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RELATIONSHIP BETWEEN ENSO PARAMETERS AND THE TRENDS AND PERIODIC FLUCTUATIONS IN EAST AFRICAN RAINFALL.

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Abstract

The study investigated the relationship between ENSO parameters and the trends and periodic fluctuations in the East African seasonal and annual decadal rainfall. The monthly rainfall data for the period 1931–2004 was obtained from the Kenya Meteorological Department, Nairobi, Kenya while the ENSO indices data was extract from the NCEP web site. The annual and seasonal rainfall from representative stations in the all homogeneous rainfall zones over east Africa were analyzed for trends and periodicities by various statistical methods. The choice of the stations was based on the availability, continuity and length of the data set. The results from the study showed significant trends in the rainfall data over some locations. However, over most stations, there were decades in which abundant rainfall was observed while during other decades depressed rainfall was recorded. The study revealed that there is a strong link between the rainfall variability over East Africa and the ENSO parameters. Variability on decadal time scale was observed to be dominant in both rainfall and ENSO parameters, especially during the October to December season. The major cycles revealed from spectral analysis were 2 – 2.5 years, 3.6 – 4.4 years, 5 years and 10 – 12 year. Previous studies have associated these quasi-periodic fluctuations to some global phenomena such as the Quasi-Biennial Oscillation (QBO), El Niño Southern Oscillation (ENSO) and the Sunspot cycle.

1. Introduction

Rainfall is a climatic parameter over the tropical region with the largest space and time variability thus making it the most important weather element. Rainfall distribution determines the population densities and the agricultural productivity and, indirectly, population densities, of large areas of the region’s countries.

Extreme occurrences of rainfall are associated with drought or floods, which are, in turn, often linked with food, energy and water shortages, loss of life and property, and many other socio-economic disruptions.

The economies of the East African countries largely depend on agriculture, which is highly vulnerable to the amounts and distribution of rainfall. Efforts to achieve food security in most parts of the region have for a long time been hampered by civil wars, political volatility, worsening conditions of international trade, rapid population growth, floods and drought. Floods and droughts are natural events, whose impacts, if not managed timely and effectively, can be catastrophic. The rainfall distribution over the Eastern African region has been characterized by successive years of below or above normal rainfall, which has been associated with global teleconnections involving the El Niño-Southern Oscillation (ENSO) and La Niña phenomena, among other factors.

Several attempts have been made to study the spatial and temporal variability of rainfall in East Africa. Using trend analysis, Winstanley (1974) predicted a decrease in rainfall over Africa, the middle Middle East and India to a minimum around the year 2030 A.D. Ogallo (1980) reported a 3.5 year periodicity in the annual rainfall in East Africa. Using data for 35 stations in East Africa, Rodhe and Virji (1976) observed no definite trend in the annual rainfall, except in northern Kenya where a trend towards increased rainfall in recent years was indicated. Spectral analysis revealed major cycles of 2.0 years, 3.5 years and 5.0–5.5 years. Ogallo (1980) and Ogallo *et al*. (1994) found the existence of three major peaks centred on the Quasi-Biennial Oscillation (QBO), ENSO and the sunspot cycle of 2.5–3.7, 4.8–6 and 10–12.5 years, respectively. Nicholson and Etekhabi (1986) observed a strong quasi-periodic fluctuation in the East African rainfall with a time scale of 5–6 years corresponding to the ENSO and sea surface temperature (SST) fluctuations in the equatorial Indian and Atlantic Oceans. Ininda (1987) determined cycles in the annual rainfall in Eastern and Southern Africa of 2.0, 3.4 and 5.2 years. The 5.2-year cycle seemed more prominent.

A historical account of several proxy data, lake levels, analyses of glacier variations, wind and Ocean current observations in the Indian Ocean and their relationship to East African rainfall indicate a general evolution of climate within East Africa over the past 150 years (Hastenrath, 1995). This study endeavours to examine the relationship between East African rainfall trends and the associated ENSO parameters and periodic fluctuations.

2. Data

The data used in the study consisted of monthly rainfall records for the period 1931–2004 for various stations that were representative of various climatic rainfall homogeneous zones over the Eastern Africa region whose delineation is shown in Figure 1. The stations used are Mombasa (Zone I), Moyale (Zone II), Kabete (Zone III), Kitale (Zone IV), Utete (Zone V), Bukoba (Zone VI) and Entebbe (Zone VII). These stations were chosen on the basis of the quality, availability, continuity and length of the data sets. The rainfall data was initially subjected to statistical quality control using mass curve analysis and found to be homogeneous. ENSO parameters, sea surface temperature (SST) data and Southern Oscillation Index (SOI) datasets for the period of study were obtained from the National Centre for Environmental Prediction (NCEP). Before carrying out an analysis of the temporal characteristics of rainfall over the region of study, it was necessary to first obtain the basic statistical parameters of the rainfall data, the means and variance The rainfall data used in this study were standardized which enables clear identification of wet and dry periods in the data.

3. Methodology

To achieve the objective of the study, time series analysis of the annual and seasonal rainfall was performed. The annual rainfall is a contribution of the seasonal rainfall and the rainfall occurring outside of the rainfall seasons. The four major components of any time series include the trend, seasonality, cyclic and random variations. Trends refer to long-term movement of a time series; cyclic variations describe periodic characteristics of the data while seasonality represent the month to month patterns.

Random variations, on the other hand represent unpredictable fluctuations, which occur by chance. A detailed description of these components is provided by Kendall *et al*., (1983). The temporal characteristics of rainfall examined in this study include the trend and cyclical variations of the annual and seasonal rainfall. However, before these were examined, the temporal distribution of rainfall over Eastern Africa was examined to define the rainfall seasons over the region.

3.1 Trend analysis

Many methods have been used to describe trend in climatological data. These methods may be grouped into several categories, some of which are: graphical, polynomial, and statistical methods. In this study the trend analysis is examined through a graphical plot of the rainfall data series and statistical methods were used.

The graphical method involves plotting the rainfall data against time. This method provides a quick visual observation of the presence of trend in a given time series. The use of the graphical approach for trend analysis, although simple, presents several drawbacks. Some of the drawbacks include its subjectivity, reduction of the data series through smoothing and the generation of fluctuations, which may otherwise be absent in the original time series. In addition, the smoothing fails to cover the full period of the original series (Kendall *et al*., 1983).

Statistical methods may be used to test the statistical significance of the observed trends in a time series. These methods are generally in two groups: parametric and non- parametric tests.

In parametric tests, the data series is assumed to satisfy known statistical distributions. In most real situations, however, this is rarely the case. Common among the parametric tests is the analysis of variance (ANOVA) approach whereby a time series is divided into two or more groups each of at least 30 years record. The means of the subgroups are then compared using the statistical distribution that best describes the time series. Such tests include the student t-test, F-test or the chi-square test. The choice of the test to use usually depends on the frequency of the series under study (Jones, 1975)

In non-parametric tests, it is assumed that the time series is not distributed according to known standard statistical distributions.

As such, the tests are useful for the series where conditions of normality are not assumed. Some of these tests are based on ranks and include the spearman's rank correlation test, and the Mann-Kendall rank test (Mardia *et al*., 1988; Kendall *et al*., 1983).

In this study the analysis of variance (ANOVA) approach was used. The null hypothesis invoked in testing for the statistical significance of the trends of the rainfall data was that the difference in the variances and means of the two grouped data sets are not equal. If the computed value falls within the range of the tabulated value, the null hypothesis is accepted implying that the statistic is significant, otherwise it is regarded as insignificant. The student t- test is expressed by Equation 1 below:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sigma_d^2} \qquad (1)$$

where the variance, σ_d^2, is given by Equation 2 below:

$$\sigma_d^2 = \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}} \qquad (2)$$

where $\bar{x}_1$ and $\bar{x}_2$ are the means of the two samples of size n_1 and n_2 and variances σ_1^2 and σ_2^2 respectively.

Graphs of rainfall amount against time were plotted to visually assess the presence or absence of trend in a given time series. Decadal moving averages were used to examine the trends in the annual and seasonal rainfall. The statistical significance of the observed trends in the rainfall time series were determined using the analysis of variance (ANOVA) parametric test.

3.2 Spectral Analysis

Spectral analysis is a modern technique for examining the hidden periodicities (cycles or oscillations) of any time series at certain frequencies. Other methods include the fast Fourier analysis method was used to detect cyclical variations of rainfall in this study. Spectral analysis has been used by many authors to examine cyclic variations. The spectral analysis density function, $h(\omega)$ can be expressed as a Fourier transform of autocovariance function R (r). Thus

$$h(\omega) = \frac{1}{2\pi} \sum_{r=-\infty}^{\infty} e^{-i\omega r} R(r) \qquad (3)$$

- p £ w £ p

Where $\omega = 2\pi f$ is the angular frequency and ¦ is the frequency and $i = \sqrt{-1}$.

In the normalized power spectrum ¦(w), the autocovariance is replaced by autocorrelation, and takes form

$$¦\,(w) = \frac{1}{2\pi} \sum_{r=-\infty}^{\infty} e^{-i\omega r} \rho(r) \qquad (4)$$

In order to obtain consistent estimates of ¦ (w), smoothing functions λ (r) are used. The smoothed spectral density function, ¦^{1}(w), may be expressed as ¦^{1}(w)£l(r)¦(w). Where $\lambda(r)$ is the smoothing weights or lag windows. Examples of lag windows that are used to smoothen the power spectrum are: Truncated Periodogram, Bartlett, Daniel, Tukey Humming, Tukey Hunning, Parsen and Barklett–Priestley windows. The most commonly used windows are the Parsen and Tukey windows (Jenkins and watts, 1968).

The window employed in this study is the parsen window. This type of window is chosen because it is non-negative over the whole range of frequency and therefore avoids leakage of the power spectrum.

The parsen window is of the form.

$$\lambda(r) = 1 - 6\left(\frac{r}{M}\right)^2 + 6\left(\frac{|r|}{M}\right)^3, \qquad |r| \le \frac{M}{2}$$

$$= 2\left(1 - \frac{|r|}{M}\right)^3, \qquad \frac{M}{2} \le |r| \le M \qquad (5)$$

$$= 0, \qquad |r| > M$$

Where M is the truncation point. For practical purposes, $M \le \frac{N}{3}$, where N is the number of observations.

When the Parsen window is used, the smoothed normalized spectral density function, f^1(w) is expressed in the following form.

