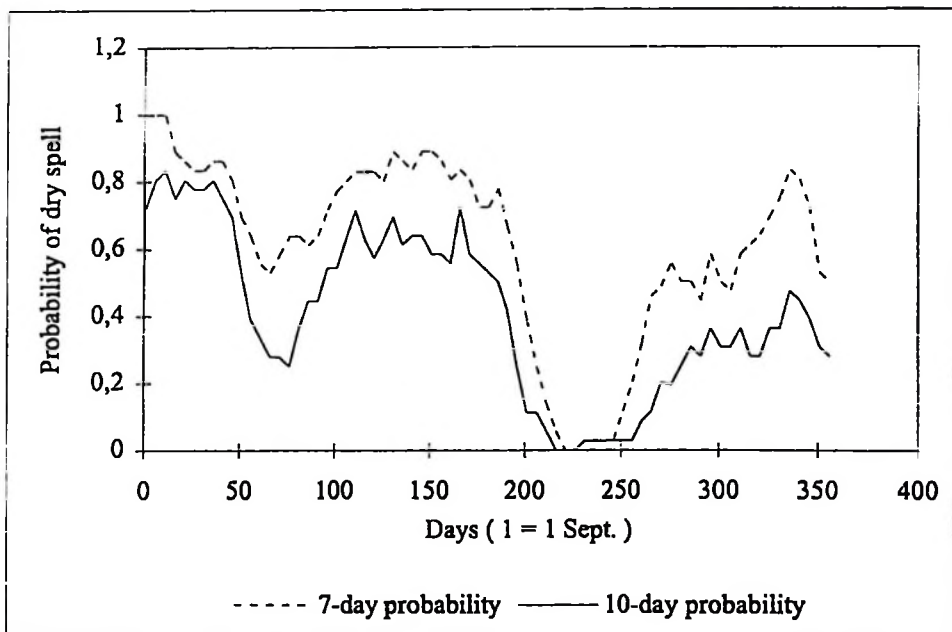


Figure C4: The probability of a 7-day and 10-day dry spell within 30 days following the date on the time axis for Lyamungo

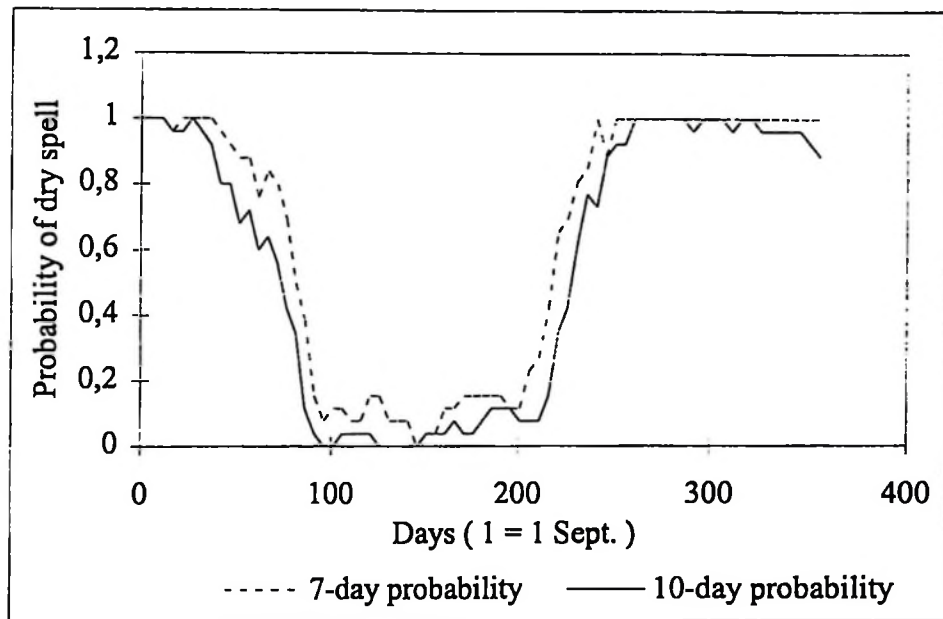


Figure C5: The probability of a 7-day and 10-day dry spell within 30 days following the date on the time axis for Njombe

