SOME ASPECTS OF THE ANOMALOUS OFF-SEASON RAINFALL OVER EAST AFRICA DURING THE DECEMBER-FEBRUARY SEASON

BY

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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DEDICATION

This work is dedicated to my mother;

My mother is a driver, who has never spared herself; a crusader, who has espoused the cause of our family; a patriot, who never questions the wisdom of devoting her time and life to the family and a warm-hearted individual, who has, and is always willing to help others.

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ABSTRACT

For effective planning, development and management of rainfall related social-economic activities there is a need to understand the characteristics of the rainfall variability during the rainy and dry seasons. East Africa, generally experiences two rainfall seasons; between March to May and September to November. These are referred to as the Long and Short rains respectively. Although these are the two major rainy periods over most parts of East Africa, there are some regions, especially over the western parts of East Africa, which receive substantial rainfall during the June-August season. Hence December-February (DJF) may be considered as the truly dry season over most parts of East Africa. However, in some years the supposedly dry season experience quite a lot of rainfall. This study attempts to understand some of the characteristics of these off-season rainfalls. Most of the agriculture activities are concentrated in the main rainfall season, while the off-season rainfall are generally under-utilised.

The data used for this study includes daily rainfall data, monthly rainfall data, winds data (surface and upper level), Southern oscillation index (SOI) and sea surface temperatures (SST) over eastern tropical pacific (Niño-3). Most of the data was obtained from Kenya Meteorological Department. However, some of the Ugandan data were obtained from Uganda Meteorological

Department through correspondence. These data extended over the Period 1961-1990. Standard statistical methods, which included regression were used to estimate missing data, whereas inhomogeneity was tested and corrected using the cumulative mass curve technique.

Various statistical methods were used to investigate the characteristics of the December-February rainfall events. Rainfall anomaly indices were used to delineate the anomalous wet years during this season. Rotated principal component analysis(RPCA) was used to investigate the space-time features of the DJF-seasonal rainfalls. Spectral analysis examined whether the rainfall anomalous events exhibited any periodic variations. Correlation analysis was used to examine whether there is teleconnection between the anomalous DJF rainfall events and the El-Niño/Southern Oscillation (ENSO). Five-day (pentad) were used to study the rainfall distribution within the anomalous wet seasons.

The results from this study indicated that a number of years had anomalous rainfall during the DJF dry season. The wettest years during this season were 1961/62, 1963/64, 1968/69, 1977/78 and 1978/79. Pentads analysis from November to the end of March indicated that the rainfall observed during the DJF season in some years was an extension of the short rains, while in others it could be from the early onset of the long rains. In some years both scenarios were observed. However some seasons like 1978/79 showed no linkage with either of the rainy seasons. The spatial characteristics revealed by the S-mode analysis of the RPCA agreed well with those observed from the anomaly indices. The wet areas are concentrated near the large water bodies and over southern Tanzania.

Spectral analysis of the seasonal rainfall showed periodic fluctuations centred around 2.3-2.7, 3.3-4.3, 4.3-6.3, 6.2-9.5, 9.5-12.2 and 10.8-16.7 years. When daily rainfalls for anomalous rainy DJF-seasons were similarly subjected to spectral analysis, cyclic variations centred around 2.1-2.5, 3.2-4.1, 3.6-4.8, 9-12.9 and 22.5-25.2 days were noted. The DJF rainfall were negatively correlated with SOI and positively correlated with SST. This suggest a possible teleconnection between the anomalous rains during the DJF season and the ENSO.

The results of this study intend to form base for the development of a model for the forecast of the off-season rainfall. This will assist in averting the adverse consequences of the heavy rainfall events and proper use of the rain water, in agriculture, industrial, domestic among others.

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CHAPTER ONE

1.0 INTRODUCTION, OBJECTIVE OF THE STUDY AND LITERATURE REVIEW

1.1 INTRODUCTION

Rainfall is one of the climatic elements with the highest spatial and temporal variability in tropical countries including East Africa (for example Basalirwa, 1991 and Ogallo, 1980). Due to the high rainfall variability, extreme rainfall events are not uncommon. In some years, the droughts, that is, a situation where the rainfall is substantially below its climatological average for an extended period are experienced. This often leads to a situation where the water supply is below the normal demand. In some other years, there is excessive rainfall (flooding). Just like droughts, floods have also adverse effects. Flooding cause water logging and hence destroy crops leading to famine. There are also cases where bridges have been washed away and houses swept away thus causing loss of life and property. In general extreme rainfall events are known to have catastrophic repercussions on socio-economic activities.

The worst floods over East Africa occurred in 1961/62. During this anomalous rainfall episode, rivers were flooded damaging the transportation system and disrupting the agricultural activities. The inhabitants of the worsthit areas were rendered homeless. Lake levels rose drastically, with lake Victoria level rising to over 2 metres (Anyamba, 1983).

Both extreme rainfall events (droughts and floods) are natural disasters whose effects if not imaginatively and effectively combated may have far reaching consequences on the socio-economy of the regions affected. The impact of droughts/floods are worsened by the fact that they occur with unpredictable frequency with the result that the countries where they occur are often unprepared for the eventuality. Therefore in order to effectively plan and manage rainfall related social-economic activities, there is need to understand the characteristics and causes of the rainfall variability.

There are two major rainfall seasons over much of East Africa. The first occurs from March to May and is referred to as the 'Long-rains' season, as it accounts for a higher proportion of the annual rainfall and also these rains generally occur for a longer duration. The second rainfall season occurs between September and November and is usually referred to as the 'Short-rains', because of its slightly shorter duration and lower average rainfall amount (Ininda, 1994). There is however a third rainfall peak in parts of western Kenya and Uganda which occurs between July and August (Davies and Vincent, 1985).

Most of the annual rainfall is generally concentrated within the rainfall seasons, hence studies on rainfall have tended to be centred on the two major rainfall seasons. Although the December to February is generally a dry period over most of the equatorial East Africa, observational studies, for example Anyamba (1983) have shown that anomalous rainfall occur in some years during this season. Since this rains occur outside the main rainy seasons, they are often referred to as 'off-seasonal rains'.

The occurrence of rainfall during the dry period when harvesting and land preparation for the next crop growing season is being done, may cause havoc. Farmers panic as they are caught unaware and don't know whether these rains are a continuation or displacement of the seasonal rains.

However since these rains occur during dry period when there is water shortage they can be put to good use if they are predicted in advance. There is therefore need for better understanding of factors associated with such rains so as to come up with a rainfall forecasting model for these off-season rains. Observational studies are not only necessary in the formulation of forecasting models but are important for simulation studies. Rainfall forecasts with sufficient lead time are vital for proper planning of rainfall dependent activities.

The aim of this study is to understand the characteristics of the anomalous rainfall over East Africa during the December to February season.

1.2 OBJECTIVE OF THE STUDY

The main objective of this study is to investigate the characteristic features of the out-of-season rains within the December-February season. In order to achieve this objective the following studies were carried out;

(i) Identification of the years which had anomalous out-of- season rains.

(ii) Determination of the temporal and spatial patterns of the off-season rainfall.

(iii) Delineation of the years/seasons with similar off-season rainfall patterns over East africa.

(iv) Attribution of causes of the out-of-season rainfall based on atmospheric and ocean patterns.

1.3 LITERATURE REVIEW

The rainfall climatology and the factors associated with interannual variability of rainfall over East Africa are discussed in this section.

1.3.1 RAINFALL CLIMATOLOGY OF THE STUDY REGION

East Africa, comprising Kenya, Uganda and Tanzania lies between latitudes 4^0N and 11^0S and longitudes 30^0E and 42^0E (see Figure 1). East Africa covers an area of about 1.8 million square kilometres and is characterised by great variation of topography. The region is bounded to the

East by the Indian Ocean, with a coastline of about 1200 Km long. In the interior, the land rises from the coastal plains to over 5000 metres in the East African eastern highland which include the Aberdares, mount Kenya in Kenya, and, mount Kilimanjaro and the Pare-Usambara mountain ranges in North-Eastern Tanzania, Asnani (1993).

The eastern highlands are separated from the western highlands by the eastern branch of the Great Rift Valley which runs through Kenya and Tanzania in a North-South direction. Within this branch are Lakes Turkana, Baringo, Nakuru, Naivasha and Elementaita in Kenya, and, Natron and Eyasi in Tanzania. To the west of the eastern Rift Valley branch is another meridionally-oriented chain of mountains comprising of Elgon on the Kenya/Uganda border, Iringa and Rungwe highlands and the Fipa plateaux in Tanzania. East Africa is bordered to the west by the western branch of the Rift Valley. Within this branch are lake Mobutu Sese Seko (formerly Albert), George, Idi Amin (formerly Edward), Kivu, Tanganyika, Rukwa and Malawi (Nyasa). The Ruwenzori mountains of South-Western Uganda lie to the East of this branch.

Lake Victoria which is the second largest lake, after lake Superior in the world is situated right on the equator in East-Africa. It is a shallow Lake, with an average depth of about 40 metres. Its surface water is at 1134 meters above mean sea level and covers an area of about 69000 square kilometres.

The above physical features over East Africa play an important role in determining spatial distribution of rainfall over the region as will be discussed in the next section.

A lot of studies have been conducted on various aspects of rainfall in the study area. Several authors, for example Ogallo (1989) and Otieno (1994) subjected the East African rainfall records to principal component analysis (PCA). This studies showed that many parts of East Africa have more than one rainy season, and there is no month in a year when all parts of East Africa are absolutely dry.

The climate of East Africa varies from equatorial rainfall forest to semi-arid/arid climate. Infact a large proportion of the region experience low rainfall contrary to what would be expected from its geographical location. Thus, East Africa has been classified as having one of the "Earth's problem climates" (Trewartha 1966) due to the wide spread deficiency of rainfall.

The distribution of the annual rainfall range from monomodal in south regions to bimodal in equatorial East Africa. There are however a few regions that display trimodal distribution .

Most areas in East Africa, North of 8^0s receive two main rainfall peaks per year. The two rainfall peaks occur in March to May and September to November/early December (Ininda, 1994). These seasons are commonly known as the Long rains and the Short rains respectively. These two rainy seasons occur when the Inter-tropical convergence zone (ITCZ) has maximum influence over most of East africa. The single maximum in southern Tanzania occurs in November-April when the ITCZ reaches its southmost extent over the continent of Africa. The topographical features together with the effects of many large inland lakes introduce significant modification to the flow patterns, so that the rains do not exactly follow the classical ITCZ patterns. thus for some locations the peak rainfall months may not coincide with the generalised rainfall seasons.For instance in some locations the short rains occurs between October to December which has made some authors such as Nyenzi(1988), to define the short rain season to be from October to December. For example the ITCZ has been observed to be very diffuse in East Africa due to the diversity of topography.

Some regions close to the equator and located to the West of the Eastern Rift Valley have a third rainfall peak in July and August. Davies and Vincent (1985) have noted that the weather systems which are responsible for the July-September rains in some parts of the region are not similar to those associated with the two main rainy seasons. The Southern part of East Africa experience a single continuous rainfall season in November and March when the ITCZ and the associated rainfall belt is located South of the equator. However, taking East Africa as a whole it is noted that generally the December-February season is the drier season.

Although during the December to February, most of the equatorial East Africa is generally dry, in some years excessive rainfall is observed over a large portion. For example January and February of 1962 and 1993 were generally wet over most parts of East Africa (Ininda, 1994).

It has been suggested that some of the out-of-season rains in East africa are due to influences from the extratropical systems (Henderson, 1949; Thompson, 1957; Forsdyke, 1960; Johnson, 1963; Lumb, 1970). For example Forsdyke (1960) has described northward movement of a cold front off the southeast African coast. According to Forsdyke, these fronts do not bring much rain to East Africa except for a few cool cloudy days. Johnson (1962) and Lamb (1966) associated some of the coastal rains with residual instabilities associated with cold fronts which had intruded into the equatorial regions. These fronts, occurring during southern winter season, are accompanied by pressure rises or surges. The pressure surges, which are recorded at all coastal stations upto Mogadishu in Somali, are associated with build up or decay of

Southern winter systems. Lamb (1966), has attributed high precipitation which caused a rise in lake levels in East Africa in early 1960s to the anomalies in the atmospheric pressure of the Northern hemisphere during the same period.

The seasonal features discussed above undergo year to year variations so that we have years of heavy rainfall leading to severe flooding, and years of deficient rainfall that lead to drought. It would be useful to predict these variations because of the influence they would have on agriculture and water resources.

1.3.2 FACTORS THAT INFLUENCE RAINFALL

Some of the factors that influence rainfall in East Africa include, the ITCZ, the Congo air mass, Subtropical anticyclones, monsoonal winds, Jet streams, Easterly and Westerly waves, ENSO, QBO, Tropical cyclones and global teleconnection, among many others.

During the Northern summer season (June to August) the overhead sun has shifted the ITCZ -induced rain belts northwards, outside East Africa. Most of the rains received within this period are restricted to near large water bodies, and the western areas which are under the moisture influx from the Atlantic Ocean and the moist Congo/Zaire Basins (Okoola, 1997).

During the Northern winter season (December to February), the overhead sun is located in the Southern hemisphere. The ITCZ and the related rainfall systems are now restricted over Southern parts of Tanzania during most of this season. Other wet areas are concentrated around the Indian Ocean, coast and the shores of the large inland Lakes (Ogallo, 1987). Lake Victoria is one of the largest fresh water lakes in the world, and it has a very strong circulation of its own (Asnani and Kinuthia, 1979). Other factors controlling seasonal rainfall over East Africa include the position, orientation, and intensity of the ITCZ, subtropical anticyclones, Indian Ocean cyclones, monsoonal winds, sea-surface temperatures, the jet streams, and several others including regional factors like topography and large water bodies (Griffiths, 1972). In general, more rainfall is received over East Africa during June to August than December-February. There are, however, some years when most parts of East Africa are excessively wet during December to February season (Nyenzi, 1988).

1.3.2.1 INTER-TROPICAL CONVERGENCE ZONE (ITCZ)

In the equatorial region the sun is overhead at any given location twice in each year. This causes two distinct monsoonal winds to flow to this zone of maximum heating and creating a region of low level hemispheric air mass convergence called the Intertropical Convergence Zone (ITCZ). The surface structure of the ITCZ in eastern and southern Africa is modified by topography and especially in East Africa where it is very much diffuse (Nienwolt, 1978 and Anyamba, 1983). The activity of the ITCZ is dependent on the nature of the trade winds (monsoons), whether they are dry (have land track) or moist (Oceanic track). There would be no formation of rain clouds without the availability of sufficient moisture in the atmosphere.

In the tropical region, in the lower troposphere, there is a surface of wind discontinuity with horizontal velocity convergence and upward vertical motion on global scale (Griffith, 1972). Naturally, there is cloudiness near this surface, aligned in nearly East-West direction. It oscillates in north-south direction in response to the relative position of the sun (Griffiths, 1972). On the surface, ITCZ seeks regions of highest temperatures for its location. Over the oceans also, the surface position of ITCZ nearly coincides with the region of highest sea surface temperature (SST). In the analysis of pressure field, ITCZ is a region of low pressure (Sansom, 1963). ITCZ is not a static zone having steady-state conditions of cloudiness. There are oscillations in the position and intensity of vertical motion in its neighbourhood. There are oscillations with a period of one day (influenced by land-sea breezes), 4-5 days (influenced by migratory tropical and extra-tropical waves) and also oscillations of larger periods associated with the position and intensity of the planetary-scale meridional cells (Hadley and Equatorial cells). The persistence of ITCZ in a region may generally lead to above normal precipitation. During the floods of the 1961/62 in East Africa, the ITCZ was intense and remained for a longer time in this region. One of the reasons given is that the axis of the Arabian high was zonally oriented strengthening the easterly component of the north easterlies (Anyamba, 1983).

1.3.2.2 MONSOONAL WINDS

There are two relatively drier seasons between the two rainy seasons when East Africa comes under the influence of the monsoon air currents of the west Indian ocean (north-easterlies). The northeast monsoon occurs during the southern hemisphere summer season while the southeast/southwest monsoon occurs during the northern hemisphere summer season (Trewartha, 1961). The northeast monsoon air current is hot and dry in most parts of East africa and is part of the equatorward outflow from the Arabian high pressure. The southeast-southwest monsoon air, on the other hand, flows from the Mascarene high in the southwest Indian Ocean and is cool and moist. These monsoon currents are shallow, being confined to the lowest 3 kilometres above mean sea level (Findlater, 1968). They are over-ridden aloft by an easterly current. The diminished precipitation activities over most parts of East Africa during the monsoon seasons have been attributed to the pronounced difluence/divergence of the monsoon currents along the East African coastal plains (Forsdyke, 1949; Glover and Henderson, 1954; Trewartha, 1966 and Findlater, 1968). They also tend to flow parallel to the coast and the north-south running East African highlands. Thus, apart from being unable to advect moisture from the Indian Ocean into the interior, these winds do not experience appreciable orographic lifting which would enhance vertical motion and hence precipitation. However, there are occasions, especially during the month of January, when the northeast monsoon current has a long track along the ocean; such occasions are accompanied by rainy periods (Shukla and Misra, 1977).

The southeast-southwest monsoon, although dry over most parts of East africa, is accompanied by extreme cloudiness especially over the eastern highlands (Atkinson and Sadler 1970). The inconsistency between cloudiness and precipitation in this area during the southeast-southwest monsoon, season has been attributed to the existence of an inversion layer whose base is near 700 mb and top near the 650 mb levels (Taljaard 1955). This inversion damps further cloud development, rendering them shallow and therefore unable to precipitate. Whereas over most regions of East Africa, the annual rainfall exhibits strong seasonality, the western parts particularly Uganda receive substantial rainfall throughout the year. Nevertheless, the seasons are by no means universal due to the varying degrees of the major rainfall enhancing mechanisms (Trewartha 1961; EAMD 1962; Graffiths 1972; Potts 1971 and Brown and Cocheme 1973).

Many extreme rainfall anomalies in East Africa during the major rainy seasons have been associated with anomalies in the monsoonal wind systems, since they are the major transport of moisture into the region. The convergence of these winds determine the location of the ITCZ. The characteristics of these winds over the region are controlled by the location, intensity, and orientation of the major semi-permanent anticyclones of Africa, together with other related general circulation parameters. Many investigators (Ininda, 1994; Cadet, 1985; Ogallo, 1988a and Janowiak, 1988), have discussed the teleconnections among the SO, sea surface winds; temperatures and pressure, the walker circulations, outgoing longwave radiation, monsoon winds, Indian rainfall, tropical storms, the 30-60 day oscillation and many other related parameters.

In 1961/62 the heavy continuous and widespread rains which occurred in East Africa were attributed to "massive horizontal convergence in the low level wind field" (Anyamba, 1983), coupled with advection of large amounts of water vapour into the East African lower troposphere. Lamb (1966) related the events of 1961/62 in East Africa to changes in the global circulation of the atmosphere.

1.3.2.3 SUBTROPICAL ANTICYCLONES

The Arabian and Saharan anticyclones are generally connected with the influx of dry continental air into East Africa. Their intensification or equatorialward shifts have been associated with dry weather over the region. Moisture advections into the region by the south easterlies are determined by the characteristics of the Mascarene and South Atlantic (St. Helena) highs

(Trewartha,1961). The south easterlies with long maritime tracks often carry more moisture and their intensification leads to increased rainfall activities. Anticyclones have been found to be dominant during the December-February season (Griffiths,1972).

1.3.2.4 JET STREAMS

A jet stream is a strong narrow current concentrated along a quasi-horizontal axis, characterised by strong vertical and lateral wind shears and featuring one or more velocity maximum (Reiter, 1961 and Wyrtki, 1973).

All jet streams in extra-tropical latitudes are associated with strong horizontal temperature gradients across their breadth. In the near-equatorial regions, even weak horizontal temperature gradients can give substantially strong vertical shears of wind, through thermal wind relationship, due to low values of coriolis parameter. However there are several places where strong low-level currents are observed after winds are averaged on monthly or seasonal basis. Such currents generally do not satisfy the WMO-recommended definition of speed equal or greater than 30 ms^{-1}, nor are their vertical and horizontal extents comparable to those of planetary-scale upper tropospheric jet streams like polar front jet stream. These low-level strong wind currents are often referred to as jet streams. These low-level jet streams are generally located in the lowest 1 to 2 km of the troposphere (Palmen and Newton, 1969). These are strongly influenced by orography, friction, diurnal cycle of heating and corresponding variations of pressure gradient and static stability. Some of the well-known jet streams are polar night stratospheric westerly jet stream, African Easterly Jet,QBO jet stream, Polar front westerly jet stream, Sub-tropical westerly jet stream, Tropical easterly jet stream, East African low-level jet stream and Marsabit jet stream (Asnani,1993).

Rainfall anomalies over parts of the region of the study have been associated with anomalies in the jet streams (Kanamitsu and Krishnamurti, 1978 and Tanaka *et al*, 1975). The jet streams are important to weather because they are associated with instabilities generated as a result of strong wind shear. They also transport enormous amount of atmospheric energy across the latitudes as well as across the longitudes. Any anomalies in their characteristics will therefore have a significant impact on the weather systems.

The Subtropical Jet Stream (STJ) is a global phenomenon. It is located at the poleward boundary of the Hadley cell in both hemisphere at a height of about 200 mb. The jet is stronger during winter months.

Tropical Easterly Jet Stream (TEJ) is also of global scale. It occurs in the upper troposphere over S. E. Asia and Africa (Kotaswatan,1958). It was observed by Okoola (1982) that the location of TEJ fluctuates with changes in the intensity of the mascarene high.

The African Easterly Jet Stream (AEJ) occurs in middle troposphere over West Africa during northern summer, between 700 mb and 600 mb level in the latitude band between 15^0N and 17^0N.

A special feature of the southerneast monsoon during northern summer is the East African Low Level Jet Stream (EALLJ), sometimes referred to as Somali Jet. Its core is located between 1 km and 1.5 km above mean sea level (AMSL) with speeds of 20 ms^{-1} (Findlater, 1968). This jet stream is important in the inter-hemispheric mass, moisture and energy exchange it accounts for about half of the total cross equatorial mass transport in the lower troposphere. The jet stream originates from the Indian Ocean near Mauritius and crosses over the northern tip of Malagasy to reach the East African Coast at about 3^0S where it flows over the low-lying eastern area of East Africa just east of the high ground.

1.3.2.5 EASTERLY WAVES

Easterly waves exist in the tropical region of both the hemispheres, all the year around. However, they are more marked in the northern tropical region during June to September.

During their movement, the easterly waves undergo considerable variations in intensity, wavelength, speed, horizontal tilt, vertical tilt, thermal structure and position of cloudiness and rain relative to the trough line of the wave.

Easterly waves move in the neighbourhood of ITCZ and cause significantly disturbed weather. The so-called North-east monsoon rains over Southeast Peninsula of India during November, December and January also get enhanced in association with easterly waves moving in the neighbourhood of near-equatorial trough north of the equator. Generally cloudiness and rain occur in the region where relative to the migratory easterly wave, the air approaches the wave-trough in the lower troposphere.

Gichuiya (1970) investigated 18 episodes of heavy rainfall at coastal stations during the cool-dry season of July-September 1967. In each case he followed the disturbance from the ocean using surface chart analysis, satellite pictures and aircraft reports. Gichuiya (1970) found that the rain-bringing disturbances exhibited similar properties to the caribbean easterly waves, over the ocean areas where one prevailing flow was easterly. The waves studied by Gichuiya exhibited the following properties:-

(i) The direction of propagation was northwest;

(ii) The cyclonic curvature was manifested most clearly between 700-500 mb where closed circulation could occur;

(iii) There were no significant temperature changes;

(iv) The disturbance were proceeded by clear weather;

(v) The area of maximum precipitation lay along a well defined line.

Ogallo (1984) suggests that the easterly wave disturbance associated with the ITCZ over the Indian Ocean contribute considerably to the enhancement of rainfall over the mainland of East Africa, through the Advective processes.

Anyamba (1984) proposes that the substantial rainfall usually received in some parts of east Africa evolves from the orographic lifting of the moisture laden easterly current coupled with convergence between the basic flow and the local land/sea/lake breezes, augmenting the large scale rain-producing mechanisms.

A trimodal seasonal pattern of rainfall is sighted by Ogallo (1984) occurring over some stations in the East African Rift-valley. This is largely attributed to the complex orographic features of the Rift-Valley and the neighbouring mountain ridges. Other areas in western Kenya and Uganda bordering the Lake Victoria receive huge rainfall amounts throughout the year due to the influence from the local land/lake breeze circulation system.

Thomsett (1969) has suggested that only three regions in Kenya do experience mean annual rainfall amounts exceeding 1000 mm. These are the central highlands, western parts and a narrow zone of the coastal region. In the central highlands the annual rainfall generally increase with altitude. In the eastern part of Kenya highlands however, the annual rainfall regimes are highly seasonal, due to the large influence imposed by the monsoon system. Uganda on the other hand benefits greatly in terms of substantial rainfall, through the well modified topography and exposure of the country, and the Lakes surrounding it. Tanzania too receive good precipitation near the large Lakes and the highland regions (Ogallo, 1989).

Wallace and Chang (1969) and Asnani and Kinuthia (1979) have indicated the importance of topographically, induced local circulations in modifying the regional diurnal distribution of precipitation.

Alusa and Gwage (1978), Ogallo (1984) and others have carried out climatological analyses of East Africa rainfall data. The results obtained from the dry spell and wet spell analysis reveal the following salient features:

(i) In the dry areas considerably long dry-spells occur during the rainy seasons. The rain falls in form of heavy but short-lived storms.

(i) There is a general lack of persistence in the sequences of wet spells in East Africa, except in the very wet regions.

(iii) High persistence in wet spells is to a large extent

associated with the influence from the local topographic features and the nearness to the large water bodies.

Lumb (1970), has recorded excessive precipitation in the years 1922-23, 1936-37, 1947, 1951 early 1960's , 1968, 1978-79 and 1982. The wettest period was during the early 1960's when the East African Lake levels rose by over 2 metres.

Asnani and Kinuthia (1979) found from an observational analysis that the diurnal variation of the rainfall in East Africa was largely determined by the mesoscale flows, synoptic-scale flows, convective instability, and interaction between the mesoscale and synoptic-scale flows.

Hills (1978) noted that an unseasonal rainfall maximum exists in North-eastern Uganda and the western parts of Kenya from June to September. In a subsequent study (Hills, 1979) examined upper air data for the whole of tropical Africa, and was able to shed some light on the causes of this regional wet season. He found a rather complex interplay between five or six air masses at different levels. He related these disturbances to the influence of the west

African monsoon. Njau (1987) presented an updated review of the aspects of daily rainfall and some current studies.

Njau (1987) subjected time series of upper wind data at Nairobi, Entebbe and Dar es salaam to spectral analysis and observed wave disturbances with periods ranging from 2-3.5, 3.7-5, 5.7-8, 9, 10, 12-15 and 17-22 days. Rainfall series exhibited fluctuations with similar periods to those observed in the wind field. Westerly winds in equatorial regions are believed to be rain bringers (Johnson and Morth, 1960).

Single rainy season are concentrated in Tanzania mainland with exception of Arusha in the north eastern tip of Tanzania, Tanzania coast and lake Victoria region. Also northern part of uganda and some station in Kenya (Kitale and Narok) have single rainy season (Alusa and Moshi 1974).

Alusa and Moshi (1974) subjected East Africa rainfalls to pentad analysis. Generally short rains cessation varied between pentads 68 and 70 while long rains onset varied between pentads 14 and 16 for most of the stations. Observations showed that short rains cease on average during the 69th pentad. Tanzania's average of onset is 64th, Uganda's average pentad of onset is 14th while the main onset pentad in the bulk of stations in Kenya is the 15th pentad. Onset and cessation pentads appear to progress in an ordered fashion along the coast but not inland of East africa. Variability of onset pentads is due to the fact that there are usually a combination of rain generating mechanisms operating in differing degrees from place to place (Nieuwolt 1977).

However, the question of the origin and frequency of the"off-season rain bearing" disturbances still seems to be partly unsolved.

1.3.2.6 EQUATORIAL WAVES

A significant advance in Tropical Meteorology has been the identification of some waves in the near-equatorial region. Their amplitude is maximum in the neighbourhood of the geographical equator and decreases very fast away from the equator. Such waves are considered important for the semi-annual oscillation in the lower mesosphere and the upper stratosphere, for quasi-biennial oscillation in the middle and lower stratosphere, for the slowly-drifting Walker circulation in the equatorial (x, p) plane in the troposphere, 30-50 day oscillation in the troposphere and even for El-Niño and the Southern Oscillation (Walker,1923). On account of their relatively large wavelengths and periods, these near-equatorial waves are considered important dynamical links in the so-called tele-connections not only in the tropics but also in the extra-tropics through interactions with the extra-tropical waves and meridional circulations. The well-known equatorial waves are mixed Rossby-Gravity waves and Kelvin waves (Rasmusson,1984).

1.3.2.7 TROPICAL CYCLONES

Tropical cyclones develop in the vicinity of ITCZ or near-equatorial trough, where relative cyclonic vorticity is already present as a quasi-steady feature. Throughout the troposphere, tropical cyclones are warmer than their surroundings. In the lower stratosphere, tropical cyclones are slightly cooler than their surroundings (Lamb, 1966). Numerical modellers for tropical cyclones have confirmed that surface fluxes of moisture and sensible heat are essential for achieving realistic rates of storm intensification (Shukla, 1984).

Strong vertical upward motion in the cloud wall and an almost unlimited supply of water vapour from a warm ocean surface at the bottom combine to give extra ordinary rates of rainfall in most tropical cyclones. The rainfall may exceed 5 cm per hour.However, the rainfall decreases rapidly inwards and may vanish altogether at the centre of the eye. The rainfall also decreases outside the cloud wall. Easterly wave enhances the tropical cyclones (Janowiak, 1988).

Tropical cyclones (or storms) have been known to have drastic impact on the weather. The effects depend on the proximity of the region to the cyclone, and vary from droughts to floods (Griffiths, 1972). Floods occur as a direct influence when the storm passes close or hits the coast. Indirect influences are noticed when the storms generated out of the region interfere with the normal flow of the seasonal monsoon winds.

1.3.2.8 GLOBAL TELECONNECTION

Teleconnection is the simultaneous correlation between temporal fluctuations in meteorological parameters at widely separated points on the earth. One of the global teleconnection is the east-west global scale sea level pressure oscillation spanning across the subtropical Pacific (east/central Pacific) and Indian ocean (western Pacific) and is called southern oscillation (Cadet, 1985; Julian and Chervin, 1978). The intensity of the southern oscillation (SO) is measured by the difference between the sea level pressure at Tahiti (central/eastern Pacific) and Darwin (western Pacific), thus, sea level pressure at Tahiti minus sea level pressure at Darwin. The intensity of the SO is referred to as Southern oscillation index (SOI). The sign of the SOI is positive during La-Niña event (cooler sea surface temperature over the central/east equatorial pacific) and negative during the El-Niño event (warmer sea surface temperature over the central/east equatorial pacific). Due to the link between the El-Niño and the SO, the term El-Niño Southern Oscillation (ENSO) is used to describe this large scale ocean-atmosphere interaction (Cadet, 1985).

Ogallo (1987) observed significant teleconnection between SO and seasonal rainfall over parts of East Africa especially during the Northern hemisphere autumn and summer season with the largest relationship being observed along the Kenya coast and western parts of East Africa.

Variation in some of the factors that control rainfall have been linked to the EL Niño/Southern Oscillation (ENSO) episodes (Cadet, 1985; Cadet and Diehl, 1984; Wright, 1985 and Ogallo, 1987). It was observed from the list of the warm episodes by Rasmusson (1984) that some of the rainfall anomalies in East Africa are associated with the warm and cold episodes over the Eastern Pacific Ocean. Cadet (1985) noted the strengthening/weakening of the South easterly monsoon wind systems during the warm/cold ENSO episodes. These monsoonal winds are the major source of moisture, especially along the coast and east of the central highlands.

The large negative/positive rainfall anomalies observed over these areas may be closely linked to the weakening/strengthening of easterly and South-easterly components of the monsoonal wind systems over the western part of the Indian ocean, together with other related phenomena. The Southern Oscillation has been linked to the zonal circulation anomalies, often referred so as "Walker-type circulation". These east-west circulations were first studied in the Indo-pacific area by (Bjerknes, 1969). A major mode of variability, called El-Niño-Southern Oscillation (ENSO), has been shown to have widespread interactions with rainfall at a regional scale (see Parthasarathy and Pant, 1984 for India; Hackert and Hastenrath, 1986, for Indonesia and Ogallo, 1988, for East Africa), or over the tropics as a whole (Ropelewski and Halpert, 1987;

Kiladis and Diaz, 1989). Negative correlations between the rainfall and the SST over the west-central pacific, suggest below average rainfall during "La Niña" years, and above-average rainfall during "EL Niño" years (Ropelewski and Halpert, 1987; Kiladis and Diaz, 1989). Associations between the southern oscillations and the upper-air wind anomalies in the pacific area, have been detailed by Hastenrath and Wu (1982) and Arkin (1982).

Such studies have been done over South Africa, for example D'Abreton (1993) has used ECMWF data to examine the causes of wet and dry summers. The low level anticyclonic anomaly centred on Madagascar was singled out as one of the mechanism for moisture inflow to Southern Africa. Global teleconnections have been observed between several atmospheric parameters, for example it has been observed that the SOI is positive when the Quasi Biennial Oscillation (QBO) is in the westerly phase (D'Abreton, 1993). Cooling of SST in the tropics, in particular the central equatorial Indian ocean is associated with warming in the sub-tropics to the southwest and southeast of Africa (Wright, 1985). Surface easterly wind is often observed over the western tropical Indian ocean when there is an anomalous upper level flow over the region (Ropelewski and Halpert, 1987). Persistence of a low level anticyclonic anomaly of radius 1000 km centred on Madagascar have been linked with reduced trade winds to the south (Kiladis and Diaz, 1989). Development of an upper level anticyclonic anomaly over the southeast coast of Africa has been associated with a standing trough in the mid-latitudes to the south of Madagascar (Cadet and Diehl, 1984). Janowiak (1988) analyzed the spatial patterns of summer (June-August) rainfall anomalies over the sahel region. Besides the dominant mode characteristic of the Sahel zone, he found an east-west opposition between the Southern part of west Africa (Gulf of Guinea Coast), and regions to the east of 25^0E, around Sudan and Northern Uganda. Rainfall over these regions has been observed to be higher during "La Niña" years. Most of the correlations between summer rains in Eastern Africa and circulation indicators over the indo-pacific area appear to be Linked to the major component of atmospheric interannual variability in this region: the Southern oscillation. Researches and findings have shown evidence of the role of ENSO towards rainfall variations in summer in Ethiopia (Haile, 1990; Beltrando and Camberlin, 1993), and over parts of Uganda and western Kenya (Ogallo, 1988).

Studies by Beltrando and Camberlin (1993) have shown that in years of above-average summer rainfall in North-East Africa there is a strengthening of the pacific walker cell as indicated by:

(i) Positive correlations with pressure over Tahiti, negative over Darwin;

(ii) Negative correlations with winds in the lower

troposphere (Zonal component of the trade winds);

(iii) Positive correlations with winds in the upper

posphere along the equator.

In the Indian Ocean sector, there is evidence showing that summer precipitation in North-Eastern Africa is strongly coupled to the intensity of the Indian monsoon. Droughts simultaneously occurred in India and Ethiopia in 1957, 1965, 1972, 1979, 1982 and 1986-87, all years of strong positive pressure anomalies over Bombay. Beltrando and Camberlin (1993) have also found significant negative correlations between Ethiopia "big rains "(Summer rains) and pressure in the Northern part of the ocean. These results are also consistent with the general patterns associated with the southern oscillations. It has been known for a long time that 'EL Niño'years were associated with droughts over India, and 'La Niña' with abundant monsoon (Walker, 1923; Bhalme *et al.*, 1983; Parthasarathy and Pant, 1984).

Some studies have been done on winds and zonal wind anomalies associated with rainfall variations in North-Eastern Africa are of opposite signs between the lower (700 hpa) and the upper (200 hpa) levels. They indicate a strengthening (westerly anomalies at low levels, easterly anomalies aloft) of the African zonal cell in case of higher than normal rains over Ethiopia, Eastern

Sudan, Uganda and western Kenya, and a weakening in case of below-normal rains. Over west Africa, the coherence between the 200 hpa and 700 hpa levels has already been investigated by Fontaine and Janitot (1992) and Moron (1993).

CHAPTER TWO

2.0 DATA SOURCES AND METHODOLOGY

This chapter is devoted to the data used in the study and the various methods which were used to achieve the various objectives of the study.

2.1 DATA

The data used in this study included daily and monthly rainfall, winds (speed and direction), Southern Oscillation Index (SOI) and Niño 3 SST. The sources of these data are discussed in the sections below.

2.1.1 RAINFALL DATA

Most of the monthly rainfall data sets were obtained from the Drought Monitoring Centre (DMC) at Kenya Meteorological Department (KMD). Some of the Uganda's monthly rainfall were obtained through Bazira (personal communication) and Okoola (personal communication).

The study covered the period 1961-90 when most of the stations had complete data. However, even within this period there were a few stations that had missing data. The missing data were estimated using the methods explained in section 2.2. The other problem that is inherent in the rainfall records is inhomogeneity. The treatment of this problem is also given in section 2.2. In East Africa, the monthly rainfall data are some of the most readily available data for spatial and temporal climatological analysis, the density of the station network is not uniform due to none availability of data at many remotely located areas. However efforts were made to select the stations which would ensure maximum representation of each of the homogeneous rainfall zones (Figure 2) derived by Ogallo (1989). Though there are various homogeneous rainfall zones derived by various authors eg, Griffiths(1972), Basalirwa(1991), Bazira(1997), etc they closely agree with Ogallo(1989). Figure 1 shows the spatial distribution of the seventy-two rainfall stations used in the present study. Their locations and other details are shown in Table 1.