The cycles appear as peaks in the graph of ¦^{1}(w) versus w.
The dominant periodicity is identified by the peaks in the spectral density function. The significant peaks at 95% confidence level were those above the threshold spectrum, $f_{CL,95\%}$ given by

$$f_{CL,95\%} = \frac{\bar{f}^1(\omega)\chi^2_{\nu,95\%}}{\nu}$$
(7)

Where $\bar{f}^1(\omega)$ is the mean of the smoothed periodogram for the spectral estimates, $\chi^2_{\nu,95\%}$ is the 95% point of the χ^2 -distribution with ν degree of freedom. For the Parzen window, which was used here, the degree of freedom, ν are determined by the formula:

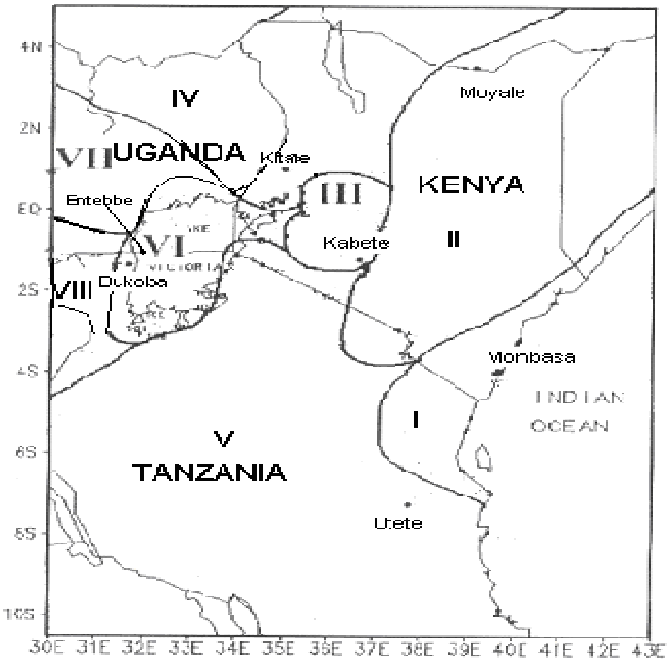
$$\nu = 3.71\frac{N}{M}$$
(8)

The details of determining the significant spectral peaks are described by Minja (1984).

Figure 1 : The eight homogeneous rainfall groupings over East Africa, obtained from combined empirical orthogonal functions (EOF) and simple correlation analyses (Indeje, M. *et al.,* (2000).

4. Results

In this section, the results obtained from the temporal variation of the rainfall are discussed first, followed by those from trend analysis of rainfall data, sea surface temperature data in the Nino 3+4 region, Southern Oscillation Index (SOI) and finally, those from spectral analysis.



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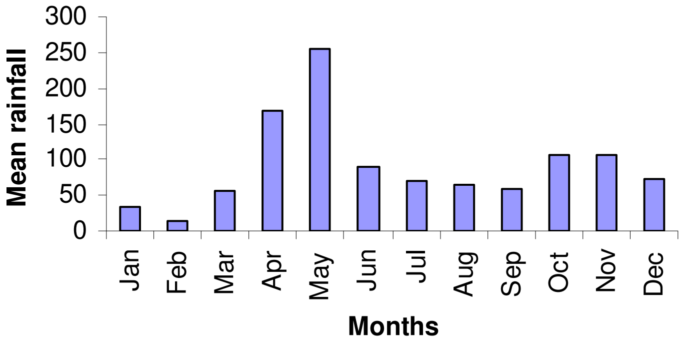
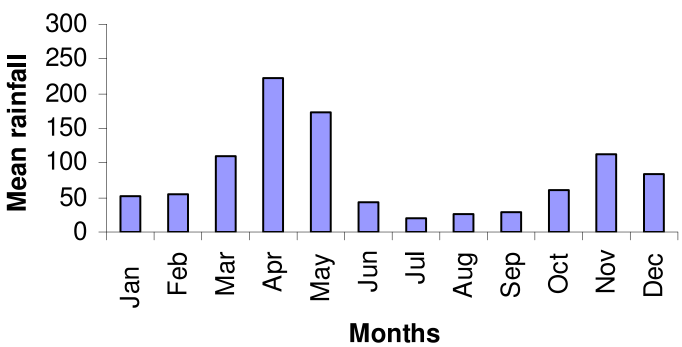
4.1 Results from Temporal distribution of rainfall

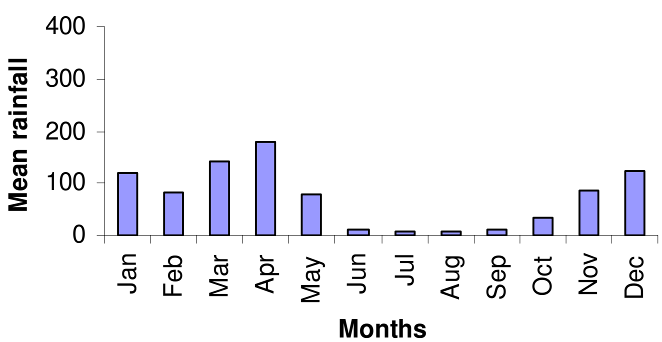
The temporal distribution of rainfall over the study region was examined. The rainfall regime over most parts of Equatorial East African, as confirmed by this result, is bimodal. The “long rains” occur in the March–April–May (MAM) season, except for the coastal area where they occur during the April – May – June (AMJ) season. The “short rains” season spans from October through December (OND). However, rainfall over the southern parts of Tanzania depicts a unimodal regime, occurring between September and May (SM).
This imply that the rainfall characteristics over the region are different. Examples of the temporal distribution of rainfall over the study area is shown in Figures 2–3.



(a) Mombasa



b) Kabete



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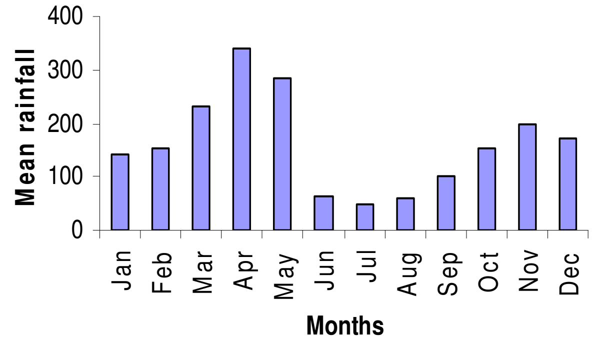

(d) Utete

Figure 2: Mean monthly rainfall at various rainfall stations (a) Mombasa (b) Kabete (c) Bukoba (c) Utete

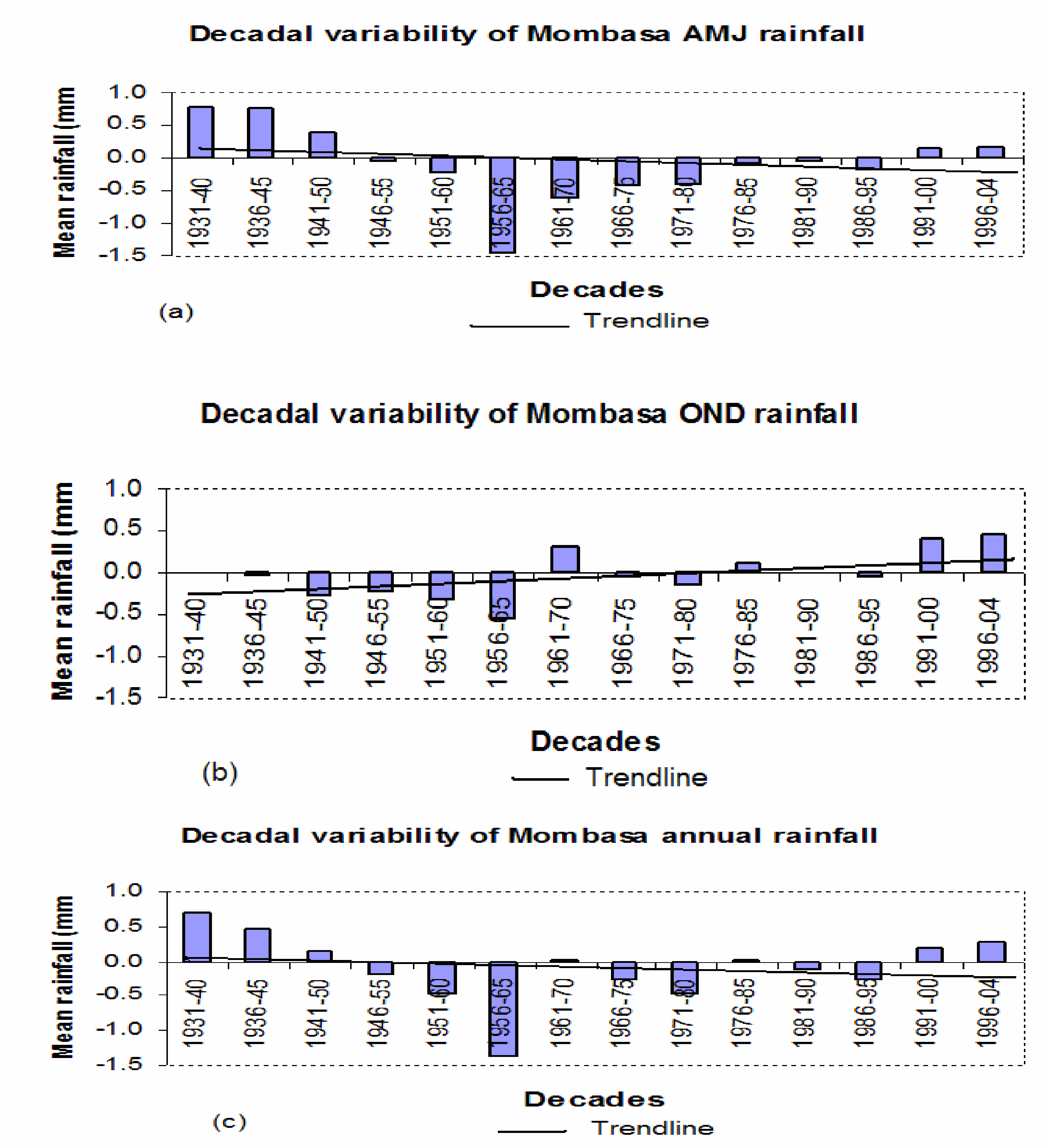

Figure 3: The decadal variation of rainfall anomalies at Mombasa (Zone II), (a) AMJ rainfall (b) OND rainfall and (c) annual rainfall

4.2 Results and discussion of trend analysis of rainfall

Examples of graphical plots from trend analysis are shown in Figure 3-9. The trends were generalized into two categories namely;

i. Increasing trends (positive)

Decreasing trends (negative)

The annual and seasonal decadal rainfall data of the stations examined depicted trends in the categories highlighted above. These trends were tested for significance using the student t-test, as given in Table 1.