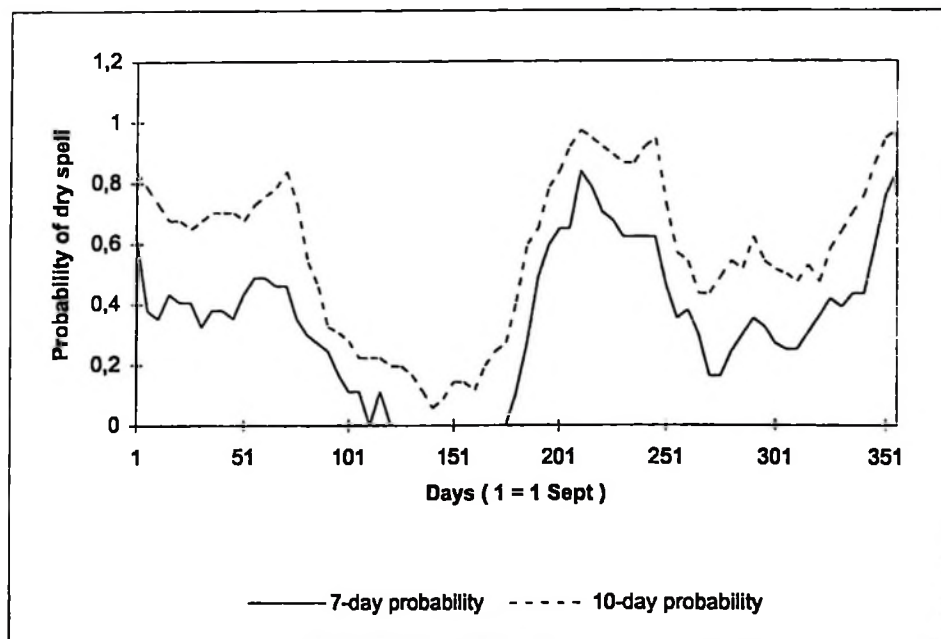


Figure C6: The probability of a 7-day and 10-day dry spell within 30 days following the date on the time axis for Tanga

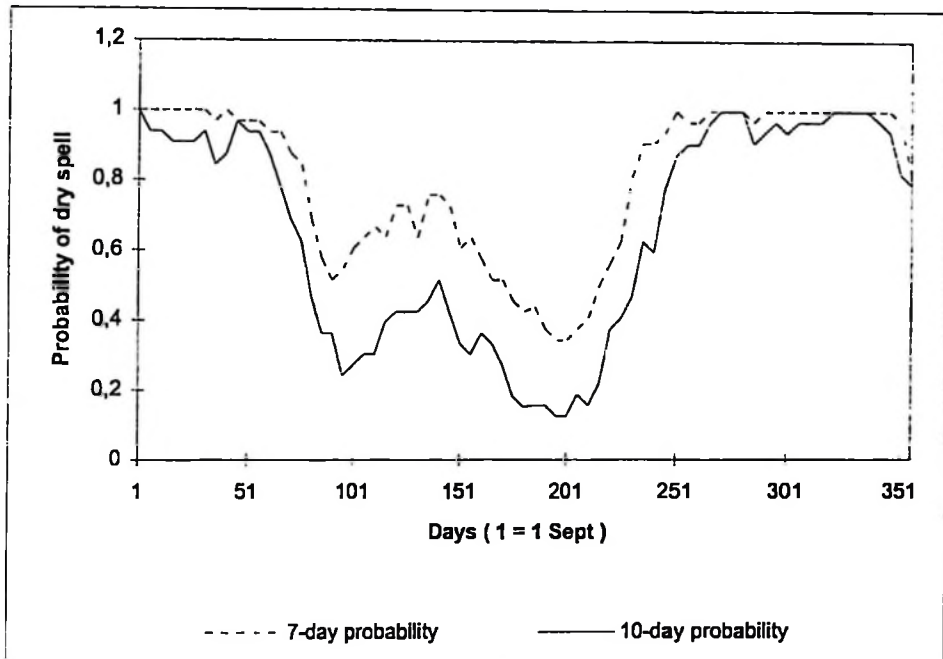


Figure C7: The probability of a 7-day and 10-day dry spell within 30 days following the date on the time axis for Lindi