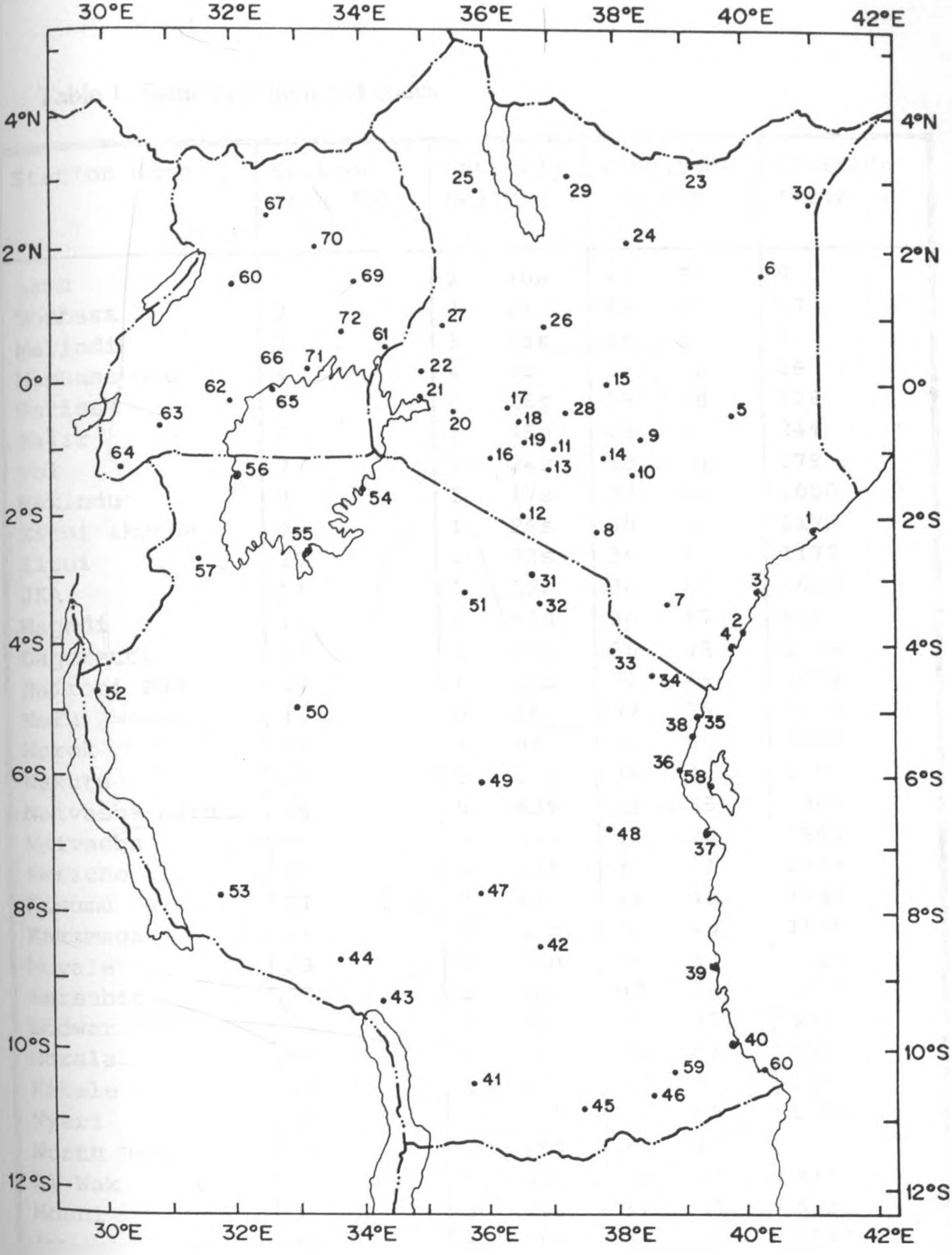


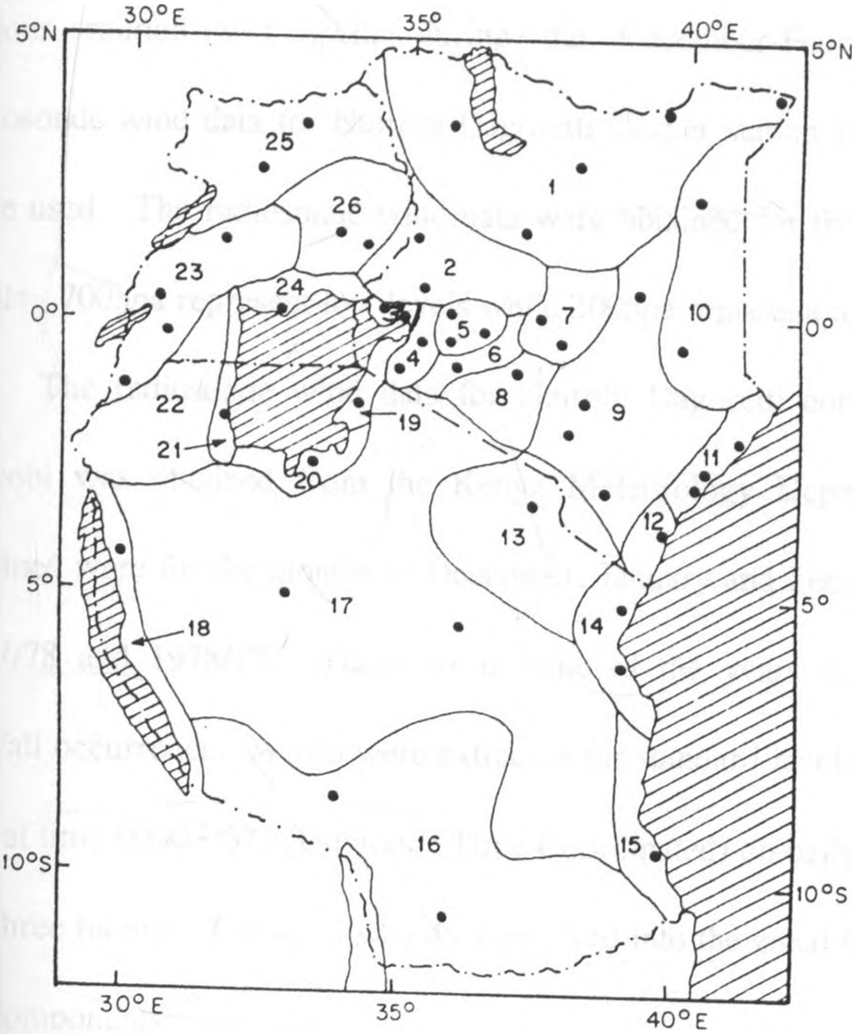
Figure 1: Network of the stations used (stations names are given in Table 1).

Table 1: Station position and codes

Station Name	Station Code No.	Latitude Deg.Min.	Longitude Deg.Min.	Altitude (metres)
Lamu	1	2 16s	40 50	9
Mombasa	2	4 2s	39 37	57
Malindi	3	3 14s	40 6	3
Mombasa Old	4	4 4s	39 42	16
Garissa	5	0 28s	39 38	128
Wajir	6	1 45n	40 4	244
Voi	7	3 24s	38 34	579
Makindu	8	2 17s	37 50	1000
Kitui ikutha	9	1 26s	38 4	1179
Kitui	10	1 22s	38 1	1177
JKA	11	1 19s	36 55	1615
Magadi	12	1 53s	36 17	615
Dagoretti	13	1 18s	36 45	1798
Nairobi PWD	14	1 19s	36 49	1676
Meru	15	0 3n	37 39	1570
Narok	16	1 8s	35 50	1890
Nakuru	17	0 17s	36 4	1991
Naivasha marula	18	0 42s	36 25	1906
Naivasha	19	0 43s	36 26	1900
Kericho	20	0 29s	35 11	2184
Kisumu	21	0 6s	34 45	1146
Kakamega	22	0 17n	34 45	1555
Moyale	23	3 32n	39 3	1113
Marsabit	24	2 18n	37 54	1219
Lodwar	25	3 7n	35 37	566
Maralal	26	1 5s	36 42	1951
Kitale	27	1 1s	35 0	1190
Nyeri	28	0 30s	36 58	1759
North Horr	29	3 19n	37 4	
El Wak	30	2 47n	40 57	394
Moshi	31	3 21s	37 20	813
Arusha	32	3 20s	36 37	1387
Same	33	5 5s	37 43	860
Amani	34	5 6s	38 36	911
Tanga	35	11 6s	39 4	49
Bagamoyo	36	6 24s	38 54	9

Table 1: (contd)

Dar es salaam	37	6	52s	39	12	53
Pangani	38	5	24s	39	0	9
Kilwa	39	8	55s	39	31	14
Lindi	40	10	0s	39	42	41
Songea	41	10	41s	35	35	1036
Mahenge	42	8	41s	36	43	1106
Tukuyu	43	9	15s	33	38	1646
Mbeya	44	8	56s	33	28	1758
Tunduru	45	11	6s	37	22	701
Masasi	46	10	42s	38	49	457
Iringa	47	7	38s	35	46	1428
Morogoro	48	6	50s	37	39	579
Dodoma	49	6	10s	35	46	1120
Tabora	50	5	5s	32	50	1182
Ngorongoro	51	3	12s	35	27	2288
Kigoma	52	4	53s	29	38	999
Sumbawanga	53	7	57s	31	36	1722
Musoma	54	1	30s	33	48	1147
Mwanza	55	2	28s	32	55	1139
Bukoba	56	1	20s	31	49	1143
Bihara Mulo	57	2	38s	31	19	1478
Zanzibar	58	2	28s	39	13	18
Nachingwea	59	10	21s	38	45	463
Mtwara	60	10	21s	40	11	113
Tororo	61	0	42s	34	10	1226
Katigondo	62	0	13s	31	44	1311
Mbarara	63	0	37s	30	39	1412
Kabale	64	1	15n	29	59	1867
Entebbe	65	0	3s	32	27	1183
Kawanda	66	0	25n	32	32	1196
Gulu	67	2	45n	32	20	1106
Masindi	68	1	41n	31	43	1146
Soroti	69	1	43n	33	37	1127
Lira	70	2	15n	32	54	1085
Mukono	71	0	21n	32	45	1184
Namulonge	72	0	32n	32	37	1236



ure 2: The delineated climatological zones of East Africa (Adopted from allo, 1989).

2.1.2 WIND DATA

To describe the general circulations which are associated with the various rainfall wet spells during the December-February period, the radiosonde wind data for Nairobi Dagoretti Corner station (1^0 18'S, 36^0 45'E) were used. The radiosonde wind data were obtained for the 700 and 200 hpa levels. 700hpa represent low levels while 200hpa represent upper levels.

The radiosonde wind data for Nairobi Dagoretti corner station within Nairobi was obtained from the Kenya Meteorology Department. The data obtained were for the months of December, January and February for the years 1977/78 and 1978/79. These were some of the years showing anomalous rainfall occurrence. Winds were extracted for standard levels 700 hPa and 200 hPa at time 0000 UTC (Universal Time Coordinated) on daily basis for each of the three months. The wind was then resolved into the zonal (u) and meridional (v) components.

2.1.3 SOI AND Niño-3 SST DATA

The Southern Oscillation Index data were provided by Ininda (personal communication). The SOI data consisted of the normalised monthly Tahiti minus Darwin Sea Level Pressure (SLP). The Niño-3 SST is the areal average of the SST over the Eastern equatorial Pacific Ocean, and extends from 150^0W to 90^0W and 5^0N to 5^0S. This data was provided by Nzau (personal comm.). Both SOI and Niño-3 were used to investigate the linkage between the December-February seasonal rainfall over East Africa and the global teleconnection.

2.2 ESTIMATION OF MISSING DATA AND DATA QUALITY CONTROL

Before any data analysis, there is need to examine the quality of the data. Data quality control is necessary if correct statistical inferences are to be made from the analysis. Inconsistency in the observed data may occur due to several reasons. For example, change of locations of observing stations or change in the instruments used at the station which may include changes in the instrument model and/or replacement of spare parts. In this case the data ceases to be homogeneous (a sample from the same statistical distribution). Other errors in the rainfall data include transmission and typographical errors, and the undercatch of the precipitation by rain gauges (Sevruk, 1982; Folland, 1988).

The undercatch of surface precipitation gauges arise due to wind, wetting of gauge walls, evaporation from the gauge, splashing into or out of the gauge (Legates and Willmolt, 1990). However, such problems are unlikely to be severe in the tropics where the winds are generally lighter and the rain drop sizes are large (Folland, 1988).

The errors due to transmission, typographic are corrected as follows: The station time series were inspected for outliers. This was achieved through first transforming the data using a square root transformation of the observed precipitation series. The transformed series were more normally distributed (Legates, 1991). The transformed values which were greater than four standard deviations from the respective monthly mean were noted, and corrected by replacing them with estimated values just like for the case of missing data. The cases where the error was obvious, for example on additional digit, or data having been entered in inches rather than millimetres, correction was made.

There are various homogeneity tests and among them are, the homogeneity test for populations with frequency distributions close to normal (Karl Pearson 1984; Neyman 1937; Baker 1930, 1941 ,1958;

Rao 1952 and Preston 1953), Homogeneity test based on cumulative frequency distributions (Gumbel 1942; Birmhanm 1953; Kac *et al* 1955; Bartlett 1955), Parametric (distribution-free) test (Thom 1966), Cumulative mass curve, double mass curve analysis (Kohler 1949; Basalirwa, 1991).

In the present study the Cumulative mass curve analysis was used to examine homogeneity in the data used. Cumulative values of a variate are plotted versus time. A straight line graph (linear relationship) is obtained from the homogeneous records.

Heterogeneity can be deduced from the significant deviations of some points from the straight line. Gradients of the respective heterogeneous portions of the graph are used to adjust the heterogeneous components of the records in order to restore the homogeneity of the data.

2.3 METHODOLOGY

The methods of analysis include; the anomaly index, Principal component analysis, Spectral analysis, Rainfall pentad analysis, Correlation analysis and Wind analysis.

2.3.1 RAINFALL ANOMALY INDICES

The December-February (DJF)-seasonal rainfall anomaly indices for the period under study were used to investigate the space-time characteristics and delineate the anomalous wet seasons. The anomaly index used in the present study are the normalised rainfall records (Rao, 1952 and Nyenzi, 1984). The records were normalised in order to have zero mean and unit variance. The rainfall anomaly index Z_{ijk} for the rainfall observation X_{ijk} during season j was expressed in the form:-

$$Z_{ijk} = \frac{X_{ijk} - \overline{X_{ik}}}{\sigma_{ik}} \qquad \text{.................................(1)}$$

Where $\overline{X_{ik}}$ and σ_{ik} are the mean and standard deviations respectively at station k. Where i is the region.

In general, anomaly index value above zero signifies wetness while vice versa implies dryness. The seasonal rainfall anomaly indices for September-November (SON) and March-May (MAM) were also computed and used to examine whether the anomalous DJF rainfall was preceded by a wet SON and/or followed by wet MAM season.

2.3.2 AREAL AVERAGE RAINFALL INDICES

It has been observed that area-averaged indices are capable of removing errors which may be associated with individual locations (Ininda, 1994). They also give better indication of the synoptic features. Areal averaged indices which were used in this study include simple averaging method and time coefficients derived from Principal Component Analysis dominant modes. Simple areal rainfall average Z'_{ij} for the individual homogeneous rainfall zones may be expressed as;

$$Z'_{ij} = \frac{\sum_{k=1}^{n} Z_{ijk}}{n} \text{ ....(2)}$$

where n is the number of stations in the respective homogeneous Zone. i is the region and j the year (season).

2.3.3 EMPIRICAL ORTHOGONAL FUNCTIONS

Under this method the normalised rainfall records given by anomaly index were expressed in terms of some imaginary orthogonal functions. Model for these Empirical orthogonal functions (EOF) in terms of m orthogonal functions F_1, F_2, F_3 ,......F_m may be expressed as:-

$$Z_{ik} = \sum_{i=1}^{m} a_{ik} F_i + \beta_k U_k \text{ ....(3)}$$

where the indices i and k correspond to time and space respectively, while a_{ik} and β_k are regression constants. The unique component of the variance $\beta_k U_k$ is hard to obtain in the case of many physical variables, and this component is often neglected when the physical variables are subjected to EOF (Barring, 1987 and Bartlett, 1955). In such a case the EOF model given by above equation reduces to the principal component analysis (PCA), see equation 4 below.

$$Z_{jk} = \sum_{j=1}^{n} a_{jk} F_j \text{ ....(4)}$$

where j and k correspond to time and space respectively.

The theory and details of EOF method have been given by Harman (1976), Child (1990) and many others. This approach has been widely used by many investigators eg, Cohen (1983), Gregory (1975), Dyer (1977), Ogallo (1980).

The orthogonal varimax rotated solutions were also compared. The number of eigenvectors retained for these solutions were determined from the standard tests (Craddock 1973, Child 1990, Priesendorfer and Barnett, 1982).

The rainfall pentads for each of the season were subjected to PCA analysis. The PCA T-mode clustered pentads with similar characteristics. The PCA gave the spatial (from S-mode) and temporal (from T-mode) characteristics of the rainfall series subjected to it.

2.3.3.1 TIME COEFFICIENTS OF THE PRINCIPAL COMPONENT ANALYSIS MODES

Time coefficient series are generated from the weighted average of observed normalised variates as derived from Principal Component Analysis (PCA). Basic details of PCA are given in section 2.3.3. Under this method, factor loading of PCA derived eigenvectors are used as weights and areal indices are obtained from the averages of the series as indicated in the following equation;

$$Z_{ij} = \frac{I}{N}\sum_{j=i}^{n} a_i X_{ij} \qquad \text{(5a)}$$

where Z_{ij} is the areal index, a_i is the weight at eigenvectors i and location j and X_{ij} is normalised variate at location j and eigenvectors i. This method has been used by several authors including Ogallo (1988), Otieno (1994) and Folland (1988).

In testing the statistical significance of the factor coefficients, the formula developed by Burt, 1952) was applied. Burt (1952) noted that factor loadings were, in effect, correlation coefficients and for purposes of specifying an acceptable level of significance they could be treated in a similar manner to correlation coefficients (Okoola, 1997). The standard error (SE) of loadings increases from the first to subsequent factors. The formula for computing the SE of a loading which includes the necessary correlation for the factor number is of the form:

$$SE\ of\ a\ loading = SE\ of\ Correlation\sqrt{\frac{n}{n+1-m}} \quad \ldots\ldots\ldots(5b)$$

Where n is the number of variables and m the number of components.

The standard errors of correlations may be estimated from the table given by Child (1990). Significant components have coefficients greater than twice the standard error of the loading. This was used in this study to determine the statistical significance of the loadings for the various components.

2.3.4 THE SPECTRAL ANALYSIS

To examine whether the rainfall series exhibited any cyclic variations the DJF-seasonal series were subjected to spectral analysis. The pentads for the wet years were subjected to spectral analysis in order to determine whether the phenomena associated with anomalous rainfall consisted any periodic oscillations. The dry years were not however subjected to spectral analysis as no valuable information can be obtained from data with consecutive zeros.

The details of the spectral analysis method are omitted here as they are available in many standard texts including Jenkins and Watts (1968) and Chatfield (1975).

The auto-correlation transform method (Jenkins and Watts, 1968) was used in the computation of the spectral estimates. Under this method, the smoothed spectral estimates for a unit time interval $F(\lambda)$ may be expressed as :-

$$F(\lambda) = \frac{1}{2}\pi[W_0 + 2\sum_{k=1}^{m} r_k W_k \text{COS}\, 2\pi\lambda k\,] \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where r_k is the autocorrelation at time lag k, m is the maximum time lag, W_k the lag window and λ the wavelength. The Parzen window was used here as the smoothing function. Periodic fluctuations appear as peaks in the graph of $F(\lambda)$ versus, λ .

Parzen window is an estimated spectrum for a given time series and does not give negative estimates. It is a function used for smoothing spectrals. This smoothing procedure tend to lower the peaks and raise troughs thus suppressing the spurious peaks. The width of the spectral window which gives an estimator with the same variance is termed as bandwidth. The variance is inversely proportional to the bandwidth.

The statistical significance of dominant peaks were evaluated on a priori grounds (see WMO, 1966; Julian, 1971; Madden and Julian, 1971); thus the peaks were tested for significance at (or above) the 95% confidence level.

2.3.5 CORRELATION ANALYSIS

Simple correlation was used to study the spatial/temporal coherence characteristics of the seasons (Ogallo,1988 and Nie *et al*,1970). It was used to investigate the correlation between the anomalous rains and corresponding SOI/ENSO. The expression for simple correlation is:-

$$r = \frac{1}{N-1}\frac{\sum_{i}^{N}(X_i-\overline{X})(Y_i-\overline{Y})}{\sigma_x\sigma_y} \quad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

where;

$\overline{X},\overline{Y}$ are the respective means.

X_i, Y_i are the variates.

N is the number of observations.

N-1 is a correction for degrees of freedoms for samples less than 30, otherwise normal distribution is assumed.

r is the correlation coefficient.

σ_x, σ_y are the respective standard deviations.

r lies between -1 and +1. A value of r close to zero indicates no relationship between the pair of variables (Okoola, 1997).

From the previous studies, for example Ininda (1987) it has been observed that rainfall anomaly persists for several months. In order to study the similarity of the preceding spatial rainfall patterns, between the DJF and the preceding season (SON) and the season following it (MAM) temporal and spatial (map) correlation was carried out for the months from October to April. In order to investigate the relationship within months and seasons lag correlation analysis was carried out for the three seasons SON, DJF and MAM both on monthly and seasonal basis. The purpose for this part of the study was to find out whether the anomalous rainfall during DJF is linked with anomalous rainfall in SON (short rains) or the MAM (long rains).

2.3.6 CHI-SQUARE (χ^2) METHOD

In addition to the correlation method, the contingence tables were used to investigate the relationships between SOI and rainfall (Panofsky and Brier, 1958).

The significance of the relationship was tested by;

$$\chi_v^2 = \sum_{j=1}^{m}\sum_{i=1}^{n}\left(\frac{(\theta_{ij}-e_{ij})^2}{e_{ij}}\right) \text{..............................} (8)$$

θ_{ij} is the observed frequency

e_{ij} is the expected frequency ,

v is the degree of freedom ,

$v=(m-1)(n-1)$,

where m and n are the rows and columns of the contingency table.

2.3.7 DETERMINATION OF A RAINY PENTAD, RAINY MONTH AND RAINY SEASON

Many authors for example Griffiths (1972) and Nienwolt (1978) have defined a rainy month to have mean precipitation of at least 50 mm. A rainy season may therefore be considered as one with a sequence of such rainy months

Five daily rainfall amounts were added up to make a pentad rainfall total. However the last pentad of February 1964, which was a leap year was made up of 6 days. This last pentad of February was scaled down by multiplying the rainfall total in this pentad by 5/6 and then treated as any other pentad (Alusa and Mushi, 1974).

To investigate East-West and North-South spatial characteristics of the anomalous rains over East Africa, various stations between latitudes 1^0N-1^0S and longitudes, 34^0E-36^0E were selected on the basis of relatively high rainfall anomaly indices observed along these regions.

Stations picked to investigate the East-West features are Meru, Rumuruti, Maralal, Eldoret, Kakamega, Jinja, Entebbe, Katigondo and Mbarara. Stations chosen to investigate the North-South characteristic are Lodwar, Kitale, Eldoret, Kakamega, Dodoma, Iringa, Mbeya and Songea (See Table 1 for stations' latitudes/longitudes). For each of the five seasons observations were made both zonally (East-West) and meridionally (North-South). Due to lack of daily rainfall data it was not possible to develop Uganda pentads for seasons 1968/69, 1977/78 and 1978/79.

For the five seasons selected for further analysis, the pentads were cumulated for the stations used over East Africa and cumulative curves plotted. Cumulatives bring out the progression, onset and cessations of the pentads more clearly. These are used in conjunction with the pentads to analyze the rainfall anomalies in more details.

2.3.8 WIND ANALYSIS

An attempt was made by studying the zonal and meridional aspects of the winds to investigate anomalous characteristics in the wind which could be connected to the off-season rainfalls

To obtain the time averages of zonal ($\bar{u}$) and meridional ($\bar{v}$) components the wind speed F was resolved into u and v components at respective levels as follows :-

$u = -FSin\theta,$

$v = -FCos\theta$ 9

where u=zonal component.

v=meridional component.

θ =wind direction in degrees from true north.

F=wind speed.

CHAPTER THREE

3.0 RESULTS AND DISCUSSIONS

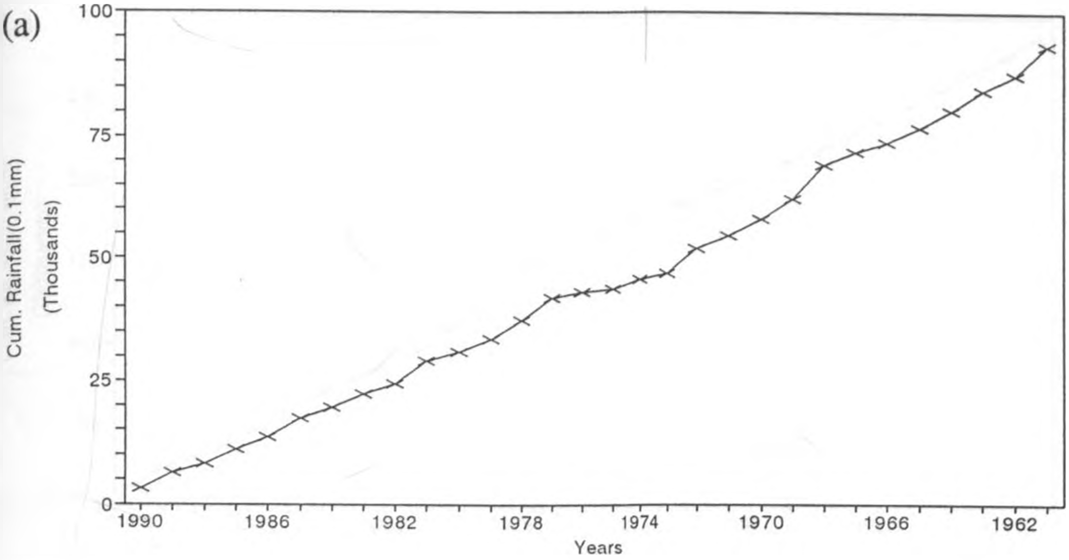
The results which were obtained when the data were subjected to the various methods which were adopted in the study are presented in this chapter. The details of the various methods were presented in Chapter Two.

3.1 ESTIMATION OF MISSING RECORDS AND CORRECTION OF HETEROGENEOUS RECORDS

Seven stations out of the seventy-two stations used, had cases of missing data. The missing values were filled in or were approximated by a statistical regression method. The stations which had missing values were Lodwar, North Horr, Magadi, Kitui, Arusha, Tabora and Kabale.

The mass curve analysis showed that the rainfall records at most stations were homogenous as depicted from the straight lines. However six stations indicated some form of heterogeneity. The names of these stations are given in Table 2. Examples of the uncorrected and corrected mass curves which were obtained from the annual rainfall records at the various locations are given in Figures 3 and 4. Some of the causes of the heterogeneity were discussed in Chapter 2.

(a)



(b)

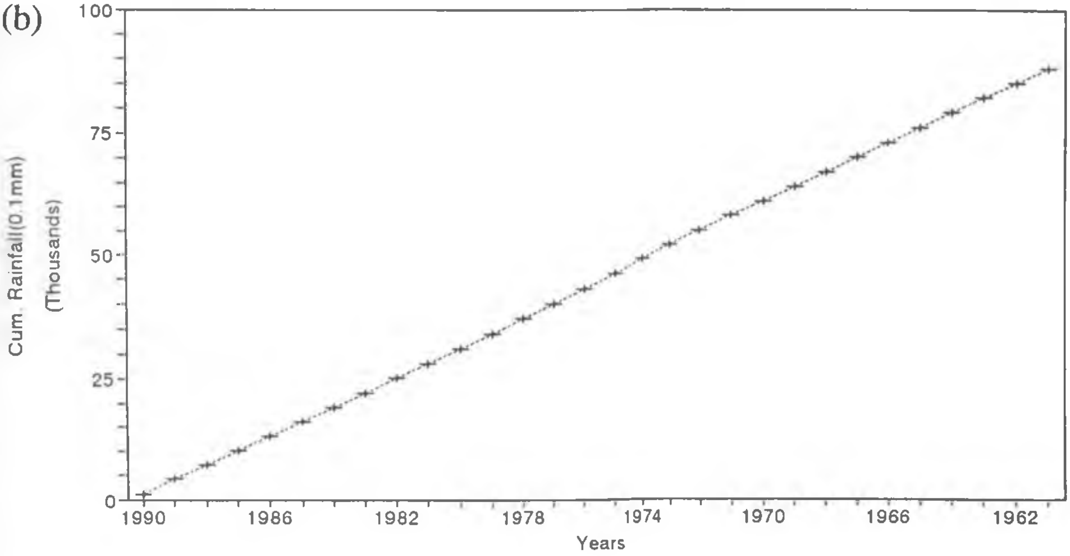


Figure 3: Mass curves for El wak; (a) before correction, and (b) after correction.

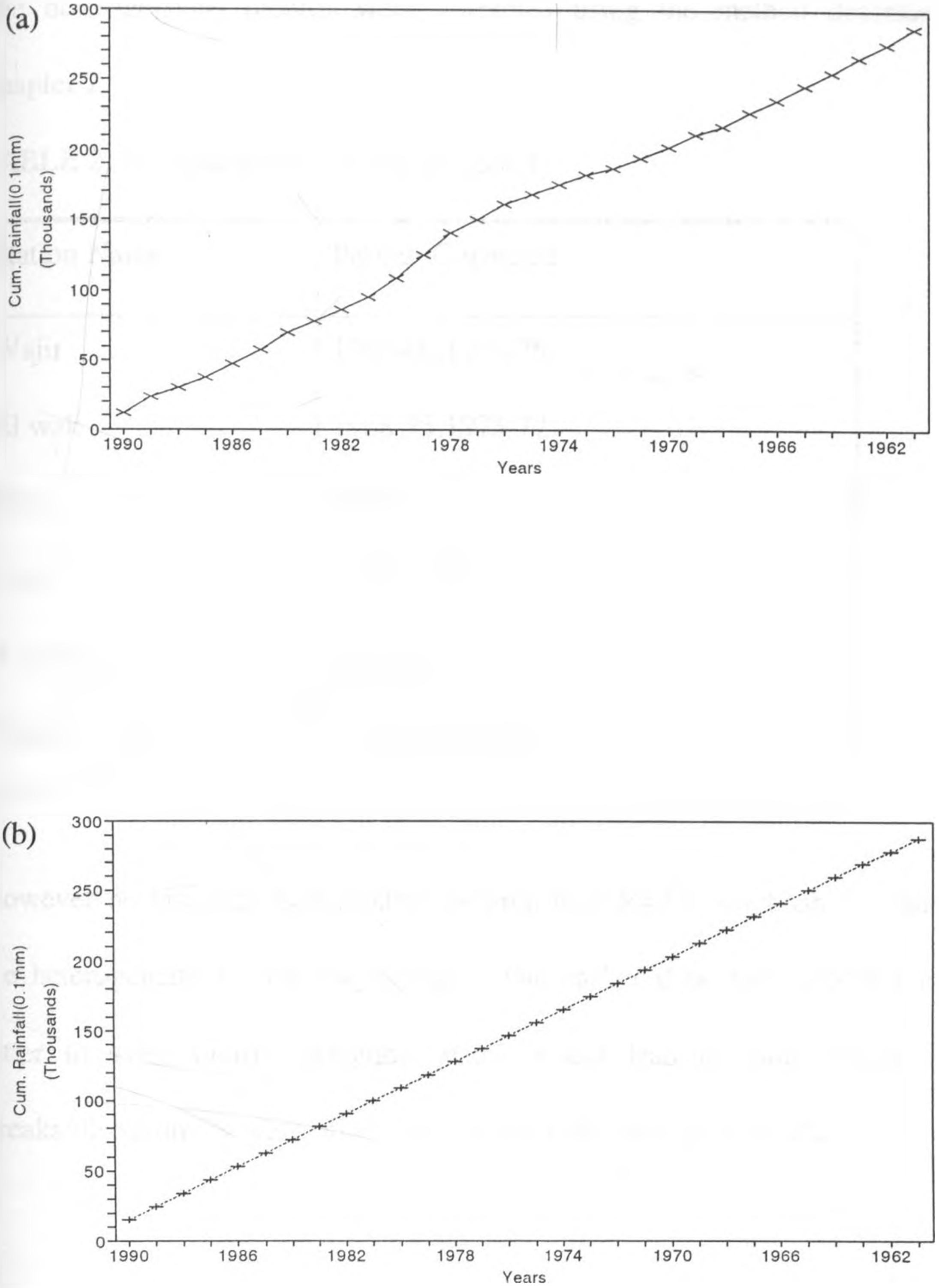


Figure 4: Mass curves for Lindi; (a) before correction, and (b) after correction.

The heterogeneous records were corrected using the method described in Chapter 2.

TABLE 2: Stations and the period corrected

Station Name	Period Corrected
Wajir	1961-66,1973-76
El wak	1968-75,1975-77
Meru	1967-71
Lindi	1971-74,1974-80
Katigondo	1961-66
Namulonge	1967-69,1982-85

However no historical background research was done to establish the cause of the heterogeneity for the six stations. The earlier data was corrected to the latter to avert future correction which would lead to more errors. No breaks/discontinuity were observed with the DJF seasonal rainfalls.

3.2 DELINEATION OF WET YEARS DURING SOUTHERN HEMISPHERE SUMMER SEASON

The December, January, February (DJF) seasonal rainfall were derived from the monthly rainfall records. The period considered in the present study was 1961-1990, giving twenty-nine complete seasons.

Rainfall anomaly indices were developed for each station and then averaged over all the stations to obtain the regional rainfall anomaly indices. The twenty-six rainfall homogeneous regions obtained by Ogallo (1989) were adopted in the present study (see figure 2). Examples of the time series of the DJF rainfall anomaly indices are shown in figure 5. Table 3 gives the frequencies (number of regions) showing the positive rainfall anomalies in each year (note that a given year includes the December of the preceding year. For example 1962 includes December of the preceding year, 1961, and the January and February of 1962). Years 1978/79, 1963/64, 1961/62, 1977/78, 1989/90 and 1962/63 were observed to be anomalously wet. 1978/79 was observed to be anomalously wet in all the 26 regions. This could mean that the system (s) responsible for the anomalous rainfall during the year were large scale. Most of the regions had between 4 and 6 extremely wet years. Each of the 26 regional DJF rainfall time series was analyzed and five wettest years picked.

Table 4 shows the five wettest years in each of the 26 region. 1978/79 season was observed to be the wettest as shown in the last column. Table 5 shows wet years and the number of regions with an anomaly index greater or equal to +0.5. The standard deviation +0.5 value was able to delineate years which were comparatively wet (on the basis of the outstanding peaks). The wettest years were further analyzed to look at the distribution on regional bases (Table 5). From table 5 it can be seen that there were 10 years with at least 6 wet regions namely 1961/62, 1962/63, 1963/64, 1967/68, 1968/69, 1972/73, 1977/78, 1978/79, 1986/87 and 1989/90. From the table it can also be seen that 1978/79 had the highest number of wet regions, suggesting that the whole of East Africa was anomalously wet.

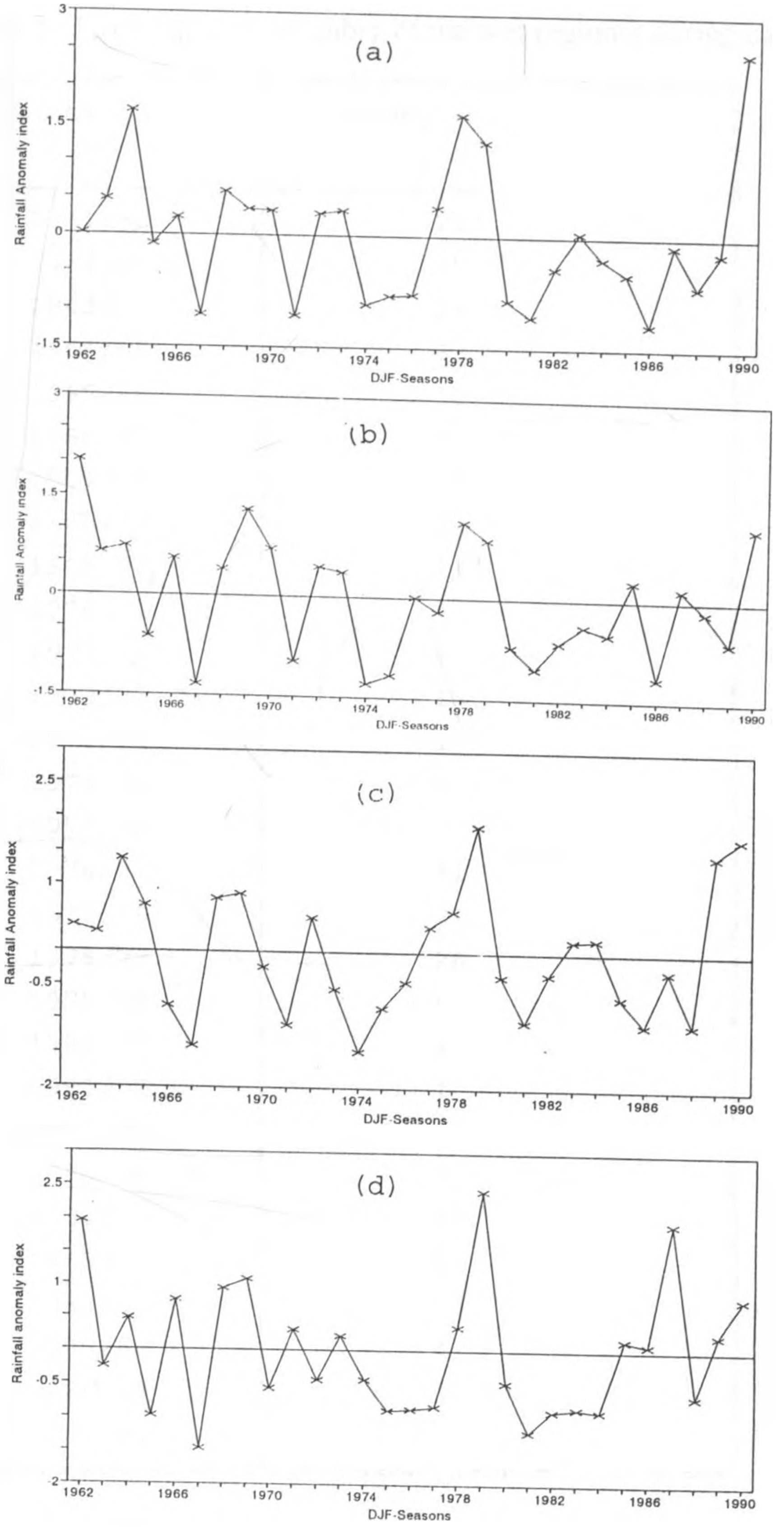


Figure 5: Examples of the DJF rainfall anomaly time series; (a) region 2, (b) region 3, (c) region 7, and (d) region 19, according to Ogallo (1989) regionalization.

TABLE 3: The frequency (number of the wet regions) during each year.

Year(Season)	Frequency
1961/62	21
1962/63	20
1963/64	24
1964/65	6
1965/66	10
1966/67	0
1967/68	14
1968/69	23
1969/70	11
1970/71	5
1971/72	13
1972/73	16
1973/74	1
1974/75	1
1975/76	2
1976/77	11
1977/78	21
1978/79	26
1979/80	6
1980/81	1
1981/82	4
1982/83	9
1983/84	5
1984/85	15
1985/86	5
1986/87	13
1987/88	4
1988/89	12
1989/90	21

TABLE 4: The five wettest years in each region (the years are given in an increasing order of wetness intensity).

Region	wet Years				
	Wetness increases ====>				
1	1967/68	1978/79	1963/64	1968/69	1988/89
2	1967/68	1978/79	1963/64	1977/78	1989/90
3	1978/79	1989/90	1977/78	1968/69	1961/62
4	1989/90	1972/73	1969/70	1967/68	1963/64
5	1961/62	1977/78	1963/64	1989/90	1978/79
6	1977/78	1972/73	1963/64	1969/70	1961/62
7	1968/69	1963/64	1988/89	1989/90	1978/79
8	1989/90	1988/89	1963/64	1961/62	1978/79
9	1964/65	1963/64	1977/78	1988/89	1978/79
10	1977/78	1963/64	1964/65	1968/69	1978/79
11	1961/62	1982/83	1963/64	1967/68	1978/79
12	1977/78	1984/85	1964/65	1978/79	1961/62
13	1977/78	1968/69	1989/90	1961/62	1978/79
14	1968/69	1989/90	1961/62	1988/89	1978/79
15	1986/87	1972/73	1963/64	1961/62	1978/79
16	1972/73	1963/64	1978/79	1967/68	1961/62
17	1978/79	1962/63	1982/83	1961/62	1986/87
18	1977/78	1968/69	1985/86	1978/79	1979/80
19	1967/68	1968/69	1961/62	1986/87	1978/79
20	1972/73	1986/87	1967/68	1965/66	1989/90
21	1962/63	1986/87	1989/90	1975/76	1978/79
22	1969/70	1962/63	1972/73	1986/87	1968/69
23	1961/62	1963/64	1976/78	1971/72	1978/79
24	1979/80	1986/87	1962/63	1968/69	1963/64
25	1963/64	1965/66	1962/63	1968/69	1978/79
26	1989/90	1962/63	1977/78	1978/79	1968/69

TABLE 5: Frequency of the regions that were wet during the anomalous wet years (summary of table 4).