Mombasa rainfall data indicated a generally decreasing trend to the sixth decade, followed by generally increasing trend for the annual and AMJ seasonal rainfall (Figure 3). Statistically significant trends in both the difference in the means and variances of the data were observed in the OND rainfall are given in Table 1. Figure 3 shows that the contribution of the AMJ rainfall to the annual decadal rainfall between the first and sixth decades was larger, followed the larger contribution by the OND rainfall in the remaining decades where the trend was generally increasing. This may suggest the relative dominance of the ENSO phenomenon during the recent decades (Ogallo et al., 1988; Ogallo, 1988; Hastenrath et al., 1993; Rowell et al., 1994). ENSO explains about 50% of the short rains variance over East Africa (Ogallo, 1988), with other factors explaining the remaining variance. ENSO events enhance moisture influx in the region resulting in increased convective activities over the area. It is important to note that the sixth and seventh decades were particularly dry, and wet, respectively.

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Figure 4 shows the distribution of annual and seasonal decadal rainfall at Moyale (Zone 11). The figure shows that the annual and seasonal data dfepicted first increasing trend to the seixth decade followed by a decreasing trend. These may be associated with changes in the local/regional circulation patterns as well as global scale systems over this area as a consequence of both natural causes and anthropogenic activities. The third and seventh decades were quite dry and wet respectively. OND seasonal rainfall depicted an increasing trend in recent decades, which may bwe associated with increased frequenct of ENSO events.

Figure 5 shows the distribution of annual and seasonal decadal rainfall at Kabete rainfall station. The figure shows a generally increasing trend to the sixth decade followed thereafter by some oscillations, mainly in the OND data. The change in the trend may imply a change in rainfall generating systems. The third and sixth decades were particularly dry and wet respectively.

Kitale rainfall station showed a generally increasing trend of annual and seasonal rainfall as seen in figure 6. Statistically significant trends in both the difference in the means and variances of the data were observed in the OND rainfall as shown in Table 1.

The increase in the MAM decadal seasonal rainfall may be associated with changes in the circulation patterns, in which pronounced westerlies from the Congo basin region combined with the temperature/pressure gradients set up between the Atlantic and Indian Oceans, play an important role in modulating the rainfall patterns (Camberlin and Okoola, 2003). The contribution of OND decadal rainfall was lower between the first and sixth decades compared to that between the twelve and fourteen decades which suggest the contribution of the ENSO events in the last decades. Note that the seventh and ninth decades were particularly wet and dry respectively.

At Utete rainfall station (Zone V) a generally decreasing decadal rainfall trend in both the annual and seasonal rainfall as seen from Figure 7. Statistically significant trends in the difference in variances of the data were observed in both the annual and September to May (SM) seasonal rainfall as given in Table 1. This may be as a result of changes in the local/regional circulation patterns as well as global scale systems over this area. The second and fourteenth decades were the wettest and driest, respectively.

The decadal rainfall trend at Bukoba rainfall station representing homogeneous rainfall zone VI shows a generally increasing trend in both the annual and seasonal decadal rainfall data to the seventh decade, followed thereafter by a gradual declining trend in the remaining decades, except for OND rainfall which indicates a generally increasing trend (Figure 8). Statistically significant trends were obtained during the OND season. The decline in recent decades may suggest changes in the rainfall generating systems in this area and a relative relaxation of the influence of mesoscale factors, the land-lake breezes (on the shores of Lake Victoria) associated with this region.

The interaction between the large-scale systems and the intense mesoscale circulation produce many patterns of diurnal variation of precipitation over the region, which would explain these trends in recent decades. It is important to note that the seventh and fourteenth decades were generally the wettest and driest decades, respectively.

Figure 9 shows the decadal variation of Entebbe annual and seasonal rainfall, representing Zone VII. The figure indicates a negative trend in the annual and MAM decadal rainfall. The OND decadal rainfall shows a generally increasing trend, associated with the interaction of the meso-scale systems over this region and global scale factors such as the ENSO phenomenon. This increase is not sufficient to compensate for the decrease in the MAM rainfall, which results in the negative trend in the annual rainfall.

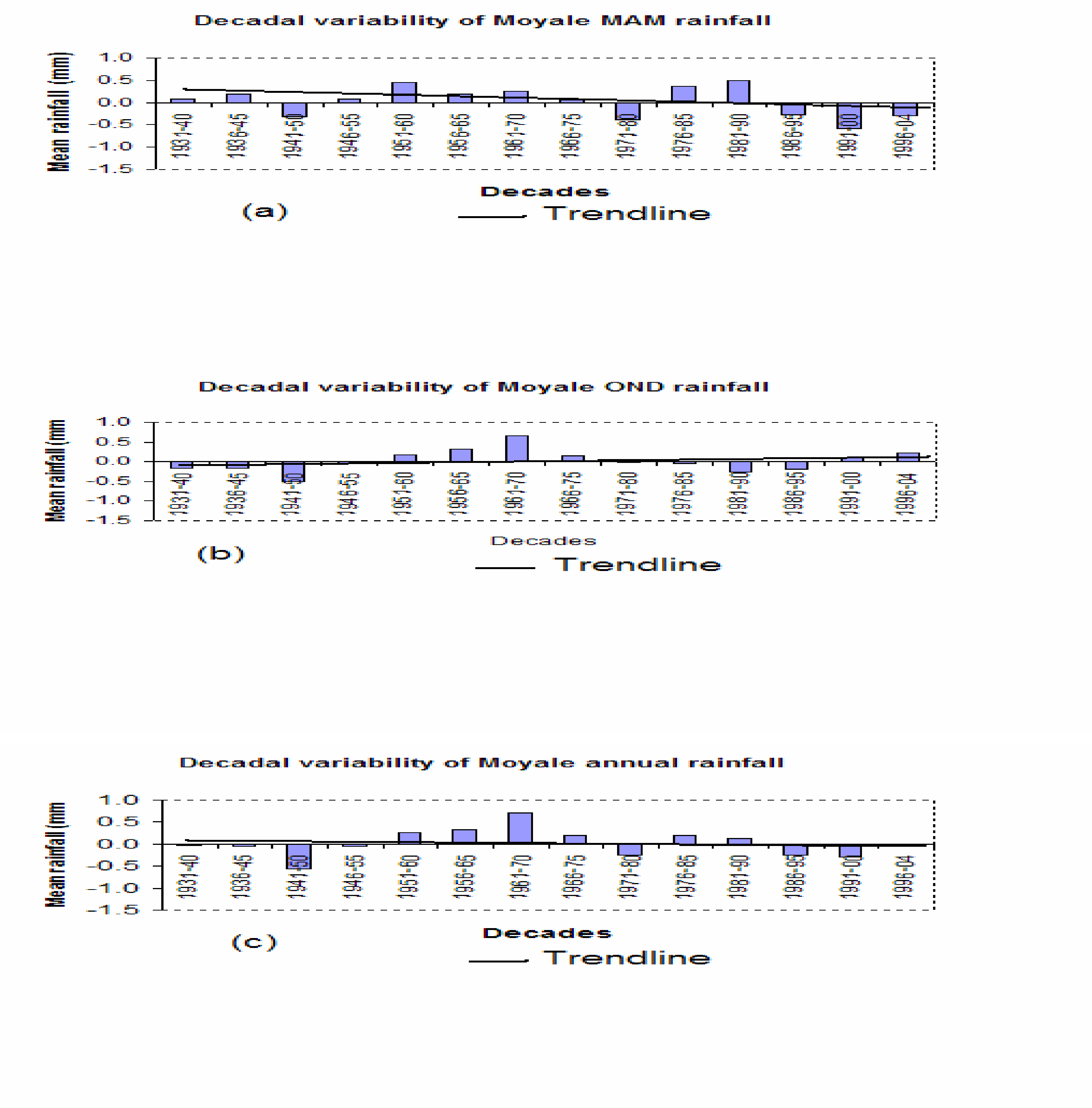
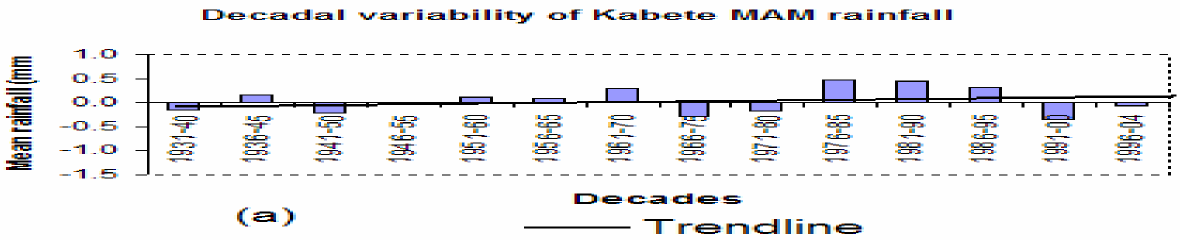
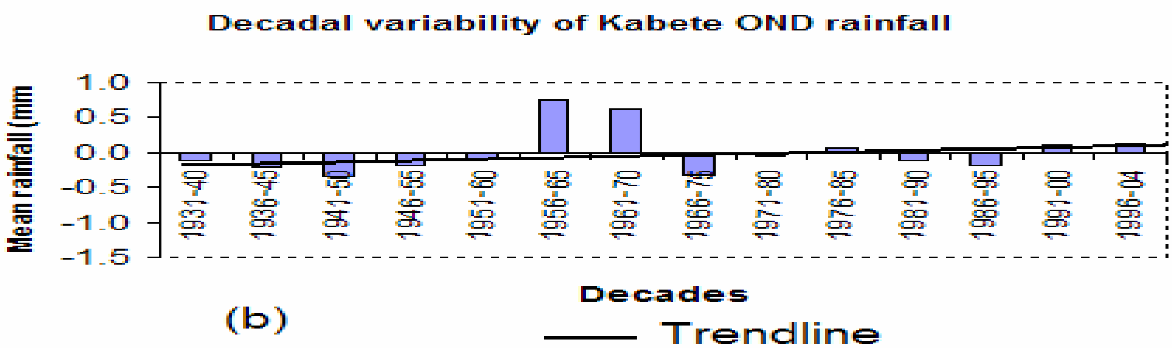