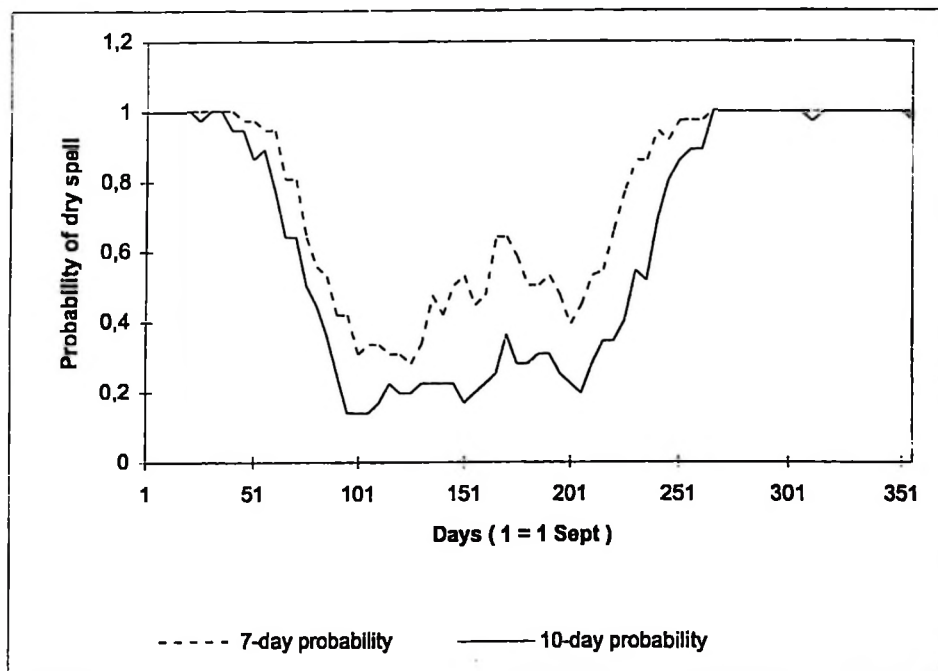


Figure C8: The probability of a 7-day and 10-day dry spell within 30 days following the date on the time axis for Mpwapwa

