# ANALYSIS AND CHARACTERIZATION OF RAINFALL IN NIGERIA

BY

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## DECLARATION

I hereby certify that this Thesis has been written by me and that it is a record of my own research work. It has not been accepted in any previous study for a higher degree. All the sources of information are acknowledged by means of references.

EKEMEZIE, Elizabeth Akatosi Date.....

CERTIFICATION

This thesis entitled "Analysis And Characterization Of Rainfall In Nigeria" by Ekemezie, Elizabeth Akatosi, meets the regulations governing the award of Master of Science degree in Geography of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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|---|---|
| Chairman, Supervisory Committee | Date |
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| External Examiner | Date |

## DEDICATION

This project is dedicated to
my husband and children.

ACKNOWLEDGEMENTS

The successful completion of this thesis would not have been possible without the guidance, patience, understanding and encouragements of my supervisor, Dr. O. E. Oladipo. I am exceptionally indebted to my husband, Mr. W. N. Ekemezie, who did the preliminary computer analysis. His constant support and affection were sources of inspiration. My thanks also go to Reverend Dr. C. C. Agunwamba, Director, University of Nigeria-University of Dublin Linkage Programme, who used the Linkage facilities on Operations Research and Data Processing to carry out some of the statistical analyses. Thanks are also due to Mr. Raph Anumba who did the principal component analysis on the computer.

Messrs Celestine Oluigbo and Prince Odoemelem typed the initial draft of the thesis while Mr. Joshua Ajuonu typed the final thesis. I am grateful to all of them. My children and Miss Ifeoma Muodum deserve special thanks for their help in the house throughout the period of my course.

## ABSTRACT

An examination of rainfall characteristics in Nigeria and an attempt at regionalization of annual rainfall using the widely accepted technigue of principal component analysis have been made in this study. The study was based on rainfall records for the period 1901 - 1984, at forty stations distributed all over the country.

The Swed and Eisenhart's runs test indicated that with the exception of Ibi, the series for the **stations were** homogeneous. The standardised coefficients of skewness and kurtosis, and the chi-square test showed that the series for 80% of the stations were normally distributed. The Mann-Kendall Rank test indicated that 75% of the stations were influenced by random processes, and that the randomness did not exhibit any regional patterns. However, the remaining 25% showed downward trends which appeared to be regional.

An S-mode principal component analysis was performed on the inter-station correlation matrix of the rainfall data for the period 1941 - 1984. The earlier years had too many missing data values and were therefore excluded from the analysis. Thirteen principal components which accounted for 81.3% of the total rainfall variance were extracted. Since the initial principal components did not exhibit any regional pattern and therefore uninterpretable, they were subjected to orthogonal (Varimax option) and oblique (Oblimin option) rotations to improve on the interpretation. The varimax rotation isolated three distinct, significant and interpretable principal components PCI, PC2, and PC3 which explained 42.2% of the total variance in the original data set. Owing to their geographical locations the first component is named the

Southern Component, the second, the Northern Component and the third, the Middle-Belt Component.

The PC loadings were plotted in the co-ordinate systems PCI - PC2, PCI - PC3, PC2 - PC3, and the distinct clusters of stations mapped. Seven homogeneous rainfall regional groups were identified, namely, the Southern Coastal Area covering stations like Lagos, Benin, Ondo, Kwale, Owerri and Port-Harcourt; Calabar which stood alone on account of the effects of relief; the Southern Upland which comprised OgbomoshOyOyo, Ilorin, Offa, Ibadan, Akure, Auchi, Nsukka and Enugu; the Middle-Belt which included Lafia, Yola, Ibi, Bida, and Kaduna South; Jos, which stood alone due to the influence of Jos Plateau; the North-West made up of Sokoto, Birnin Kebbi, and Yelwa and North-East which comprised Katsina, Kano, Hadejia, Potiskum, Maiduguri and Nguru.

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# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND

Rainfall is the most important source of water supply for general economic activities in Nigeria. However, it is highly seasonal. The rainy season starts by May in the North and ends by October, while it begins by March and ends by November in the South. Apart from this seasonality, the rainfall suffers from extreme fluctuations from year to year, and in its distributions across the country. These fluctuations sometimes result in drought in some areas and flood in others. Knowledge and experience of the fluctuations reveal that various regions of the country do not suffer equally, and this is reflected in spatial variations in the extent and severity/intensity of droughts and floods.