Figure 4: The decadal variation of rainfall anomalies at Moyale (Zone III), (a) MAM rainfall (b) OND rainfall and (c) annual rainfall





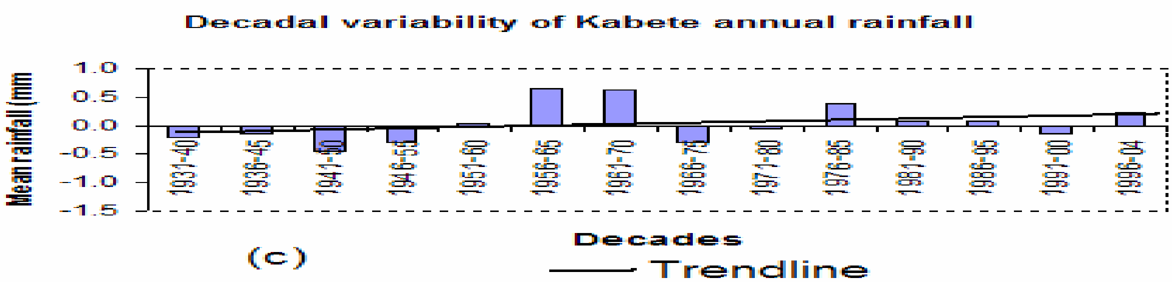


Figure 5: *The decadal variation of rainfall anomalies at Kabete (Zone III), (a) MAM rainfall (b) OND rainfall and (c) annual rainfall*

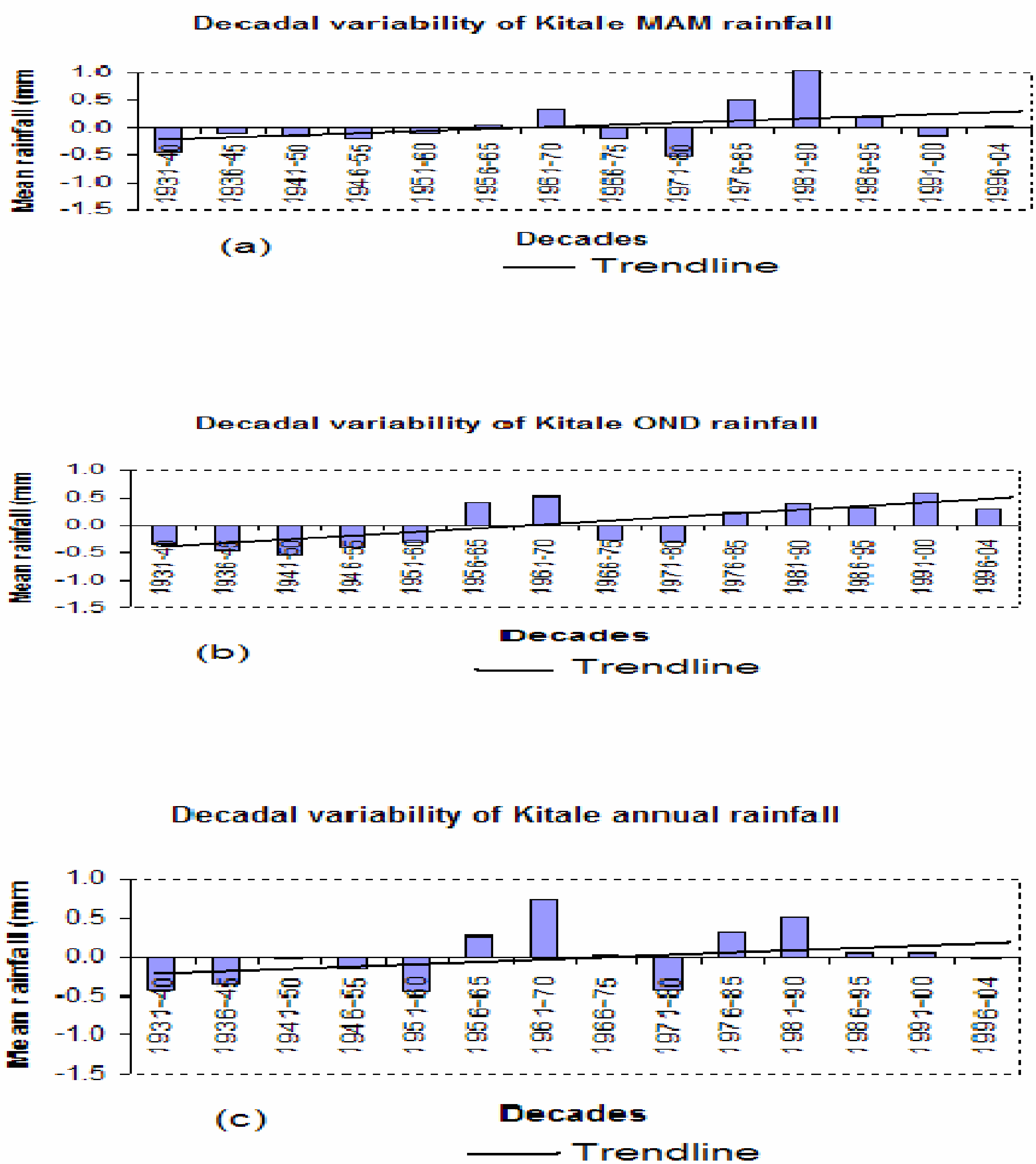


Figure 6: The decadal variation of rainfall anomalies at Kitale (Zone IV), (a) MAM rainfall (b) OND rainfall and (c) annual rainfall

Table 1: The annual and seasonal decadal rainfall t-test statistic results at 90 % confidence interval for the decades at the stations studied. The bolds indicate statistically significant values.

Station	Rainfall	Trend	Difference in variances	Difference in means
Mombasa	Annual	Negative	-0.01	-0.01
	AMJ	Negative	0.19	0.15
	OND	Positive	-1.85	-1.93
Moyale	Annual	Negative	0.82	0.68
	MAM	Negative	0.29	0.34
	OND	Positive	1.26	1.01
Kabete	Annual	Positive	-0.05	-0.05
	MAM	Positive	-0.12	-0.11
	OND	Positive	0.69	0.87
Kitale	Annual	Positive	-0.67	-0.70
	MAM	Positive	-1.02	-0.98
	OND	Positive	-1.61	-2.23
Utete	Annual	Negative	1.56	1.30
	SM	Negative	1.50	1.29
Bukoba	Annual	Negative	-0.10	-0.12
	MAM	Negative	0.45	-0.44
	OND	Positive	-1.60	-1.65

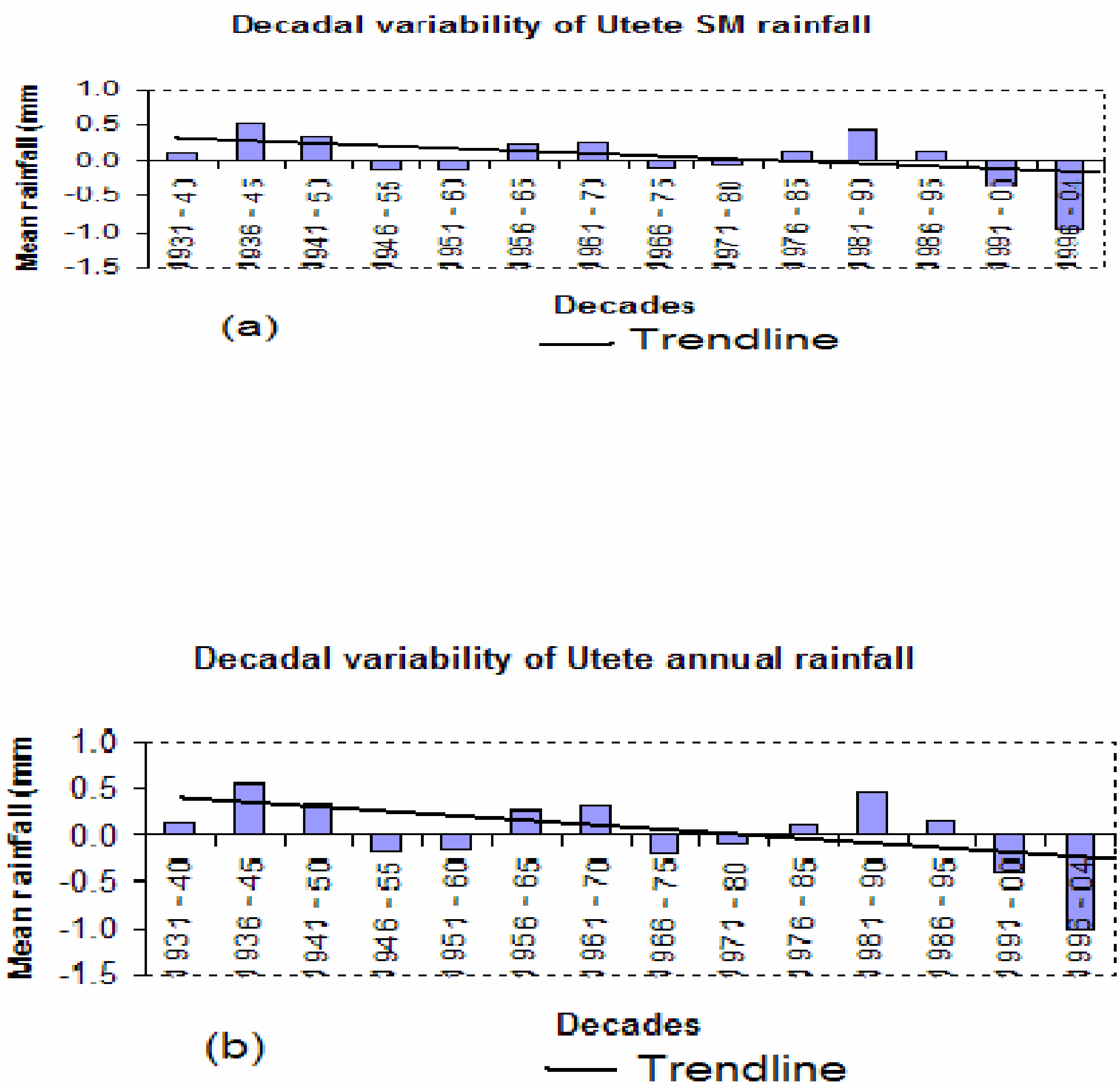


Figure 7: The decadal variation of rainfall anomalies at Utete (Zone VI), (a) SM rainfall (b) annual rainfall