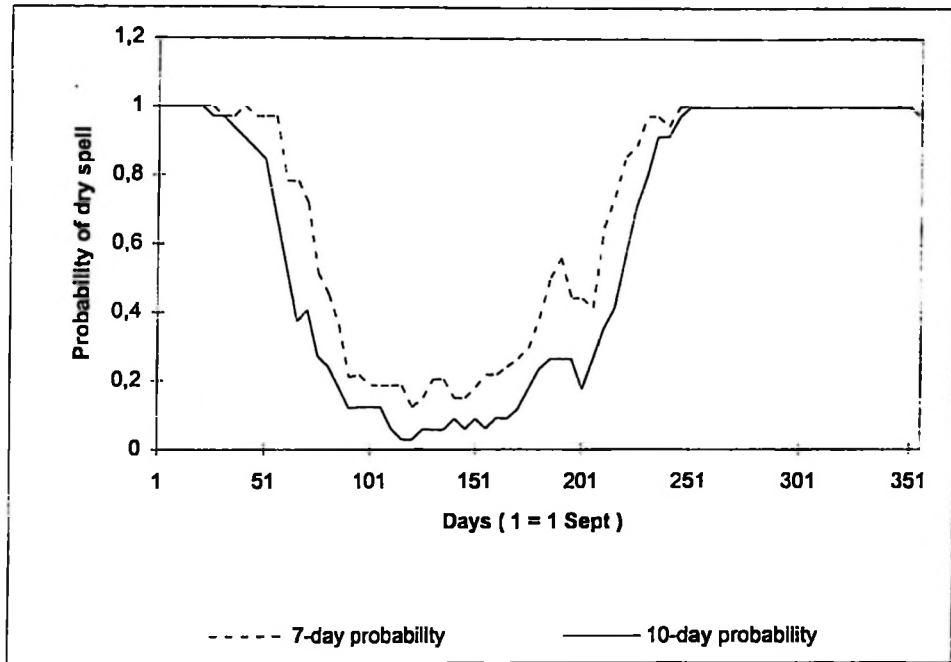


Figure C9: The probability of a 7-day and 10-day dry spell within 30 days following the date on the time axis for Sumbawanga

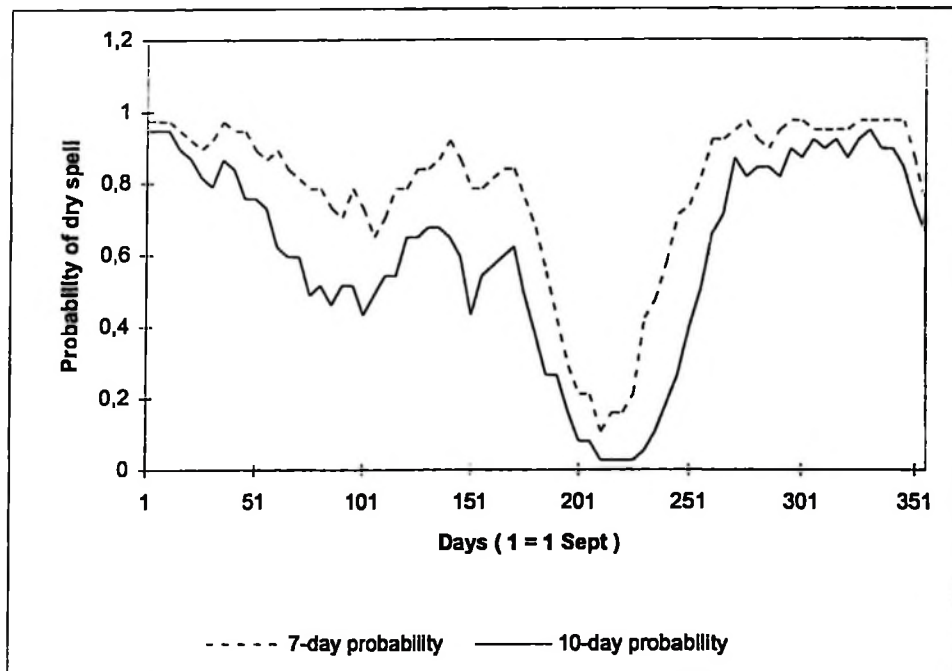


Figure C10: The probability of a 7-day and 10-day dry spell within 30 days following the date on the time axis for Morogoro