Season (DJF)	No. of wet regions
1961/62	13
1962/63	6
1963/64	15
1964/65	3
1965/66	2
1966/67	0
1967/68	7
1968/69	12
1969/70	3
1971/72	1
1972/73	6
1975/76	1
1976/77	1
1977/78	10
1978/79	21
1979/80	2
1982/83	2
1984/85	1
1985/86	1
1986/87	6
1988/89	5
1989/90	11

However the Southern part of East Africa experiences its main rainfall season during December-February, when the ITCZ has the largest influence over the region. The equatorial East Africa, experiences little influence from the ITCZ during this season. Thus further analysis was done by considering the equatorial East Africa region (within 5^0N and 5^0S) and the Southern part of East Africa (South of 5^0S) separately. The rainfall anomaly index for the equatorial portion was obtained by averaging the anomaly for the stations north of 5^0S, while the anomaly for the stations South of 5^0S were averaged to obtain the index for the southern part. The overall East Africa rainfall anomaly index was also obtained by averaging rainfall anomaly indices for all the stations over East Africa. Figure 6 shows the three rainfall anomaly indices respectively.

The wettest years (with anomaly index $> +0.5$) observed from the equatorial index, southern index and overall East African index are tabulated in Table 6.

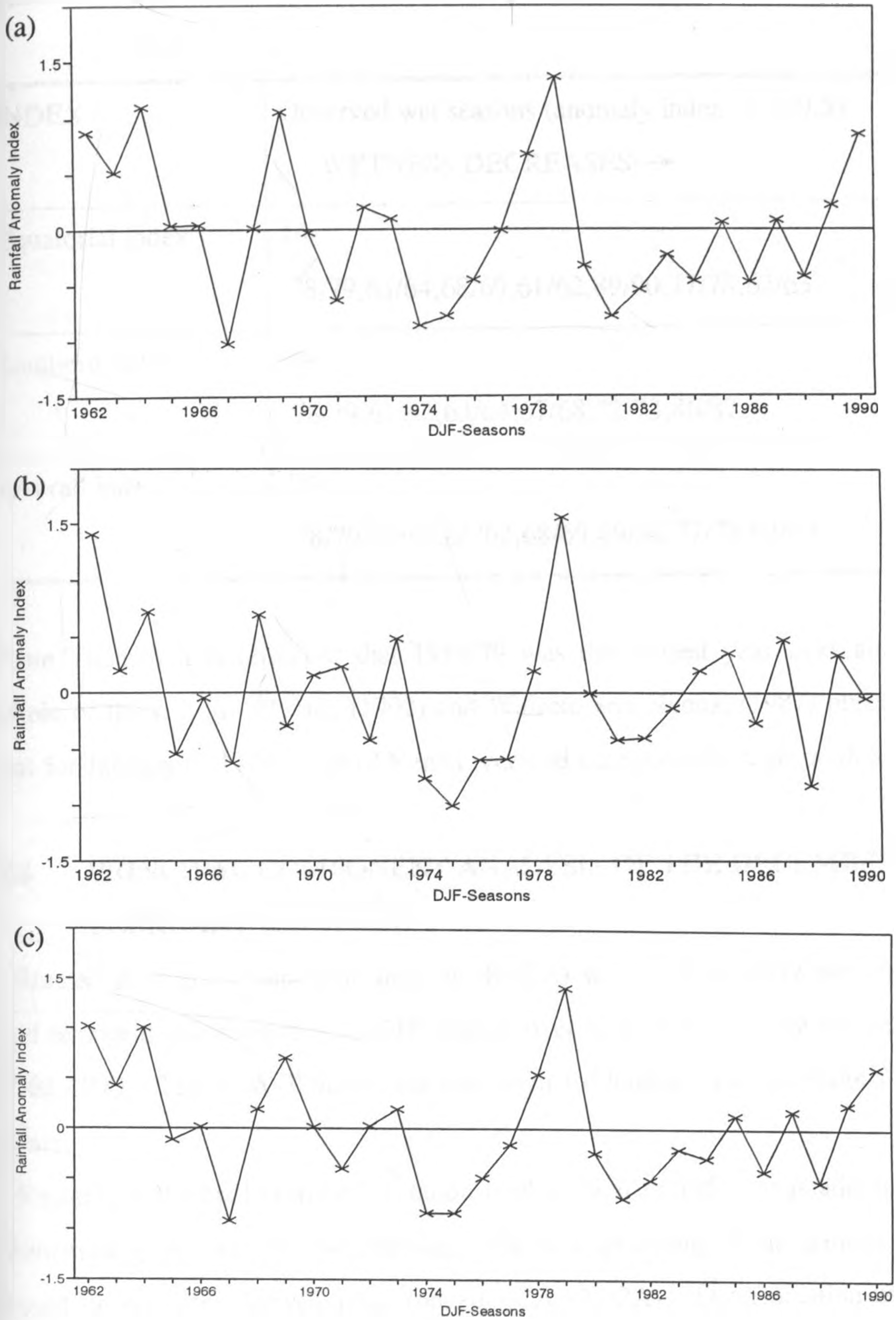


Figure 6: Regional Rainfall anomaly indices; (a) Equatorial East Africa, (b) Southern part of East Africa, and (c) The whole of East Africa.

TABLE 6: The wet years from the rainfall anomaly averaged over a large region.

INDEX	Observed wet seasons (anomaly index > +0.5) WETNESS DECREASES→
Equatorial index	19- 78/79,63/64,68/69,61/62,89/90,77/78,62/63.
Southern index	19- 78/79,61/62,63/64,67/68,72/73,86/87.
Overall index	19- 78/79,63/64,61/62,68/69,89/90,77/78,62/63.

From Table 6 it is observed that 1978/79 was the wettest year over all the whole of the region. Nyenzi (1992) and Wairoto and Nyenzi (1987) observed that for January of 1979, most of Kenya received exceptionally high rainfall.

3.3 PRINCIPAL COMPONENT ANALYSIS OF THE DECEMBER-FEBRUARY RAINFALL

Rotated principal component analysis (RPCA) was used to study the spatial and temporal characteristics of DJF-rainfall over East Africa during the period 1961-1990. The PCA T-mode was also used to delineate the anomalous wet years.

Kaiser's orthogonal (varimax) rotation method (Kaiser 1959), was adopted in determining eigenvectors for rotation. The final grouping of the stations was based on solutions derived from rotated PCA (RPCA). Determination of the number of the eigenvectors to be rotated was based on Kaiser's criterion (Kaiser 1959), the scree test (Catell 1966), the logarithm of the eigenvalue (lev) test, and the use of sampling errors in the eigenvalues (North *et al* 1982).

Table 7 illustrates results obtained from the sampling error test, while figure 7 shows results obtained from both the scree test and the lev test for S-mode case.

Table 8 gives the summary of the four methods. The four methods retained almost the same number of eigenvectors for the varimax rotations during these seasons. They suggest that the cut-off was between 14-19 and thus the four methods harmonise in this case. Thus Kaiser (1959) criterion, which represented average was adopted and varimax rotation done.

TABLE 7: Example of significance of sampling errors of the eigen values for DJF rainfalls.

Factor	Eigen value λ_i	Sampling error $[\lambda_i(\frac{2}{N})^{\frac{1}{2}}]$	$\lambda_{i-1}-\lambda_i$
1	25.6038	4.2681	
2	6.2487	1.0417	19.3551
3	5.2734	0.8791	0.9753
4	3.9082	0.6515	1.3652
5	3.5922	0.5988	0.3160
6	3.1001	0.5168	0.4921
7	2.2118	0.4354	0.4883
8	2.2537	0.3757	0.3581
9	2.1822	0.3638	0.0715
10	2.1435	0.3573	0.0387
11	1.9074	0.3180	0.2361
12	1.5814	0.2636	0.3260
13	1.4093	0.2349	0.1721
14	1.3238	0.2207	0.0855 <
15	1.1271	0.1879	0.1967
16	1.0875	0.1813	0.0396
17	0.9957	0.1660	0.0918
18	0.9571	0.1595	0.0386
.	.	.	.
.	.	.	.

< Cut off-point.

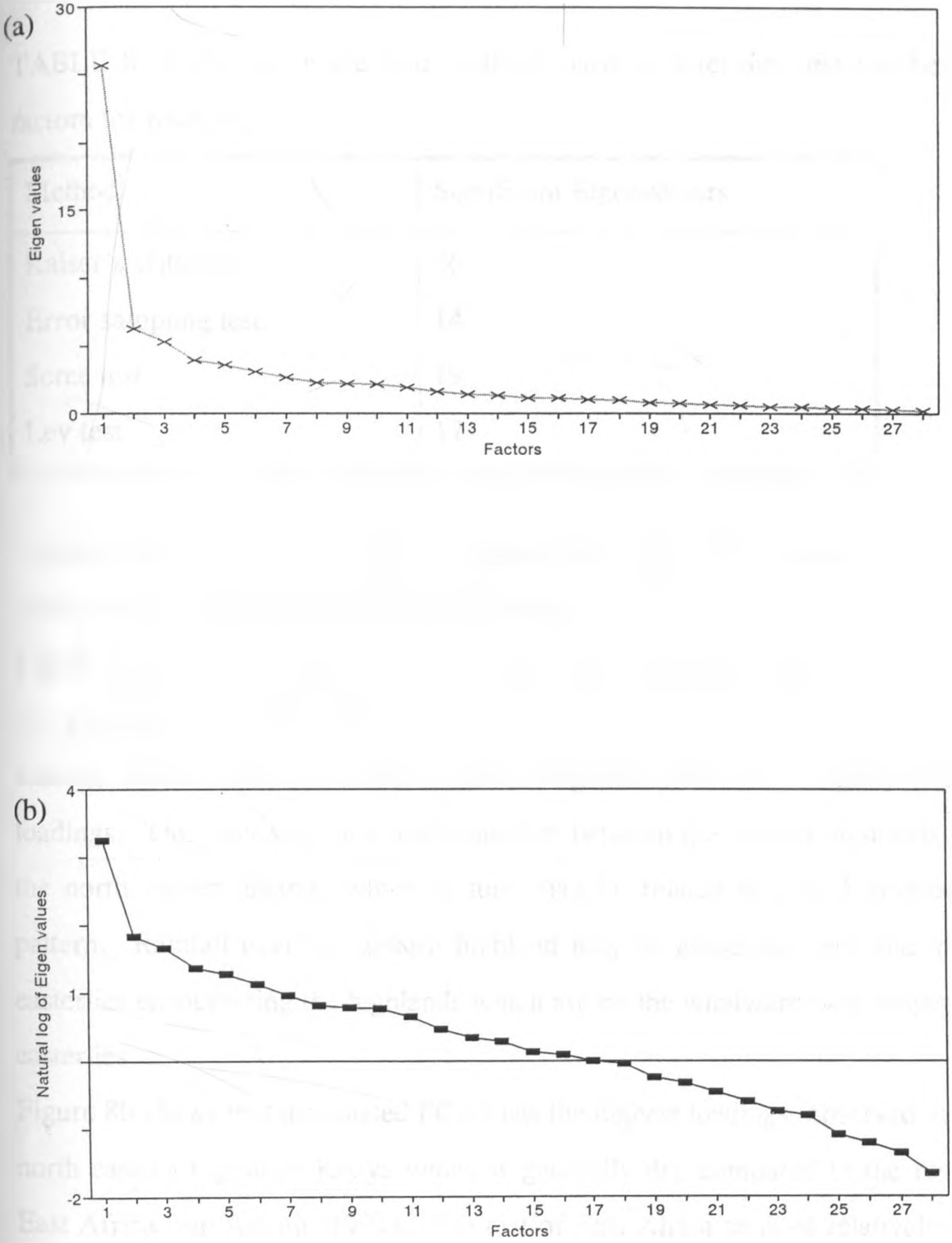


Figure 7: Example of the results from the, (a) Scree test, and (b) LEV test.

TABLE 8: Summary of the four methods used to determine the number of factors for rotation.

Method	Significant Eigenvectors
Kaiser's criterion	16
Error sampling test	14
Scree test	19
Lev test	17

Factor loadings were plotted out (Figure 8). Figure 8 shows the spatial pattern of the first four Rotated factor loadings.

Figure 8a show that the rotated PCA1 had high loadings concentrated around the Eastern highlands with the rest of East Africa generally showing low loading values except the north eastern Uganda which has slightly higher loadings. This may suggest a teleconnection between the eastern highlands and the north eastern uganda which in turn may be related to global circulation pattern. Rainfall over the eastern highland may be associated with the moist easterlies encountering the highlands which are on the windward with respect to easterlies.

Figure 8b shows that the rotated PCA2 has the highest loadings observed in the north eastern region of Kenya which is generally dry compared to the rest of East Africa (see Asnani, 1993). The rest of East Africa showed relatively low values. The high loadings could suggest the occurrence of large negative/positive rainfall anomalies over the region.

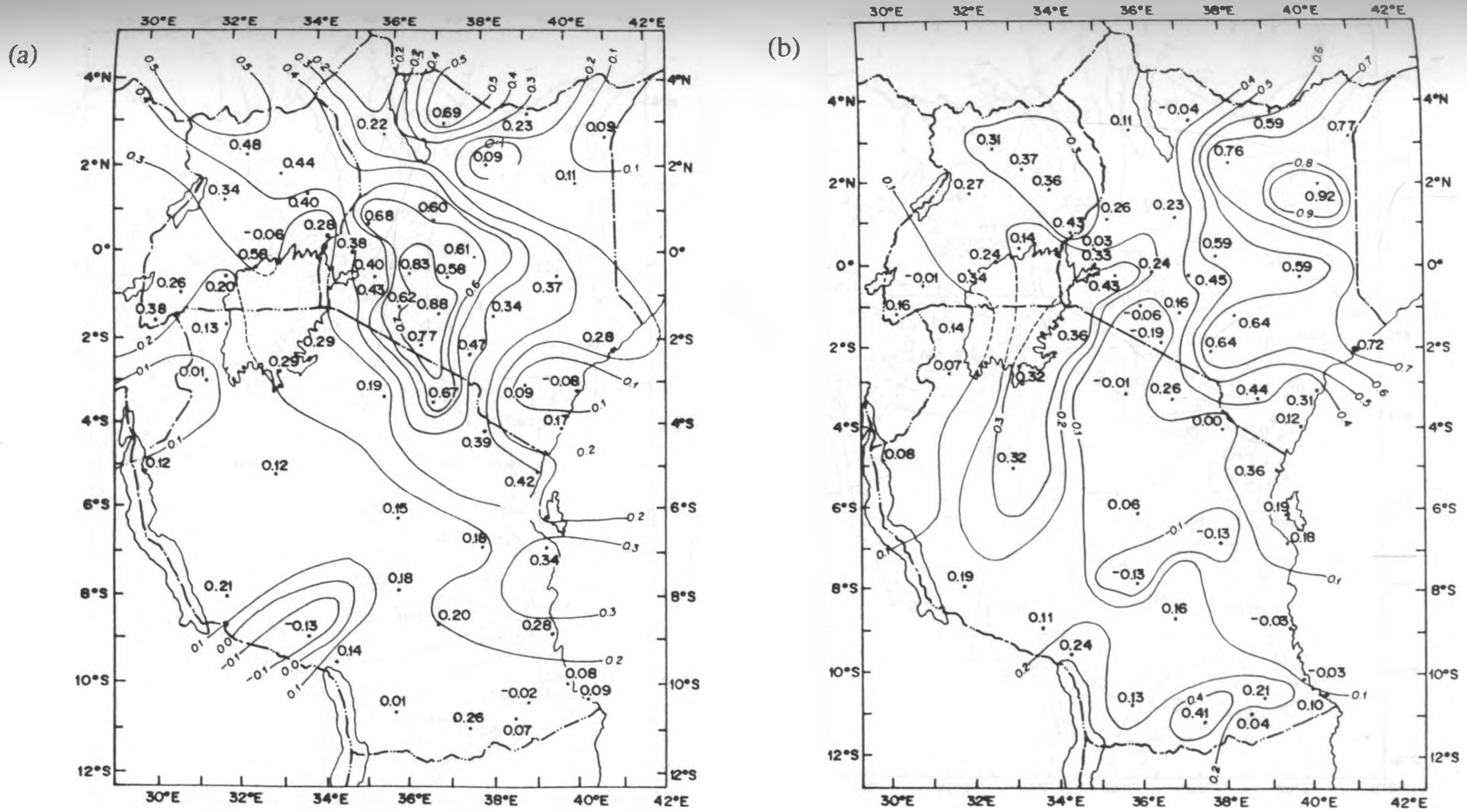


Figure 8: Map patterns of factor loadings for DJF seasonal rainfall for (a) Factor 1, (b) Factor 2, (c) Factor 3, and (d) Factor 4.

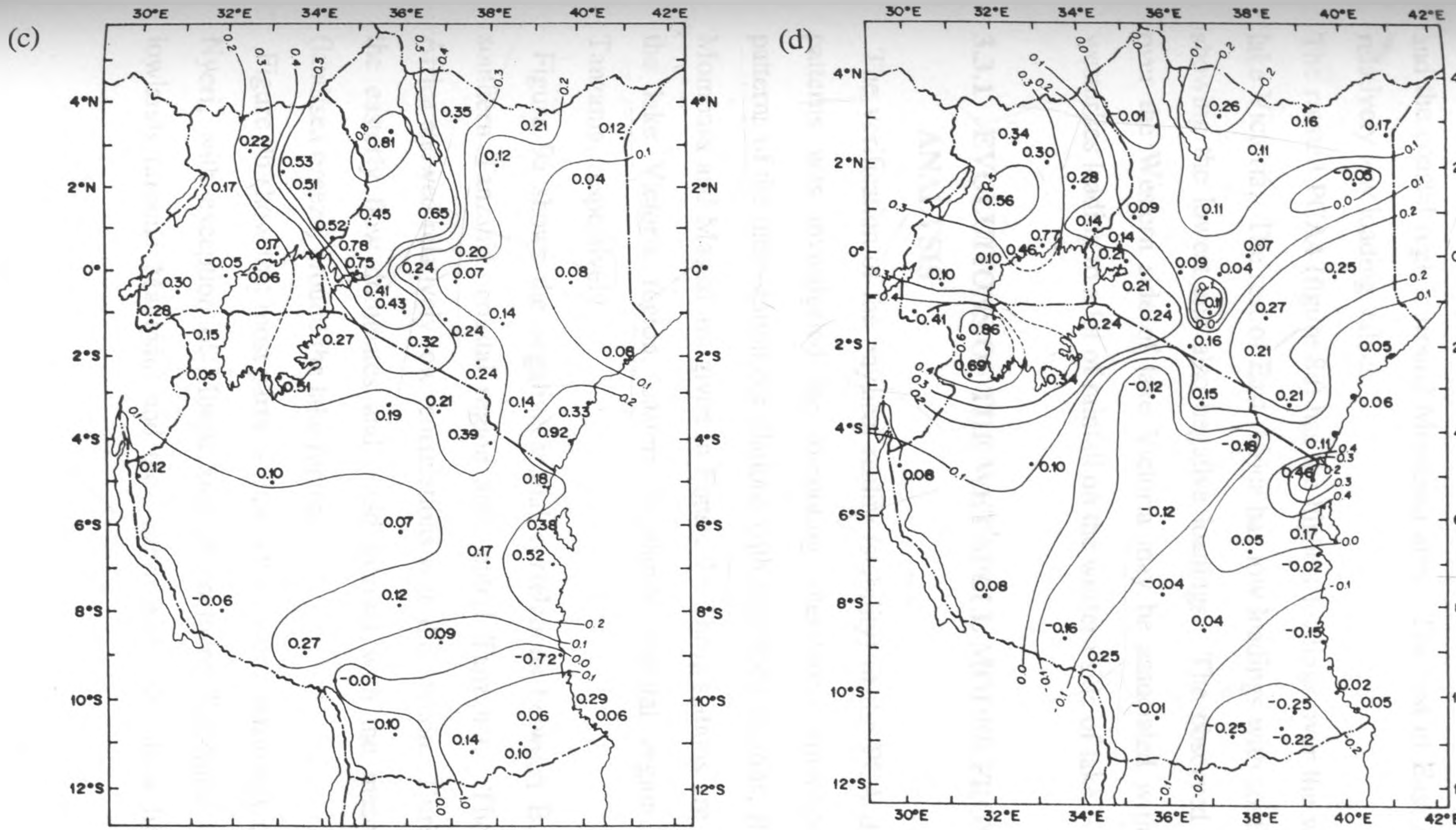


Figure 8. (Contd)

The rotated PCA3 (figure 8c) has high positive loadings over Western Kenya and the coastal region around Mombasa area. The rest of East Africa showed relatively low loading values.

The rotated PCA4 (figure 8d) has the highest loadings over the western side of lake Victoria. The rest of East Africa has low loadings with southern Tanzania showing the lowest and also negative loadings. The observed high loadings over the Western side of lake Victoria may be associated with the surge of westerlies leading to a lot of rainfall on the western side of lake Victoria.

3.3.1 EVOLUTIONS OF THE WET SPELL MODES FROM PCA ANALYSIS

The verification of the physical reality (stability) of the PCA derived rainfall patterns was investigated by computing interstation correlations. Spatial patterns of the inter-station correlations with reference stations; Bukoba, Nyeri, Mombasa and Masasi are given in Figure 9. These stations are located within the lake Victoria region, eastern highlands, coastal region and southern Tanzania, respectively.

Figure 9a shows the negative spatial correlations between Bukoba and the southern Tanzania, coastal region and central Tanzania. The rest of East Africa showed relatively low correlations with this station. During this season the easterly flow dominates and could interact with the mesoscale features (land/sea breeze) around the lake region.

Figure 9b show that most parts of East Africa were positively correlated with Nyeri, with exception of Mbeya area in southern Tanzania. The southern lowlands (around Makindu) and the eastern highlands show high correlation

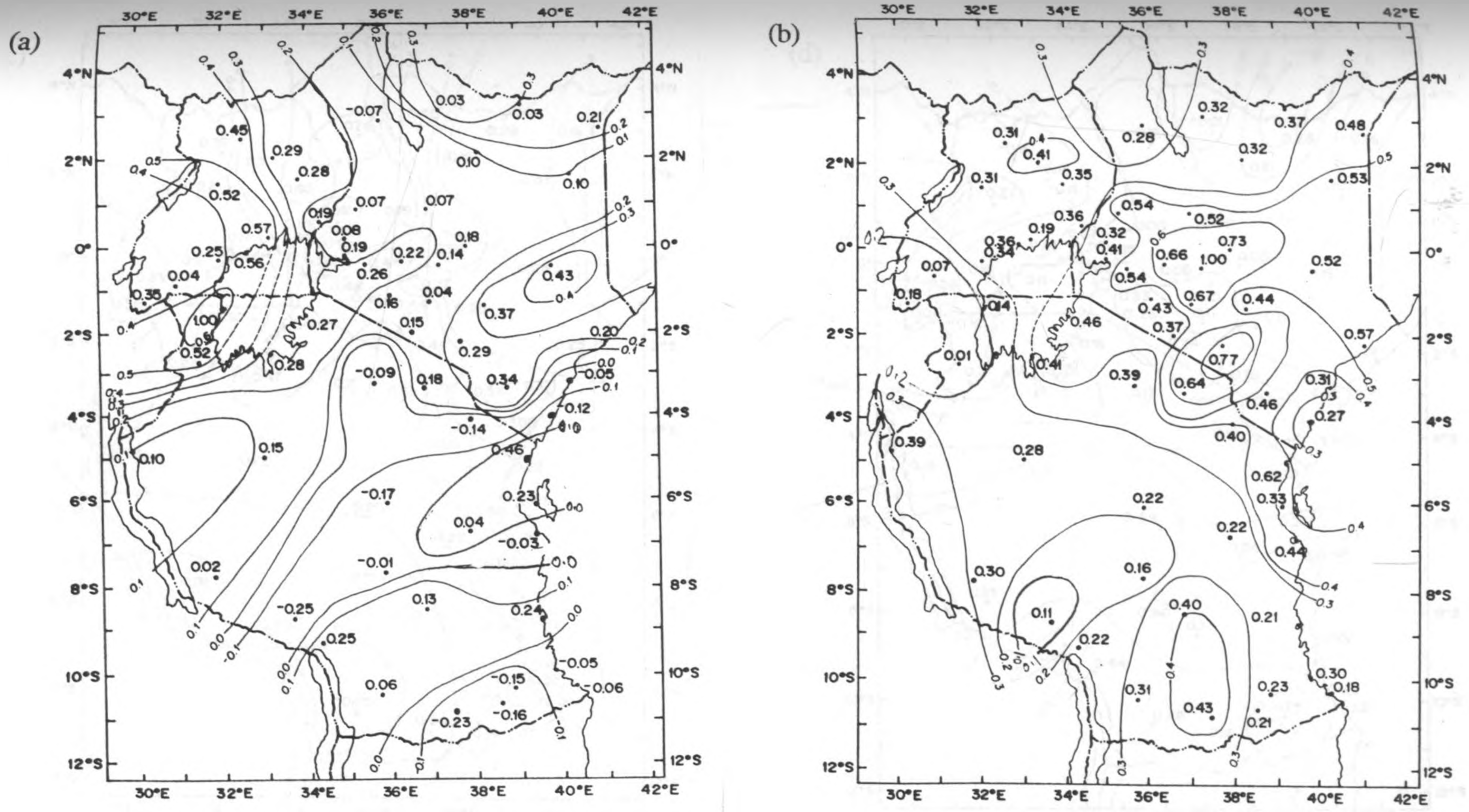


Figure 9: Spatial patterns of the inter-station correlations with reference stations (a) Bukoba, (b) Nyeri, (c) Mombasa, and (d) Masasi.

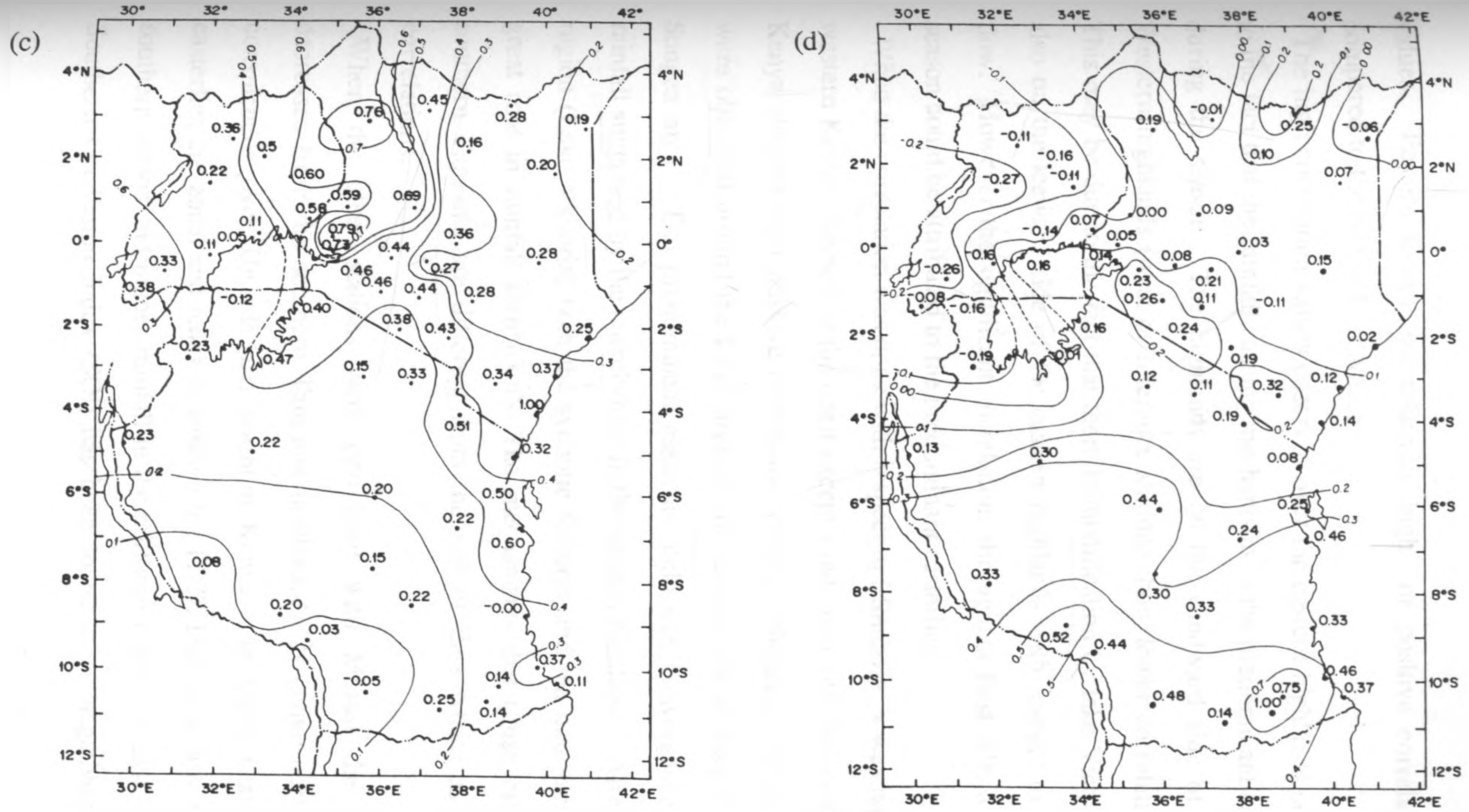


Figure 9.(Contd)

values. Eastern Kenya had relatively high or positive correlation values compared to the rest of East Africa.

The high correlation values observed over the eastern highlands could be due to the fact that the rainfall causing mechanisms is the predominant easterly flow during the season. The highlands are on the windward side of the flow. Western highlands (west of reference station) show lower correlation values. This may be due to the fact that there is modification by lake Victoria and it is also on the leeward side of the eastern highlands with respect to the eastern flow. However the significant correlations throughout East Africa during this season could be attributed to the predominant easterlies.

When the correlation was done with respect to Mombasa, it was noted that the western Kenya, the rest of the coast except Lindi area and the north eastern of Kenya showed high positive correlation values. Negative correlation values were observed around the Lindi area, north eastern side of lake Victoria, and Songea area. The predominant easterlies enhances convergence leading to rainfall suggested by the correlations in the eastern highlands. Around the lake region (Lake Victoria) both the synoptic features and the meso-scales plays a great role in rainfall formation. The mechanisms that cause rainfall in the southern Tanzania are different from the rest of East Africa as implied by correlations.

When the other stations were correlated with Masasi the correlations decreases from the southern Tanzania northwards. Negative correlations are conspicuous over Uganda and northern Kenya. In some years the north easterlies are zonal and tends to weaken the ITCZ leading to low rainfall over southern region and higher rainfall in the northern region of East Africa. The Southern Oscillation Index (SOI) has been found to be negatively correlated with the southern part of East Africa and positively correlated with the Equatorial Eastern Africa (Ininda, 1987).

The T-mode actually confirmed the characteristics observed when rainfall anomaly indices were used to single out the wet seasons. Basically the seasons observed to be wet using the rainfall anomaly indices were picked out by the T-mode.

3.4 THE OBSERVED SPATIAL AND TEMPORAL CHARACTERISTICS OF RAINFALL DURING THE ANOMALOUSLY WET PERIODS

From both the rainfall anomaly indices and the PCA T-mode analysis the following years were delineated as wet (with anomaly index $> +0.5$), during the DJF season; 1961/62, 1962/63, 1963/64, 1967/68, 1968/69, 1972/73, 1977/78, 1978/79, 1986/87 and 1989/90. For each of the ten years, the monthly (December, January, February) rainfall anomaly index was computed for each station. This was done by standardising the departures from the mean.

In discussing the temporal characteristic of rainfall, we consider the Equatorial East Africa and the Southern part of East Africa separately. These regions were defined in section 3.2.

The station monthly rainfall anomaly were averaged over each of the two regions to obtain a regional monthly rainfall anomaly indices. The monthly rainfall for the preceding season (September, October, November) and following season (March, April, May) were subjected to similar analysis. The monthly anomaly indices for all the ten years over the equatorial East Africa and Southern East Africa are given in table 9a-c.

During the 1961/62 DJF season, most stations indicates December as having the highest anomaly values, and the degree of wetness was observed to decrease as the season progressed averaged over both the equatorial region and southern region(see table 9a). From both table 9b and 9c, it appears that the anomalous rainfall during the DJF season of these years was an extension of the short rains (SON) into the dry season. Anyamba (1983) also observed a similar result.

The 1962/63 DJF season showed the same temporal characteristics as the 1961/62 over the equatorial East Africa region; Thus the highest rainfall anomaly being observed in December and decreasing towards February. Over the Southern part of East Africa, however January was the wettest of the three months. One possibility may be that the rainfall belt (ITCZ) persisted over the equatorial East Africa, thus causing the short rains to extend to the dry season.

The temporal rainfall anomaly pattern for the 1963/64 season was similar to that of 1962/63 described above.

During the 1967/68 season, over the equatorial region, February was the wettest of the three months. Since the rainfall in March 1968, was generally below normal, it is not easy to ascertain whether this anomalous rainfall in February occur as a result of early onset of the 1968 long rains. Over the Southern part, December was the wettest month in this season.

During the 1968/69 season, most of the stations over both the equatorial and Southern region showed that both December and February had large positive rainfall anomaly. It was noted that both the preceding (Short rains) season and the following (Long rains) season had above normal rainfall. This may suggest the extension of the Short rains and early onset of Long rains. From table 9a, it can be noted that during the 1972/73 season, December had the largest positive rainfall anomaly when compared to the other two months over the equatorial. 1972/73 is one of the El Niño years. During El-Niño years, the Short rains over East Africa are known to be above normal and to extend into the beginning of the usually dry DJF season (Ininda, 1994).

During the 1977/78 season, both December and February had positive rainfall anomaly over the equatorial East Africa, February being the wettest. Over the Southern region, however, December and January had positive anomaly, with December being the wettest.

TABLE 9a: Rainfall anomaly indices for DJF-seasons

DJF-Season	Averaged monthly rainfall anomalies					
	Equatorial region			Southern region		
	DEC.	JAN.	FEB.	DEC.	JAN.	FEB.
1961/62	0.903	-0.085	-0.818	0.731	-0.085	-0.647
1962/63	0.194	-0.001	-0.193	-0.282	0.402	-0.121
1963/64	0.817	-0.688	-0.128	-0.112	0.397	-0.285
1967/68	-0.232	-0.726	0.959	0.928	-0.746	-0.182
1968/69	0.186	-0.237	0.052	0.141	-0.298	0.157
1972/73	0.041	-0.059	0.019	0.166	0.451	-0.617
1977/78	0.063	-0.237	0.173	0.491	0.195	-0.686
1978/79	-0.031	-0.009	0.040	-0.067	0.123	-0.056
1986/87	0.787	-0.286	-0.501	0.697	0.084	-0.780
1989/90	0.577	-0.745	0.167	0.621	-0.827	0.205

TABLE 9b: Rainfall anomaly indices for SON-seasons

Year	Averaged monthly rainfall anomalies					
	Equatorial region			Southern region		
	Sept.	Oct.	Nov.	Sept.	Oct.	Nov.
1961	-0.637	-0.072	0.708	-0.835	-0.186	1.020
1962	-0.817	0.119	0.198	-0.795	0.243	0.552
1963	-0.641	-0.390	1.031	-0.609	-0.542	1.151
1967	-0.487	-0.024	0.511	-0.264	-0.512	0.775
1968	-0.707	-0.065	0.772	-0.571	-0.443	1.014
1972	-0.645	0.295	0.350	-0.791	-0.099	0.890
1977	-0.822	0.116	0.706	-0.544	-0.339	0.883
1978	-0.440	0.126	0.314	-0.567	-0.451	1.018
1986	-0.483	0.131	0.352	-0.795	-0.262	1.057
1989	-0.464	0.203	0.260	-0.665	-0.125	0.791

TABLE 9c: Rainfall anomaly indices for MAM-seasons

Year	Averaged monthly rainfall anomalies					
	Equatorial region			Southern region		
	March	April	May	March	April	May
1962	-0.414	0.243	0.171	0.397	0.487	-0.884
1963	-0.460	0.714	-0.254	0.360	0.618	-0.978
1964	-0.462	0.896	-0.434	0.815	0.118	-0.933
1968	-0.137	0.628	-0.492	0.551	0.420	-0.971
1969	0.130	-0.419	0.289	0.372	0.502	-0.874
1973	-0.834	0.699	0.135	0.272	0.538	-0.810
1978	0.288	0.341	-0.629	0.674	0.212	-0.886
1979	-0.430	0.324	0.107	0.159	0.458	-0.617
1987	-0.601	0.312	0.289	0.418	-0.070	-0.348
1990	0.203	0.384	-0.588	0.470	0.380	-0.850

While during the 1978/79 season, the areal average anomaly values in table 9a are generally low, a large number of stations over the equatorial East Africa had positive anomaly in February, but a few stations had negative anomaly, which tended to lower the areal average. Over the southern region most stations showed positive anomaly in January.

1986/87 was an El Niño year and the rainfall over most stations both over the equatorial East Africa and the southern regions had December as the month with the largest positive anomaly. Again, as for the case of 1972/73, this was an extension of the Short rains.

During the 1989/90 DJF season, most of the station had positive rainfall anomalies over East Africa in both December and February, with December having the highest values in the season. This characteristic was observed over both the equatorial region and the southern region (see table 9a). Analysis done on both the preceding usually wet season and the normally wet season that follows suggest that they could have influenced the season's wetness (see table 9b and 9c).

From the above discussion it is noted that either the short rains or long rains or both could have influenced the wetness of the otherwise usually dry DJF season. Thus late onset of the short rains may start late and continue into the dry season (DJF-season). However in some years short rains may start on normal or even earlier and still continue into the dry season. In some cases the wetness during the dry season may occur as a result of early onset of the Long rains. The study suggest that there is an intense coherence between the dry season's wetness and the short rains.

3.5 INTERMONTHLY RAINFALL RELATIONS

In the temporal correlation the rainfall anomaly averaged over the equatorial East Africa for the period 1961-90 for the seven months from October to April were correlated with each other (Table 10). The correlation coefficients do not decrease monotonically, for example the correlation coefficients between October and January is 0.151 while the correlation coefficients between October and February is 0.285. The correlation between November and December is higher when compared to February and March, which suggest that the anomalous rainfall occurring during the SON season may persist to DJF season. However the correlations between February and March was significant showing that the Long rains could in some years start from February.

TABLE 10: Intermonths correlations from October to april

Months	Oct.	Nov.	Dec.	Jan.	Feb.	March
Nov.	0.696					
Dec.	0.329	0.534				
Jan.	0.151	0.256	0.186			
Feb.	0.285	0.304	0.213	0.229		
March	0.104	0.329	-0.026	0.230	0.375	
April	-0.078	0.061	-0.150	-0.016	0.129	0.426

Table 10 gives the intermonths correlation matrix from October to April. The correlation coefficients between December and November/March and February are significant and suggests influence of the short and long rains on this season.

The three seasons (SON, DJF and MAM) were correlated for the period 1961-90. The correlation coefficient value between DJF and SON was found to be 0.491. The correlation coefficient between DJF and MAM was found to be 0.091 while correlation coefficient between SON and MAM was 0.151. The correlation coefficient between the seasons DJF and SON is relatively significant. Thus the anomalous rainfall occurring during SON is likely to continue into DJF season.

3.5.1 SPATIAL/MAP CORRELATION

An attempt was made to examine the correlation between the various map patterns within the DJF season for the ten anomalous wet years (Table 11).