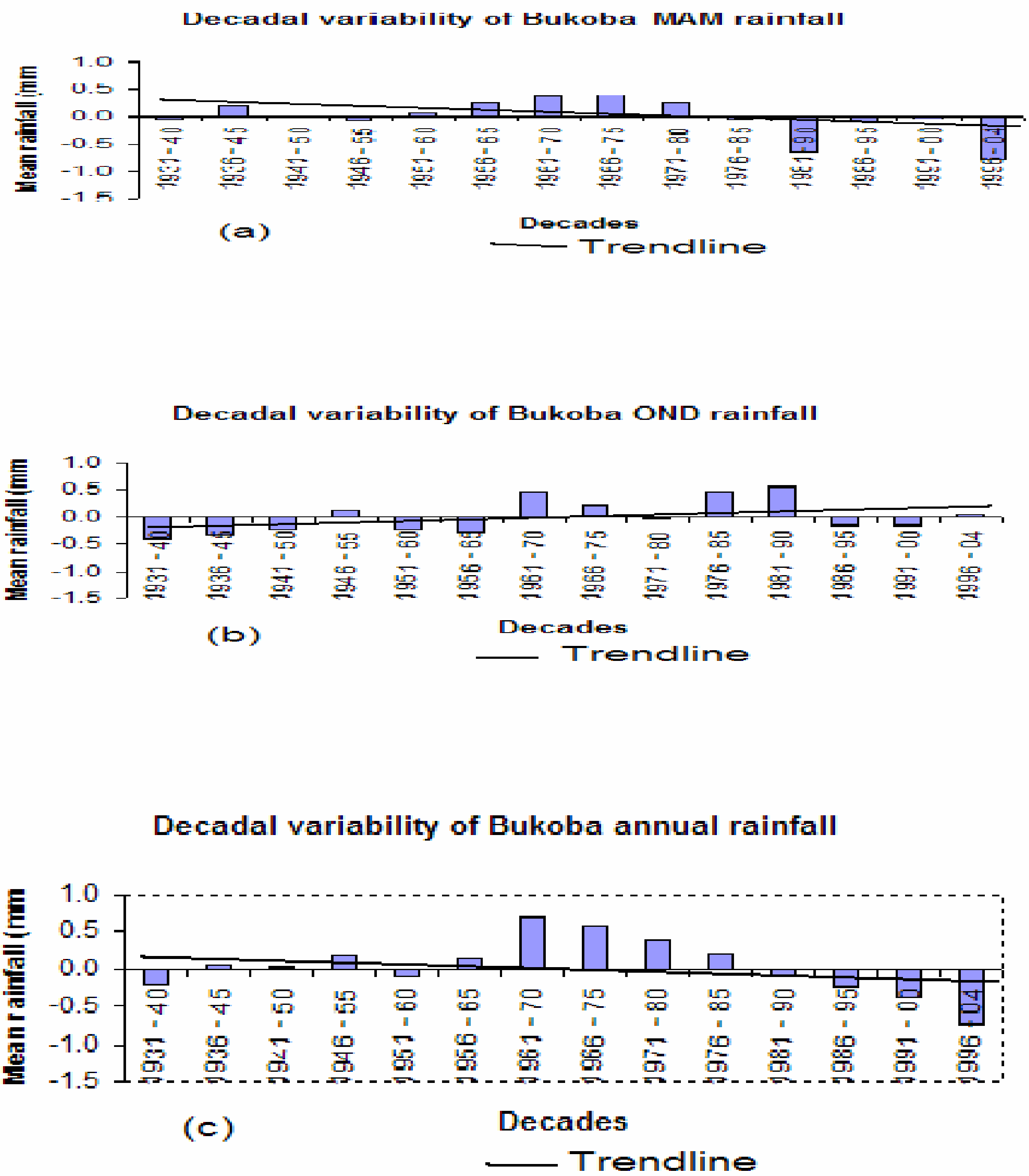


Figure 8: *The decadal variation of rainfall anomalies at Bukoba (a) MAM rainfall (b) OND rainfall and (c) annual rainfall*

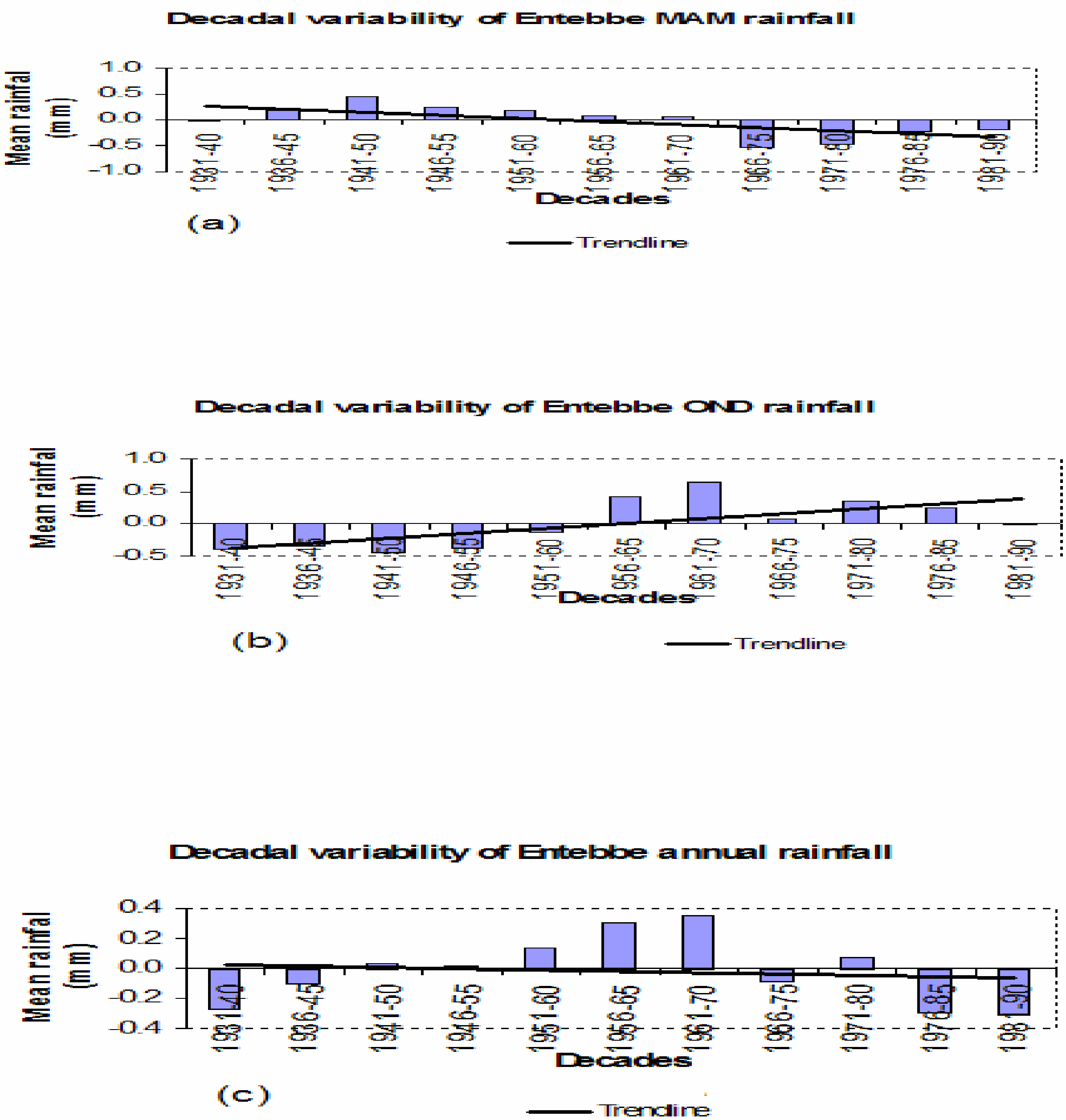


Figure 9: *The decadal variation of rainfall anomalies at Entebbe (Zone VII), (a) MAM rainfall (b) OND rainfall and (c) annual rainfall*

4.3 Results and discussion from trend analysis of ENSO parameters

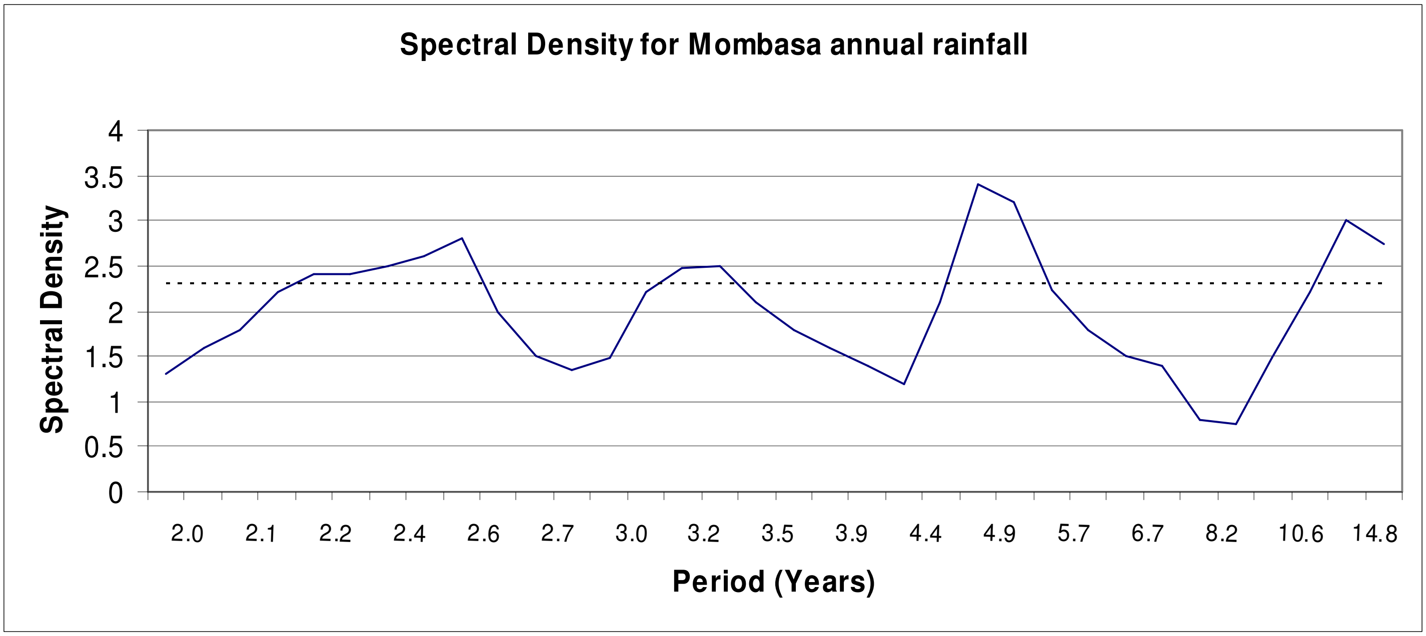
El *Niño* refers to the appearance of warm sea surface temperatures (SSTs) over the eastern and central Pacific Ocean on a time scale ranging between 3 to 7 years. Oscillation index (SOI) is a statistic that indicate the pressure sea saw between Tahiti and Darwin. An El *Niño* event occurs when the SSTs are warming off the East coast of Peru accompanied by corresponding lower index of SOI while the converse explains the La *Niña* event associated with dryness over much of the tropical regions. Figure 10a shows the variation of the Nino 3+4 SSTs. The figure indicates a gradually increasing trend in the SSTs, with the largest warming occurring in the 1986 – 1995 decade. This positive trend shows that the El Niño events have been stronger in recent decades, hence the pronounced positive trend in rainfall mainly during the short rains season (OND) over the study region. On the other hand, the time series of the Southern Oscillation index indicates a negative trend, with the lowest index observed during the 1986 – 1995 decade (Figure 10b). Hence lower indices of SOI and warmer SSTs are sufficient indicators of an eminent ENSO event.