APPENDIX D : Day numbers

Table D1: Day numbers (starting from 1st September) for the days of the year

Day .	Month											
	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Jul	Aug
1	1	31	62	92	123	154	183	214	244	275	305	336
2	2	32	63	93	124	155	184	215	245	276	306	337
3	3	33	64	94	125	156	185	216	246	277	307	338
4	4	34	65	95	126	157	186	217	247	278	308	339
5	5	35	66	96	127	158	187	218	248	279	309	340
6	6	36	67	97	128	159	188	219	249	280	310	341
7	7	37	68	98	129	160	189	220	250	281	311	342
8	8	38	69	99	130	161	190	221	251	282	312	343
9	9	39	70	100	131	162	191	222	252	283	313	344
10	10	40	71	101	132	163	192	223	253	284	314	345
11	11	41	72	102	133	164	193	224	254	285	315	346
12	12	42	73	103	134	165	194	225	255	286	316	347
13	13	43	74	104	135	166	195	226	256	287	317	348
14	14	44	75	105	136	167	196	227	257	288	318	349
15	15	45	76	106	137	168	197	228	258	289	319	350
16	16	46	77	107	138	169	198	229	259	290	320	351
17	17	47	78	108	139	170	199	230	260	291	321	352
18	18	48	79	109	140	171	200	231	261	292	322	353
19	19	49	80	110	141	172	201	232	262	293	323	354
20	20	50	81	111	142	173	202	233	263	294	324	355
21	21	51	82	112	143	174	203	234	264	295	325	356
22	22	52	83	113	144	175	204	235	265	296	326	357
23	23	53	84	114	145	176	205	236	266	297	327	358
24	24	54	85	115	146	177	206	237	267	298	328	359
25	25	55	86	116	147	178	207	238	268	299	329	360
26	26	56	87	117	148	179	208	239	269	300	330	361
27	27	57	88	118	149	180	209	240	270	301	331	362
28	28	58	89	119	150	181	210	241	271	302	332	363
29	29	59	90	120	151	182	211	242	272	303	333	364
30	30	60	91	121	152		212	243	273	304	334	365
31		61		122	153		213		274		335	366

APPENDIX E : Rainfall characteristics vis-a-vis shifts in rainfall pattern

Table E1 : Length of growing season and total seasonal rainfall for years with significant shifts in start dates of rains (Zone III-VI).

station	zone	shifted Season	year	shifts (days)	growing season			seasonal rainfall (mm)
					start	end	length	
Tukuyu	III	Seasonal	1965-	46	13 Sept	03 Mar	172	1092
			1967-	49	10 Sept	10 Mar	182	1233
			1972-	54	12 Nov	02 Mar	172	2536
			1975+	58	26 Dec	18 Mar	83	598
			1978-	54	05 Sept	08 May	246	1993
			1981-	56	03 Sept	08 Mar	187	811
			1983+	43	11 Dec	02 Mar	82	645
			1986-	57	02 Sept	02 Mar	182	831
			1989-	51	08 Sept	01 Mar	175	1254
Lushoto	III	Long	1993+	45	13 Dec	26 Apr	135	1408
			1964+	62	19 Apr	24 May	5	25
			1965+	51	08 Apr	29 Apr	21	87
			1986-	43	04 Jan	03 Apr	90	260
			1994-	44	03 Jan	01 Apr	89	111
		Short	1996+	43	31 Mar	24 Apr	24	113
			1967-	79	06 Sept	15 Dec	100	350
			1972-	67	08 Sept	06 Dec	89	349
			1975-	57	26 Sept	05 Feb	132	446
Shinyanga	IV	Seasonal	1988-	45	08 Oct	17 Apr	192	660
			1993+	47	09 Jan	25 May	137	342
			1975-	57	26 Sept	05 Feb	132	446
Lyamungo	IV	Long	1961-	51	04 Jan	12 June	160	897
			1962-	57	01 Jan	12 June	163	842
			1964-	57	01 Jan	22 May	142	726
			1969-	47	11 Jan	01 June	142	1028
			1972-	55	03 Jan	01 Apr	89	271
			1985-	47	11 Jan	13 June	160	1218
			1992-	45	13 Jan	01 Apr	79	183
			1993+	53	20 Apr	15 July	86	634
			1994+	47	14 Apr	15 June	62	989
			1975-	72	10 Sept	01 Dec	82	44
Short	1967-	104	06 Sept	11 Dec	96	323		
	1969-	75	05 Oct	15 Dec	71	122		

+ Year with late start of rains - Year with early start of rains

Table E1: cont.