TABLE 11: Intermonths correlations for DJF SEASONS

DJF-season	Intermonths Correlations		
	DJ	DF	JF
1961/62	-0.722	-0.103	-0.613
1962/63	-0.578	-0.537	-0.379
1963/64	0.009	-0.629	-0.783
1967/68	-0.654	-0.831	0.123
1968/69	-0.526	-0.479	-0.494
1972/73	-0.693	-0.542	-0.230
1977/78	-0.242	-0.714	-0.508
1978/79	-0.364	-0.614	-0.511
1986/87	-0.188	-0.536	-0.728
1989/90	-0.096	-0.749	-0.588

For 1961/62 seasons the correlations suggest general decrease of wetness from December to February. Seasons 1962/63, 1968/69 and 1972/73 shows consistency in the three months over the region. General wetness decrease from December to February is observed for seasons 1963/64 and 1986/87. Due to the insignificance of the correlations, the decrease could have occurred over few stations. 1967/68 season suggests that December was wetter than January and a significant correlation between December and February is observed.

The three seasons 1972/73, 1978/79 and 1989/90 show similar correlation patterns. They suggest that December was wettest of the three months.

Generally the following observations are made;

There is significant negative correlation between December and February as 8 out of the 10 seasons suggest.

7 seasons out of 10 suggests negative correlation between January and February.

5 seasons out of the 10 suggest negative correlations between December and January.

Thus negative intermonths correlations dominate. In summary the intermonths/seasons correlations supports some of the characteristics observed in the analysis of the ten selected seasons using rainfall anomaly indices and PCA.

3.6 MAP PATTERN (PCA ANALYSIS, T-MODE)

The PCA T-Mode analysis showed that the ten seasons selected previously could cluster into three groups. Seasons 1961/62, 1962/63, 1963/64 and 1986/87 formed one cluster showing that they had similar patterns. The seasons 1967/68 and 1978/79 formed a second cluster. Seasons 1968/69, 1972/73, 1977/78 and 1989/90 formed the third cluster.

From the PCA T-mode and other methods, five wettest years were selected for detailed study. The selected five seasons are 1961/62, 1963/64, 1968/69, 1977/78 and 1978/79. The seasonal mean rainfall map for the DJF is shown in the figure 10. From figure 10 it is observed that the southern Tanzania receives the highest rainfall during this season. This is expected as the ITCZ is located south of the equator during this season. High rainfall values were also observed over the highlands and lake Victoria region. The northern and eastern regions of Kenya and northern Uganda receive the lowest rainfall values during this season.

Over most of the regions, values above mean threshold value for aridity were observed during these seasons. The aridity threshold value is 50 mm/month as defined by the Drought Monitoring Centre. The 50 mm/month threshold value has also been used in many studies including Jackson (1986) and Jackson and Winand (1994). In general the values decreases from southern region towards the northern region.

For the five seasons under study, their rainfall anomalies were obtained and Figure 11 shows their spatial patterns.

From Figure 11a, it can be seen that during 1961/62 high positive rainfall anomalies were observed in the southern region of East Africa and around the eastern highlands. The western region of lake Victoria showed low values compared to the eastern region and same was observed for northeastern region of Kenya. Spatial pattern show a general decrease in the magnitude of the anomaly from south towards north.

The 1963/64 anomalies (Figure 11b) show that most of the regions had positive rainfall anomalies and particularly to the Southern parts of Kenya.

During the 1968/69 DJF season (Figure 11c) the southern region had negative rainfall anomalies while the northern region had comparatively large positive anomalies. The largest positive anomalies were observed in the north eastern region of Kenya. Northwestern Uganda also had relatively large positive anomalies.

During the 1977/78 DJF season, the regions which registered large negative rainfall values included the southern part of Tanzania, northwestern

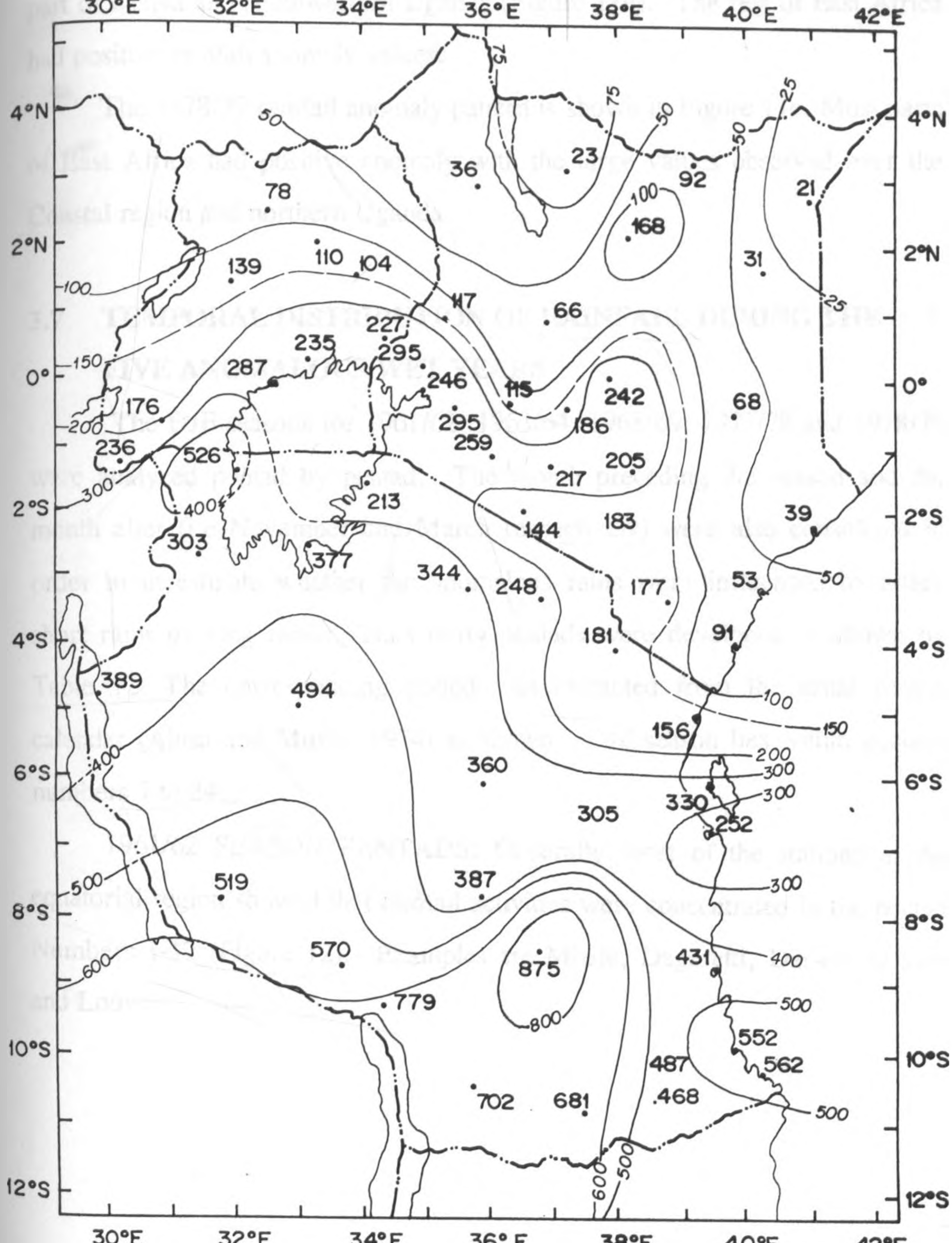


Figure 10: Mean seasonal patterns of DJF-rainfall over East Africa (rainfall in tenth of mm), over 1961-1990 period.

part of Kenya and southwestern Uganda (Figure 11d). The rest of East Africa had positive rainfall anomaly values.

The 1978/79 rainfall anomaly pattern is shown in Figure 11e. Most parts of East Africa had positive anomaly with the large values observed over the Coastal region and northern Uganda.

3.7 TEMPORAL DISTRIBUTION OF RAINFALL DURING THE FIVE ANOMALOUS WET YEARS

The DJF seasons for 1961/62, 1963/64, 1968/69, 1977/78 and 1978/79 were analyzed pentad by pentad. The month preceding the season and the month after (i.e November and March respectively) were also considered in order to investigate whether the anomalous rains were influenced by either short rains or long rains. Thus thirty pentads were developed as shown by Table 12. The corresponding period was extracted from the usual pentad calendar (Alusa and Mushi, 1974) as shown. DJF-season lies within pentads numbers 7 to 24.

1961/62 SEASON PENTADS: Generally most of the stations in the equatorial region showed that rainfall activities were concentrated in the pentad Numbers 1-12 (Figure 12). Examples are Mbale, Dagoretti, Dar-es- Salaam and Lodwar.

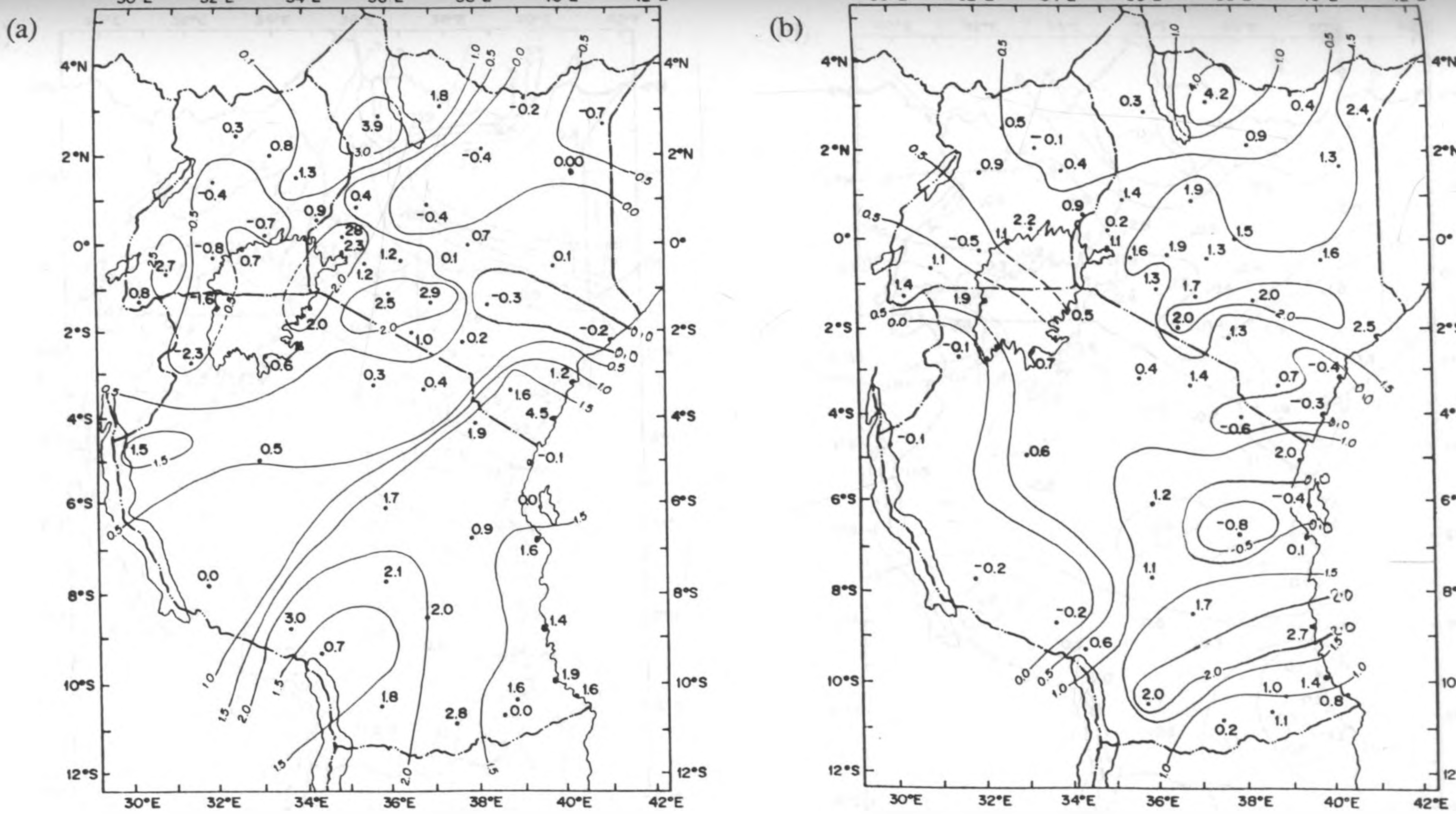


Figure 11: Spatial patterns of the rainfall anomalies for seasons; (a) 1961/62, (b) 1963/64, (c) 1968/69, (d) 1977/78, and (e) 1978/79.

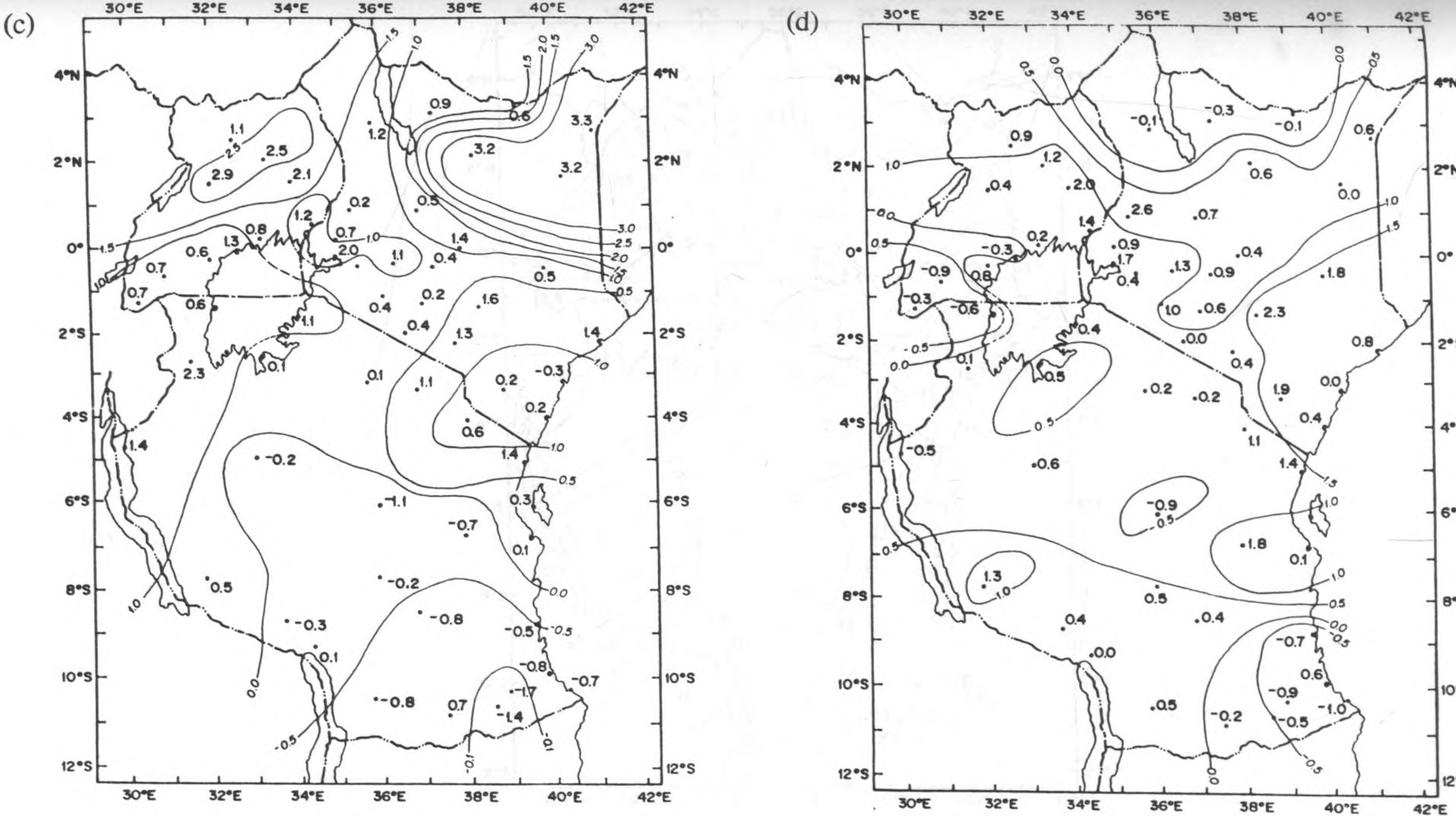


figure 11.(Contd)

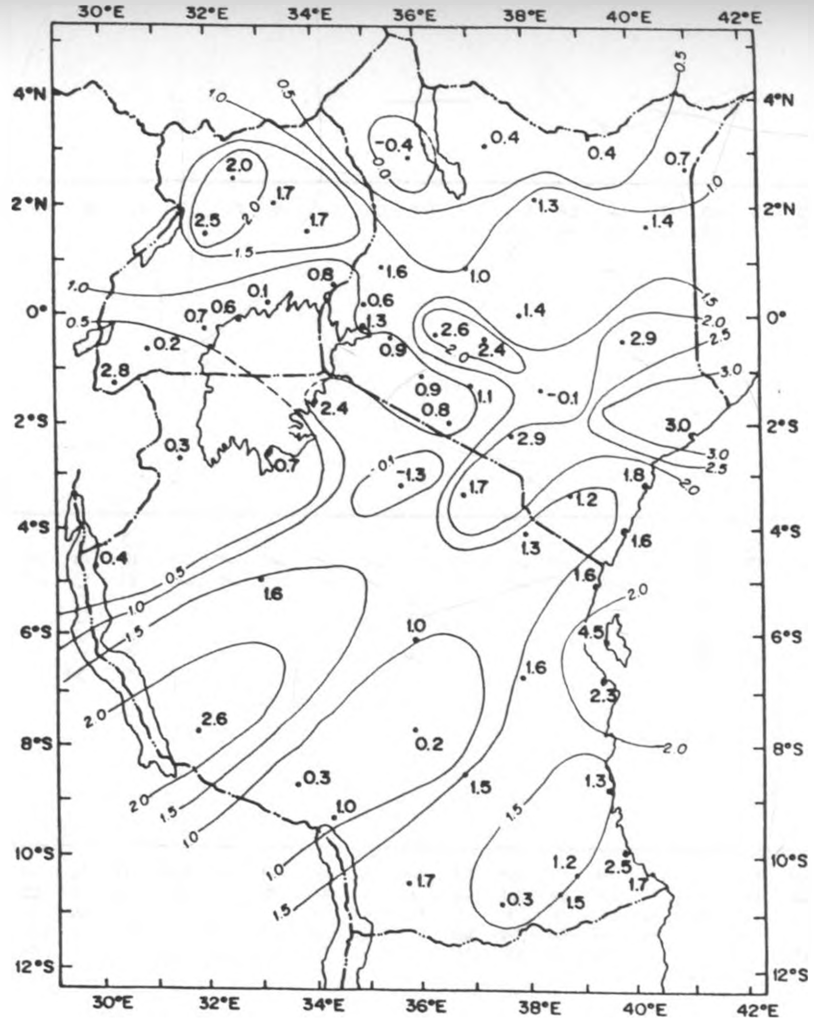


Figure 11.(Contd)

TABLE 12: Pentad calendar for November till March.

Pentad No.	Pentad Calendar (pentad No.)	Month	Date
1	62	November	2-6
2	63	//	7-11
3	64	//	12-16
4	65	//	17-21
5	66	//	22-26
6	67	Nov.-Dec.	27-1
7	68	December	2-6
8	69	//	7-11
9	70	//	12-16
10	71	//	17-21
11	72	//	22-26
12	73	//	27-31
13	1	January	1-5
14	2	//	6-10
15	3	//	11-15
16	4	//	16-20
17	5	//	21-25
18	6	//	26-30
19	7	Jan.-Feb.	31-4
20	8	February	5-9
21	9	//	10-14
22	10	//	15-19
23	11	//	20-24
24	12	Feb.-March	25-1
25	13	March	2-6
26	14	//	7-11
27	15	//	12-16
28	16	//	17-21
29	17	//	22-26
30	18	End of march	27-31

The Southern regions show high pentad rainfall values throughout the period of analysis. The same was observed around the lake Victoria region; examples are Songea, Mbeya, Bukoba and Musoma (See Figure 12a-f). From Figure 12, it can be seen that the rainfall that occurred during the DJF season was a continuation of the short rains.

In general the stations lying north of latitude 5°s showed low pentad rainfall amounts after the 12^{th} pentad(see Figure 12b, Tables 1 and 12). Note that, in all the five cases pentads are in accordance to Table 12 and also refer to Table 1 for latitudes/longitudes of the stations.

1963/64 SEASON PENTADS: For most of the stations lying north of latitude 5^0S rainfall activities were mainly concentrated within the pentads 1-15, for example Mombasa and Makindu. The pentads peak oscillates within pentads 1-12 for most of the stations. Most of the stations to the South of latitude 5^0s showed rainfall distributed throughout the pentads studied; for example Tabora. The stations around lake Victoria region had the same rainfall distribution as the southern region, see Bukoba. For equatorial stations cessation is observed after the 12-13th pentads for most of the stations (see figure 13a-f. The local events/systems cannot be ruled out on influencing rainfall as station rainfall patterns are not exactly similar.

It is observed that the pentad patterns for seasons 1961/62 and 1963/64 are generally similar (for example see Dar-es-salaam for both seasons).

1968/69 SEASON PENTADS: A large number of the stations had rainfall concentrated within the last pentads i.e pentads 17 to 30; for example see Lodwar, Narok and Mbeya (figure 14). However some stations had rainfall concentrations in the earlier pentads, thus pentads 1 to 9, for example Kakamega and Dar es salaam. This suggests that the season could have been influenced by both the preceding short rains and the long rains that follows with the latter having more impact. However the stations around the lake region and those in the southern Tanzania observed wetness throughout the DJF season; see Bukoba and Mbeya. (See figure 14a-f). A marked peak at around the 18th pentad was observed for most of the stations. This season experiences three rainfall concentration patterns (i.e earlier wet pentads, wet pentads around 18th pentad and late wet pentads).

1977/78 SEASON PENTADS: Quite a number of stations experiences wet pentads lying within the first pentads (pentads 1 to 11) and the last pentads(pentads 22 to 30, See figure 15a-f). This suggest that the rainy seasons neighbouring the season under scrutiny are likely to have influence. Conspicuous peaks are observed at both the 11th pentad and the 16th pentad (see Dagoretti and Kitale for example). The peak at around 16th pentad is more pronounced. The lake Victoria region and the southern region of Tanzania experiences rainfall throughout the period under study (see Iringa).

1978/79 SEASON PENTADS: Quite a number of stations showed wet pentads clustering around pentads 1 to 9, 14 to 23 and also 27 to 30; refer to figure 16a-f. Pentads 14th to 23rd were quite wet for most of the stations observed. Outstanding peak was around the 18th pentad for most of the stations. However, the lake region and the southern region was generally wet throughout the pentads (see Kigoma and Iringa). The observations suggest that both the short rains and long rains did not have much influence over this particular season.

From the pentads analysis it is observed that conspicuous rainfall peak was around the 18th pentad. This is at the end of January and beginning of February, the period which is otherwise expected to be driest under normal

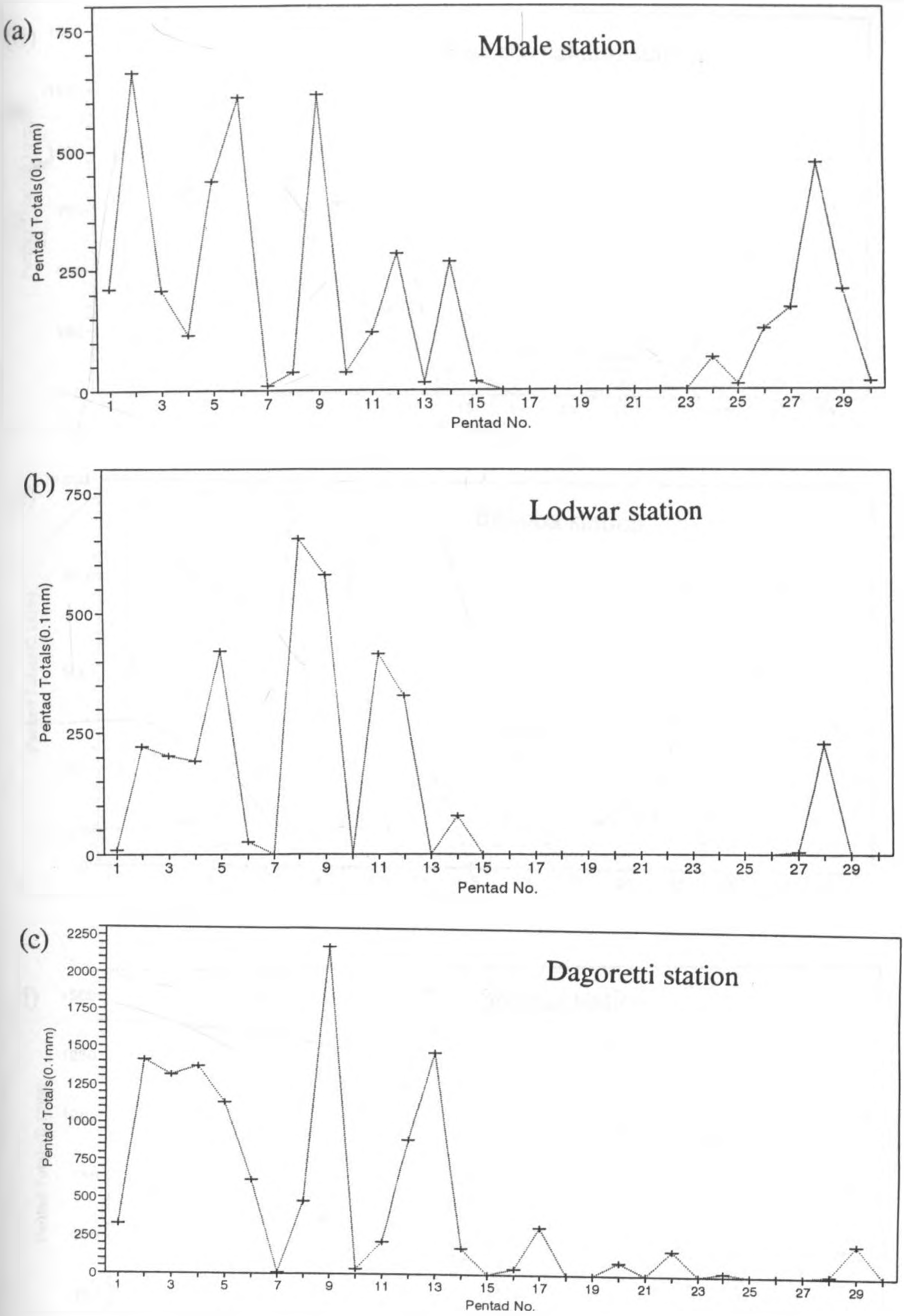


Figure 12: Examples of time series for pentad rainfall totals during 1961/62 season at some stations; (a)-(f).

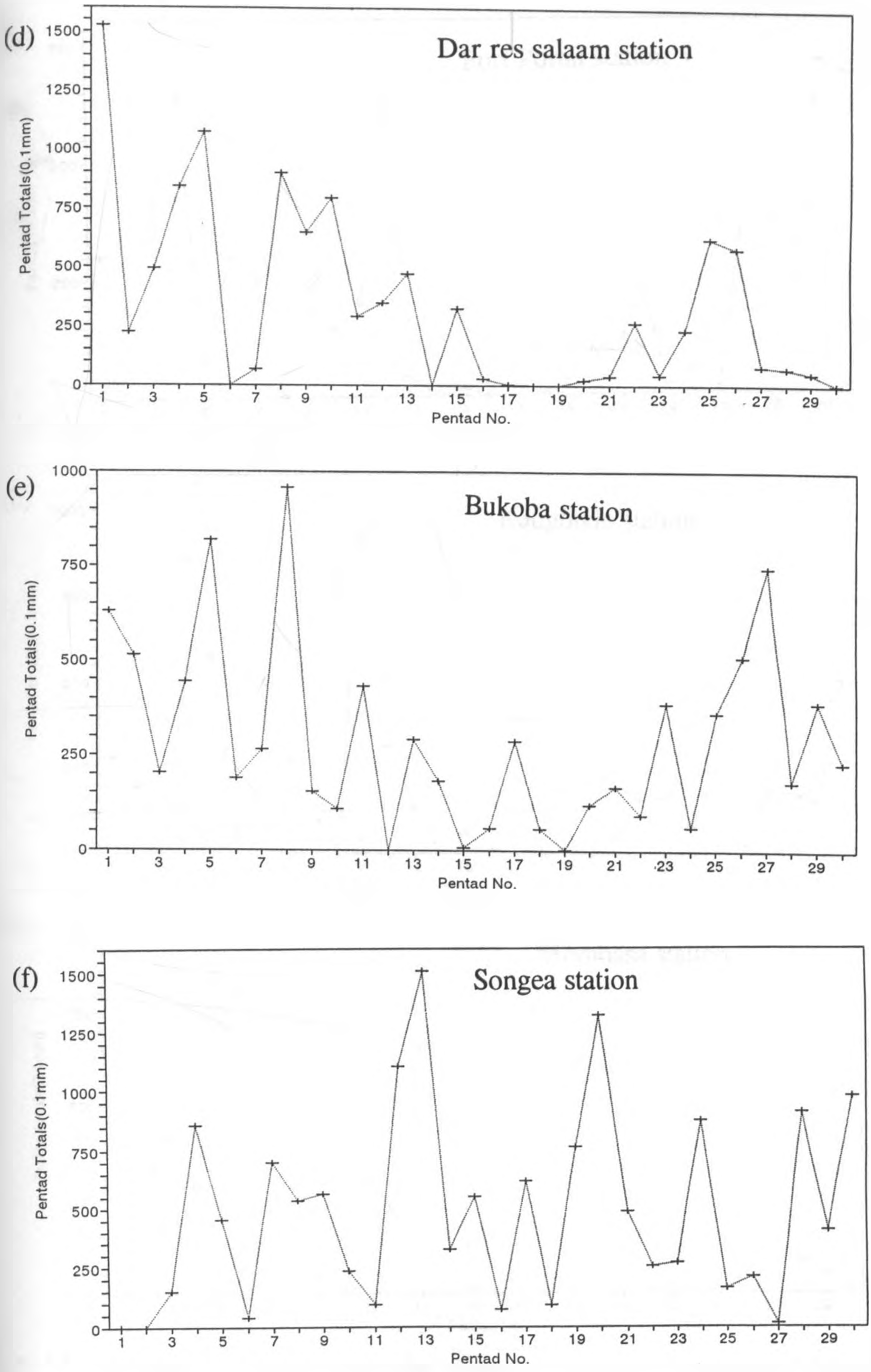


Figure 12.(Contd)

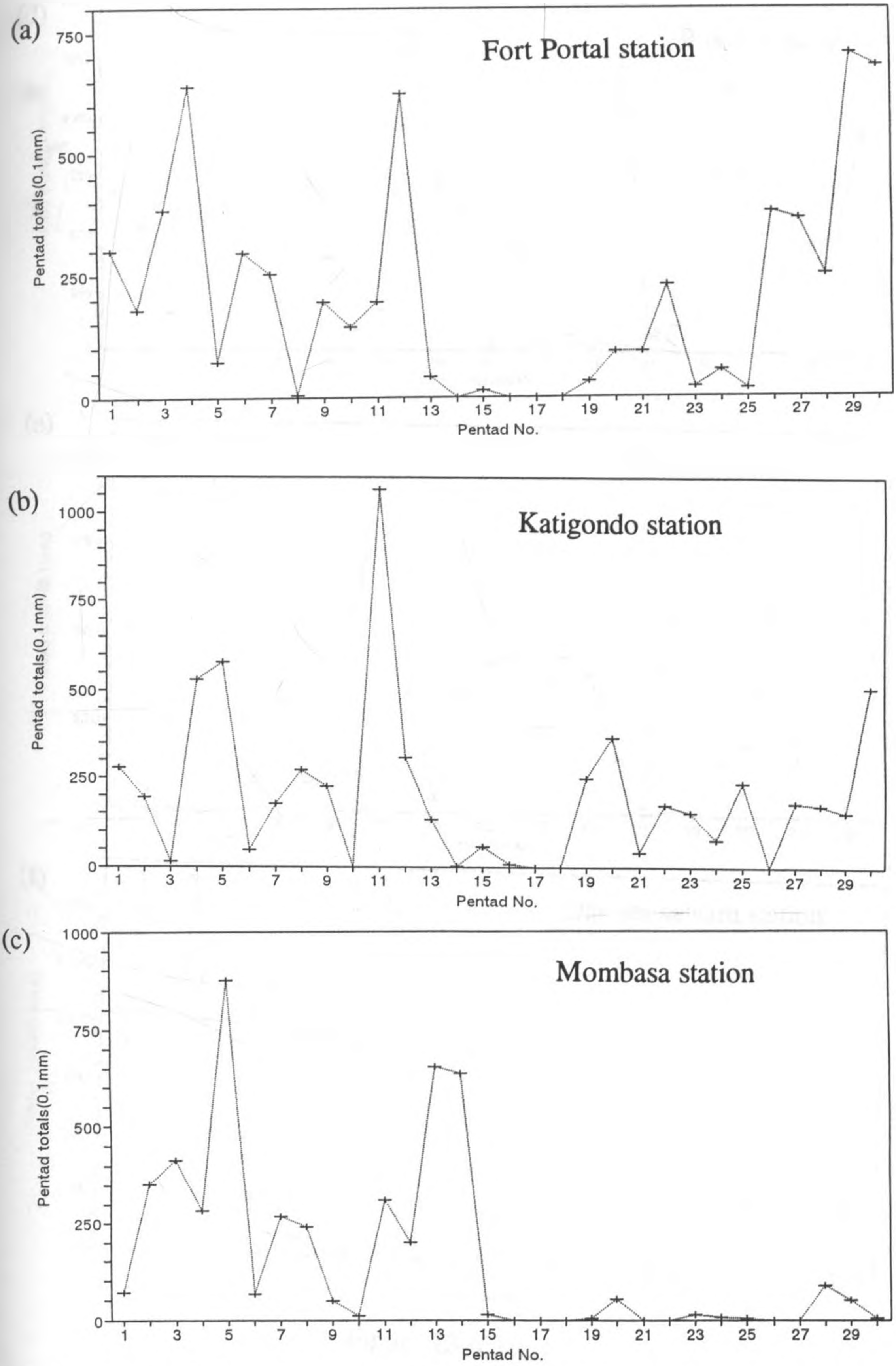


Figure 13: Examples of time series for pentad rainfall totals during 1963/64 season at some stations; (a)-(f).

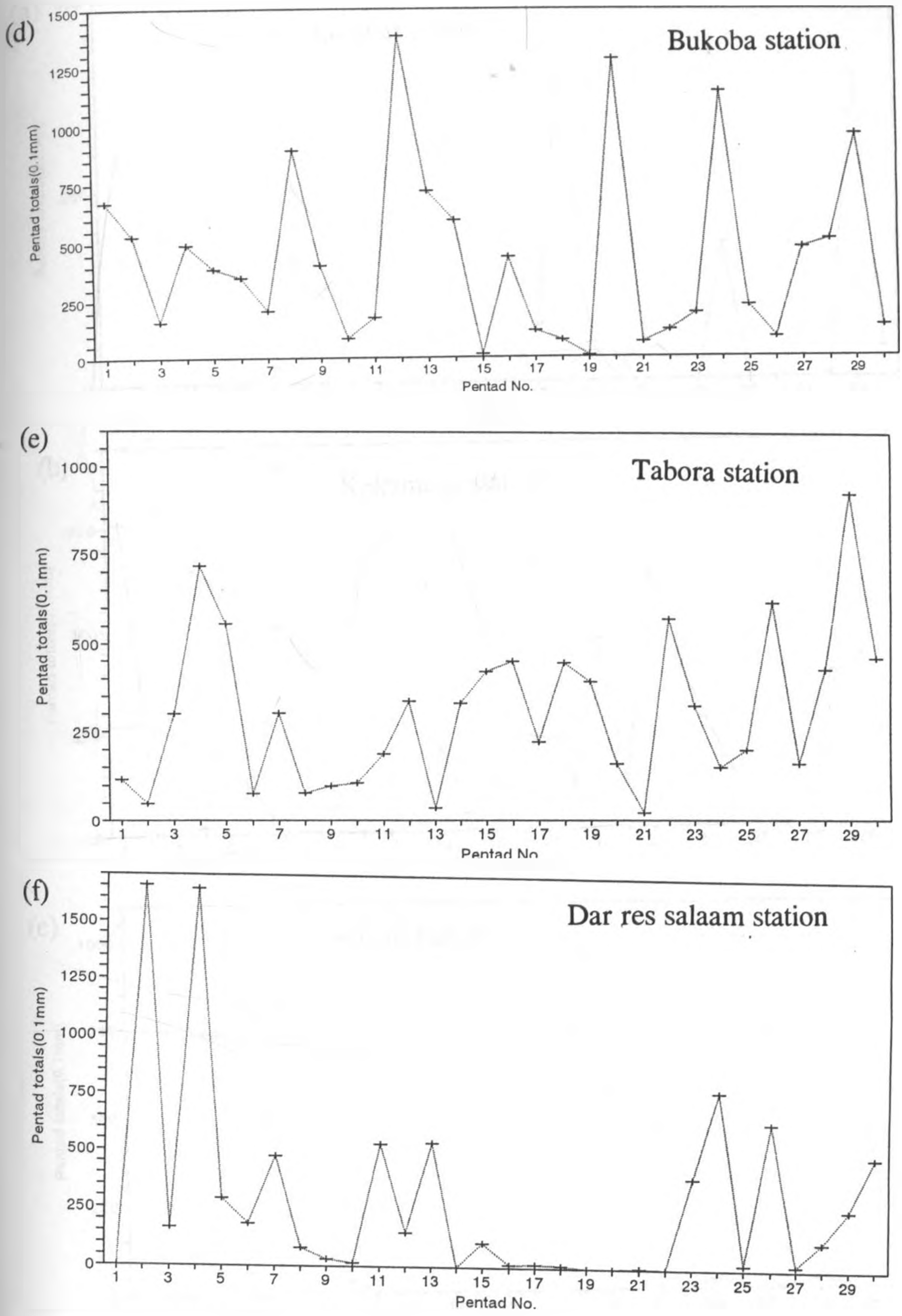


Figure 13.(Contd).