From this perspective, it has been observed that while some areas have 'normal' rainfall conditions, others experience either drought or flood. Expectedly, the synoptic conditions will differ from place to place, although, the general condition is governed by the orderly movements of two air masses, namely, the tropical maritime (mT) air mass from the Atlantic Ocean and the tropical continental (cT) air mass from the Sahara Desert (High et al., 1973). The character and intensity of the prevailing weather conditions are determined by the surface location of the moisture boundary zone separating the two air masses. This boundary zone is known as the Inter-Tropical Discontinuity (ITD). The periodic fluctuations of the rainfall in the country can be ascribed to the fluctuations of the ITD. Thus, whenever the ITD advances inland in response to the increasing insolation

and decreasing pressure in the continental interior, the whole country enjoys heavy rainfall, but when it fails to advance inland, the amount of rainfall in the north is reduced, and this may result in drier conditions in the interior while at the same time the areas south of the ITD may enjoy excessive rain (Oguntoyinbo et al., (1978).

There is a general close relationship between the latitudinal distribution of rainfall and the latitudinal movement of the ITD. This implies that the surface position of the ITD in Nigeria varies not only seasonally but also from day to day. According to Adejokun (1966), the average rate of the movement of the ITD ranges from $2.0^{\circ}$ to $5.0^{\circ}$ of latitude per month, with the southward movement being faster than the northward advance. This fact accounts for the gradual advance of the rains over the country at the beginning of the wet season and their abrupt retreat towards its end. Orography also has a relatively modifying effect on the rainfall pattern as reflected in the high rainfall amounts in Jos Plateau and Calabar. However, as shown by Nicholson (1981), rainfall abnormalities over West Africa in general may not be easily explained in terms of even latitudinal distribution. That implies that in Nigeria, for example, different sub-regions within the country may have unique ways of responding to changes in the general atmospheric circulation pattern as manifested in the rainfall distribution.

## 1.2 STATEMENT OF THE PROBLEM

In Nigeria, rainfall is the principal controlling element in agriculture. The amount of rainfall that is normally received decides which types of agriculture could be carried out and which crops to be cultivated.

The seasonal rainfall distribution determines the moisture range in which field preparation begins and when sowing and harvesting can be undertaken. Introduction of hybrid plant varieties that require constant supply of moisture along with innovative farming methods is also constrained by the rainfall regime in the country. In addition, the rainfall variability from year to year is the main factor responsible for the fluctuation in agricultural yields and total agricultural production. Either a deficiency or a surplus of rain can cause crop failure, as has been the case during the drought of 1968-1973 and 1979-1983. Almost every year, one part of the country or the other suffers from such calamities. Although, it is difficult to prevent natural calamities such as drought, previous studies (Gibbs, 1975;Adefolalu et al.,1985) have shown that its effects can be minimised by making adequate contigency plans.

In view of this background, the problem of the study is identification of the characteristic spatial patterns of rainfall variation in the country. Also problems of forecasting seasonal and short-term trends in rainfall are compounded by insufficient rain-guage stations which are not standardised and uniformed as well as inadequate knowledge of the nature and the development of the rain-producing systems. However, there is a need for analytical study on the spatial and temporal aspects of the country's rainfall distribution for this will help in understanding the character of rainfall

## 1.3 OBJECTIVES OF THE STUDY

The overall purpose of this study is to investigate the characteristics of rainfall in Nigeria with a view to grouping

the country into homogeneous rainfall regions. Specifically, the objectives are to:

(a) Examine some of the statistical properties of the available rainfall time series;

(b) Examine the rainfall fluctuations in Nigeria;

(c) Use the principal component analysis (PCA) procedure to obtain a regionalization of Nigeria based on annual rainfall.

## 1.4 SIGNIFICANCE OF THE STUDY

There is the need to characterise the country's rainfall in order to understand the availability of water resources and also shed some light on the combination of spatial and temporal factors that cause these patterns. The knowledge of rainfall characteristics will help in the planning of agricultural activities and also in predicting and planning against the consequences of drought and flood. Provision of high density rain-guage network would be expensive. If the rainfall patterns could be represented by fewer sub-regions that are homogeneous, then fewer rain-guages would be needed to capture the patterns.