4.4 Results and discussion from cross correlation analysis

Table 2 presents the results from cross correlation among the Nino 3+4 sea surface temperatures, Southern Oscillation Index and seasonal rainfall over the stations used. The table indicates stronger correlation between OND seasonal rainfall and SSTs at most of the stations compared to that of MAM rainfall.

The correlations between rainfall and SOI are also stronger during the OND season, mainly at Mombasa, Moyale, Kitale and Bukoba. The intensity of association tends to decrease inland from the coastal region. These imply that the rainfall over the study region has some associations in terms of the generating systems that involve global scale teleconnections, among other factors. Hence there is a relationship between the rainfall over the study region and the ENSO parameters.

From the above analyses, statistically significant results in the differences in the means and variances of the annual and seasonal decadal rainfall at Mombasa, Kitale, Utete and Bukoba. The observed trend in the annual decadal rainfall may be associated with changes in the local/regional circulation patterns in relation to global scale systems over the region. The rainfall trend in the short rains (OND) season was linked to the pronounced effect of the El Nino southern oscillation (ENSO) events and sea surface temperature (SST) fluctuations in the equatorial Indian and Atlantic Oceans. Strong correlations were observed between rainfall, Nino 3+4 SSTs and SOI over most of the stations particularly during the OND season implying a similarity in rainfall generating systems. It has been reported previously that the main rainfall season (MAM) over the region is weakly linked with ENSO (Ogallo *et al*., 1988, Ogallo, 1988). The interaction between the large-scale systems and the intense mesoscale circulations over the region also produce many patterns of diurnal variation of precipitation, which would also explain the trends in the MAM seasonal decadal rainfall. Hence regional and global scale factors have an influence on the rainfall over the study region. The inter-annual variation in the rainfall data at all the locations was attributed to the increased frequency of the ENSO phenomenon. The results from trend analysis and significance tests show that the short rains season mainly accounted for the variations in the rainfall.



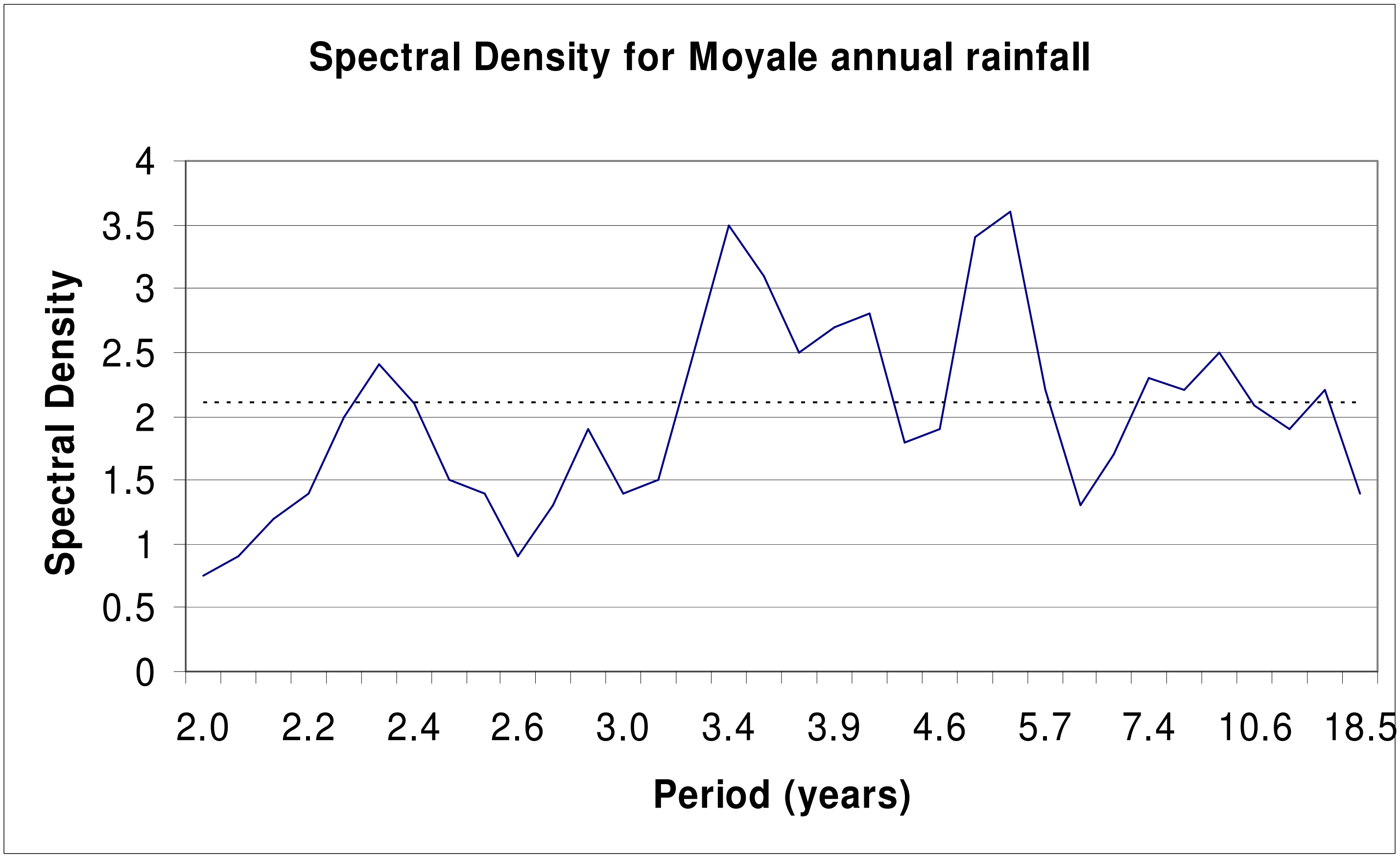


Figure 10: Time series plots of (a) decadal variation of the Nino 3+4 SSTs and (b) the Southern Oscillation Index.

Table 2: Cross correlation matrix between the seasonal Nino 3+4 SSTs, Southern Oscillation Index (SOI) and seasonal rainfall.

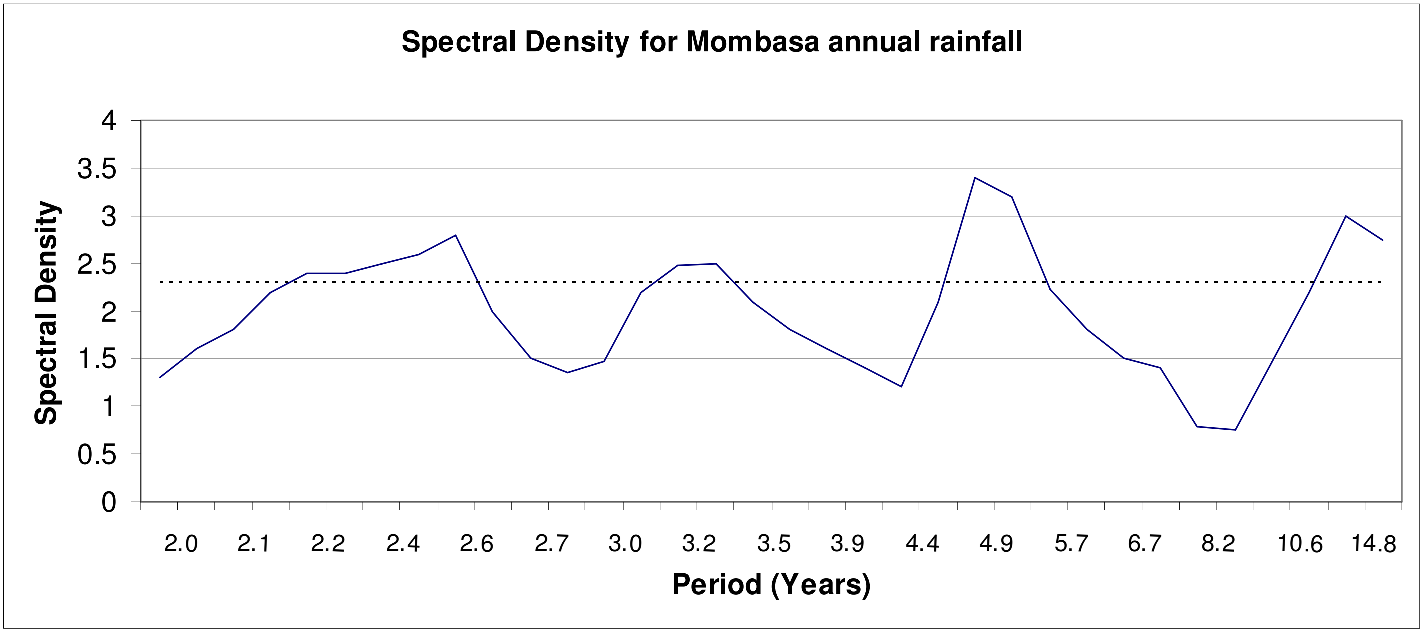
Rainfall	**NINO 3+4 SSTs**		**SOI**	
	MAM	**OND**	**MAM**	**OND**
Mombasa AMJ	0.2	0.2	-0.1	-0.2
Mombasa OND	-0.1	**0.3**	-0.2	**-0.5**
Moyale MAM	0.0	**0.3**	0.0	**-0.4**
Moyale OND	0.0	**0.4**	-0.2	**-0.5**
Kabete MAM	0.0	0.1	0.0	-0.2
Kabete OND	0.1	0.2	-0.2	-0.2
Kitale MAM	0.1	0.2	-0.2	**-0.4**
Kitale OND	0.2	**0.3**	**-0.3**	**-0.3**
Utete SM	0.0	0.0	-0.1	-0.1
Bukoba MAM	**-0.3**	-0.1	**0.3**	0.1
Bukoba OND	0.0	**0.3**	-0.2	**-0.4**
Entebbe MAM	0.2	-0.2	-0.1	0.0
Entebbe OND	-0.1	0.2	-0.1	-0.2