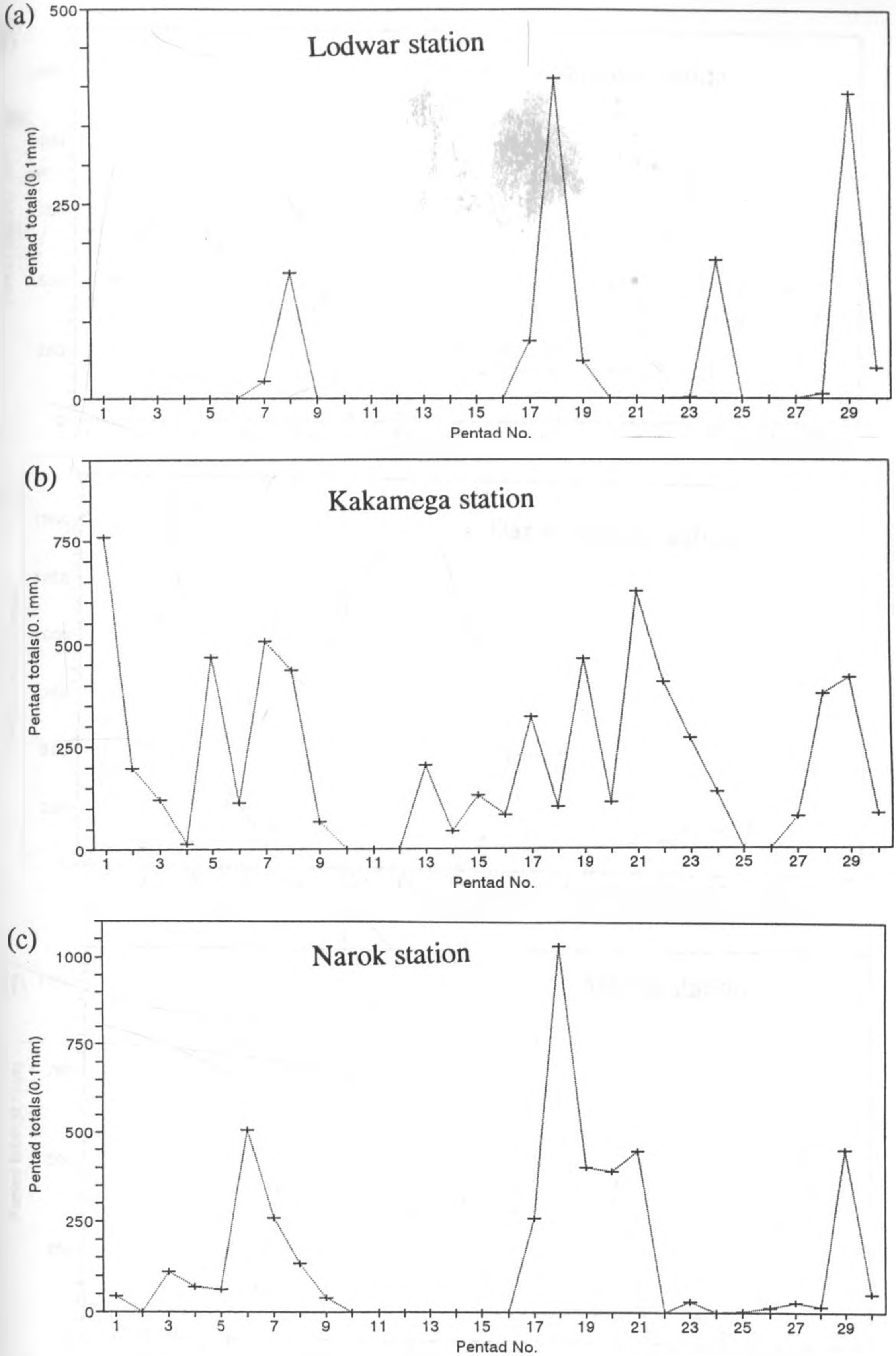


Figure 14: Examples of time series for pentads rainfall totals during the 1968/69 season at some stations; (a)-(f).

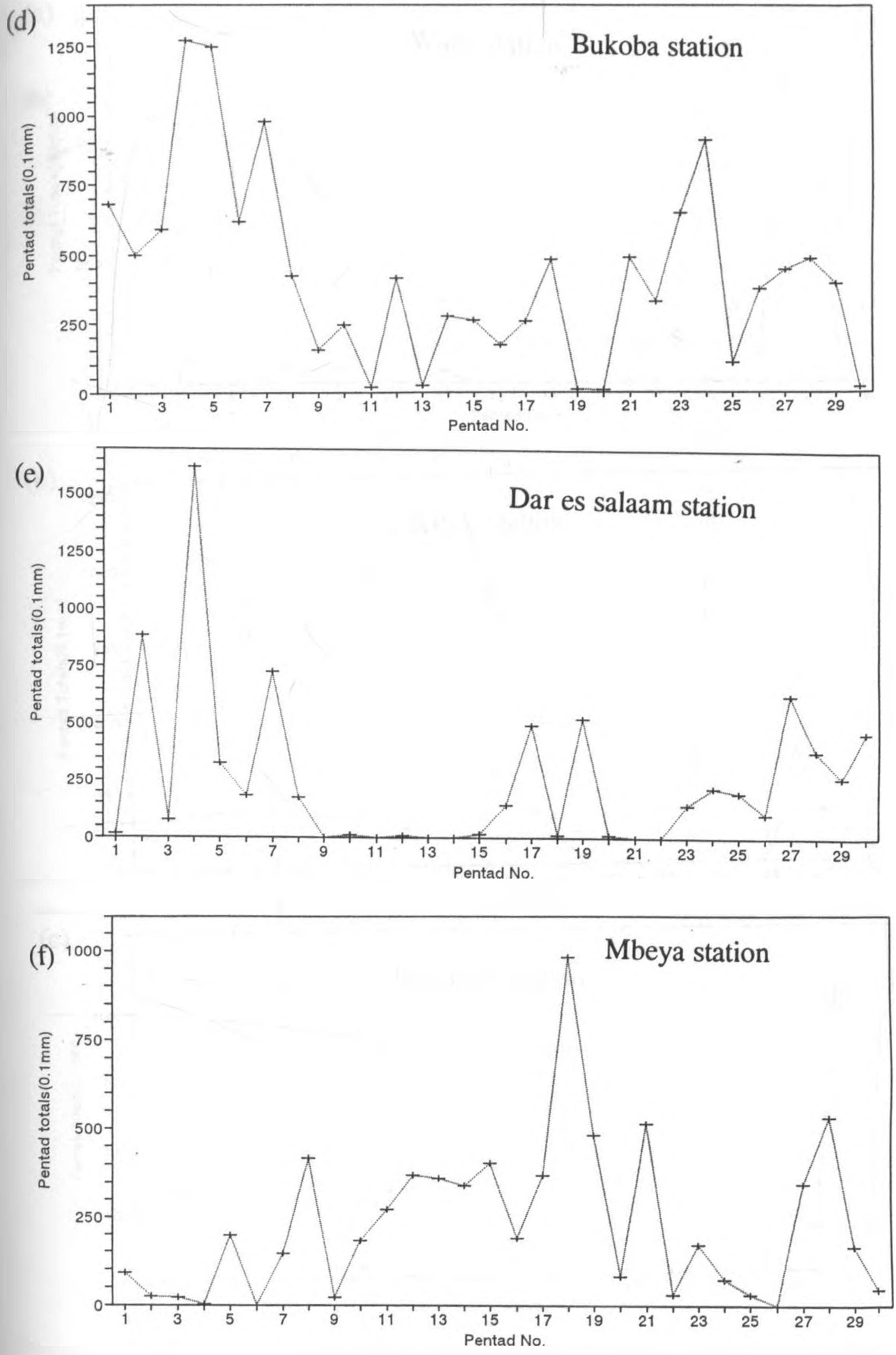


Figure 14.(Contd)

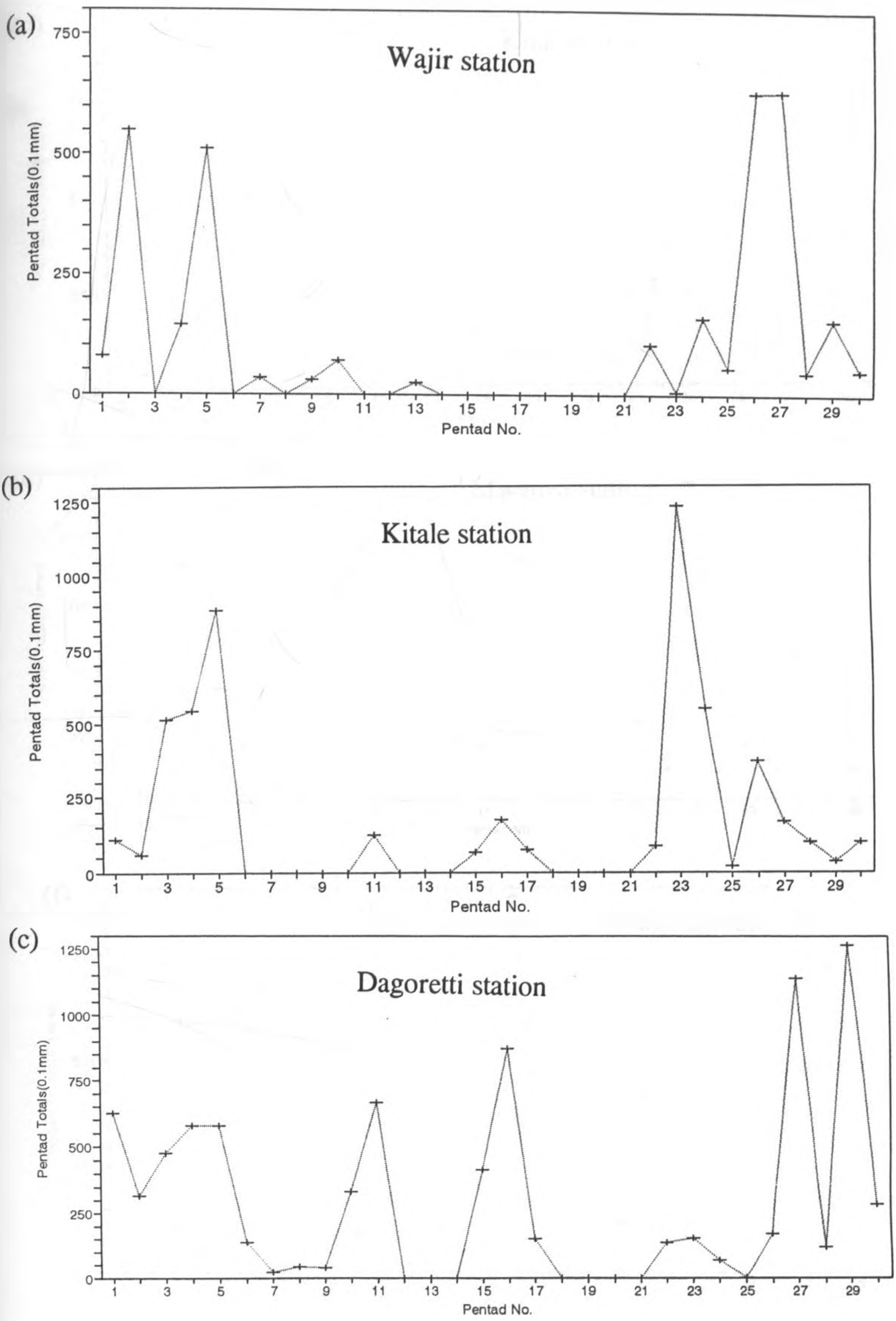
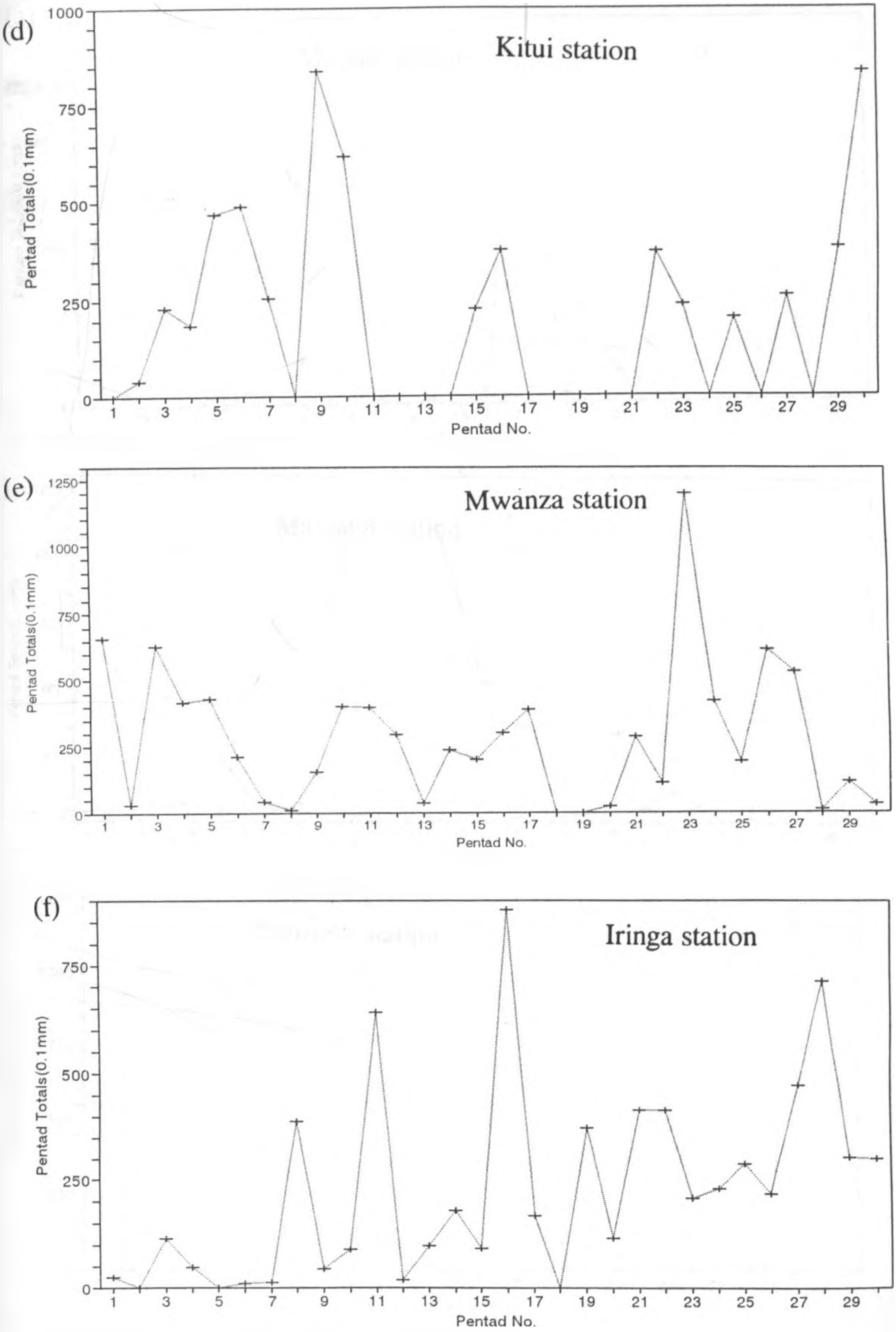


Figure 15: Examples of time series for pentad rainfall totals during the 1977/78 at some stations; (a)-(f).



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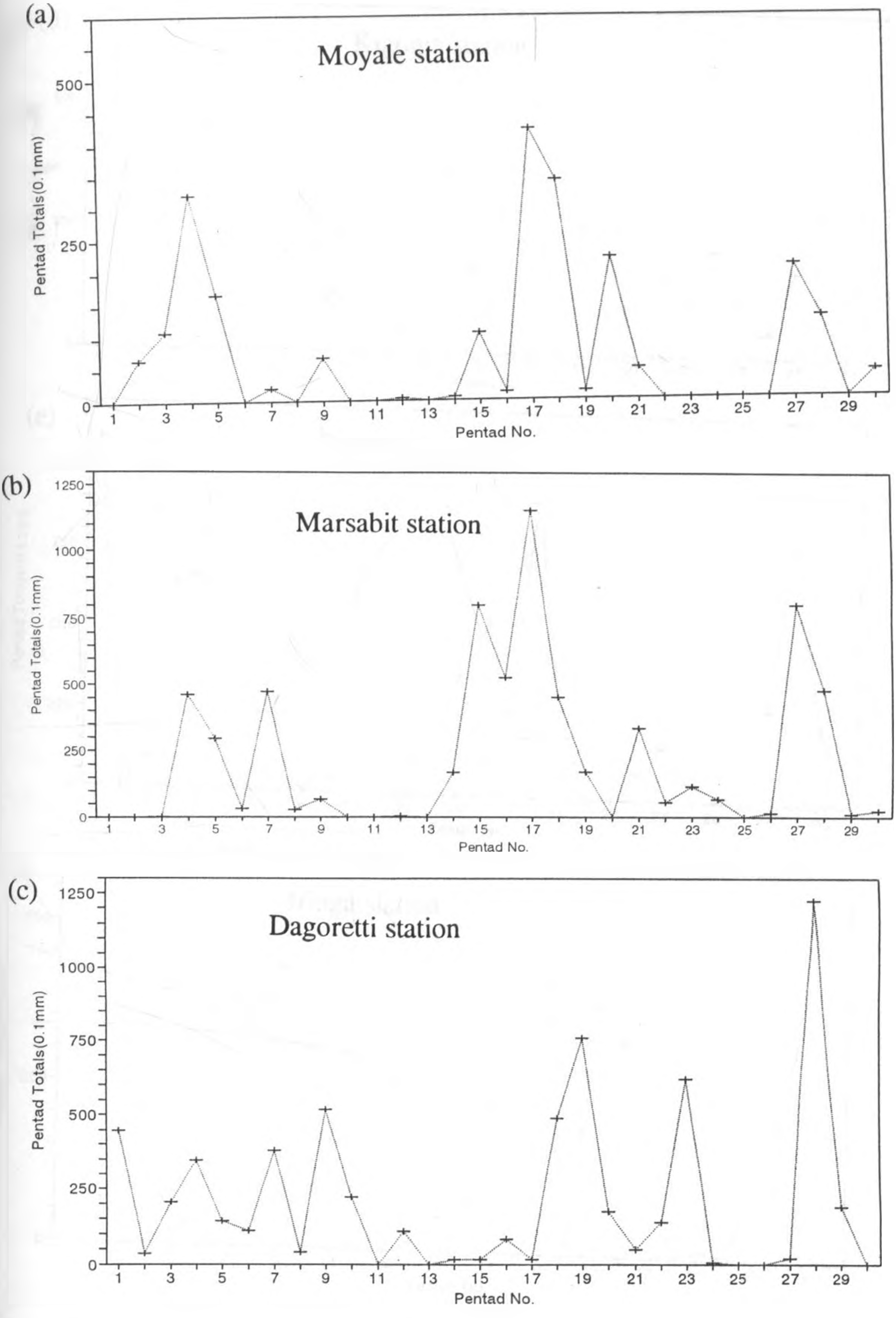


Figure 16: Examples of time series for pentad rainfall totals during the 1978/79 at some stations; (a)-(f).

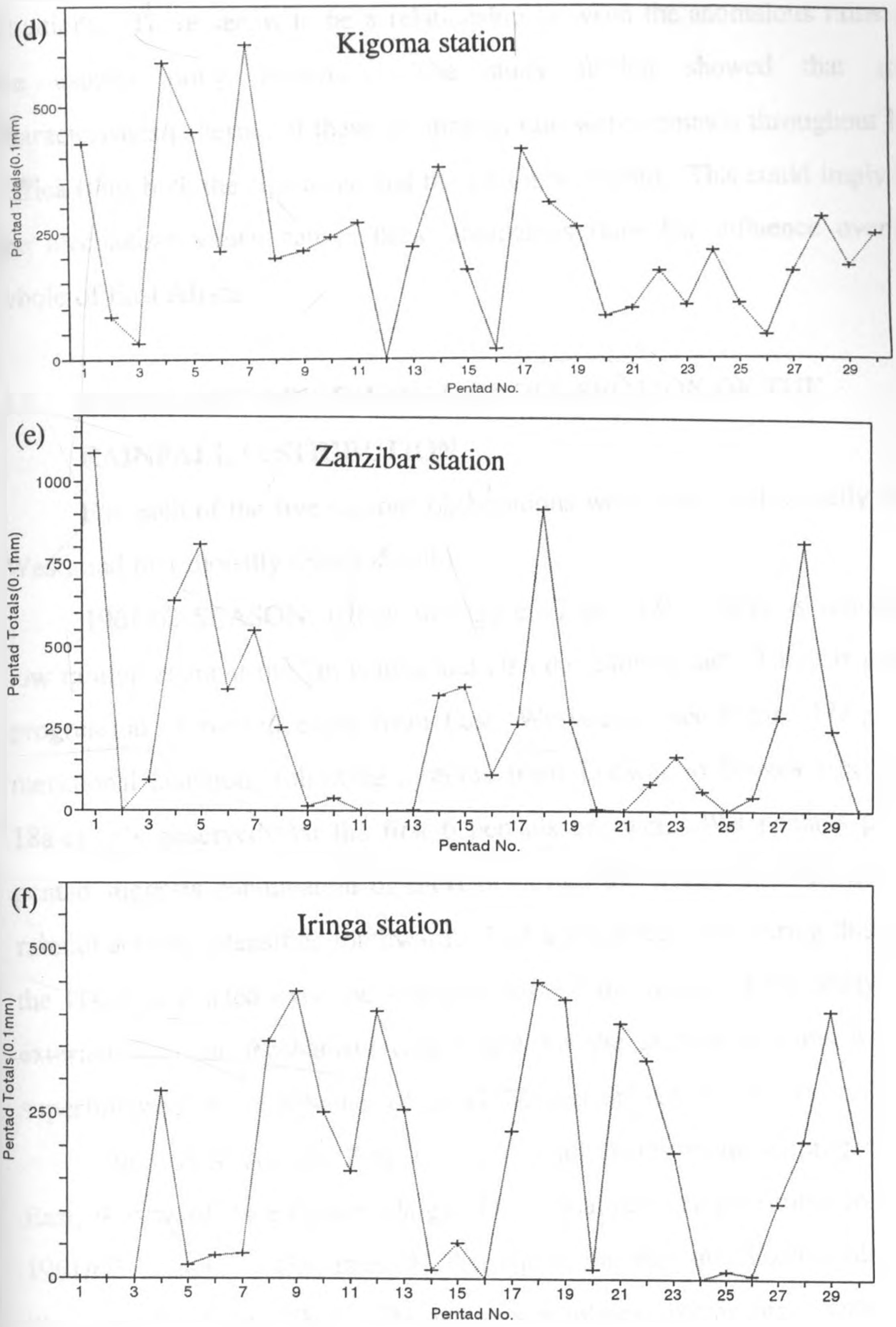


Figure 16.(Contd)

situations. There seems to be a relationship between the anomalous rains and the usually rainy seasons. The study further showed that some characteristics/patterns, of these anomalous rain were common throughout East Africa (thus both the equatorial and the southern region). This could imply that the mechanism which causes these anomalous rains has influence over the whole of East Africa.

3.8 ZONAL AND MERIDIONAL CROSS-SECTION OF THE RAINFALL DISTRIBUTION

For each of the five seasons observations were made both zonally (East-West) and meridionally (North-South).

1961/62 SEASON: (Refer to Figure 17 and 18). There is remarkable low rainfall event at the 7th pentad and also the 24th pentad. There is positive progression of rainfall event from East, Westwards, see Figure 17a-g. For meridional situation, following systems from Lodwar to Songea (see Figure 18a-e), it's observed that the first 6 pentads are wet. Wet pentads past 7th pentad suggests continuation of short rains into the season (DJF-season). The rainfall activity intensifies southward. This is expected since during this season the ITCZ is located over the southern part of the region of the study. Any external force or mechanism responsible for the anomalous rains would be superimposed on the influence of the ITCZ over the southern region.

1963/64 SEASON: Zonally, the rainfall events seems to progress from East, Westwards (see Figure 19a-g). The spatial patterns are similar to those of 1961/62 season. The rainfall distribution in the meridional pattern are illustrated by figure 20a-f. The wetness amplifies southwards. This suggest influence of the short rains as observed in the previous cases. Thus the pattern suggest southward progression of rainfalls.

1968/69 SEASON: Zonally, the rainfall systems are observed to intensify from the east, westwards (see figures 21a-e). A peak is observed at around the 18th pentad and intensifies westwards. For meridional characteristics see figures 22a-g. Two wet events are observed occurring on early pentads and late pentads. The latter is more intense. The systems suggests possibility of influence from both the short and the long rains. The rainfall systems progresses from north, southwards.

1977/78 SEASON: The zonal patterns could not be obtained due to unavailability of daily rainfalls as mentioned earlier. However for meridional situation see figures 23a-d. The season is observed to have greater coherence with the season which follows than the preceding one. Pentads suggest rainfall intensification southwards from north.

1978/79 SEASON: Due to data unavailability it is not possible to make conclusive observation for the zonal patterns (see figure 24). However meridional patterns as illustrated by figures 25a-d confirm the previous observations (seasonal rainfall monthly analysis). The 7th pentad which marks the end of the wet season (short rains) and the 24th pentad which marks the end of the dry season were dry delinking likely influence of the usually rainy seasons. A wet event is observed around the 17th pentad. The wet event intensifies southwards. This season has a different pattern from the other four as previously observed. Generally these analysis supports previous observations.

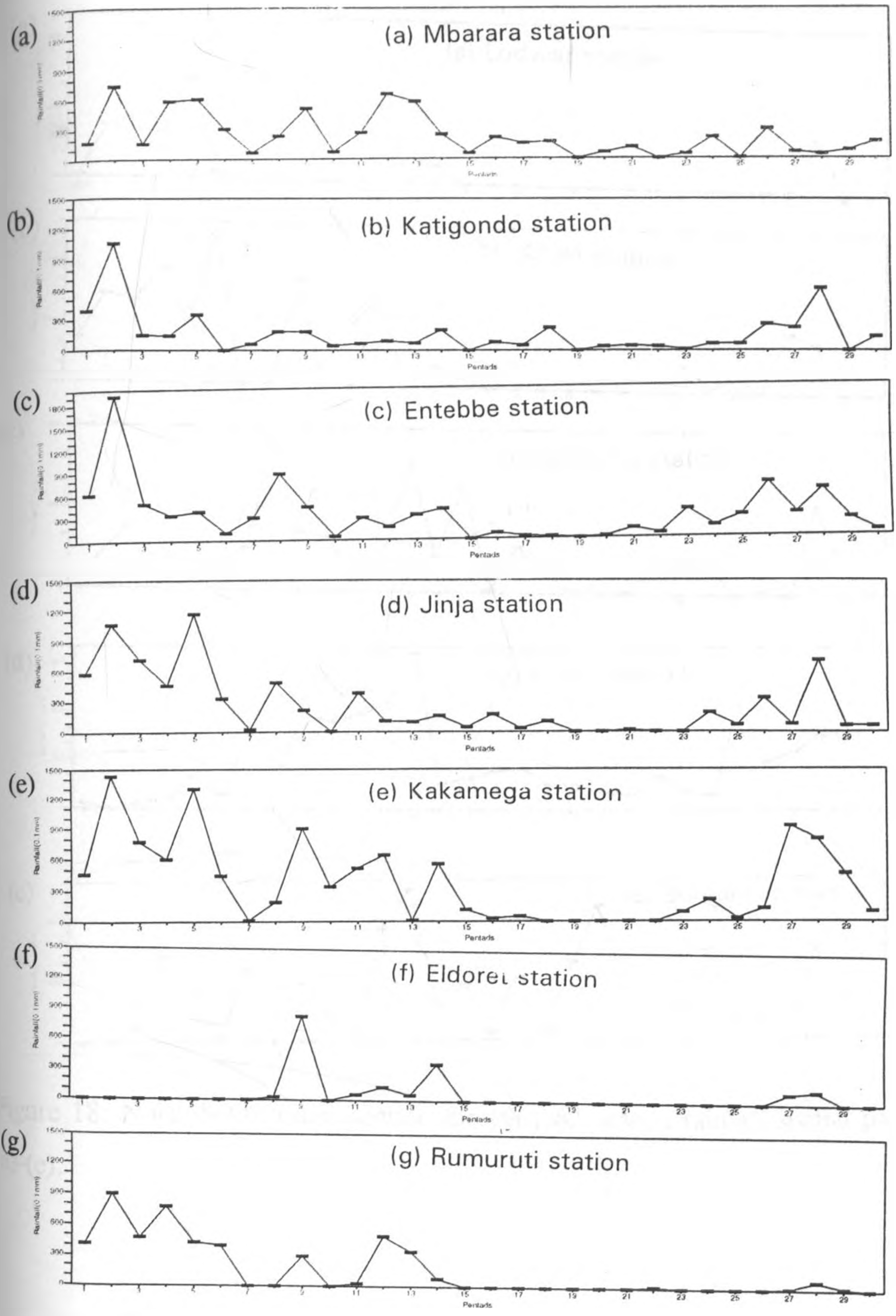


Figure 17: East-west cross section for 1961/62 season rainfall spatial pattern; (a)-(g).

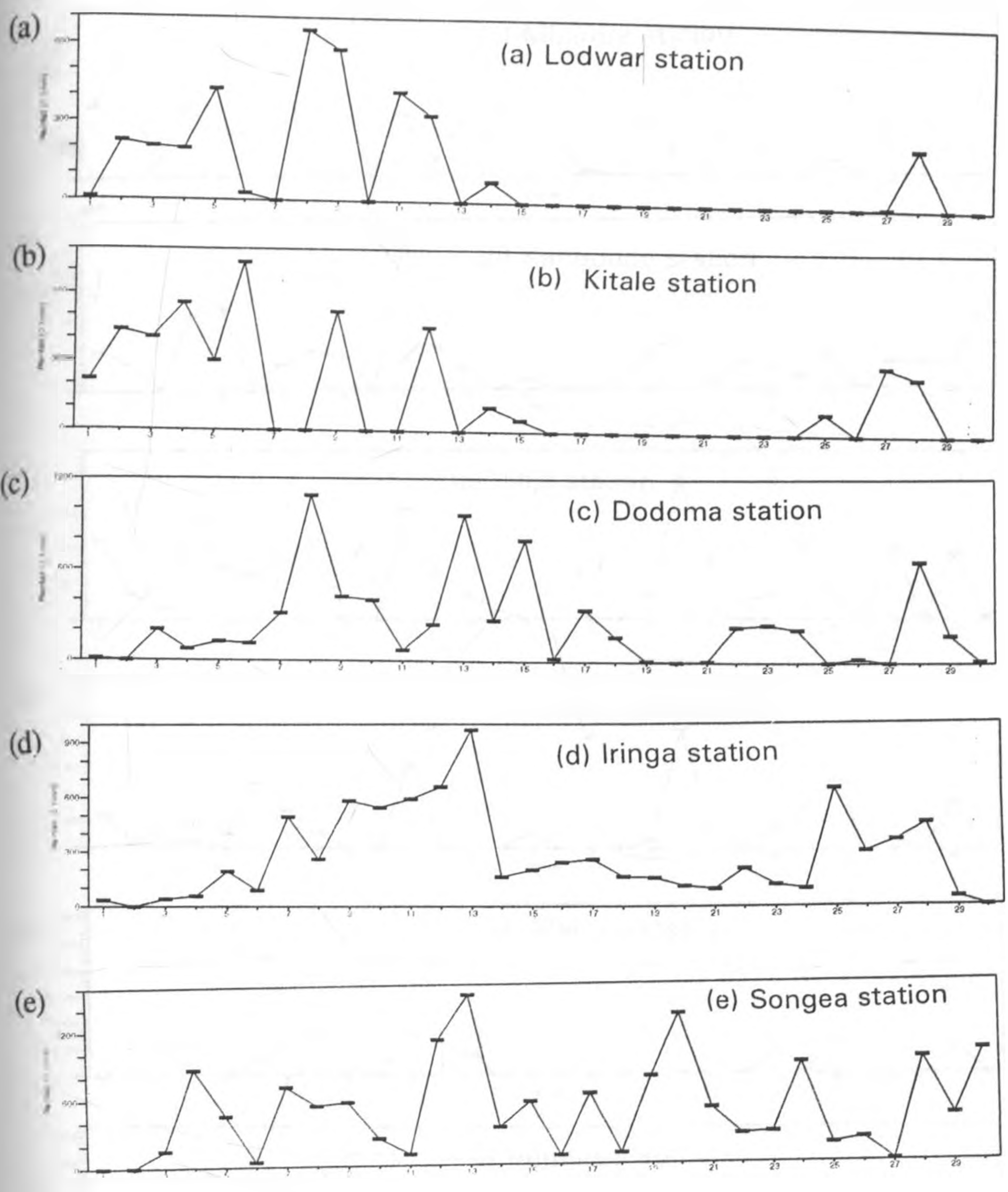


Figure 18: North-South cross section for 1961/62 season rainfall spatial pattern; (a)-(e).

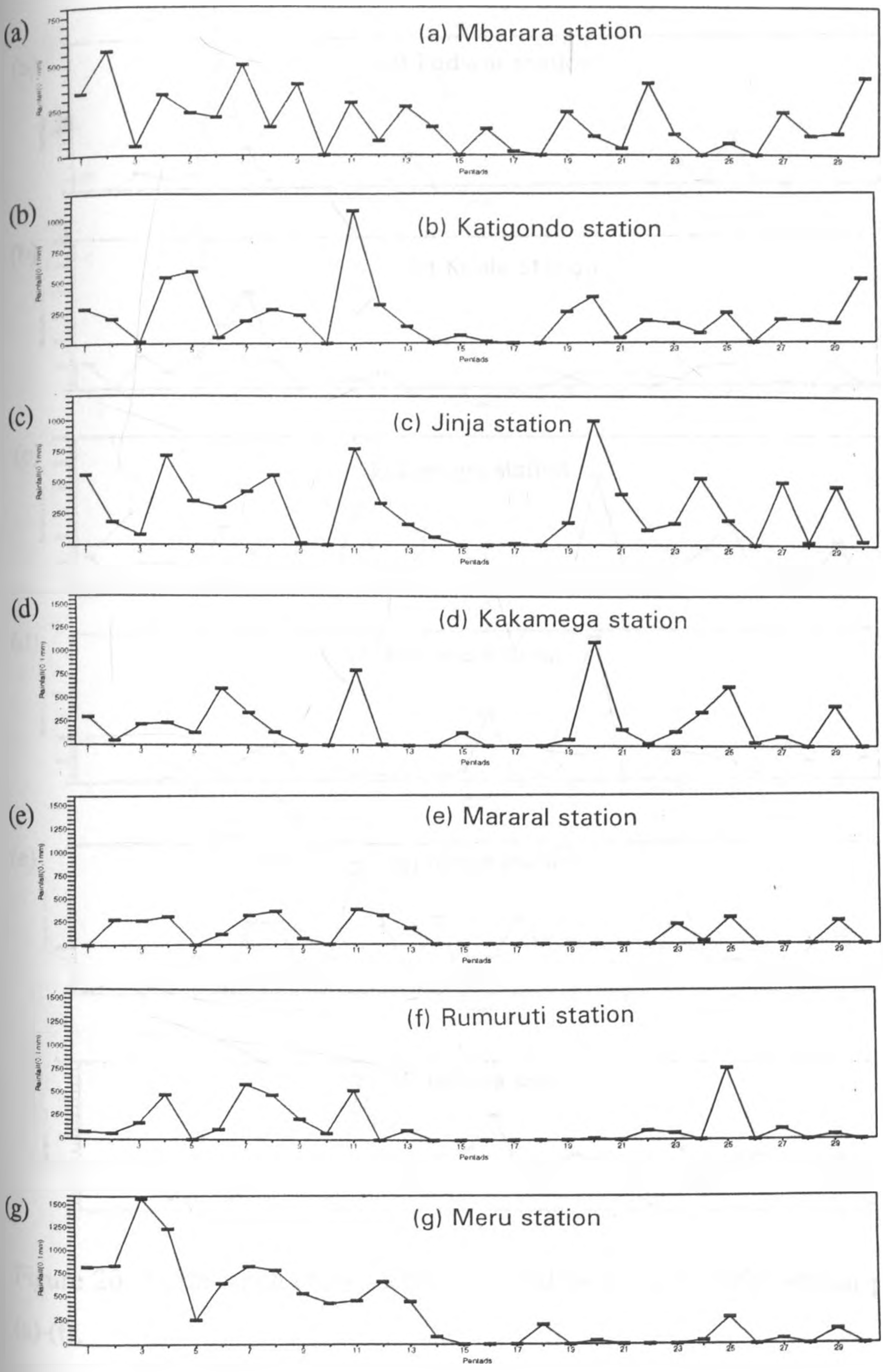


Figure 19: East-West cross section for 1963/64 season season rainfall spatial pattern; (a)-(g).

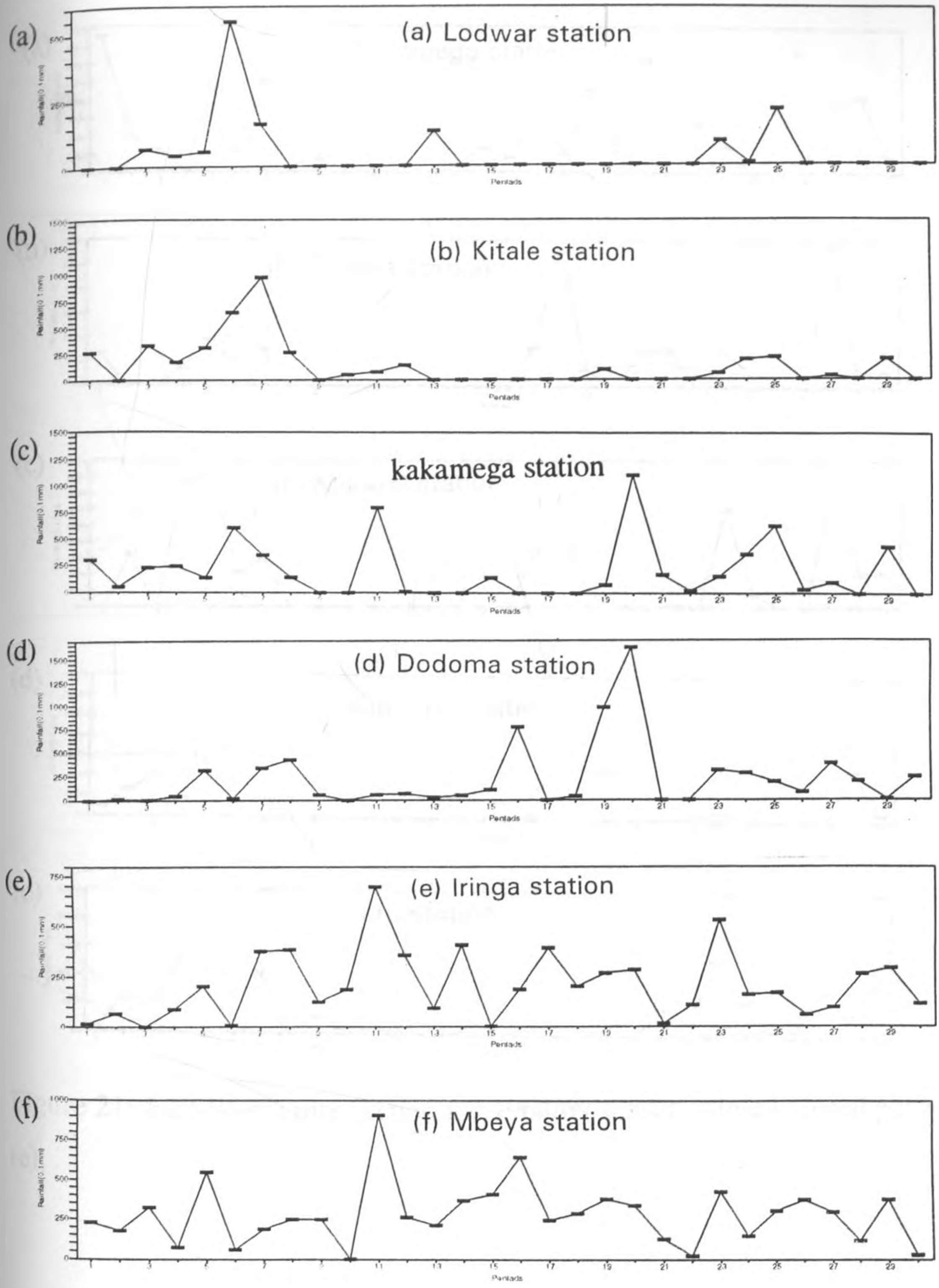


Figure 20: North-South cross section for 1963/64 season rainfall spatial pattern; (a)-(f).