## 1.5 DATA AND METHODOLOGY

The data for the study were obtained from the Nigerian Meteorological Services, Oshodi, Lagos. The data set consisted of daily rainfall records of sixty-nine stations for the period between 1901 and 1984. The stations, 60% of which are located in the northern part of the country, were randomly selected, and they represent the best available network of climatological stations (Fig 1).




FIG. 1.1. RAINFALL STATIONS

For each station, the daily rainfall values were summed up to yield the January - December monthly totals. Subsequent analyses were performed by the computer. Initial analyses were carried out on the data to obtain the descriptive statistics and some measures of dispersion. The series for each station were tested for homogeneity and randomness using the Swed and Eisenhart's (1943) runs test. In addition, the frequency distribution were examined for normality using the standardised coefficient of Skewness and Kurtosis, and confirmed by chi-square test. The Mann-Kendall Rank test was used to test for trends against randomness in the time series. A five-year moving average was applied to smoothen the periodicities in the graph of the original series for some selected representative stations to bring out the trend.

It was found that sixty nine stations were not all suitable for the principal component analysis since some contained many missing values. As Barring (1988) observed, two many missing values may lead to degeneration of the matrix which could make the analysis biased, and in extreme cases impossible. Thus, only the rainfall series for the period 1941-1983 at forty stations were used for the principal component analysis. The missing values were replaced by their means.

## 1.6 ORGANIZATION OF THE THESIS

The thesis examines the features of rainfall in Nigeria. It attempts to partition the country into homogeneous ranfall regional groups.

Chapter One, which is an introduction, outlines the general background of the study along with a statement of the problem, the objectives and significance of the study. It discusses the data used and methodology adopted in the investigation.

Chapter Two deals with the review of the literature and theoretical framework. It examines briefly the various methods used in classification and regionalization studies and gives a detailed discussion of the technique of the principal component analysis.

Chapter Three deals with the data analysis and discusses the results of the initial statistical tests.

Chapter Four examines in detail the features of rainfall and weather systems in the country, and examines the rainfall patterns using the statistics generated during the preliminary analysis of data. Trends in rainfall during the period of study were investigated in terms of rainfall fluctuations.

Chapter Five presents and discusses the results of the principal component analysis while Chapter Six gives the summary and conclusion of the study.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

Many different methods have been used for the study of rainfall characteristics in relation to atmospheric and agricultural production and their effects on crop growth and yield. Ilesanmi (1969) calculated mean five day rainfall for the period 1951 - 1968 for Nigeria. The percentage of the mean annual rainfall that occurs at each five day interval were derived and the accumulated percentage determined and plotted. The time of the start of rainfall was defined as the first point of maximum positive curvature. Similar studies by Walter (1967) and Stern et al., (1982) in Nigeria have defined the onset of the rains in terms of the date when accumulated rainfall exceeds certain threshold values. Earlier studies in Nigeria by Hamilton and Archbold (1945) and Garnier (1967) have suggested that the main rains start much earlier in the southern Nigeria and advance northwards under the influence of large scale weather systems associated with the Inter-Tropical Convergence Zone and this was confirmed by Ilesanmi (1970). Based on potential evaporative demands of crops, Benoit (1977) defined the start of the rainy season as the date when accumulated rainfall exceeds and remains greater than half of potential evapotranspiration.

Regionalization is the grouping of individual locations or areas in a spatial framework which are correlated with respect to their particular attributes or variables. (Atwoki, 1975).

In most regionalization and classification studies, the underlying principle is to minimize within-group differences and maximize between-group differences. The primary purpose is to obtain an efficient arrangement of information in a simplified and generalized form. Essentially, it is a way of organizing or imposing order on complex phenomena. Regionalization or classification may be done in a subdivision procedure which is accomplished in a series of steps using defined criteria (Abler et al., 1971) or by aggolomerating individuals into classes according to some grouping procedure. The basic assumption of any regionalization or classification is that there exist some sort of pattern and organization in the phenomenon, such as in geography where spatial considerations are important.