4.5 Results and discussion from spectral analysis

Spectral analysis results indicated four major quasi-periodic fluctuations in the annual rainfall data. The peaks for annual rainfall were centred on 2–2.5 years, 2.6–3.4 years, 5 years and 10–12 years. Figure 11 shows some of the results from the spectral analysis of annual rainfall.

On seasonal scale, the long rains season had peaks centred mainly around 2–2.5 years, 3–3.7 years and 4–5 years (Figure 12) whereas the periods of the peaks for the short seasonal rainfall were centred around 2–2.5 years, 3–3.7 years and 4–5.8 years (Figure 13).

Previous studies obtained similar results and have associated the physical significance of these peaks to some global scale phenomena such as the QBO, ENSO and the sunspot cycle. For instance, the 2–2.5 year cycle has been associated with the reversal of the tropical stratospheric winds (QBO, e.g, in Edbon, 1975 and Bier 1977), the 3.3–3.7 year, 3.6–4.4 year and 5 year cycles have been observed in many general circulation parameters including ENSO (Namias, 1959; Kreuger and Gray, 1969; Favorite and McLain, 1973; Trenberth, 1976). The 10–12 year cycle has been associated with the sunspot cycle (Willet, 1965; Despande, 1967; Lawrence, 1971). The quasi- periodicity associated with the ENSO phenomenon was dominant during the OND season. The ENSO phenomenon is known to be a fundamental and quasi-periodic feature of the ocean atmosphere system, with periodicities ranging from seasonal to about 8 years (Rasmusson and Carpenter, 1983; Halpert and Ropelewski, 1987).



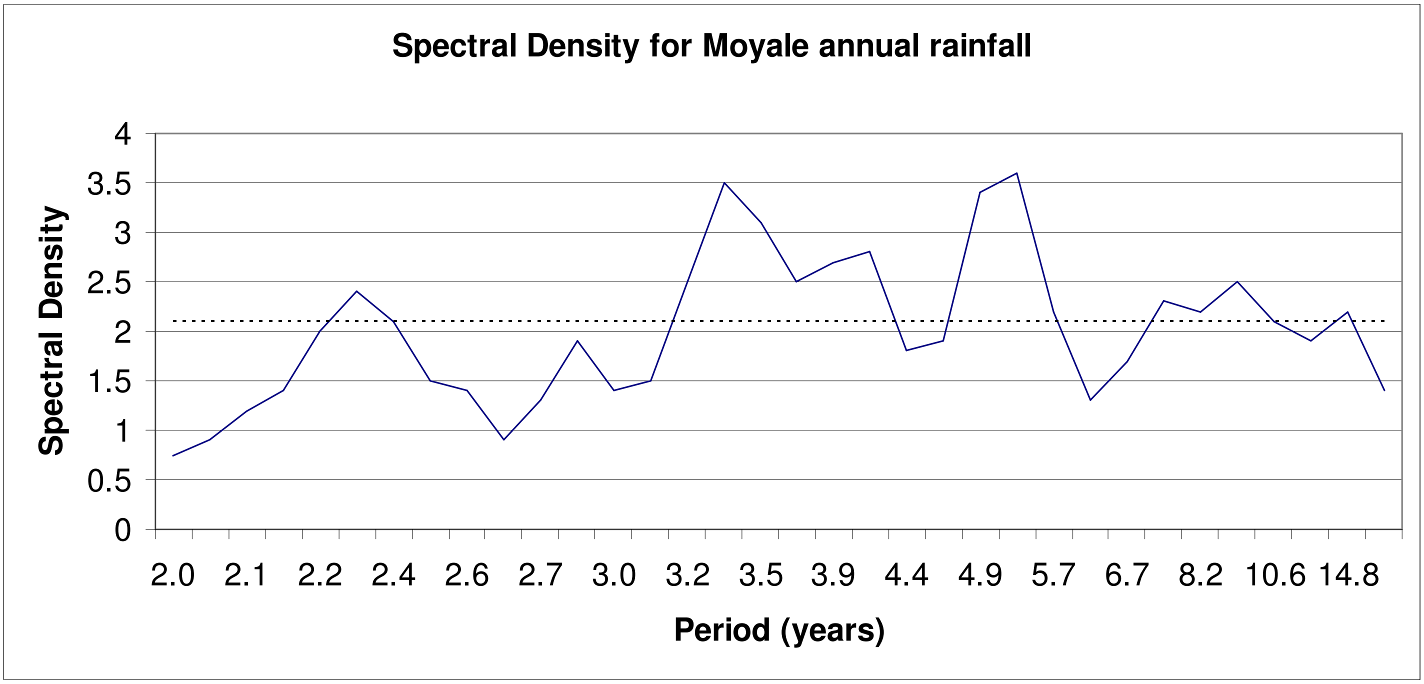
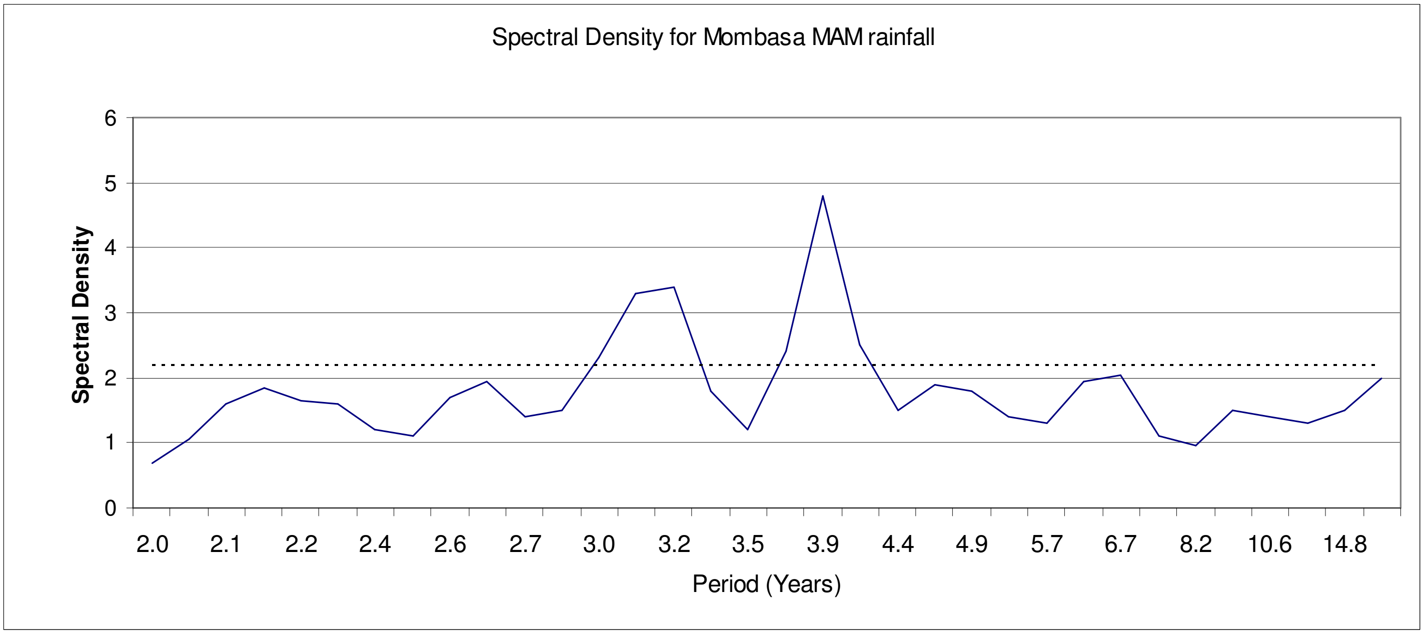


Figure 11: : Spectral density for the Annual rainfall (a) Mombasa (b) Moyale
The peaks above the doted line are significant at 95% confidence level)

Figure 12: : Spectral density for the Annual rainfall (a) Mombasa (b) Moyale (The peaks above the doted line are significant at 95% confidence level)