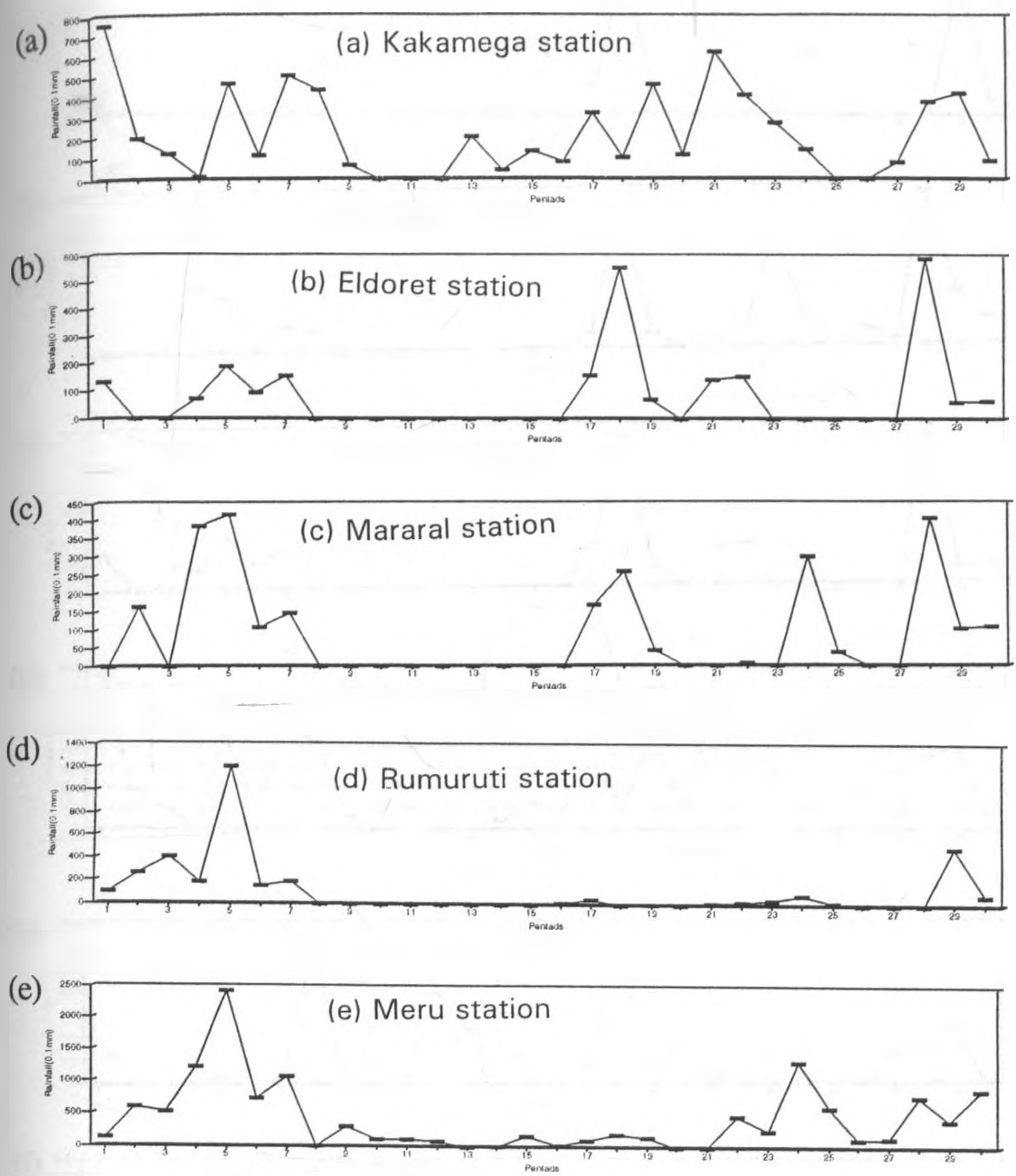


Figure 21: East-West cross section for 1968/69 season rainfall spatial pattern; (a)-(e).

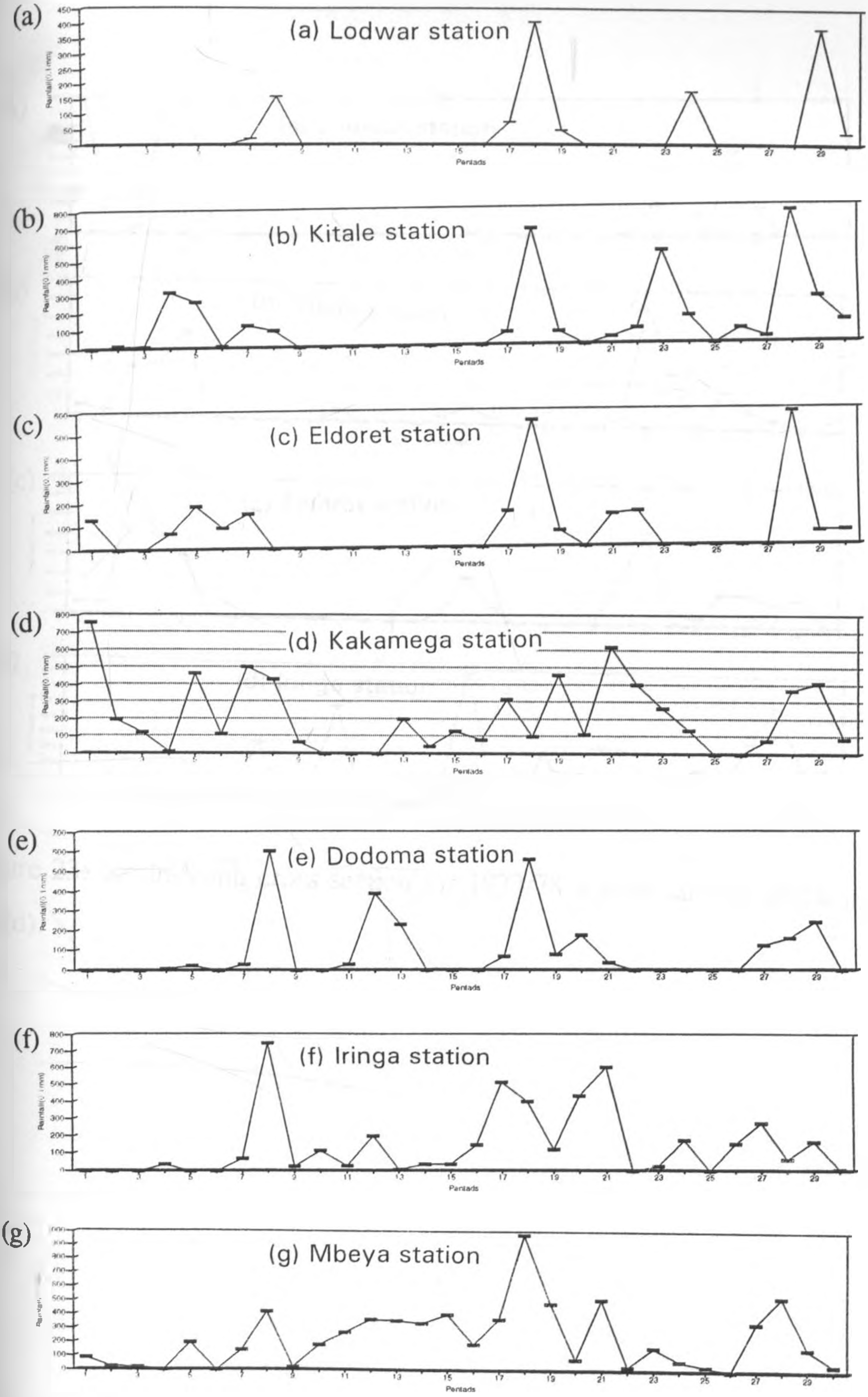


Figure 22: North-South cross section for 1968/69 season rainfall spatial pattern; (a)-(g).

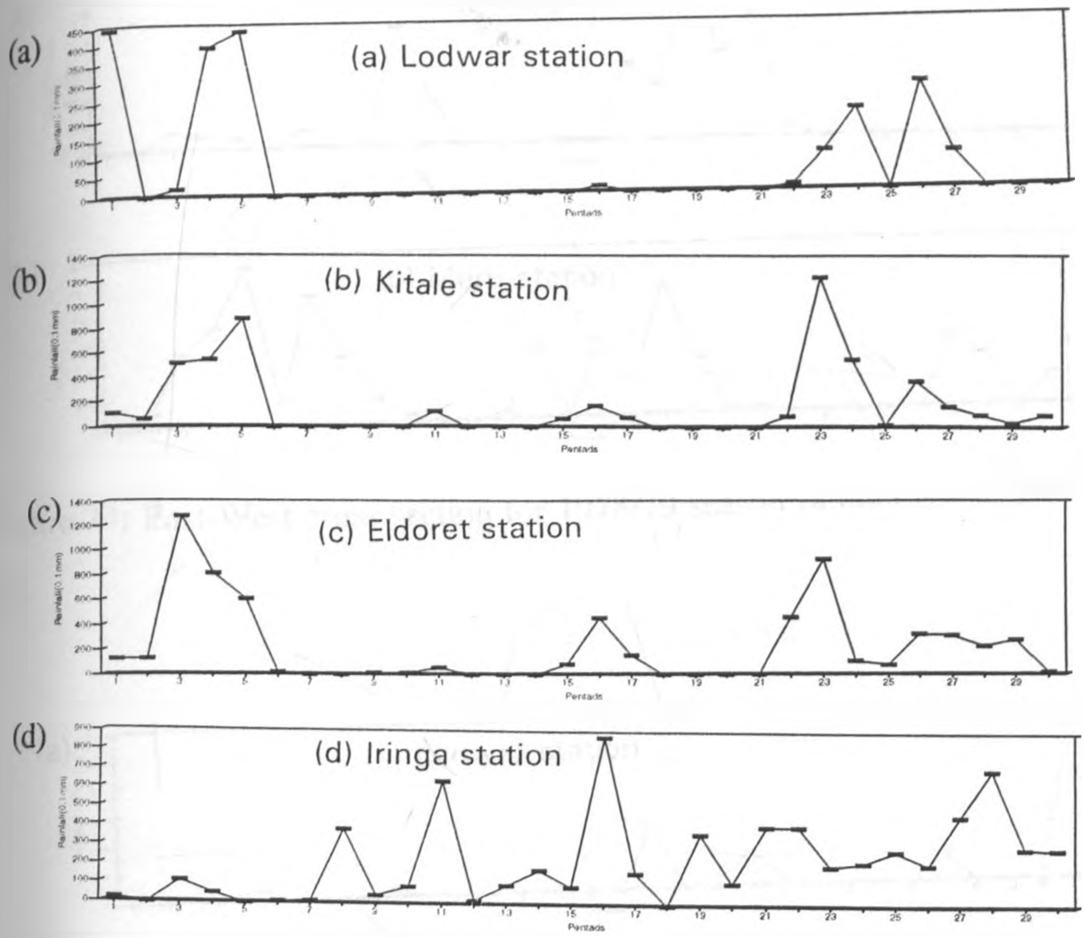


Figure 23: North-South cross section for 1977/78 season rainfall spatial pattern; (a)-(d).

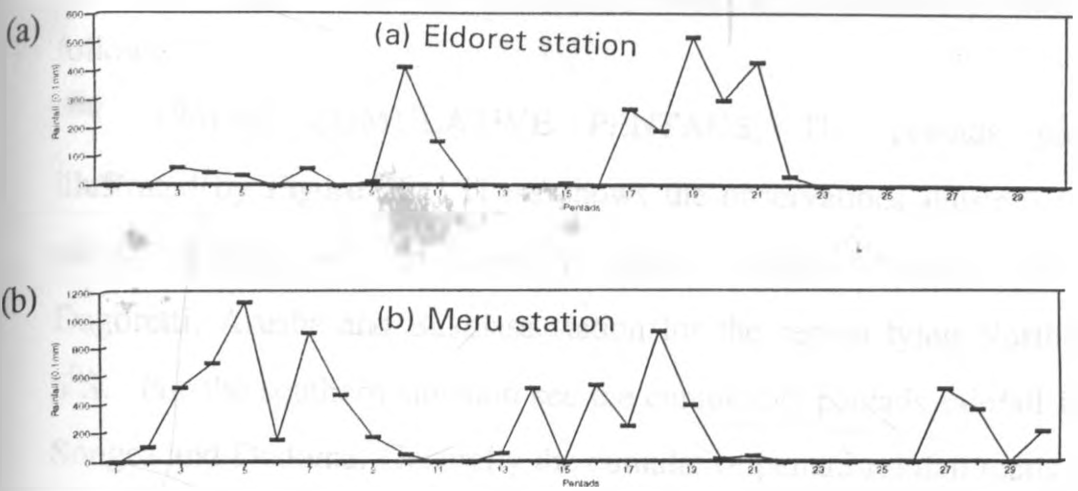


Figure 24: East-West cross section for 1978/79 season rainfall spatial pattern; (a)-(b).

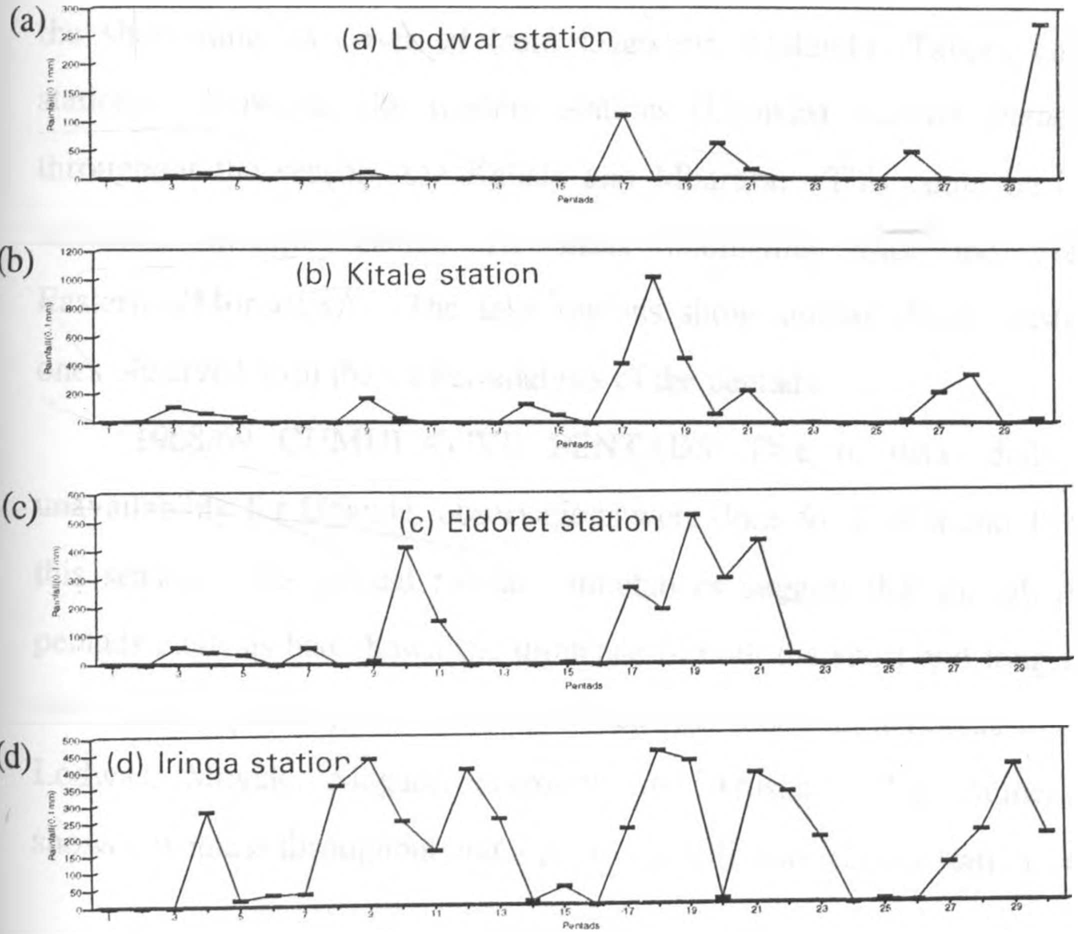


Figure 25: North-South cross section for 1978/79 season rainfall spatial pattern; (a)-(d).

3.8.1 CUMULATIVE PENTADS ANALYSIS

Examples of cumulated rainfall pentads are illustrated for each season as follows;

1961/62 CUMULATIVE PENTADS; The pentads patterns are illustrated by Figure 26. These shows the observations illustrated by pentad rainfall analysis and the monthly rainfall analysis. Examples are Lodwar, Dagoretti, Arusha and Bukalasa station for the region lying North of latitude 5^0S. For the southern situation see the cumulative pentads rainfall analysis for Songea and Dodoma. Generally the cumulative pentad rainfall totals show what has already been observed as illustrated by stations picked for examples previously. See section 3.4 and 3.7 above.

1963/64 CUMULATIVE PENTADS: From the monthly and the pentads analysis, the observations made were that the season could have benefited from the short rains as observed from Dagoretti, Makindu, Tabora and Bukoba stations. However the western stations (Uganda) showed wetness almost throughout the season, see Kabale and Mbarara. This could be due to the influence of the Congo air mass interacting with the predominate Easterlies(Monsoons). The lake regions show similar characteristics as the ones observed with the earlier analysis of the pentads.

1968/69 CUMULATIVE PENTADS: Due to data (daily rainfalls) unavailability for Uganda, observations were done for Kenya and Tanzania for this season. The pentad rainfall cumulatives suggest that though the earlier pentads analysis had shown the influence of both the short and long rains over this season, the long rains that followed had more influence as observed for Lodwar, Moyale, Magadi, Dagoretti and Arusha. The southern stations showed wetness throughout and a good example was Tabora station. Generally the pentad cumulatives for most of the stations confirms the earlier observations (see section 3.4 and 3.7 above).

1977/78 CUMULATIVE PENTADS: The pentads and monthly analysis had suggested that the season benefited from short and long rains. From the cumulatives analysis we observe that the long rains had more influence compared to the short rains, see figure 27. The lake Victoria region stations and the southern stations showed wetness throughout the season, for example see Tabora and Bukoba station. Generally the observations supports previous observations.

1978/79 CUMULATIVE PENTADS: The pentad rainfall and the monthly rainfall totals analysis suggested that the short and long rains did not have influence over this season's anomalous rains (see section 3.4 and 3.7 above). The pentad rainfall cumulatives also support this, refer to Figure 28. During this period/season the Tanzania's stations proved to be generally wet throughout. This suggests that the mechanism (s) which caused these anomalous rains amplified the summer rain generating mechanisms in the southern region of East Africa. The lake region stations observed remarkable wetness.

In summary, it is clear from the observations made that, the pentad rainfall cumulatives support what was observed and deduced from the monthly and pentads analysis as discussed in section 3.4 and 3.7.

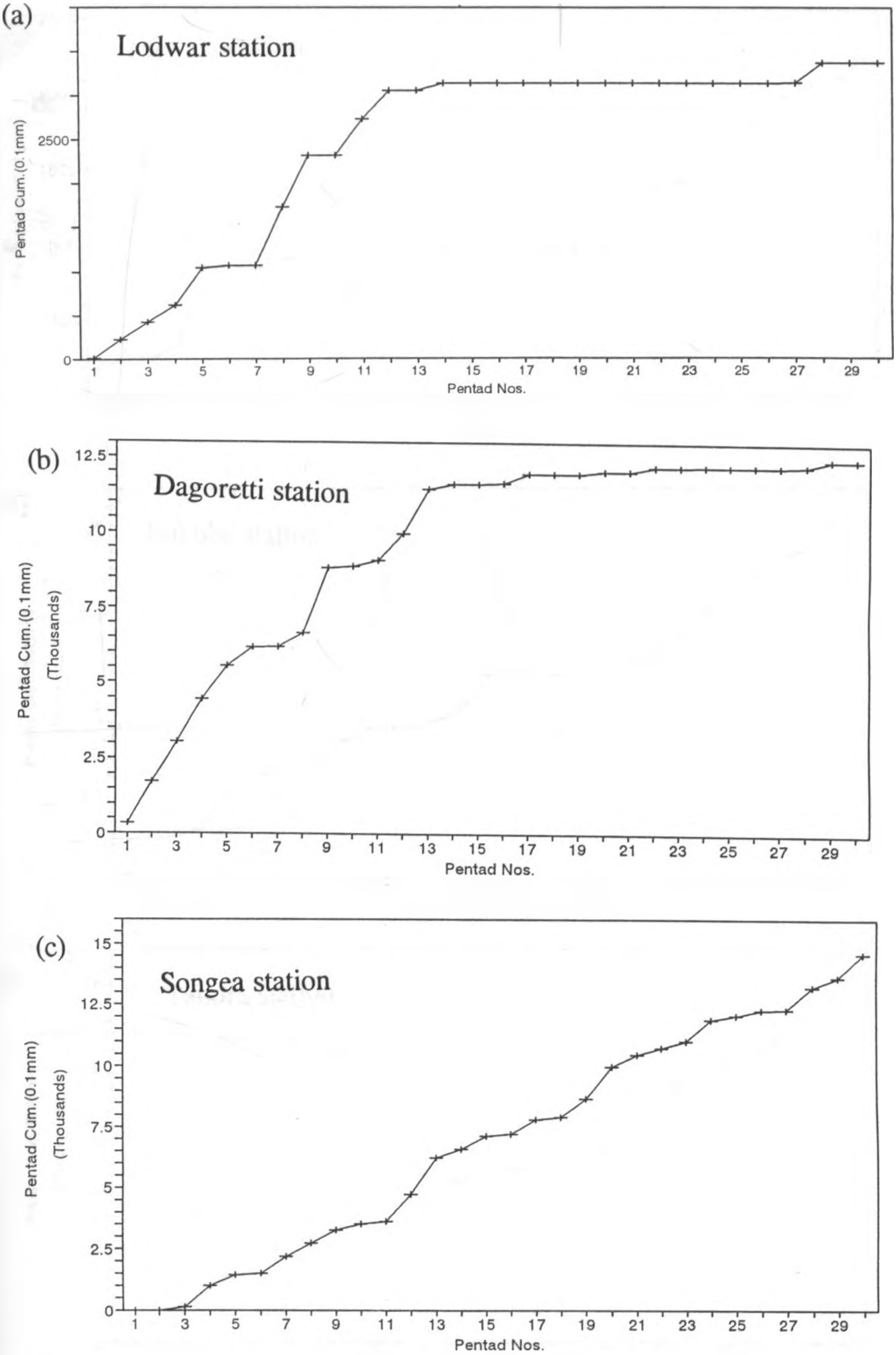


Figure 26: Examples for 1961/62 season pentads rainfall cumulative at some stations; (a)-(c). (a) (b) (c)

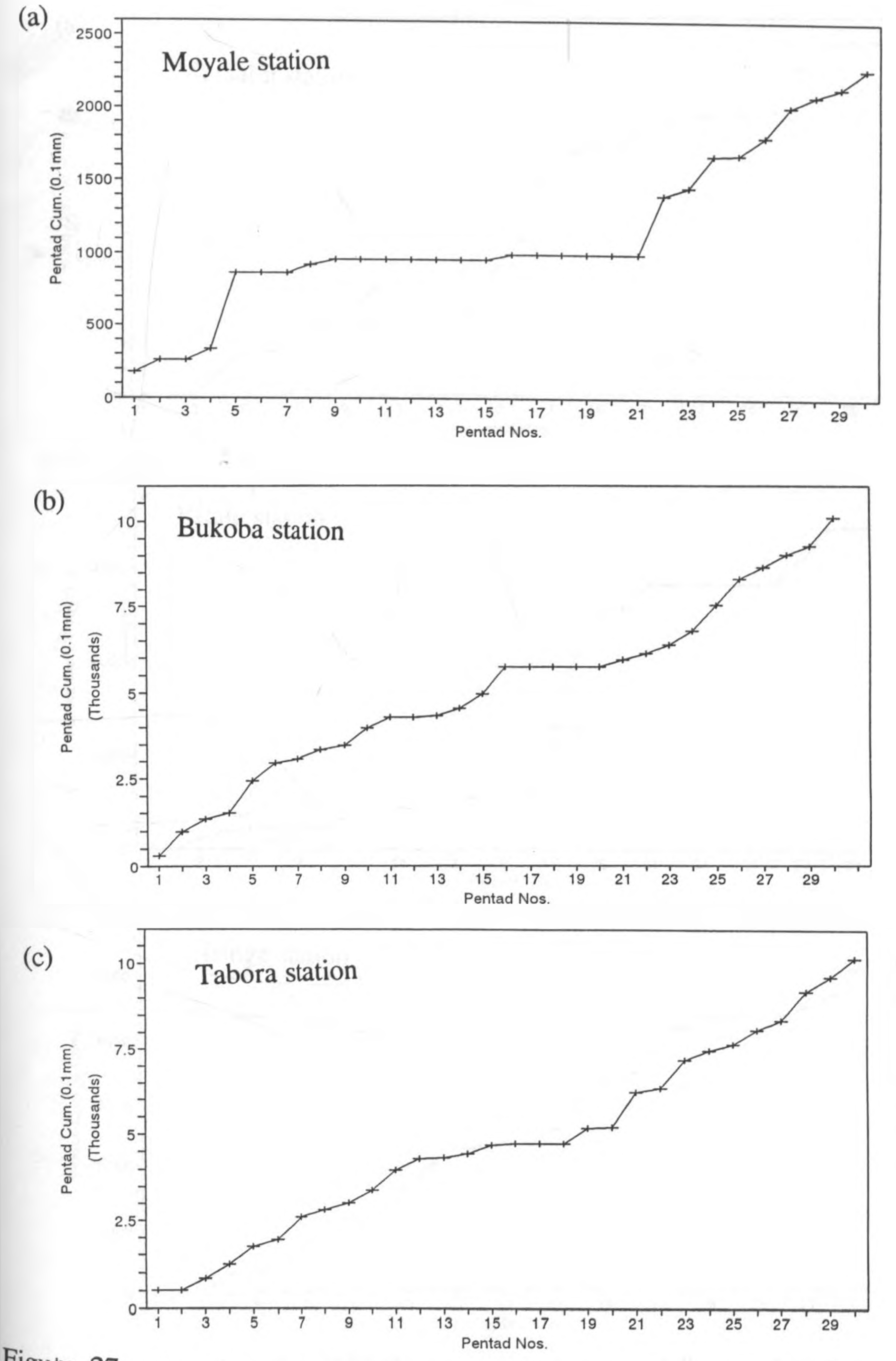


Figure 27: examples for 1977/78 season pentads rainfall cumulative at some stations; (a)-(c).

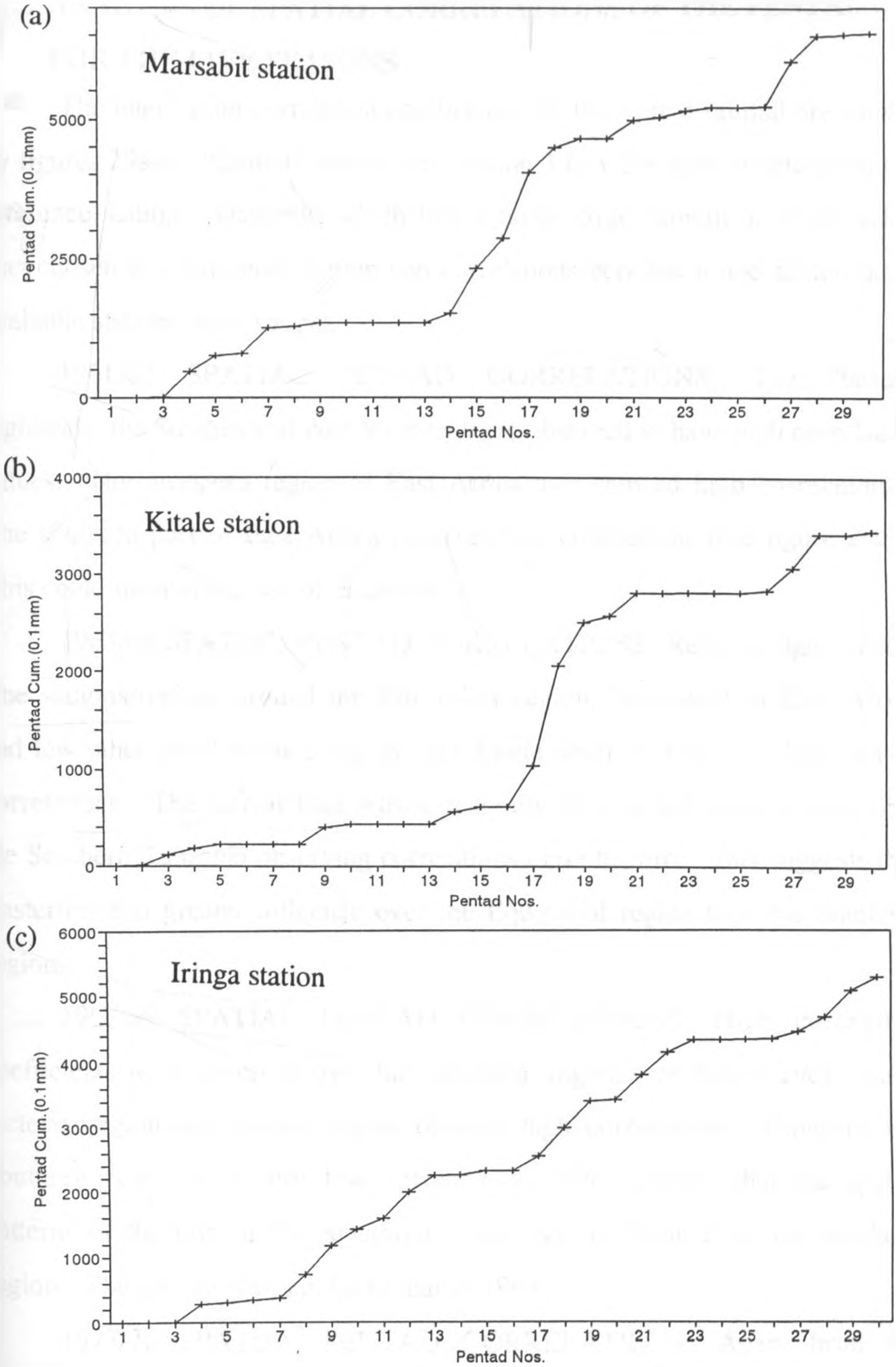


Figure 28: Examples for 1978/79 season pentads rainfall cumulative at some stations; (a)-(c).

3.8.2 ANALYSIS OF SPATIAL CORRELATIONS OF THE PENTADS FOR THE FIVE SEASONS

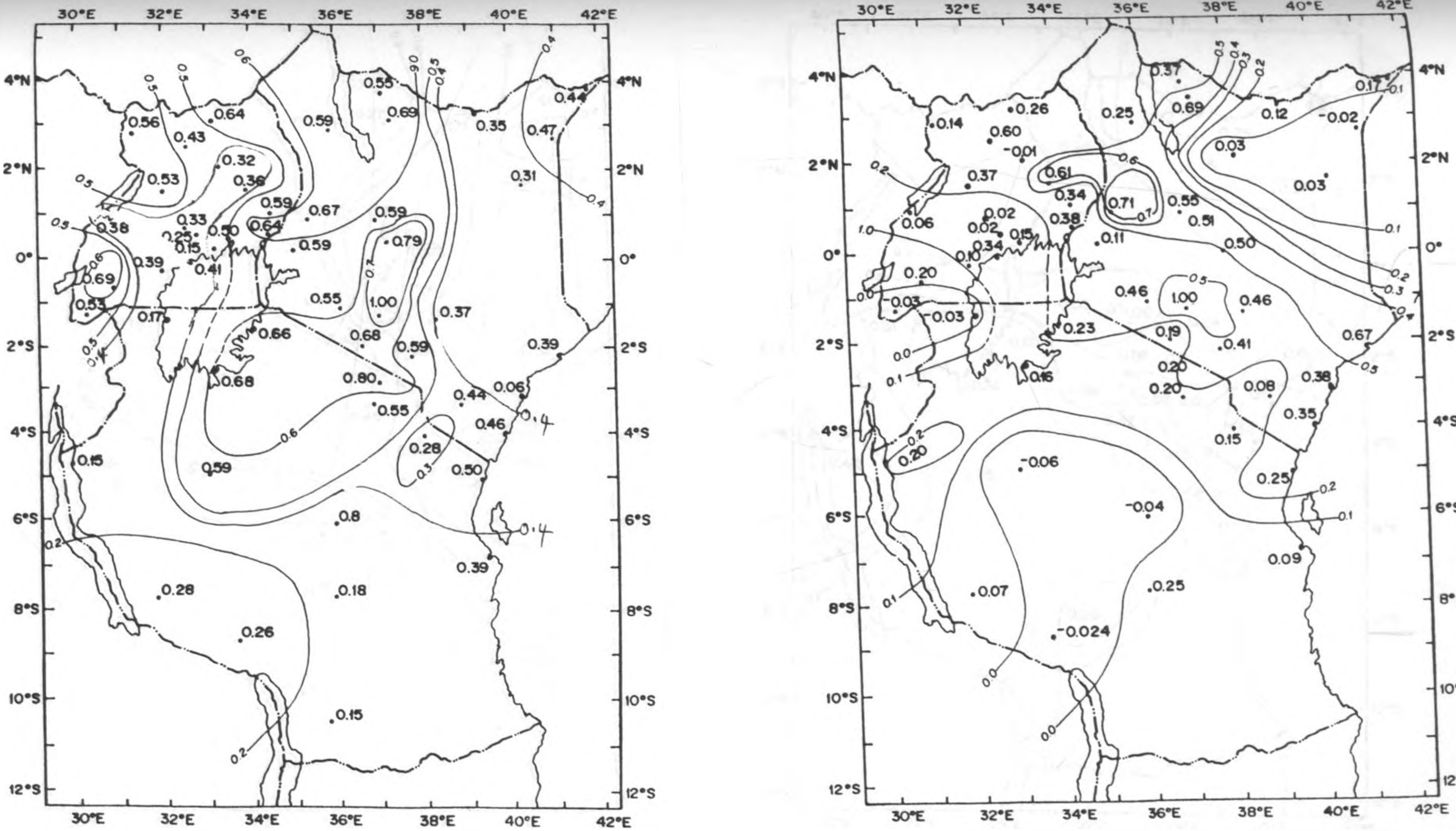
The interstation correlation coefficients for the pentad rainfall are shown by figures 29a-e). Rainfall indices (see section 3.6) were used to determine the reference station. Dagoretti which had a fairly large rainfall anomaly index was chosen as a reference station and correlations between it and all the other available stations were sought.

1961/62 SPATIAL PENTAD CORRELATIONS: The Eastern highlands, the Southeast of lake Victoria were observed to have high correlation values. Northwestern region of East Africa also showed high correlations. The southern part of East Africa observes low correlations (see figure 29a). This could mean influence of Easterlies.

1963/64 SPATIAL PENTAD CORRELATIONS: Refer to figure 29b. The stations/regions around the Rift valley region, Northwest of East Africa and few other small isolated regions like Lamu observes relatively high spatial correlations. The rest of East Africa generally showed low correlations, with the Southern Tanzania observing correlations close to zero. This suggests that Easterlies had greater influence over the Equatorial region than the Southern region.

1968/69 SPATIAL PENTAD CORRELATIONS: High correlation coefficients were observed over the equatorial region (see Figure 29c). Lake victoria region and coastal region observe high correlations. However the Southern region had very low correlations. This implies that the spatial patterns of the rain in the equatorial region was different from the southern region. The pattern was similar to that of 1963/64.

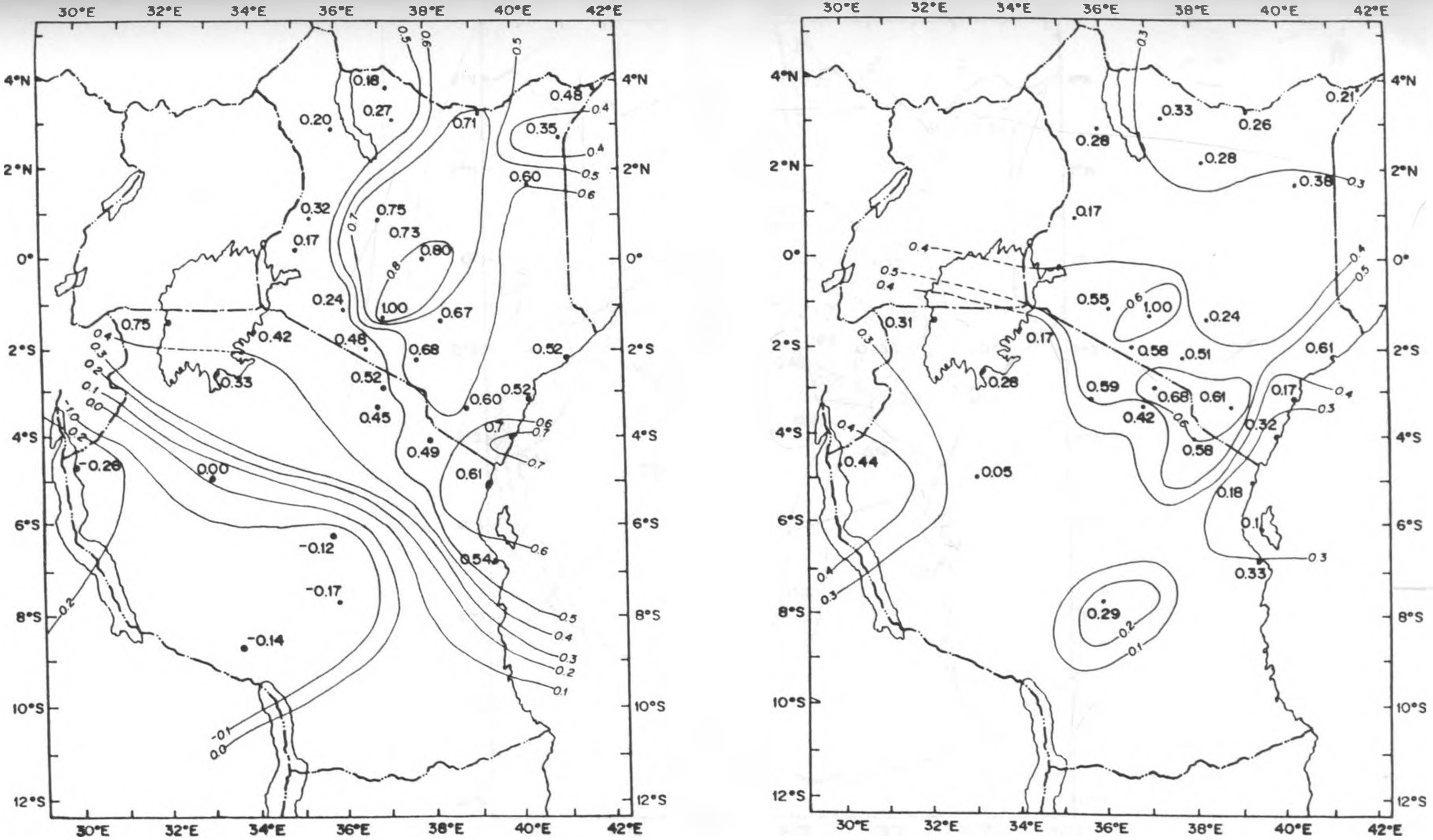
1977/78 SPATIAL PENTAD CORRELATIONS: Apart from the Eastern highlands, the rest of East Africa is observed to have generally low spatial coherence (see Figure 29d). This implies that the Easterlies could have



(a) spatial pentad correlations for 1961/62 season

(b) Spatial pentad correlations for 1963/64 season

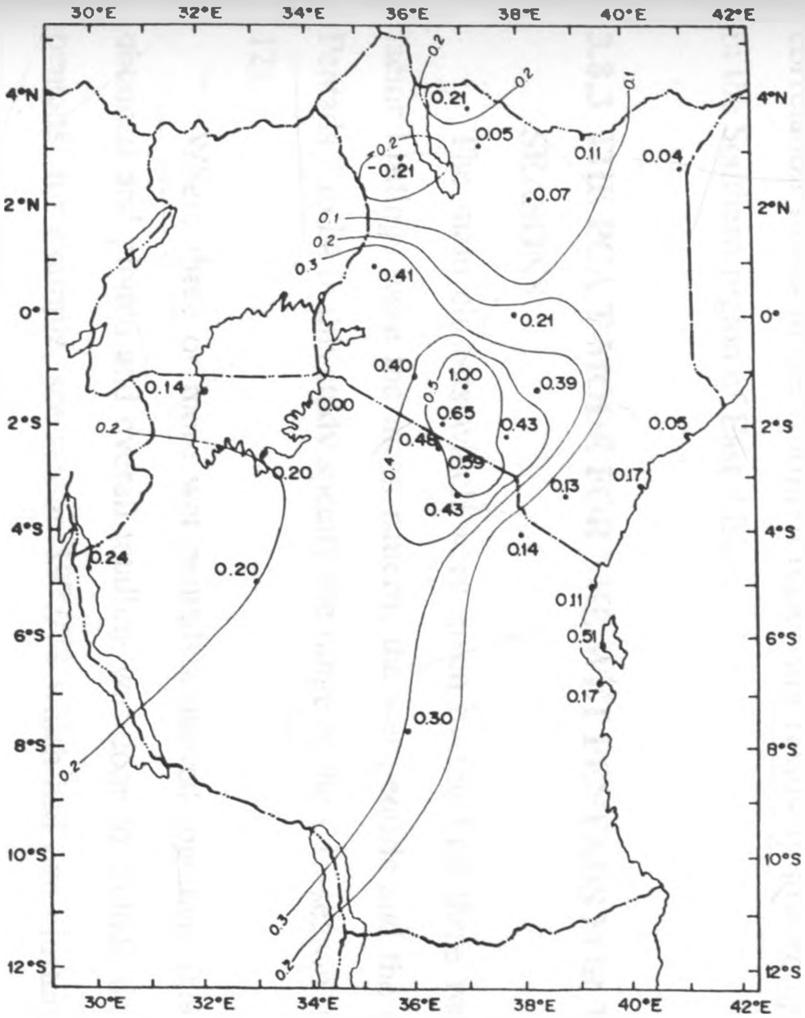
Figure 29: Spatial patterns of the inter-station correlations with reference station, Dagoretti; (a)-(e).