In recent years, there has been an increase in the number of classification and regionalization studies of climatic elements in the literature. Dyer (1975) and Gregory (1975) delimited the regional patterns of the annual rainfall in the United Kingdom and South Africa respectively. Similar studies were carried out by Ogallo (1986) in East Africa and Goosens (1986) in the European Mediterranean countries. Ehrendorfer (1987) established a regionalization of Austria's precipitation for summer and winter half-year totals. Anyadike (1987) classified and regionalised West African climates into ten regions while Barring (1988) delimited the spatial patterns of daily rainfall in Central Kenya.

Many methods have been used in the analysis of meteorological data and most of them are grouped together into regionalization and classification procedures.

These include elementary linkage analysis, map-pattern or correlation method, factor analysis and principal component analysis (PCA) or eigenvector analysis. All these are discussed briefly but detailed discussion of principal component analysis which is used in this study is made. Generally, most classification and regionalization procedures are based on the matrix of similarity coefficients obtained from the raw data, usually summarised in an n x m data matrix, where n is the number of objects and m is the number of attributes (variables) by which each object is described (Ayoade, 1977). From this, a similarity coefficient matrix is computed. This is a square matrix of the order of n. There are various types of similarity coefficeints and the one selected is largely determined by the nature of the data being analysed since these similarity coefficients have their own assumptions. Once the appropriate matrix of similarity coefficients is obtained, grouping takes place according to a particular kind of algorithm.

## 2.2 ELEMENTARY LINKAGE ANALYSIS

This technique, developed by McQuitty (1957) allows grouping to be carried out by inspection of the matrix of correlations among objects to be classified. Since every object is assigned to a group in terms of its highest index of association with another object, the lower limit of associations used in building the clusters is exclusively determined by the data. But the groups so defined are characterised by the fact that every member of a group would have a higher correlation with some other member of

that group than it would with any object not in the group (Ayoade, 1977).

The limitation of this grouping procedure is that the number of groups obtained depends exclusively on the number of reciprocal pairs which might change from one sample to another. The method is, however, simple and has the advantages of speed and objectivity provided the sample is small. This technique has been used by Gregory (1965) and Ayoade (1972) in their studies of rainfall characteristics in Sierra Leone and Nigeria respectively. According to McQuitty (1957), elementary linkage analysis gives a grouping result that approximates to that of orthogonally rotated factor analysis. This has been confirmed by Gregory (1975).

## 2.3 MAP-PATTERN OR CORRELATION TECHNIQUE

This technique was developed by Lund (1963) to identify recurring map-pattern configuration. It is a method which correlates two variables in a manner analogous to the simple correlation of time series of two or more variables. This technique involves the measurement of similarities between variables. The correlation technique is useful in differentiating between two synoptically distinct climatic anomalies.

Nicholson (1980) and Blasing (1981) pointed out that the main weakness of this method is its being dependent on correlations between time periods (weeks and months) rather than stations. A significant advantage of this approach is that various meteorological parameters can be grouped into map types. Lund(1963), used map-pattern

method to classify a large number of daily weather types. Blasing (1975) modified the method for climatic studies and compared it with PCA which produces orthogonal characteristic anomaly pattern, thereby reducing the variance in a statistically efficient manner. The result of Blasing was also discussed by Blasing and Lofgren (1980), who used the map-pattern correlation method in their description of characteristic climatic anomaly patterns over the North Pacific sector and Western North America.

## 2.4 FACTOR ANALYSIS (FA)

Factor analysis is a key techique in multivariate studies (Cattel, 1965 and Rummel, 1970). This is a method of studying the convariance structure of a set of inter-related variables (Muliak, 1972; Lawley and Maxwell, 1971). It is capable of analyzing correlation matrices into as many common factors as possible, and describing the variables so as to account for all the observed correlation (Cattel, 1965).

The primary aim of factor analysis is to deliver a parsimonious description of a data matrix. This model differs from other eigentechniques as the total data variance is separated into categories. The first category, the common variance (communality), contains only that variance which is common to two or more variables. Therefore, it is a measure of the overlap of variables in the analysis. The interpretation of the analysis is based totally on this common variance. The second category, the unique variance is the remaining variance which is not common. This is typically considered to be largely

comprised of error variance and therefore, is treated as a residual. This residual is discarded prior to analysis through the use of communalities in the principal diagonal of the dispersion matrix (Walsh et al., 1982)

The major weakness of factor analysis is in the estimation of the common variance. That is, if unity is not placed in the principal diagonal of the correlation matrix, then an estimate correlation must be calculated. The communality estimate can critically affect the factor loading, unless the sample size is very large (Dickman, 1960; and Pennell, 1968).