station	zone	season	shifted year	shifts (days)	growing start	season end	season length	seasonal rainfall (mm)
Mpwapwa	V	Seasonal	1962-	54	13 Oct	04 May	204	913
			1972+	27	03 Jan	29 Apr	147	537
			1986-	36	31 Oct	02 May	184	1112
			1993+	30	06 Jan	12 Apr	97	560
Morogoro	V	Long	1963+	21	23 Mar	27 Apr	35	285
			1969+	23	25 Mar	28 May	64	306
			1991+	20	22 Mar	23 May	62	321
			1974+	23	25 Mar	04 Apr	10	39
			1980+	32	03 Apr	16 May	43	122
			1990+	25	27 Mar	30 May	64	315
		Short	1966-	64	06 Sept	31 Dec	116	507
			1981-	31	09 Oct	14 Dec	66	228
			1988-	36	04 Oct	07 Dec	64	124
			1971-	36	04 Oct	05 Dec	62	109
			1997-	63	07 Sept	03 Jan	118	523
			1989-	36	04 Oct	07 Dec	64	124
			1992+	35	13 Jan	05 May	113	698
Njombe	VI	Seasonal	1965-	28	11 Nov	16 May	187	1257
			1985-	29	10 Nov	03 May	175	1205
			1992+	35	13 Jan	05 May	113	698
			1993+	28	06 Jan	27 May	142	1078
Sumbawanga	VI	Seasonal	1986-	35	30 Oct	03 May	186	805
			1987+	30	04 Jan	21 Apr	108	490
			1991+	31	05 Jan	21 Apr	107	537

+ Years with late start of rains - Years with early start of rain

Table E2: Correlation between shifts of start of growing season (S), length of the growing season (L) and seasonal rainfall (R) for bi-modal stations.

Zone	Season	Regression equation	Correlation coefficient
I	long	$S = 136.6 - 0.869L$	-0.576
		$S = 122.1 - 0.244R$	-0.309
		$L = 64.3 + 0.097R$	0.064
	short	$S = 39.5 + 0.005L$	0.015
		$S = 39.5 + 0.002 R$	0.116
		$L = 99.2 + 0.112R$	0.938
II	long	$S = 74.6 - 0.051L$	-0.037
		$S = 70.1 - 0.004R$	-0.062
		$L = 105.9 + 0.052R$	0.627
III	long	$S = 73.24 - 1.298L$	-0.995
		$S = 67.5 - 0.450R$	-0.544
		$L = 3.27 + 0.357R$	0.578
IV	long	$S = 61.1 - 0.769L$	0.435
		$S = -35.3 + 0.005R$	0.001
		$L = 65.2 + 0.074R$	0.380
	short	$S = 0.04 - 1.121L$	-0.799
		$S = -86.5 - 0.04R$	-0.135
		$L = 72.4 + 0.065R$	0.556
V	long	$S = 24.4 - 0.008L$	-0.002
		$S = 27.8 - 0.016R$	-0.214
		$L = 11.37 + 0.151R$	0.710
	short	$S = -1.72 - 0.517L$	-0.952
		$S = -25.75 - 0.066R$	-0.815
		$L = 44.9 + 0.135 R$	0.950

APPENDIX F : Length of growing season (rainfall criterion) and seasonal rainfall for normal years

Table F1: Probable dates for start and effective length (days) of growing seasons at three level of probability (rainfall criterion)