(c) Spatial pentad correlations for 1968/69 season

(d) Spatial pentad correlations for 1977/78 season

Figure 29.(Contd)



(e) Spatial pentad correlations for 1978/79 season

Figure 29.(Contd)

contributed. The equatorial region and the Southern region observed comparable close correlation values. Uganda not investigated due to lack of data.

1978/79 SPATIAL PENTAD CORRELATIONS: The stations in the Eastern highlands showed relatively high spatial correlation values (see Figure 29e). The rest of East Africa observes low spatial correlations. However the correlation values in the Northern region are relatively low compared to those in the Southern region of East Africa.

3.8.3 THE PCA T-MODE FOR THE WET PENTADS FOR THE FIVE SEASONS

The main clusters which were given by the first three rotated T-mode factor loadings were the mean pattern, the wet pentads and the dry pentads. Pentads 7 to 24 in this study specify the range of the DJF-season (refer to Table 12).

Where three or more wet pentads clustered together, their totals were obtained and plotted and overall totalling was done to include the isolated wet pentads; for example, see season 1977/78 which had two clustering groups of wet pentads and an isolated wet pentad.

1961/62 WET PENTADS: The picked wet pentads in this case were pentads 9, 12 and 13. Figure 30 shows that the Eastern highlands and the Southern region had high pentad rainfall totals as would be expected (see figure 30). The Northern region observed relatively low totals with the North-Eastern showing the lowest values. The Equatorial region generally showed high values.

1963/64 WET PENTADS: For this season the picked wet pentads are 9, 12, 13 and 14. Due to the clustering of pentads 12, 13 and 14, analysis was first done for the cluster and then overall done to include pentad 9. The Eastern highlands and the South-West of Lake Victoria observes high pentad totals. The Northern region of East Africa showed the lowest pentad totals. The Southern region did not observe very large values. Overall analysis for the four pentads just amplified observations made with the three pentads (see figure 31).

1968/69 WET PENTADS: The pentads studied in this case were pentads 17, 18 and 19. The Eastern highlands, Southern Tanzania and the Eastern region of Lake Victoria shows relatively high pentad rainfall totals(see figure 32). The rest of East Africa observes low totals with the North-Eastern and Coastal regions observing the lowest values. Sabarei, (Northern region of Kenya) shows quite high pentad rainfall values. Since Sabarei is located on a sloppy region, orographic forcing would result into heavy rains.

1977/78 WET PENTADS: The T-mode picked the following wet pentads, 7, 8, 9, 10, 11, 16, 22, 23 and 24. As evident from the order of the pentads, analysis was done in three ways; pentads 7, 8, 9, 10 and 11 were first analyzed, then 22, 23 and 24 were analyzed after which overall total analysis was sort to include pentad 16. Pentad totals for each case were compared and plotted.

(a) Analysis For Pentads 7, 8, 9, 10 and 11: The Eastern highlands, lake Victoria region and Southern region of East Africa were observed to have high pentad totals. The rest of East Africa shows relatively low pentad totals with the North-western Kenya observing the lowest pentad totals. The observations

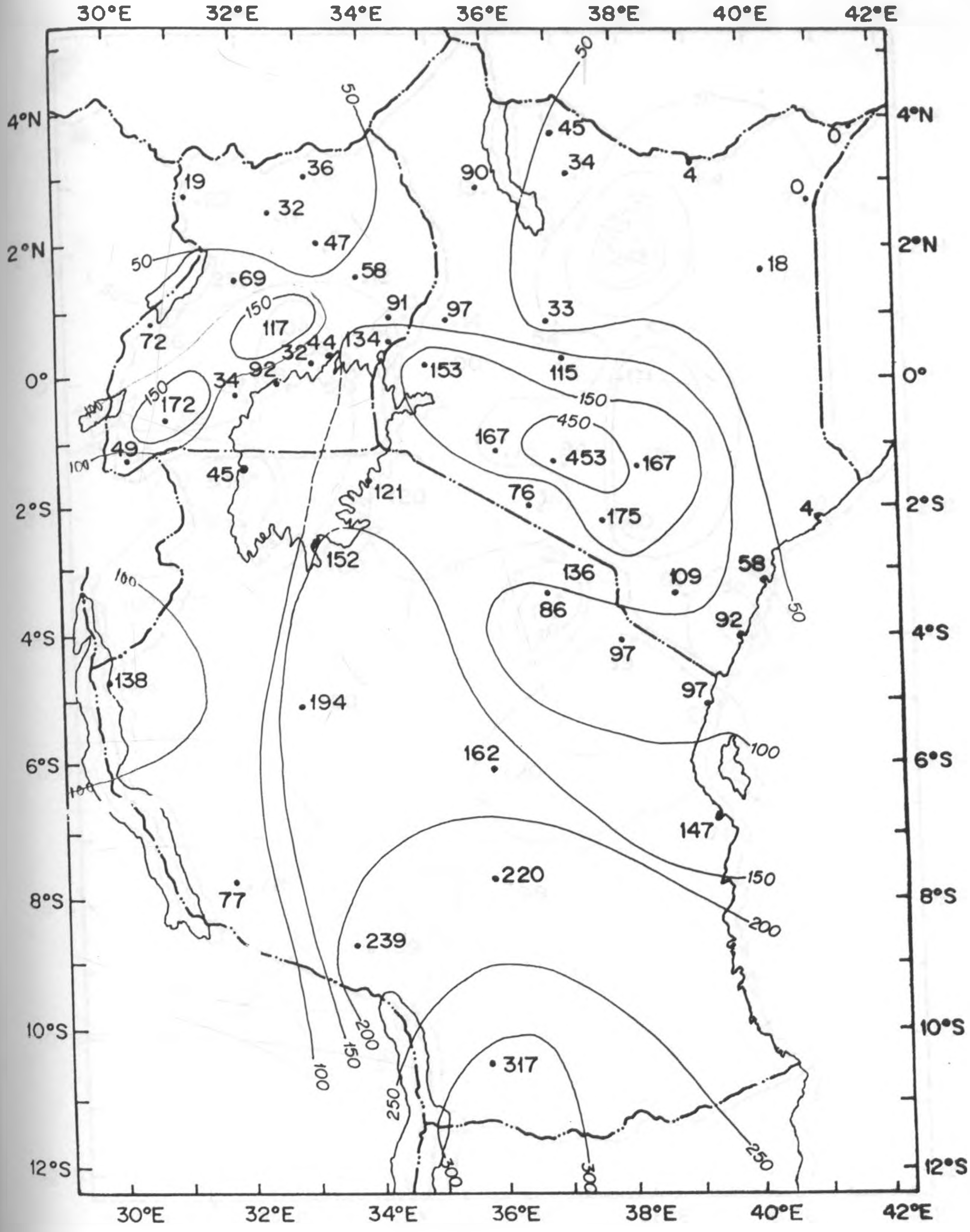


Figure 30: Spatial patterns for wet pentads 9, 12 and 13 for 1961/62 season

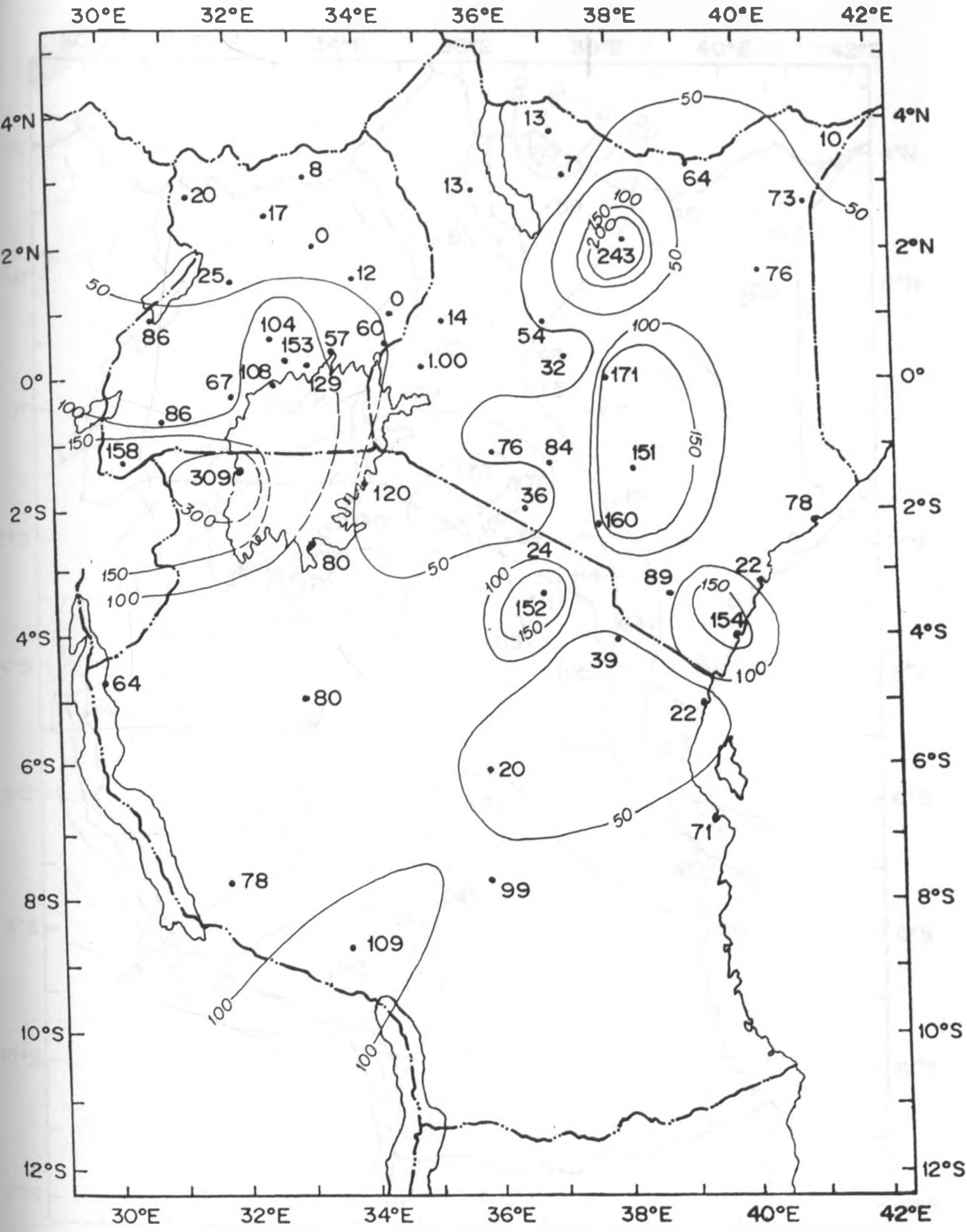


Figure 31: Spatial patterns for wet pentads 9, 12, 13 and 14 for 1963/64 season.

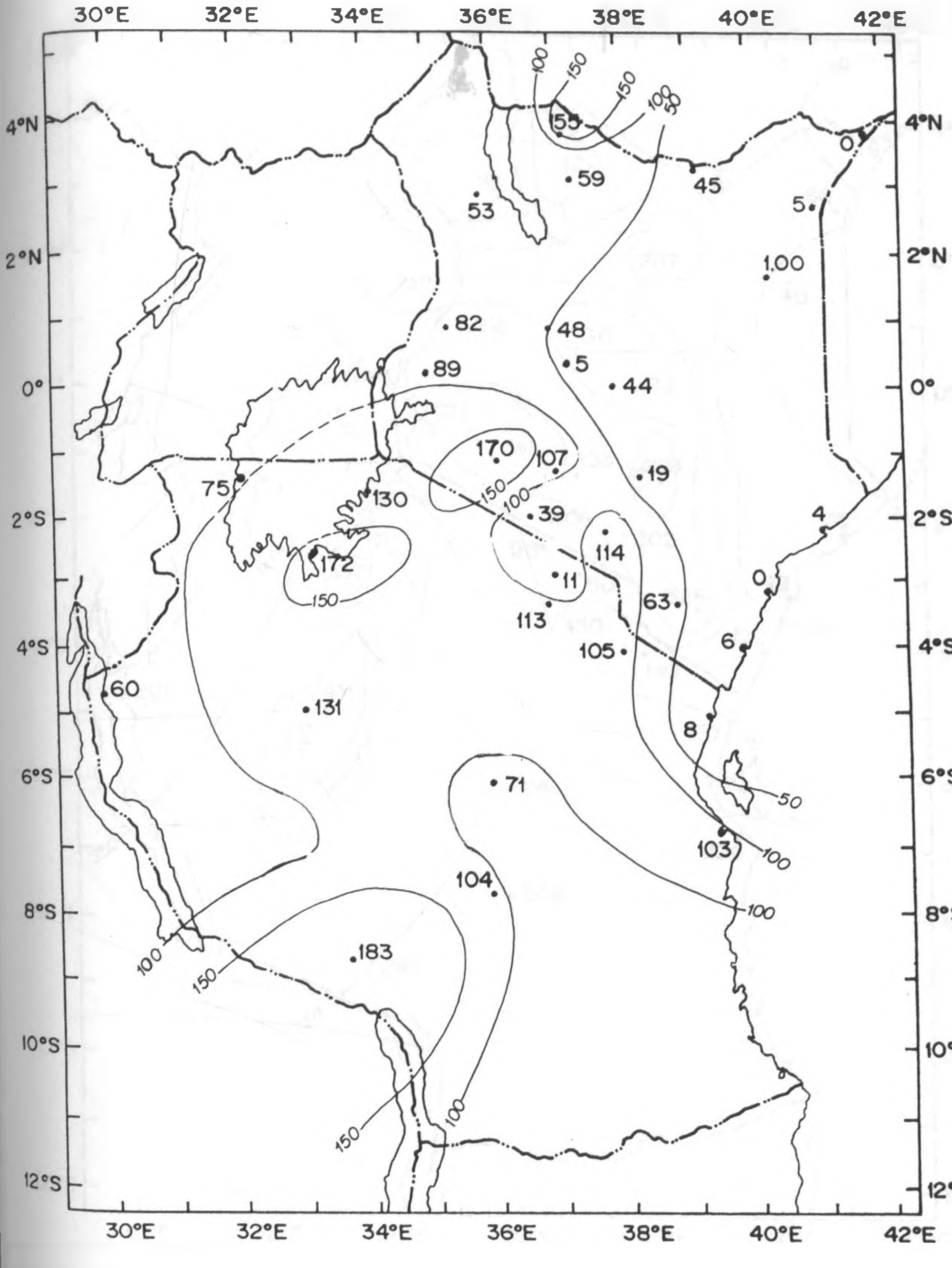


Figure 32: Spatial patterns for wet pentads 17, 18 and 19 for 1968/69 season.

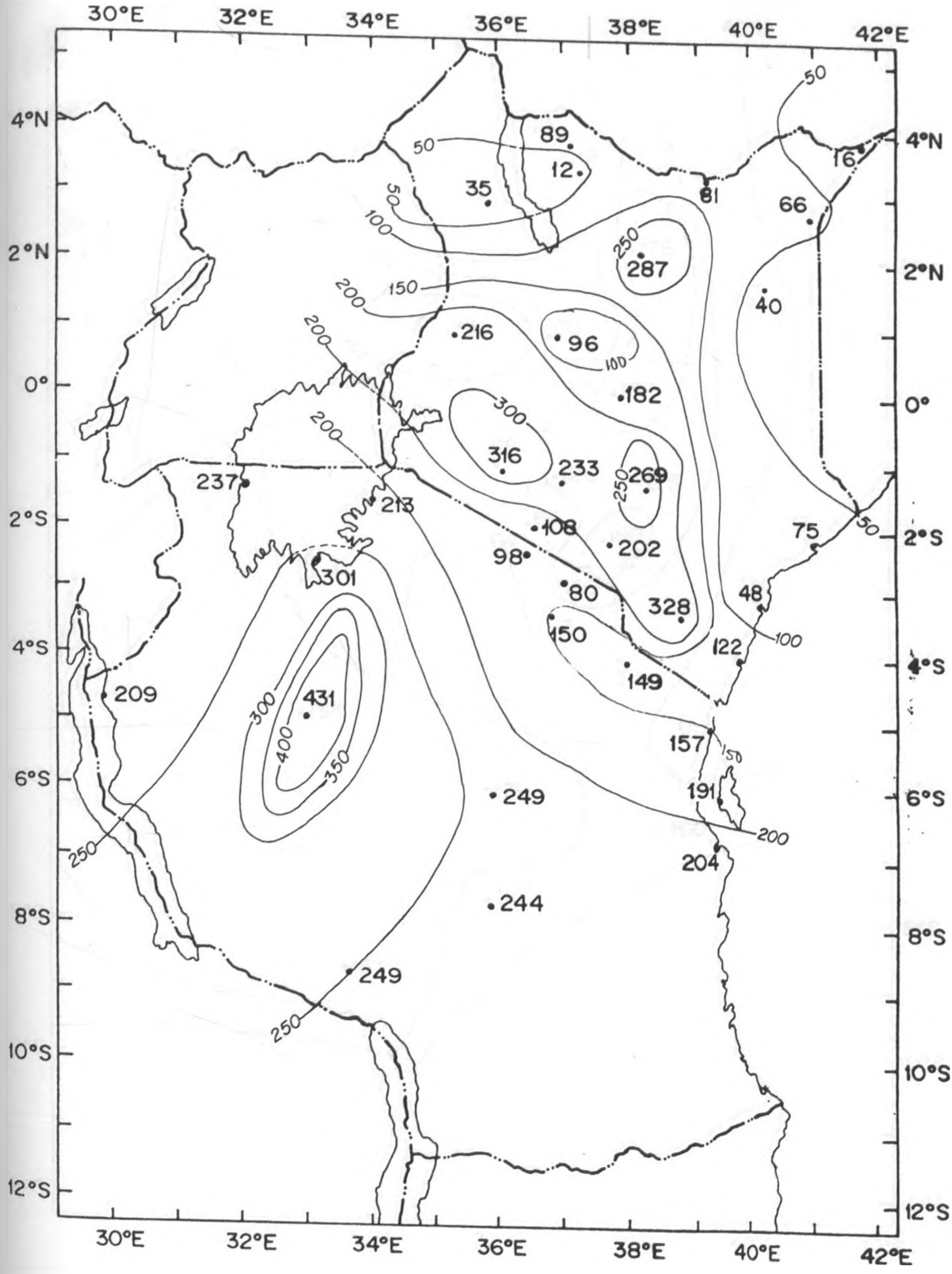


Figure 33: Spatial patterns for wet pentads 7, 8, 9, 10, 11, 16, 22, 23 and 24 for 1977/78 season.

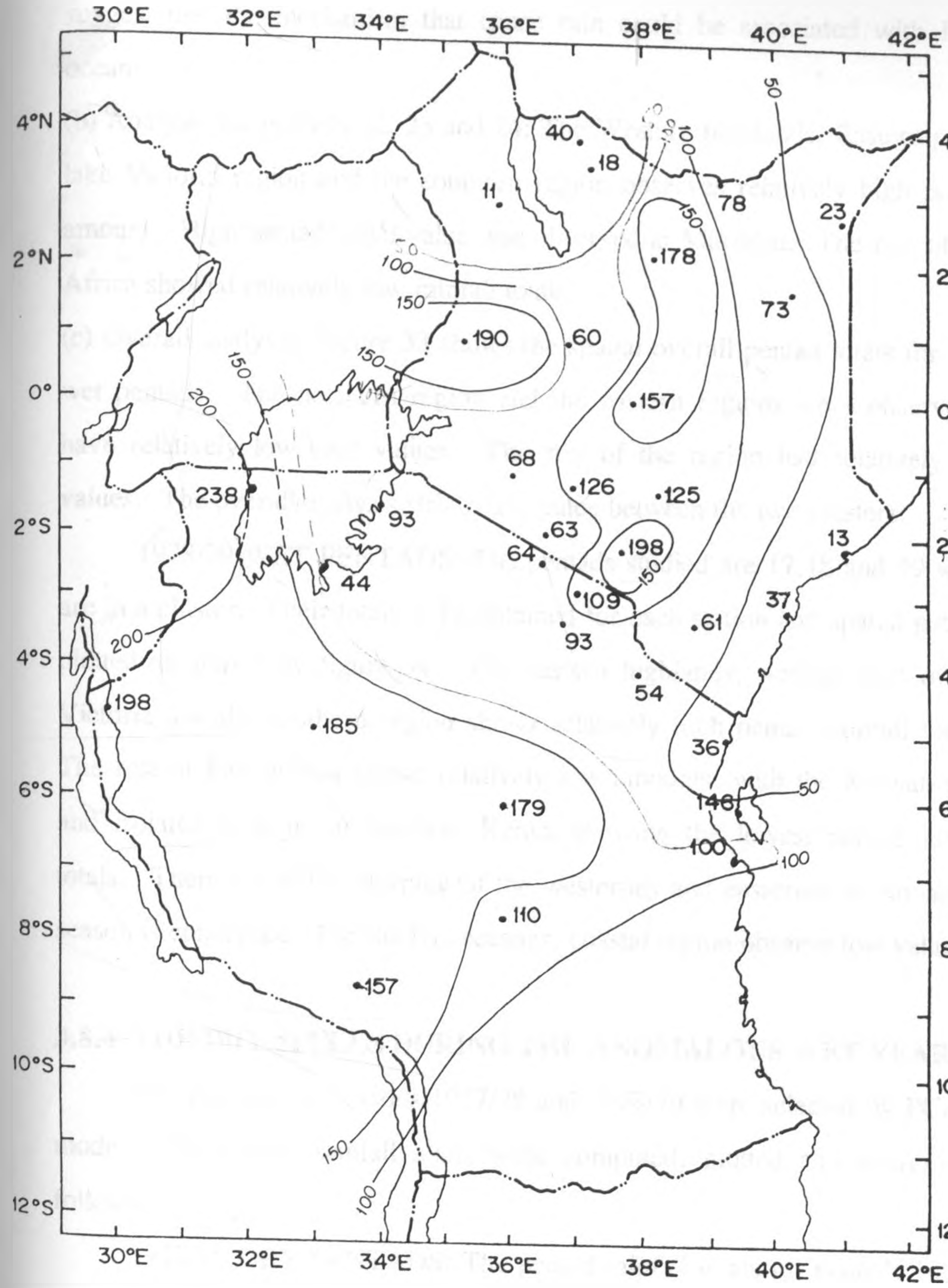


Figure 34: Spatial patterns for wet pentads 17, 18 and 19 for 1978/79 season.

suggest that the mechanism that cause rain could be associated with Indian ocean.

(b) Analysis for pentads 22, 23 and 24: The Western highlands, Eastern part of lake Victoria region and the southern region observes relatively high pentads amount. High pentads total value was observed at Marsabit. The rest of East Africa showed relatively low rainfall totals.

(c) Overall analysis: Figure 33 shows the spatial overall pentad totals for the 9 wet pentads. The northern region and the eastern regions were observed to have relatively low total values. The rest of the region had relatively high values. The overall analysis strikes a balance between the two clusters.

1978/79 WET PENTADS: The pentads studied are 17,18 and 19 which are in a cluster. Their totals were obtained for each station and spatial patterns plotted as shown by figure 34. The eastern highlands, western part of lake Victoria and the southern region shows relatively high pentad rainfall totals. The rest of East Africa shows relatively low amounts, with the Kenyan coast and isolated sections of northern Kenya showing the lowest pentad rainfall totals. There could be interplay of the westerlies and easterlies as far as this season is concerned. For the five seasons, coastal region observe low values.

3.8.4 THE DRY SPELLS DURING THE ANOMALOUS WET YEARS

Dry pentads for seasons 1977/78 and 1978/79 were selected by PCA T-mode. The pentad rainfall totals were computed, plotted and analyzed as follows;

1977/78 DRY PENTADS: The pentad rainfall totals for pentads 14, 18, 19, 20 and 21 were obtained. Almost all the Kenyan stations recorded zero rainfall. Tanzania shows relatively low rainfall values.

1978/79 DRY PENTADS: The dry pentads selected by help of T-mode are 12, 13, 22, 23 and 24. They were grouped into two i.e 12 and 13 / 22, 23 and 24 and plotted separately and then finally combined.

(a) Analysis for pentads 12 and 13: The spatial patterns observes lowest rainfall values in northern Kenya and the coastal region (most stations having zero pentad rainfall value). The lake Victoria region and the Southern region showed relatively low pentad rainfall totals.

(b) Analysis for pentads 22, 23 and 24: The Northern region was observed to be driest with the exception of Sabarei. The Southern region showed relatively low pentad rainfall totals. The Eastern side of lake Victoria and the highlands regions compared well with the Southern region.

(c) Overall pentads 12, 13, 22, 23 and 24: The pentad totals for the five pentads was computed and spatial patterns studied. Generally the overall analysis strikes balance between the two cases.

Wet pentads around the 7th pentad means wetness concentration in the early part of the DJF, while wet pentads around the 14th pentad means wetness concentrated in the middle of the season and wetness around the 24th pentad implies, wet phenomena towards the end of the season (see table 13). Table 13 gives a general summary of the pentads for the five wet DJF seasons. Short dry spells during rains facilitate acquiesce state of hydrodynamic cycles.

TABLE 13: Summary of the wet and dry pentads for DJF (for the five years)

Season	Wet pentads	Dry pentads
1961/62	9,12,13	16,18,19
1963/64	9,12,13,14	16,17,18,19,20,24
1968/69	17,18,19	10,11,13,14,15,20
1977/78	7,8,9,10,11,16,22,23,24	14,18,19,20,21
1978/79	17,18,19	11,12,13,22,23

3.9 SPECTRAL ANALYSIS

Results obtained by spectral analysis are in the following sections 3.9.1 and 3.9.2.

3.9.1 SPECTRAL ANALYSIS OF THE SEASONAL RAINFALL

Figure 35 shows examples of spectral analysis of DJF-rainfall over East Africa, when the 29 seasons were subjected to spectral analysis. The bandwidth (i.e the width of the spectral window) adopted in this case was 0.1667.

The results from the study generally indicated periodic fluctuations centred around 2.3-2.7 years, 3.3-4.3 years, 4.3-6.3 years, 6.2-9.5 years, 9.5-12.2 years and 10.8-16.7 years. Similar quasi-periodic characteristics have been observed on many general circulation parameters which may influence rainfall. These parameters include the Southern Oscillation, the Walker's circulation, sea surface temperature, winds, pressure and many others.

Various studies and literature (e.g Trenberth, 1976) show that these cyclic variations can be associated with various climatological phenomena. For examples, ENSO recurs once in every 2 to 7 years; The Quasi-bianial Oscillation (QBO), which refers to the regular alternation of the easterly and westerly winds in the lower stratosphere/upper troposphere with a period of 24 to 30 months; Intraseasonal wave (Madden-Julian wave) which has an oscillation of period 30-60 days. ENSO effect is truly an important global teleconnection (Rasmusson and Carpenter, 1982).

3.9.2 SPECTRAL ANALYSIS ON DAILY RAINFALL FOR THE FIVE SEASONS

For the five anomalous rainfall seasons selected, their daily rainfalls for various stations were subjected to spectral analysis (see figures 36-40). The bandwidth adopted was 0.1222. The results indicated periodic fluctuations which varied from one station to another. However some of the observed fluctuations were common in a number of stations.

For 1961/62 season, the periodic fluctuations centred around 2-2.2, 2.3-2.6, 2.4-2.7, 2.9-3.3, 3.3-3.9, 3.6-4.3, 4.7-6, 5.3-6.9, 4.7-6.9, 6-8.2, 8.2-12.9, 10-18, 18-90 and 30-90 days (see figure 40).

When the 1963/64 season was assessed, periodic fluctuations centred around 2.1-2.5, 2.3-2.7, 2.7-3.3, 3.3-3.6, 3.6-4.8, 7-13, 13-91 and 22.7-91 days (see figure 39).

The results indicated that for 1968/69 season, the periodic fluctuations centred around 2.1-2.2, 2.2-2.6, 2.4-2.9, 2.9-3.6, 3.2-4.1, 4.7-6.9, 5.6-9 and 12.9-90 days (see figure 38).

1977/78 season showed periodic fluctuations centred around 2.1-2.2, 2.6-3.2, 2.9-3.6, 3.2-4.1, 4.7-6.9 and 12.9-90 days (see figure 37), while the

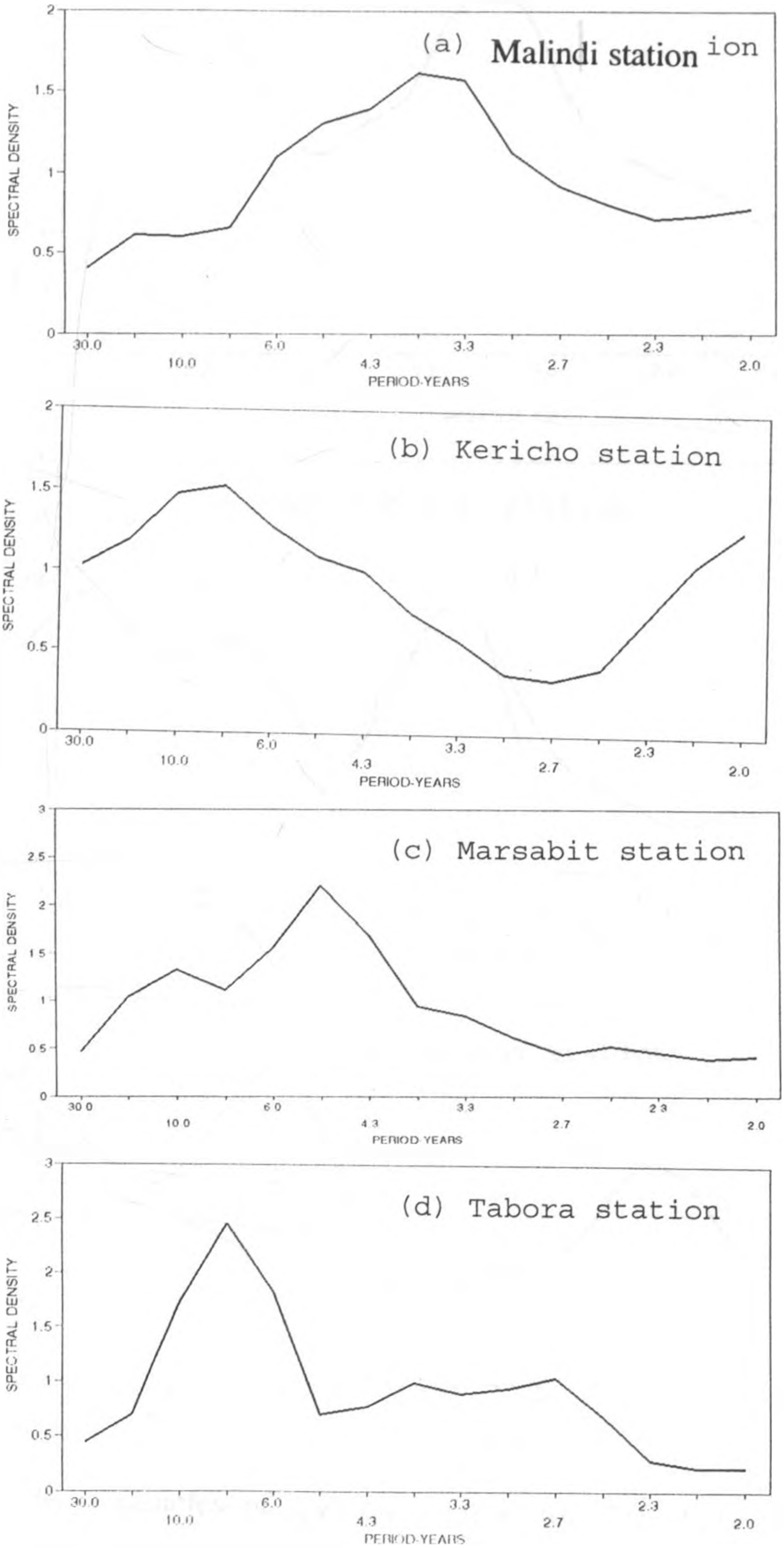


Figure 35: Examples of spectral analysis for DJF rainfalls over East Africa for the 29 seasons at various stations;

(a)-(d).

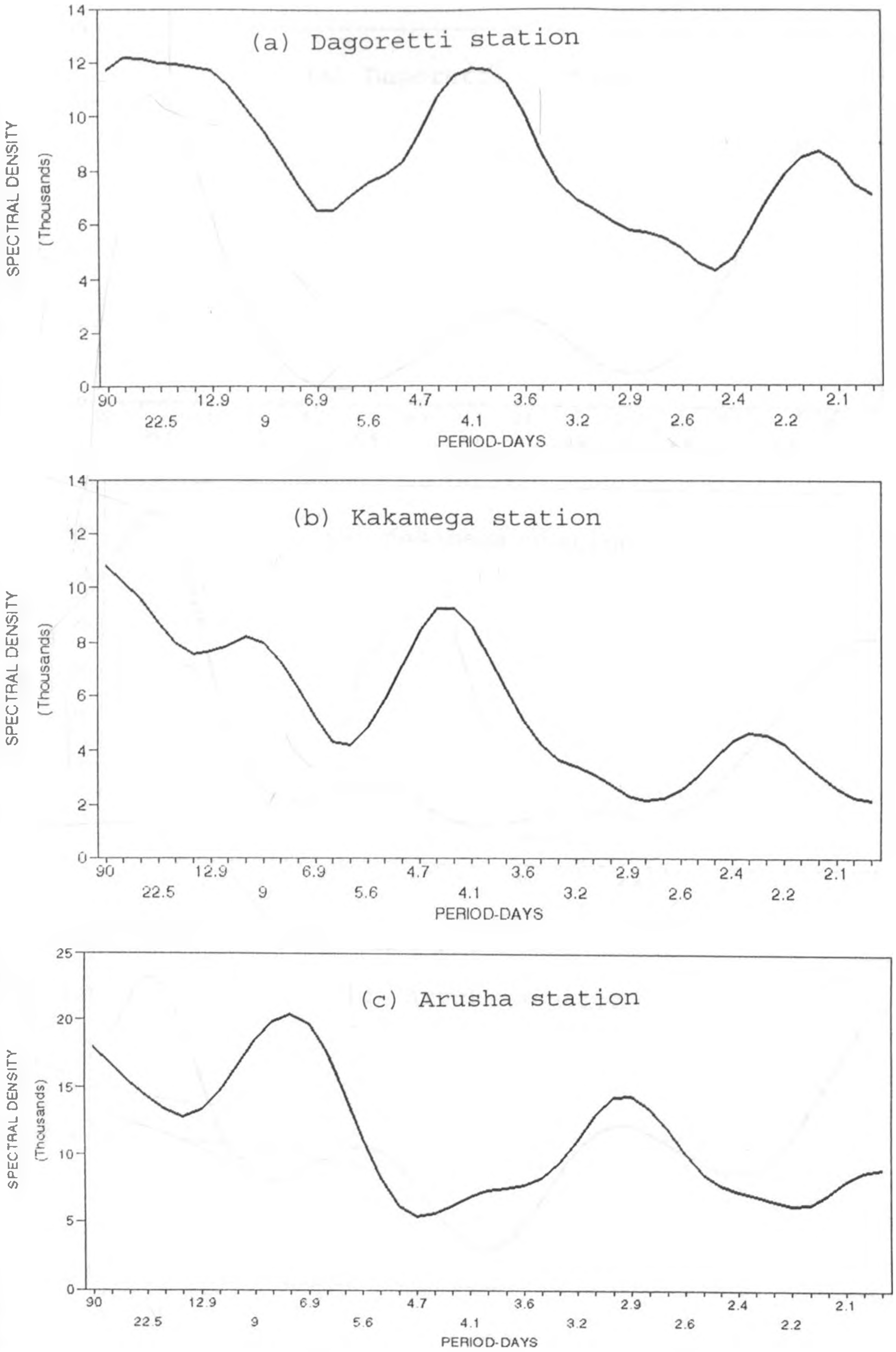


Figure 36: Examples of spectral analysis for DJF daily rainfall for 1978/79 season at various stations; (a)-(c).

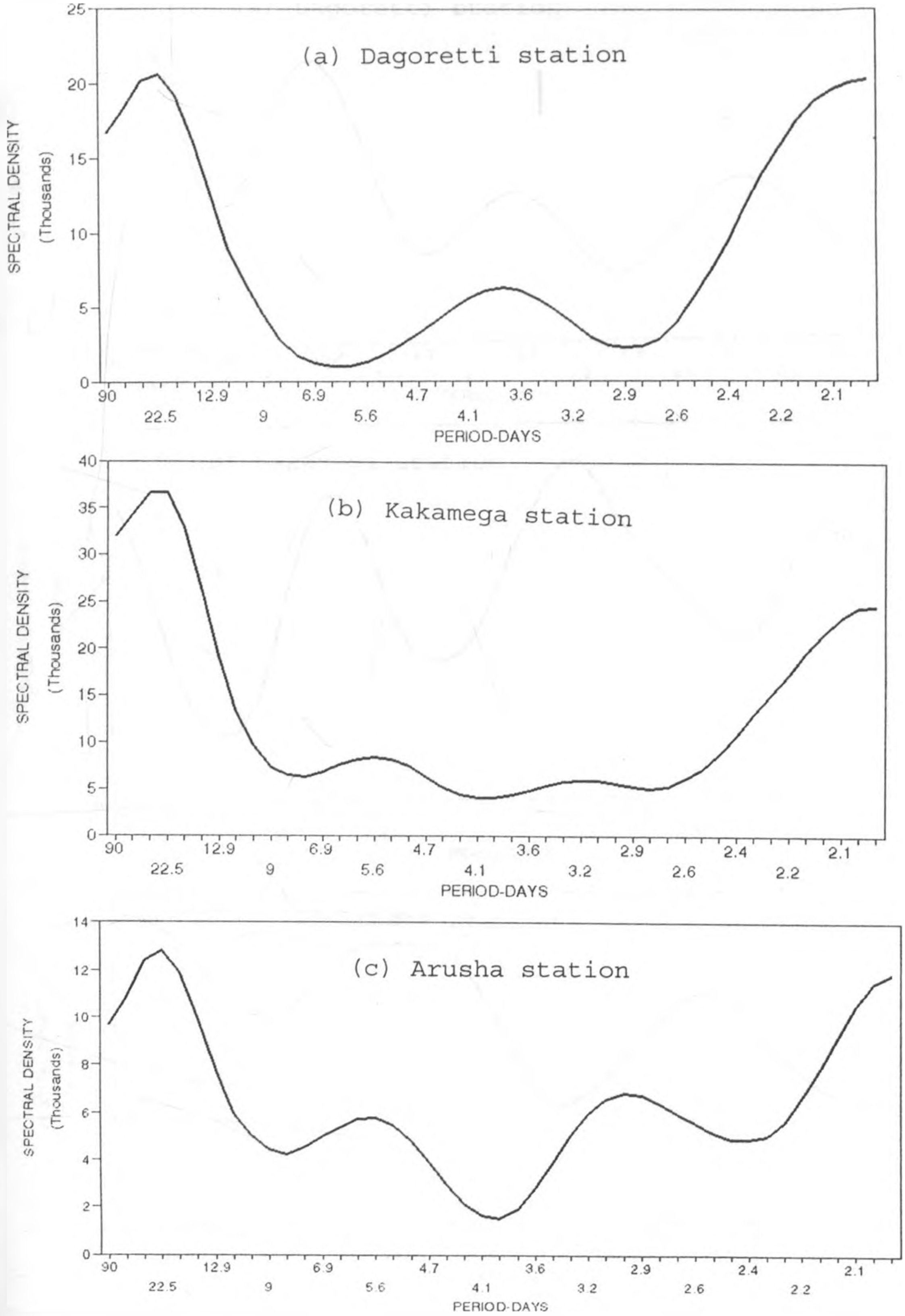


Figure 37: Examples of spectral analysis for DJF daily rainfall for 1977/78 season at various stations; (a)-(c).