Early application of this technique was made by Steiner (1965), who analysed 16 variables for 67 stations in the United States, McBoyle(1971) who provided a computer classification of Australian climate. Walsh, et al.,(1982) and Richman (1983) applied this model to precipitation data and geopotential height in the United States. Atwoki (1975) used this method in the delimitation of rainfall regions and regional patterns of climatic fluctuations in Uganda.

2.5 PRINCIPAL COMPONENT ANALYSIS

Principal component analysis (PCA) is a variant form of factor analysis, when the principal diagonal of the input correlation matrix is set to unity. Therefore, the principal component analyis differs in that a variable is assigned a perfect correlation with itself while in factor analysis a variable should not have 1.0 correlation with itself since emphasis is placed on the covariances between variables within the input matrix, rather than the variances. This apparently minor difference from the more general model

creates much more mathematically elegant operations (Richman, 1981).

Principal component analysis was developed by Hotelling (1933). Harris (1964) and Gould (1967) discuss the philosophical and statistical rational behind this technique. Lawley and Maxwell (1971) and Harman (1976) point out that it works best when all the variables are measured in the same units since the method is dependent on the total variance of the original variables.

Principal component analysis has been used by many authors in meteorological and climatological studies as data reduction devices and a technique to aid in forecasting atmospheric parameters (Gilman, 1957) and a procedure to identify coherent modes of various climatic parameters such as rainfall, temperature (Barnett, 1978; and Richman, 1983). The first application to meteorological data was by Fukuoka (1951). Kutzbach (1967) analyzed the spatial distribution of the January monthly means of sea-level pressure, surface temperature and precipitation over North America. Sellers (1968) studied monthly rainfall over Western United States for a 36-year period, performing a different analysis for each month. Klaus (1978) carried out similar analysis using mean annual rainfall south of the Sahara, and performed a spectral analyses of the time coefficient of the selected eigenvectors. Correlations among time - dependent amplitudes of eigenvectors of temperature, precipitation and sea-leval presure over United States were investigated by Walsh and Mostek (1980) while seasonal and annual values of temperature and precipitation in the same area were analysed by Diaz and Fulbright (1981) in connection with the frequency of synoptic

scale systems. Similar analyses were performed by Molteni et al.,(1983) in Northern Italy, Ehrendorfer (1987) in Austria using annual rainfall and Goosens (1988) in European Mediterranean countries using annual mean temperatures. It is a method which involves an orthogonal transformation whereby each of the **n** original variables is explained in terms of new principal components so that the first component extracted accounts for the largest percentage of the total variance (Harman, 1976; Morrison, 1976). One of the advantages of principal components is that it frequently enables the dimensionality of the data to be reduced with little loss of information by grouping one or more of the smallest size components. It also has the advantage of depending on, and exploiting the inter-relationships among the data themselves. However, it has certain characteristics which limit its usefulness in certain situations. The first limitation is related to its reflection property. This means that an eigenvector pattern is fixed, but its signs assume both negative and positive values. Thus, the method classifies the negative of each eigenvector as a realistic departure pattern. The other constraint is related to its orthogonal property, which requires that modes of variations represented by the eigenvectors be statistically independenct, whereas in nature, the modes of atmospheric behaviour are not necessarily so constrained (Blasing, 1975). Due to the orthogonality constraint, the principal components depend on the particular domain used for the analysis, for example, a principal component which describes the variability of rainfall in Nigeria will not necessarily be evident in a similar principal component analysis when the domain encompasses the entire Africa. In many meteorological applications, the

principal component analysis has been used because it is mathematically elegant, variance-oriented and requires no initial assumption of any statistical model in the data set.