Station	Season	start date				length of growing season			
		20%	50%	80%	s.d	80%	50%	20%	s.d
Bukoba	Long	14 Jan	05 Feb	26 Feb	25.	91	115	138	27.3
	Short	12 Sept	30 Sept	17 Oct	20.	70	88	105	20.2
Musoma	Long	17 Feb	07 Mar	25 Mar	22.	57	76	94	21.3
	Short	19 Sept	11 Oct	11 Nov	15.	37	54	70	18.7
Ngara	Seasonal	10 Sept	25 Sept	14 Oct	17.	224	247	260	21.2
Dar es salaam	Long	02 Mar	14 Mar	25 Mar	13.	56	73	89	19.3
	Short	12Oct	05 Nov	28 Nov	27.	39	61	82	25.0
Zanzibar	Long	05 Mar	07 Mar	21 Mar		68	82	104	26.6
	Short	17 Oct	25 Oct	10 Nov	12.	64	80	98	19.5
Bagamoyo	Long	13 Mar	25 Mar	09 Apr	11.	60	71	96	26.7
	Short	15 Oct	28 Oct	05 Dec	23.	45	64	86	19.9
Tanga	Long	08 Mar	25 Mar	04 Apr	15.	65	82	98	19.5
	Short	18 Sept	04 Oct	19 Oct	18.	45	65	84	23.2
Lindi	Seasonal	22 Nov	03 Dec	16 Dec	12.	138	164	183	23.9
Mtwara	Seasonal	21 Nov	10 Dec	28 Dec	21.	126	152	177	29.2
Mbeya	Seasonal	21 Nov	28 Nov	07 Dec		146	156	175	17.4
Tukuyu	Seasonal	08 Nov	14 Nov	23 Nov		214	230	259	30.8
Lushoto	Long	04 Mar	09 Mar	20 Mar	12.	80	110	127	31.3
	Short	09 Oct	30 Oct	17 Nov	18.	51	73	98	28.2
Shinyanga	Seasonal	18 Oct	30 Oct	14 Nov	16.	176	194	206	19.7
Lyamungo	Long	15 Mar	24 Mar	01 Apr		107	142	172	34.1
	Short	08 Nov	15 Nov	01 Dec	14.	52	71	90	25.8
Maswa	Seasonal	27 Oct	06 Nov	04 Dec	16.	168	184	209	22.9
Mpwapwa	Seasonal	19 Nov	30 Nov	12 Dec	13.	140	167	188	23.4
Morogoro	Long	02 Mar	15 Mar	27 Mar	14.	47	69	86	20.2
	Short	27 Oct	12 Nov	01 Dec	23.	27	37	46	23.4
Njombe	Seasonal	13 Nov	22 Nov	07 Dec	13.	149	174	183	20.1
Sumbawanga	Seasonal	08 Nov	19 Nov	02 Dec	14.	147	168	179	19.1
Tabora	Seasonal	04 Nov	16 Nov	27 Nov	13.	134	154	173	22.9
Iringa	Seasonal	19Nov	04 Dec	19 Dec	17.	121	138	155	19.8

Source: Kassase, (1992) and Kingamkono, (1994)

Table F2: Total seasonal rainfall (mm) at given probability of exceedence for years
with normal start dates of rains for selected stations

station	zone	season	total seasonal rainfall			CV
			80%	50%	20%	
Musoma	I	Long	364	516	602	0.24
		Short	133	166	261	0.43
Ngara	I	Seasonal	695	879	1124	0.26
Tanga	II	Long	129	196	380	0.73
		Short	65	120	205	0.69
Lindi	II	Seasonal	611	781	1042	0.89
Tukuyu	III	Seasonal	1408	1634	2027	0.21
Lushoto	III	Long	266	365	477	0.37
		Short	148	246	338	0.49
Shinyanga	IV	Seasonal	577	650	813	0.17
Lyamungo	IV	Long	637	866	887	0.21
		Short	25	51	102	0.65
Mpwapwa	V	Seasonal	527	689	839	0.23
Morogoro	V	Long	305	391	477	0.23
		Short	87	134	282	0.71
Njombe	VI	Seasonal	934	1071	1253	0.19
Sumbawanga	VI	Seasonal	652	746	935	0.36

APPENDIX G : ENSO and La-Nina events

Table G1: Occurrence of El-Nino/ Southern oscillations (ENSO) and La-Nina events
in Tanzania

ENSO years	LA-NINA years
1900	1903
1902	1906
1905	1908
1911	1916
1914	1920
1918	1924
1923	1928
1925	1931
1930	1938
1932	1942
1939	1949
1940	1954
1941	1964
1946	1970
1953	1972
1954	1975
1957	1988
1963	1995
1965	
1969	
1972	
1976	
1977	
1982	
1983	
1986	
1987	
1991	
1992	
1993	
1997	

Source: Blench, R. and Marriage, Z. (1998)