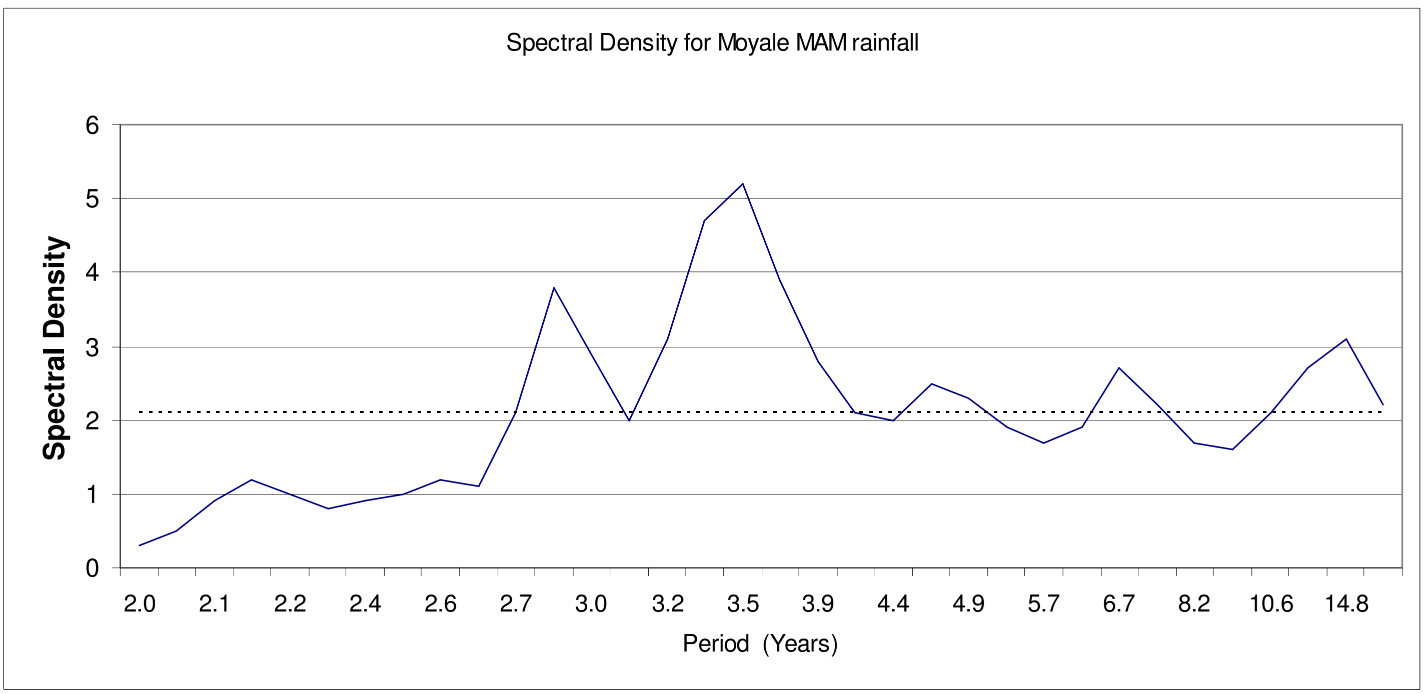
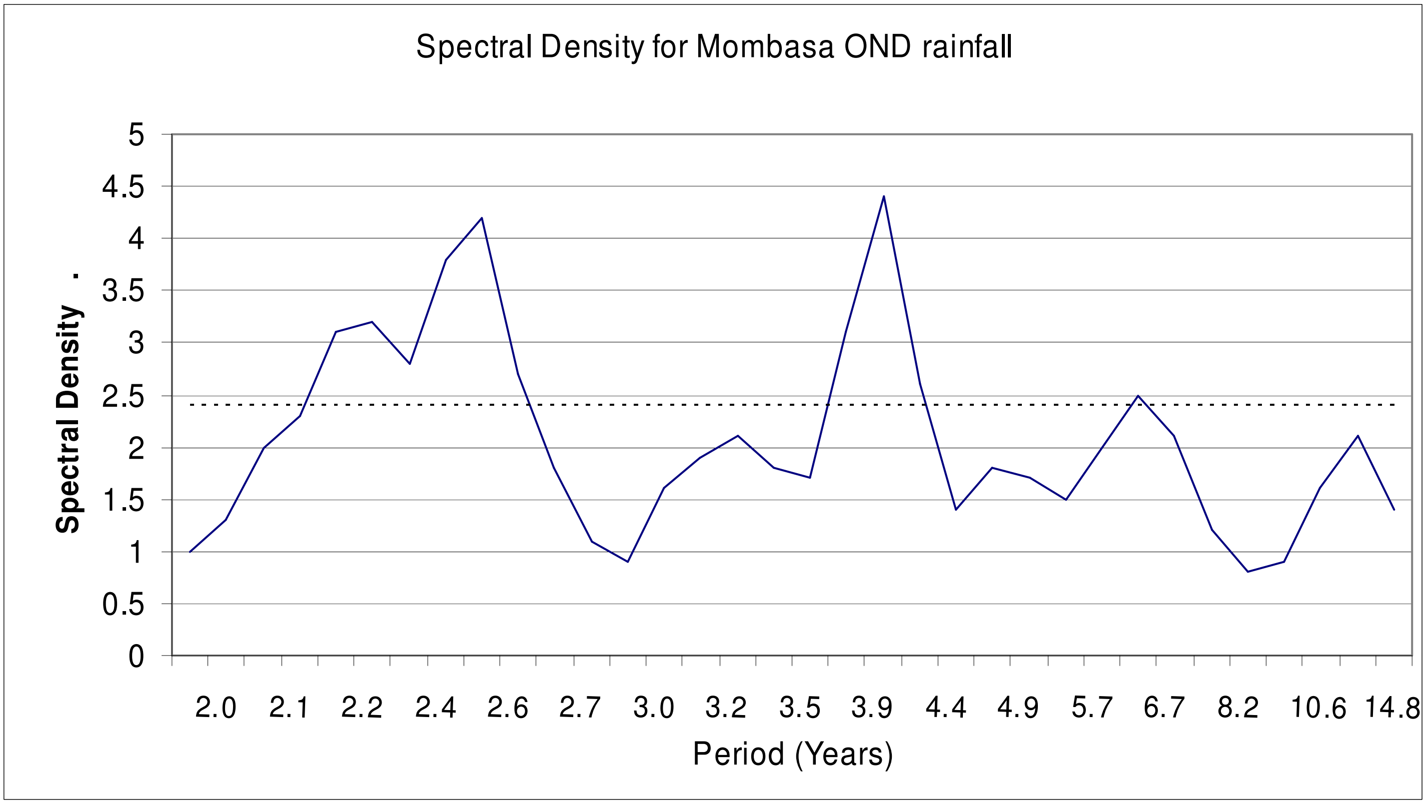
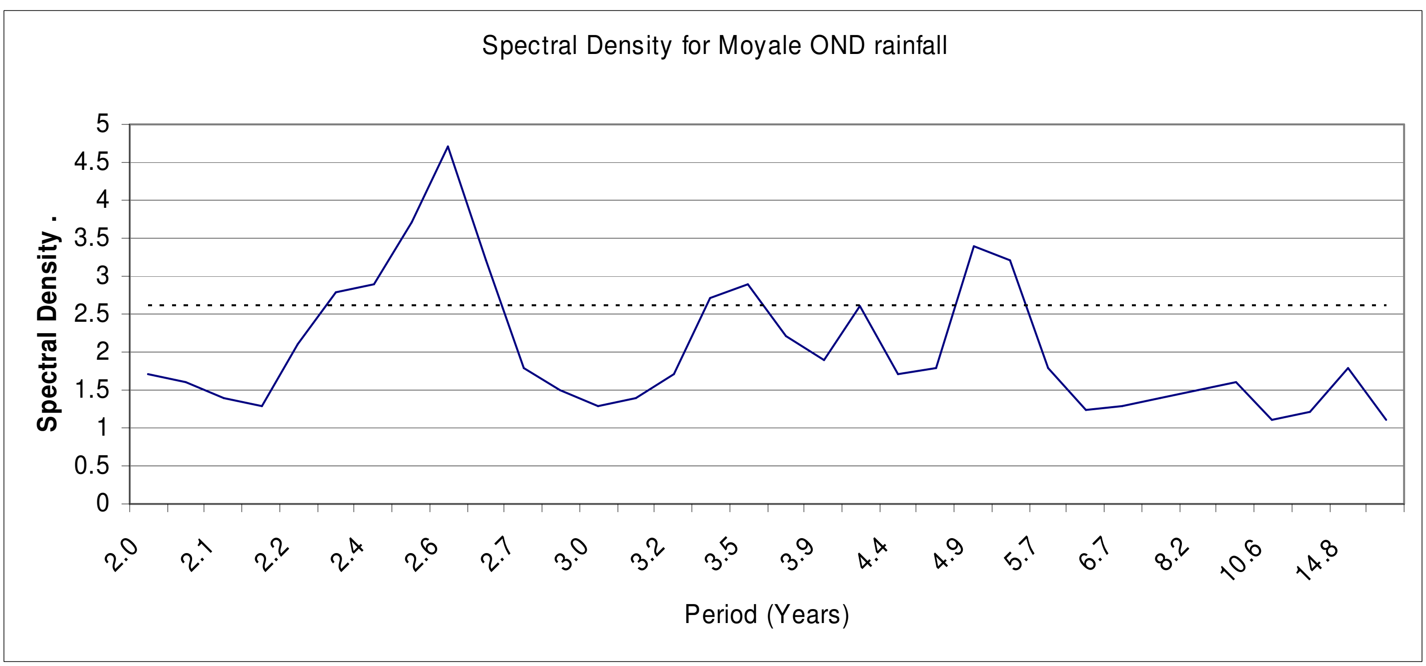


Figure 13: Spectral density for the OND rainfall (a) Mombasa (b) Moyale (The peaks above the doted line are significant at 95% confidence level)





5.1 Conclusions

This study examined the trends and periodic fluctuations in the rainfall over East Africa. Results from temporal characteristics of the East African rainfall classified the rainfall into bimodal and unimodal rainfall regimes. Results from graphical and time series analyses showed significant trends and variations in the annual and seasonal decadal rainfall for some of the stations used. It is possible that localized trends in climatic parameters are associated with changes in surface parameters such forest cover, surface roughness and albedo. The changes in surface parameters may be caused by deforestation, overgrazing and urbanization, among many other factors which have contributed to climate change. The study also revealed strong correlations between rainfall over the study region and the ENSO parameters (Nino 3+4 SSTs and SOI). It is further deduced that, although the major cycles in rainfall revealed from spectral analysis of 2 – 2.5 years, 3.6 – 4.4 years and 5 years, and 10 – 12 years are associated with the QBO, ENSO phenomena and sunspot cycles, respectively.

5.2 Significance of the results

The results obtained from the present study indicate a possibility of climate change over the region of study. Indeed climate change manifest as a shift in the mean or change in the variance both of which were noted from the study. The climate change is likely to impact on the socio-economy of the region and hence affect the quality of life. The result of the present study will therefore form the basis of enactment of policies that will assist in environmental conservation and mitigation of the impacts of climate change such as the occurrence of extreme weather events.

5.3 Some recommendation

The study has demonstrated the existence of trends in both seasonal and annual rainfall. There is need, however for numerical simulation in order understand the physical processes that lead to climate change. The study also revealed the existence of quasi-periodic fluctuations in the rainfall. The quasi-periodic characteristics could form the basis of development of empirical models for prediction of rainfall on seasonal and annual time scale.

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