2.5.1 Number Of Components To Retain

The exact number of principal components that should be retained had been a subject of some controversy. Retaining too few components results in the blending of spatial patterns which are actually more discrete, while retaining too many components delineate areas which represent nothing more than randomly generated variations (Richman, 1981). A number of statistical tests are available for calculating the appropriate number of factors to retain. These include Kaiser's (1958) test, the Horn's (1965) test, the Scree test, and maximum likelihood test. Richman (1981) surveyed a number of these tests to determine an appropriate number of components to retain. He concluded that none of the methods was entirely satisfactory. Cattel (1958) recommended overfactoring by extracting components accounting for 99% of the variance and then rotating. The trival components can then be left uninterpreted. Perhaps the best available test to separate out the noise eigenvalues are the Preisendofer and Barnett (1977) and Monte Carlo's test. In the present study, the Kaiser (1958) criterion is used to determine when to stop factoring since the Preisendofer-Barnett method and the Monte Carlo's test are not in the computer package used. According to Kaiser's criterion, factoring is stopped when the eigenvalue is less than 1.0.

### 2.5.2 Rotation

The unrotated principal components loading matrix contains components accounting for decreasing amounts of variance. The first unrotated PC accounts for the largest amount of variance of all the data points. And each consecutive component is orthogonal to the others and accounts for the maximum residual variance remaining in the input matrix (Richman, 1981). A problem arises when the first component is located between two or more distinct clusters of inter-related variables, thus resulting in spatial patterns which cannot be easily interpreted. Rotation is therefore usually applied to facilitate the interpretation.

There are two types of rotation, namely oblique and orthogonal. The orthogonal type rigidly rotates the predetermined principal components to better define a distinct grouping or cluster of inter-correlated data, while retaining the constraint that the individual components remain orthogonal to each other. The orthogonal rotation include varimax, quartimax and equimax. These types usually yield similar results, but the varimax routine is more widely used. This is because the varimax method conserves the independence of different PCs more than others (Kaiser, 1958). The oblique rotation does not constrain orthogonality, thereby allowing the rotated component to more precisely identify the data cluster.

These include the oblimin, Harris-Kaiser Case II, and promax. One of the most widely used oblique transformations is promax because it uses an oblique Procrustes rotation to achieve a simple structure solution. In most component analytic studies, once the meaningful principal components have been identified, they are orthogonally rotated to a simple structure. In the present study, varimax and oblimin which are in the computer package were applied and the results compared.

# CHAPTER 3

# DATA ANALYSIS

## 3.1 INTRODUCTION

The validity of any statistical analysis depends essentially on the quality of the data and the objectives of the study. Consequently, a number of preliminary tests were carried out. These include:

(a) Test for homogeneity, which tests the null hypothesis that the rainfall series for each station came from identical and random population.

(b) Test for normality, which tests the null hypothesis that the rainfall series for each station is normally distributed.

(c) Test for trend against randomness which tests the null hypothesis that the rainfall series for each station is random.

In order to be able to discuss the rainfall pattern of the country, the mean annual, mean monthly, standard deviation of the mean monthly rainfall and coefficient of variation of the mean monthly rainfall for each station are computed.

A five-year moving average which eliminates cyclical, seasonal and irregular patterns in the annual rainfall series for some selected representative stations are calculated and graphed.

## 3.2 HOMOGENEITY AND RANDOMNESS OF THE SERIES

The annual rainfall for each station for the period between 1901 and 1984 were tested for homogeneity and randomness using the Swed and Eisenhart's (1943) runs test. A count of runs above and below the median were made, ignoring missing data values. Too many runs would indicate oscillation, while too few runs would indicate trend. If neither oscillation nor trend is present, the series can be taken as random. The mean, median, number of cases N, number of runs R and the probalility of too many or too few runs are detailed in Table 3.1. For the series to be homogeneous and random at 5% level, the probability of getting too few or too many runs should lie within 0.025 and 0.975 inclusive (Owen, 1962).

As can be seen from Table 3.1, only Ibi with a probability of 0.0086 showed a significant departure from homogeneity at 5% level. From statistical tables of Owen (1962), for N = 59, the number of runs (39) lie outside the range 25-34. It can be inferred that since 39 is more than the upper limit 34, there are too many runs for Ibi which suggest oscillation. Also the results show that with the exception of Ibi, there are neither too few nor too many runs about the median for all the stations, indicating that the series for each of the stations is random. Inspite of this apparent inhomogeneity and the oscillatory nature of the series for Ibi, all the forty stations will be used in the subsequent analyses since its inclusion will not affect the results.