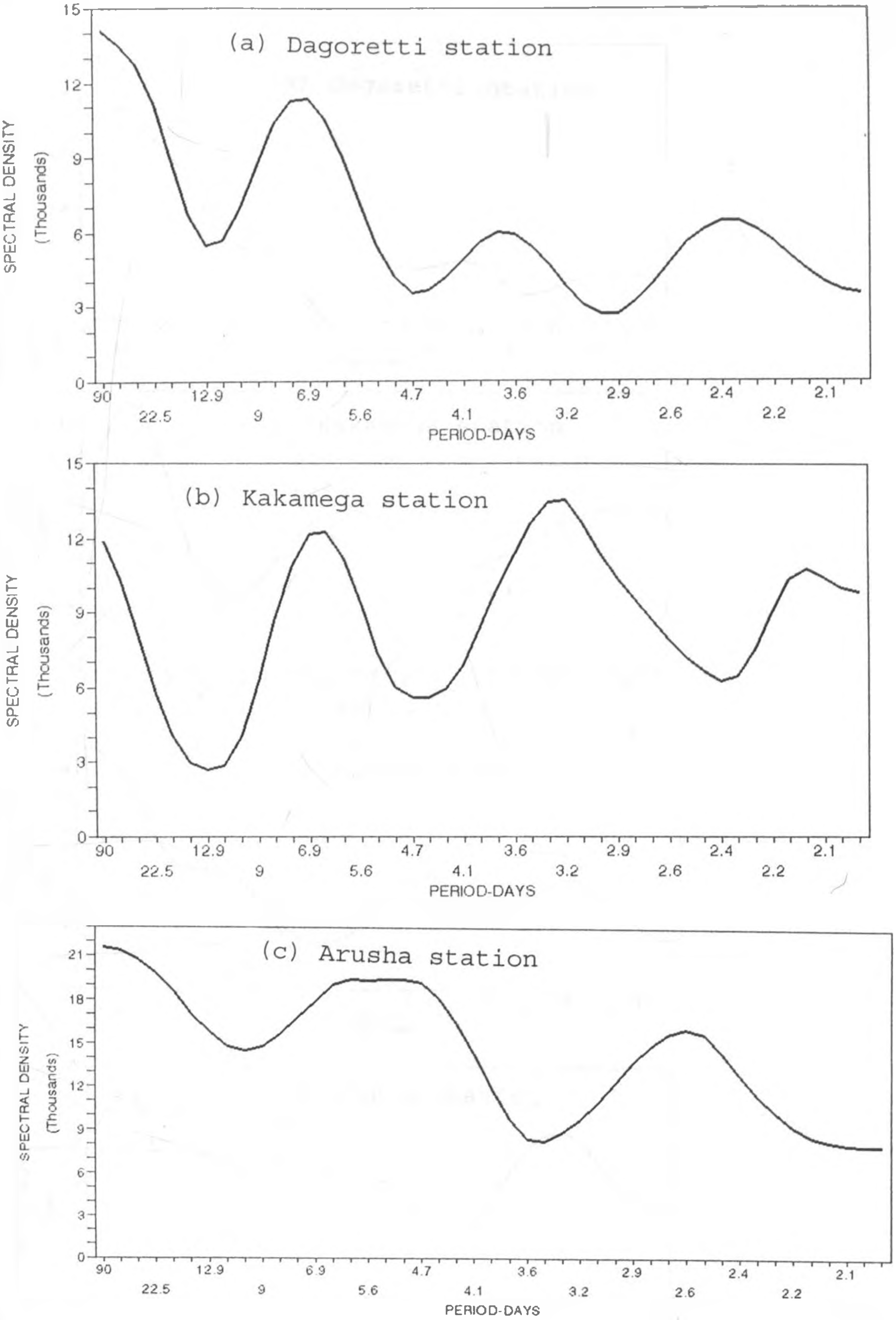


Figure 38: Examples of spectral analysis for DJF daily rainfall for 1968/69 season at various stations; (a)-(c).

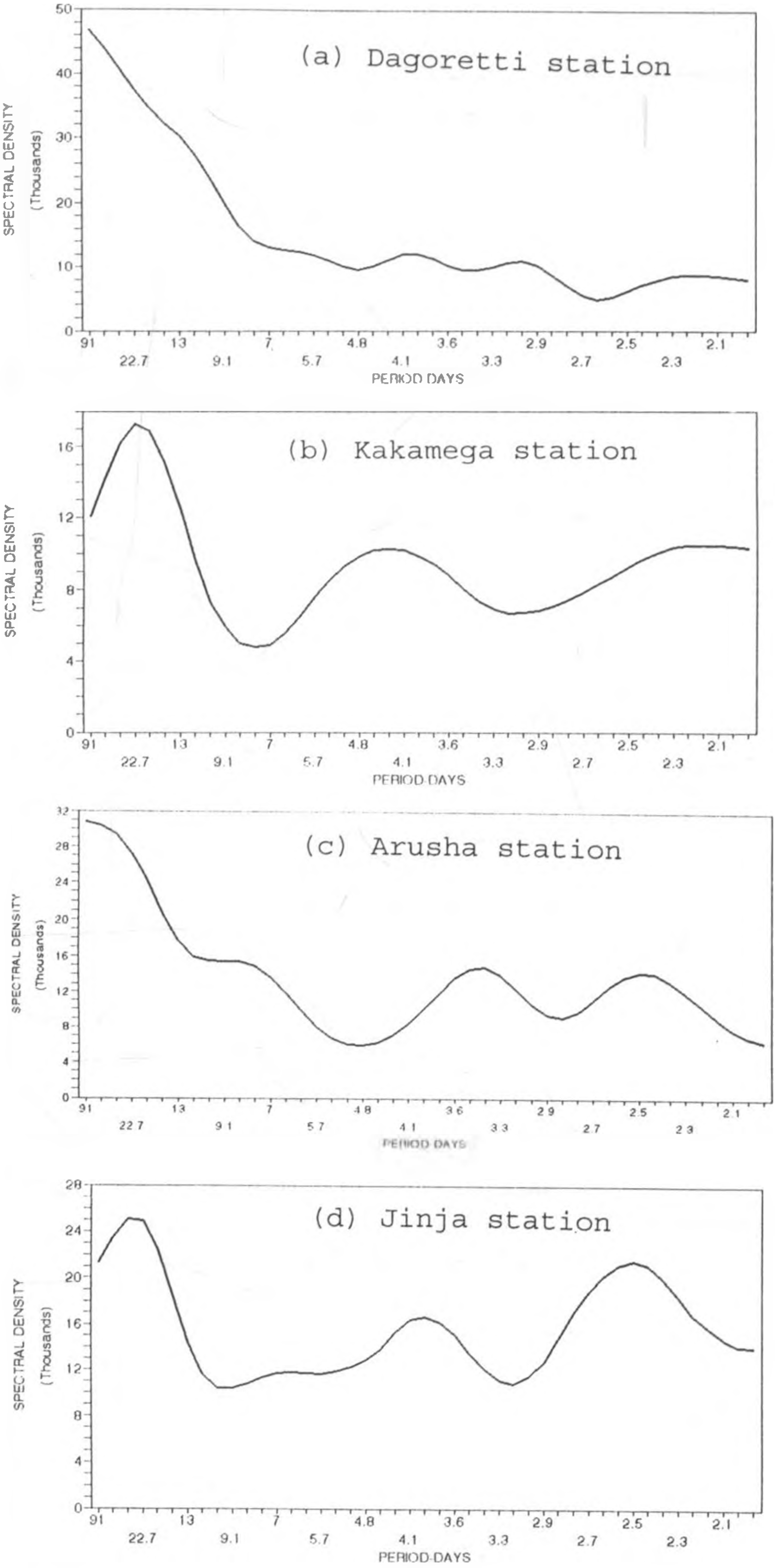


Figure 39: Examples of spectral analysis for DJF daily rainfalls for 1963/64 season at various stations; (a)-(d).

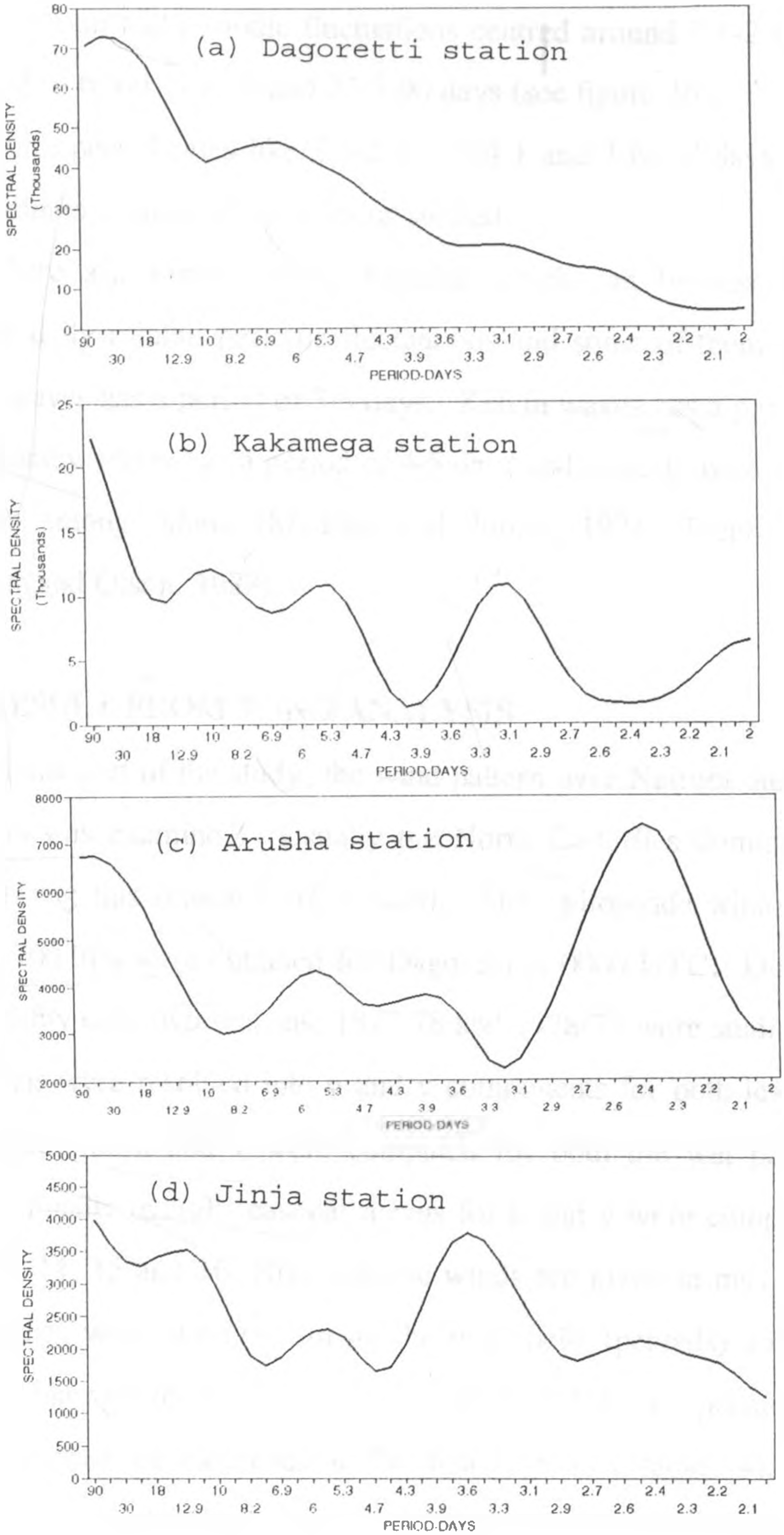


Figure 40: Examples of spectral analysis for DJF daily rainfalls for 1961/62 season at various stations; (a)-(b).

1978/79 season had periodic fluctuations centred around 2.1-2.4, 2.6-3.2, 3.6-4.7, 4.1-5.6, 6.9-9, 9-12.9 and 22.5-90 days (see figure 36).

Some periodicities like 2.1-2.5, 3.2-4.1 and 3.6-4.8 days were observed to be common in most of the seasons studied.

There are various cyclic features which can be associated with the observed daily rainfall periodic fluctuations and some of them are as follows; Gravity waves has a period of 3-5 days. Kelvin waves has a period of about 15 days. Rossby waves has a period of 4-5 days and easterly wave has a period of 3-4 days among others (Madden and Julian, 1971; Trenberth, 1984 and Trenberth and Olson, 1988).

3.10 RESULT FROM WIND ANALYSIS

In this part of the study, the wind pattern over Nairobi during one of the wet years was examined. Usually the North Easterlies dominates over East Africa during this season (DJF-season). The radiosonde winds at levels 200 hPa and 700 hPa were obtained for Dagoretti at 0000 UTC. Due to wind data unavailability only two seasons; 1977/78 and 1978/79 were studied in this case. The winds were resolved into u and v components for both levels. Then the mean values for u and v were computed for both the wet pentads and dry pentads. Finally overall seasonal means for u and v were compared as shown by Tables 14, 15 and 16. Note that the winds are given in ms^{-1}. For 1977/78 the easterlies were stronger during the wet spells (pentads) compared to dry spells and likewise the northerlies were. For 1977/78 wet pentads, there was a general decrease of Easterlies at 700 hpa level (see table 14). Decrease of Easterlies in low levels is conducive to rainfall (Okoola, 1997 and Ininda, 1994).

TABLE 14: 1977/78 season analysis.

Pentads	700 hPa		200 hPa	
Wet pentads	$\bar{u}$	$\bar{v}$	$\bar{u}$	$\bar{v}$
7, 8, 9	-7.36	-3.78	2.89	6.69
8, 9, 10	-6.19	-3.30	-1.76	5.64
9, 10, 11	-5.57	-2.40	-6.83	4.35
22, 23, 24	-3.53	-2.81	-0.06	6.73
Dry pentads				
18, 19, 20	-3.40	-2.76	-10.71	5.66

TABLE 15: 1978/79 Season analysis.

Pentads	700 hPa		200 hPa	
Wet pentads	$\bar{u}$	$\bar{v}$	$\bar{u}$	$\bar{v}$
11, 12, 13	-2.42	-3.70	-3.79	5.80
Dry pentads 17, 18, 19	-3.59	-3.07	-3.45	7.25

TABLE 16: Overall season means for wind components.

Season	700 hPa		200 hPa	
	$\bar{u}$	$\bar{v}$	$\bar{u}$	$\bar{v}$
1977/78	-4.48	-4.44	-5.79	11.26
1978/79	-3.49	-3.21	-4.00	7.48

For the overall season means, the mean flow for 1977/78 was stronger than 1978/79. The moisture could have been influenced by convectional activities.

Anyamba (1983) attributed the 1961/62 rainfall anomalies to the Westerlies (westerly-to-southwesterly perturbations) which suppressed the normally dominant Easterlies (northeasterlies) over East Africa during DJF-season. This constitutes one of the occasions when there is an incursion of westerly winds in East Africa (Thompson 1957; Johnson and Morth 1961; Nakamura 1968). These westerly winds originated from two source areas, one source consisted of a westerly flow from the congo region and southeast

Atlantic ocean and the other source from a recurved northeasterly current emanating from the northwest Indian ocean. Thus it may be that different mechanisms that influence rainfall operate in different years.

3.11 CORRELATION BETWEEN RAINFALL AND ENSO PARAMETERS

In this study an attempt was made to investigate relationship between the SOI (southern oscillation index) and the DJF-seasonal rains. The spatial pattern of the Correlation coefficients between DJF-SOI and rainfall is shown in figure 41. The correlations coefficients are observed to be generally low and negative for most of the stations over East Africa. Using a similar approach as Wright *et al* (1988) it was noted that values greater or equal to 0.3 in magnitude were significant. The SOI was also correlated with the DJF-overall rainfall index which was computed by averaging the station anomalies all over East Africa.

The Equatorial rainfall index and southern rainfall index were computed by averaging the station rainfall indices, North of latitudes 5^0s and south of latitudes 5^0S respectively (refer to previous analysis). Table 17 gives a summary of the correlations between SOI and the three indices;

TABLE 17: Correlation of the SOI with the three rainfall anomaly indices

Anomaly index	Correlation value
Equatorial rainfall index	-0.252
Southern rainfall index	-0.046
Overall rainfall index	-0.213

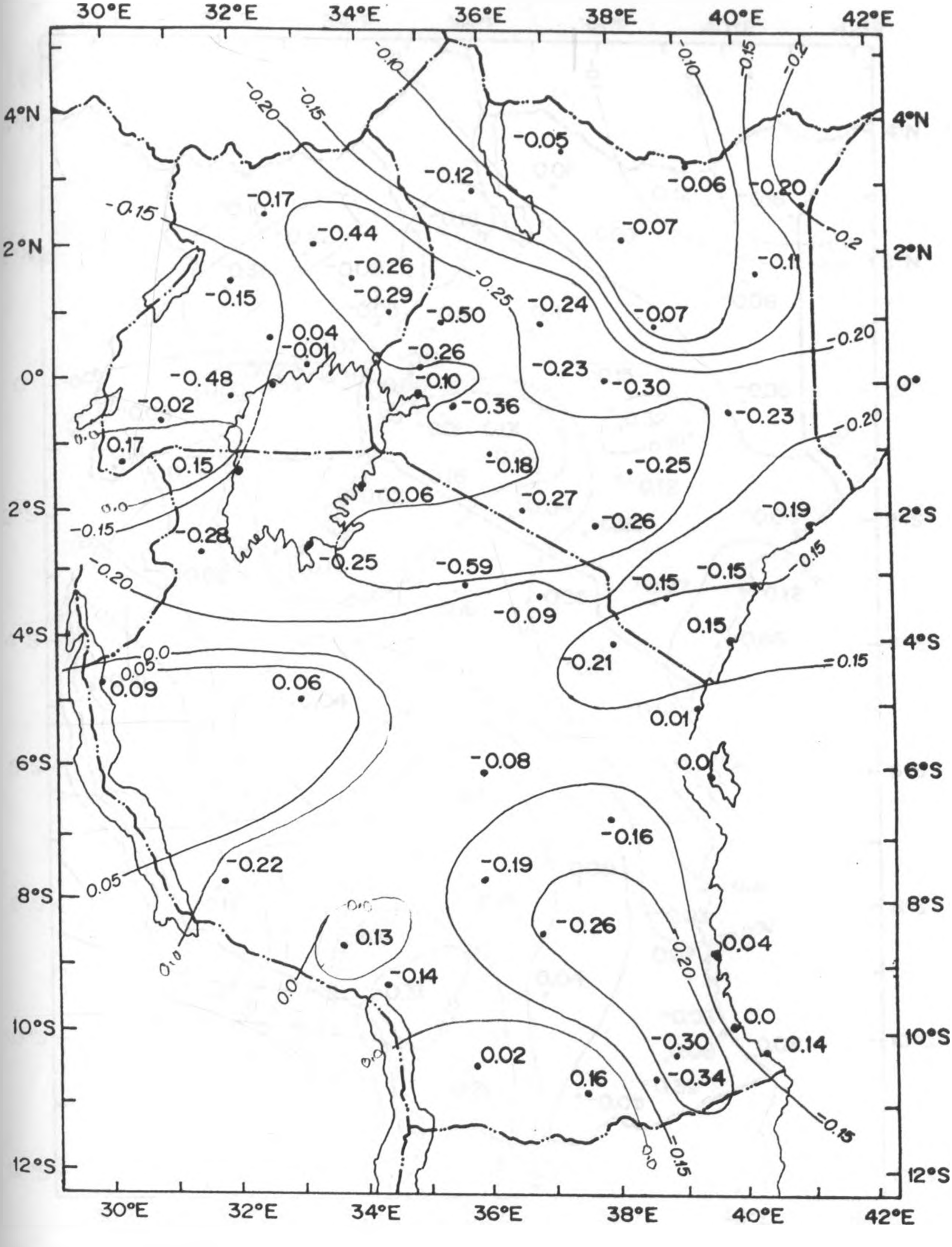


Figure 41: Spatial patterns of the correlations between the DJF-SOI and DJF-rainfall anomalies

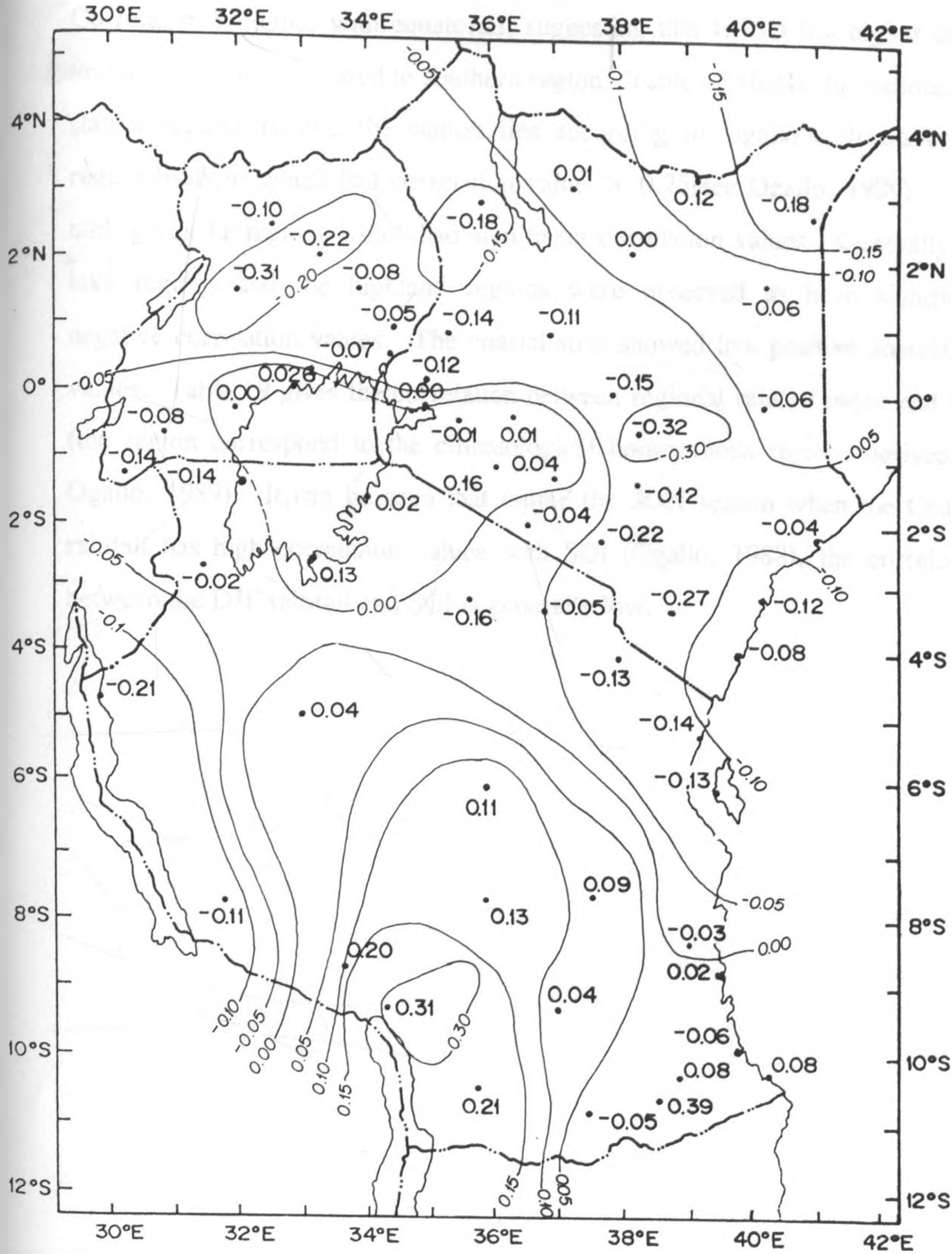


Figure 42: Spatial patterns of the correlations between the SON-SOI and DJF-rainfall anomalies.

Correlation is higher with equatorial, suggesting that ENSO has higher effect on the equatorial compared to southern region. Table 18 shows the stations and station regions (where the station lies according to Ogallo's climatological regionalisation) which had correlation value > 0.25(see Ogallo, 1989). This table gives 11 regions which had significant correlation values. Generally the lake regions and the highland regions were observed to have significant negative correlation values. The coastal strip showed low positive correlation values. Table 19 gives the correlation between regional rainfall index and SOI (the region correspond to the climatological homogenous regions derived by Ogallo, 1989). It can be seen that unlike the SON season when the Coastal rainfall has high correlation values with SOI (Ogallo, 1988), the correlation between the DJF rainfall and SOI is generally low.

TABLE 18: Examples of station rainfall anomaly indices when correlated with the SOI.

Station code	Station region	Station name	Correlation value
10	9	Kitui	-0.253
12	8	magadi	-0.271
14	8	Nairobi pwd	-0.399
18	6	Naivasha	-0.406
20	4	Kericho	-0.364
22	2	Kakamega	-0.261
27	2	Kitale	-0.496
42	16	Mahenge	-0.258
46	16	Masasi	-0.343
51	17	Ngorongoro	-0.586
55	20	Mwanza	-0.253
57	22	Bihara mulo	-0.280
59	16	Nachingwea	-0.295
61	2	Tororo	-0.292
62	21	Katigondo	-0.481
69	26	Soroti	-0.258
70	26	Lira	-0.443

TABLE 19: Correlations of the SOI with the 26 regional rainfall anomaly indices.

Region no.	Correlation value
1	-0.105
2	-0.402
3	-0.247
4	-0.364
5	-0.291
6	-0.181
7	-0.199
8	-0.255
9	-0.262
10	-0.205
11	-0.221
12	0.150
13	-0.116
14	0.073
15	-0.040
16	-0.059
17	-0.304
18	-0.085
19	-0.060
20	-0.253
21	-0.215
22	-0.205

TABLE 19:(contd)

23	0.174
24	-0.003
25	-0.170
26	-0.384

The highland regions and the lake Victoria region observes relatively high correlation magnitude value (see figure 41 and table 18). The region north of latitude 1^0S observes low negative correlation values for most of the stations. Though southern region was dominated by negative correlations there were isolated cases of positive correlations.

The 11 regions summarised by Table 18 were further analyzed by contingencies. Chi-square (χ^2) test was carried out for all the 11 regions. Since the correlation values were less than 0.5 in magnitude, the null hypothesis was adopted. This hypothesis was rejected and hence we concluded that there is relationship. The contingence tables for region 22 are shown by table 20a-b where;

RB=rainfall below normal (rainfall index < -0.5).

RN=normal rainfall ($-0.5 \le$ rainfall index ≤ 0.5).

RA=rainfall above normal (rainfall index >0.5).

SB=standardised SOI below normal (<-0.5).

SN=normal standardised SOI ($-0.5 \le$ standardised SOI ≤ 0.5)

SA=standardised SOI above normal (>0.5).

The contingency Tables showed dominance of the negative correlations over East Africa as implied by the high values in the secondary diagonal (table 22a).

TABLE 20: Example of Contingency table analysis for the region 22.

(a) Observed contingency;

	RB	RN	RA	Total
SB	1	3	4	8
SN	4	6	3	13
SA	6	2	0	8
Total	11	11	7	29

(b) Expected contingency results;

	RB	RN	RA	Total
SB	3.03	3.03	1.93	7.99
SN	4.93	4.93	3.14	13
SA	3.03	3.03	1.93	7.99
Total	10.99	10.99	7	29

The spatial correlations between the SOI for the preceding season (SON-season) and the DJF-rainfall season were computed and are illustrated by Figure 42. Most of the stations generally observes low negative correlation values. There were remarkable positive correlations in central and southern Tanzania. Most of the stations lying north of latitude 5^0S observes negative correlation values.

Further investigations of teleconnection was done by correlating SST with rainfall anomalies (see table 21)

Table 21: Correlation matrix of the SST with rainfall anomaly indices

	SOI	SINDEX	EINDEX	OINDEX
SINDEX	-0.046			
EINDEX	-0.252	0.665		
OINDEX	-0.213	0.805	0.978	
SST	-0.820	0.079	0.197	0.178

Where

Sindex = Southern rainfall anomaly index

Eindex = Equatorial rainfall anomaly index

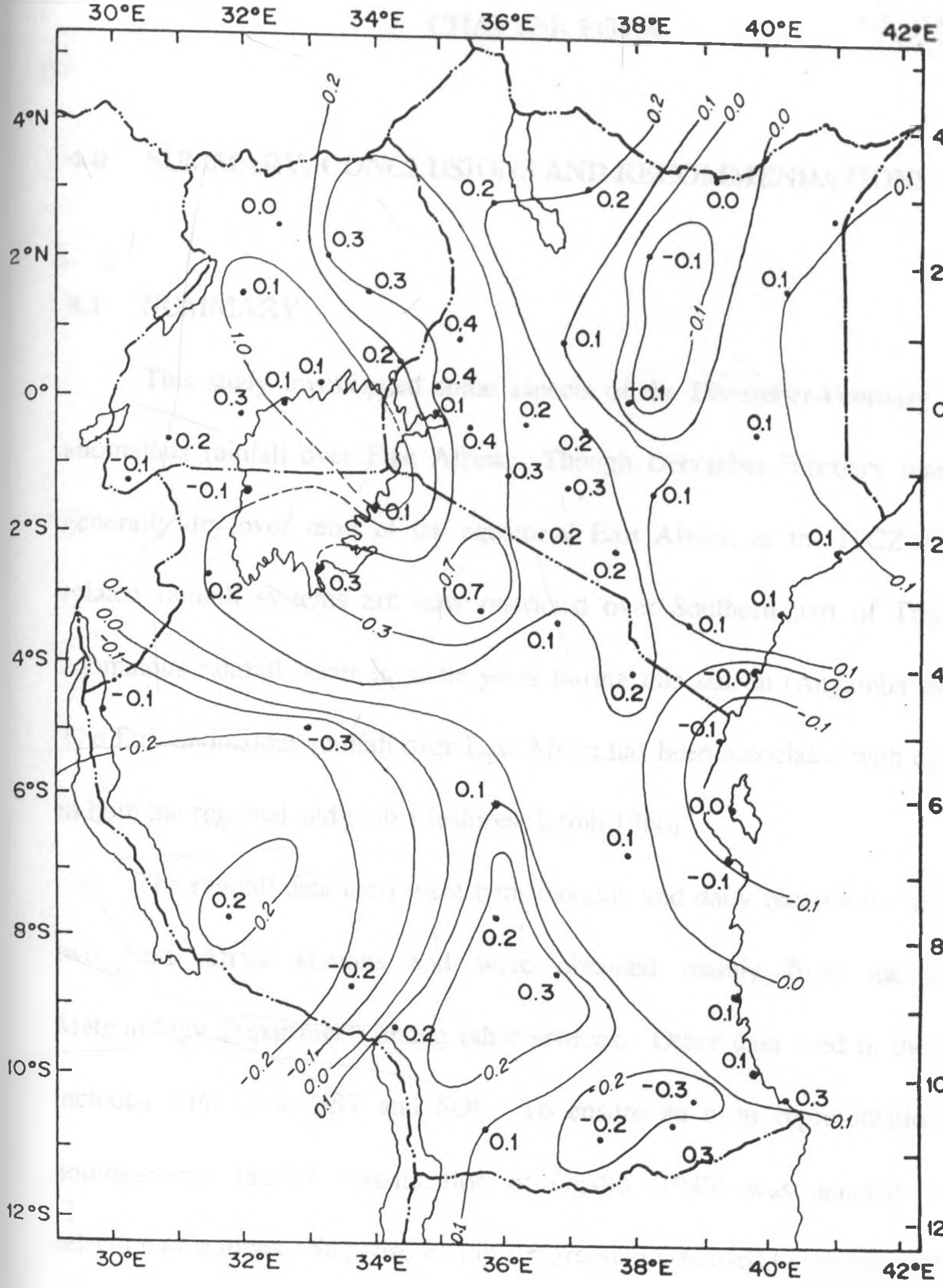
Oindex = Overall rainfall anomaly index

SST = sea surface temperatures

SOI = southern oscillation index

It was observed that the correlation between SST and the three rainfall anomaly indices was positive. SOI is included to compare the two when correlated with the three rainfall anomaly indices; (See table 21).

Figure 43 shows the spatial patterns of correlations between DJF-rains and SST over East Africa. Relatively high correlation values were observed on the Eastern side of lake Victoria, Western highlands and some isolated regions of southern Tanzania. Negative correlation values were noted along the Coastal strip and some isolated parts of southern Tanzania. The rainfall anomalies are negatively correlated with SOI and positively correlated with SST (table 21). This suggests that the ENSO and the anomalous rainfall could be globally teleconnected.



'igure 43: The spatial correlations between the DJF rainfall and the SST over
'ast Africa.

CHAPTER FOUR

4.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

4.1 SUMMARY

This study investigated some aspects of the December-February (DJF) anomalous rainfall over East Africa. Though December-February season is generally dry over most of the equatorial East Africa, as the ITCZ and the related rainfall systems are now restricted over Southern part of Tanzania, anomalous rainfall occur in some years during this season (Anyamba 1983). The DJF anomalous rainfall over East Africa has been associated with changes in both the regional and global features (Lamb 1966).

The rainfall data used were both monthly and daily records for seventy-two East Africa stations and were obtained mainly from the Kenya Meteorology Department among other sources. Other data used in the study included wind data, SST and SOI. To ensure an even representation, the homogeneous rainfall classification of Ogallo (1989) was adopted in the selection of stations. Stepwise-multiple regression was used to estimate missing data while the inhomogeneity in the data was tested and corrected using the cumulative mass curve technique. The earlier data was corrected to the latter to avoid future correction if physical characteristics of the gauge site or observational methods do not change.

Various methods were used to study various characteristics of the DJF-anomalous rainfall. Rainfall anomaly index (based on the deviation from the mean) was used to delineate and determine anomalous wet years. Principal Component Analysis was performed on the rainfall data to confirm the spatial and temporal rainfall characteristics obtained by both rainfall anomaly indices and areal average rainfall indices. Correlations analysis was carried out between the DJF rainfall and both the SOI and Niño-3 SST in order to investigate the teleconnection between the anomalous rainfall during this season and the ENSO phenomenon. Spectral analysis examined whether the rainfall series exhibited any cyclic variations. Pentad rainfall totals was used to investigate in more details the spatial and temporal characteristics of the selected anomalous wet years.

In chapter three, the results were discussed. Most of the rainfall stations had homogeneous data except six of them, namely Wajir, El Wak, Meru, Lindi, Katigondo and Namulonge which were adjusted to reflect homogeneity. Among the wettest years delineated by both the rainfall anomaly index and PCA T-mode analysis were 1961/62, 1963/64, 1968/69, 1977/78 and 1978/79. However within the period of study the wettest year was 1978/79.

The spectral analysis was capable of picking the outstanding cyclic variations during the DJF-season. The main periodic fluctuations centred around 2.3-2.7 years, 3.3-4.3 years, 4.3-6.3 years, 6.2-9.5 years, 9.5-12.2 years and 10.8-16.7 years. Periodic fluctuations 2.3-2.7 and 9.5-12.2 years could be associated with QBO and sunspots respectively. Daily rainfall for DJF-season indicated various periodic fluctuations which varied from one station(region) to another. However some fluctuations were common for most of the stations. The common fluctuations centred around 2.1-2.5, 3.2-4.1, 3.6-4.8 and 9-12.9 days. There was significant correlation between the DJF-rainfall over several regions in East Africa and the ENSO parameters. This suggested a possible teleconnection between the anomalous rainfall during this season and ENSO.

4.2 CONCLUSIONS

The various objectives of this study have been adequately achieved. Both temporal and spatial characteristic of DJF-season anomalous rainfall over East Africa were studied. The study has shown that although DJF season is generally dry over most of equatorial East Africa, in some years substantial rainfall is received during this season.

The dissimilarity in the characteristics of the rainfall during different wet years selected in the present study suggest that the cause of the anomalous rainfall differ from one year to another. Some of the causes may be associated with global teleconnection as evident from significant correlation between DJF rainfall and some of the ENSO parameters. In most of the wet years examined, the rainfall generating system originated from the east and travelled westward which may suggest the influence of the easterly waves during this season.

In many of the cases, the short rains seemed to extend to the dry season and this was particularly so for the El-Niño years. However in a few cases there were early onset of the long rains, while the cases of DJF rainfall not associated with both the short and long rains were not uncommon. This added to the complexity of the spatial and temporal characteristics of the DJF rainfall.

Like other seasons, the highest rainfall was observed near large water bodies and the highland, emphasising the importance of the meso-scale systems in the modification of the local weather.

The existence of several periodic fluctuations show that the anomalous rainfall during DJF do not occur at regular interval, making the prediction difficult. During the wet years periodicity of as long as 13 days were observed in the daily rainfall, suggesting that wet/dry spells could last for a long time.

This would cause a strain in agriculture and other social-economic activities which may be intended to benefit from these rains.

This study being observational study can be very useful in simulation studies. However, if these anomalous rains are predicted in good time they can be utilised; for a case where the short rains seems to intrude into DJF-season eg 1961/62, 1963/64 seasons, long-growing crops can be considered as they would give a better yield. For situations where the long rains appear to be connected with the DJF-season eg seasons 1968/69, 1977/78 ,etc, farmers can be advised to prepare land and plant in time. However for the case like season 1978/79 when the anomalous rains seems to have no connection with the seasonal rains, farmers can use the rains to prepare seedlings or plant crops which can withstand dry conditions for sometime, awaiting the long rains that follow. Hydrologists would also benefit from such rains as they occur when there exists water shortage. Measures can be taken to avert resulting flooding and associated impacts.

4.3 RECOMMENDATIONS

Further research needs to be done in more details in this area, especially on the causes, to establish the nature of Ocean-surface-atmosphere anomalies and mechanisms associated with the off-seasonal rains. It would be interesting to analyze in details the wind, outgoing longwave radiation (OLR), temperature and pressure fields for the anomalous years. The evidence of the link between the anomalous rainfall and the ENSO can be further developed to come up with forecasting models for DJF rains. Better understanding of the anomalous rains will lead to improved prediction of rainfall over the globe at large and East Africa in particular.

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I give all the glory unto our God, the creator and giver of life for His mercies, care and grace over my life. But I trust in you, O Lord; I say, " You are my God". My times are in your hands. -Psalm 31: 14-15.

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