TABLE 3.1: STATISTICAL PARAMETERS OF THE RUNS TEST FOR DATA HOMOGENEITY AND RANDOMNESS

| STATIONS | MEAN | MEDIAN | TOTAL NO OF RUNS R | NO OF CASES N | PROB OF RUNS R | |
|---|---|---|---|---|---|---|
| BENIN | 2038.0 | 2026.0 | 34 | 79 | 0.9143 | |
| CALABAR | 2956.8 | 2919.0 | 36 | 84 | 0.9373 | |
| ONDO | 1575.5 | 1525.0 | 35 | 79 | 0.8728 | |
| JOS | 1381.0 | 1380.0 | 31 | 63 | 0.6011 | |
| MAIDUGURI | 634.3 | 641.1 | 32 | 70 | 08323 | |
| BIRNIN KEBBI | 779.9 | 764.4 | 27 | 62 | 0.8998 | |
| YANDEV | 1317.0 | 1308.0 | 26 | 45 | 0.1800 | |
| OWERRI | 2440.6 | 2408.0 | 27 | 66 | 0.9588 | |
| BIDA | 1212.0 | 1231.0 | 34 | 57 | 0.0887 | |
| KADUNA SOUTH | 1289.3 | 1260.0 | 35 | 67 | 0.4020 | |
| MAKURDI | 1283.7 | 1279.0 | 22 | 42 | 0.5000 | |
| PORT-HARCOURT | 2508.5 | 2508.0 | 37 | 71 | 0.3098 | |
| ILORIN | 1269.2 | 1260.0 | 33 | 68 | 0.6875 | |
| KATISINA | 686.9 | 690.8 | 24 | 61 | 0.9658 | |
| YOLA | 948.4 | 947.8 | 34 | 75 | 0.7618 | |
| YELWA | 997.7 | 988.6 | 19 | 43 | 0.8257 | |
| LOKOJA | 1137.7 | 1106.0 | 31 | 69 | 0.8358 | |
| AKURE | 1412.2 | 1374.0 | 28 | 44 | 0.0636 | |
| OTURKPO | 1431.6 | 1460.0 | 24 | 38 | 0.9317 | |
| ENUGU | 1787.7 | 1807.0 | 34 | 56 | 0.0887 | |
| NSUKKA | 1565.7 | 1586.0 | 20 | 43 | 0.7340 | |
| SOKOTO | 707.1 | 707.1 | 33 | 71 | 0.7273 | |
| MINNA | 1299.9 | 1298.0 | 40 | 69 | 0.1109 | |
| KANO | 823.8 | 814.8 | 40 | 80 | 0.5890 | |
| POTISKUM | 719.4 | 714.8 | 18 | 49 | 0.9795 | |
| IBI | 1134.2 | 1133.0 | 39 | 59 | 0.0086 | • |
| NGURU | 500.6 | 509.0 | 17 | 43 | 0.9409 | |
| BAUCHI | 1086.9 | 1073.0 | 40 | 70 | 0.1677 | |
| KABBA | 1492.7 | 1417.0 | 19 | 39 | 0.4331 | |
| OGBOMOSHO | 1189.1 | 1135.0 | 34 | 64 | 0.4005 | |
| LAFIA | 1280.6 | 1264.0 | 24 | 53 | 0.7996 | |
| IBADAN | 1239.6 | 1230.0 | 44 | 78 | 0.1809 | |
| AUCHI | 1261.3 | 1284.0 | 21 | 37 | 0.7996 | |
| LAGOS | 1833.0 | 1837.0 | 36 | 70 | 0.5000 | |
| OYO | 1168.2 | 1161.0 | 37 | 79 | 0.7530 | |
| UYO | 2464.8 | 2446.0 | 15 | 37 | 0.1171 | |
| KWALE | 2193.6 | 2213.0 | 25 | 46 | 0.3828 | |
| OFFA | 1268.6 | 1187.0 | 29 | 60 | 0.6988 | |
| HADEJIA | 627.7 | 623.5 | 25 | 55 | 0.7951 | |
| PANKSHIN | 1081.1 | 1037.0 | 30 | 53 | 0.2004 | |

• Not significant at 5% level.

## 3.3 TEST FOR NORMALITY OF THE SERIES

The frequency distribution of the series for each station was tested for normality using the standardised coefficient of skewness $Z_1$, calculated, following Brazel, et al.,(1986) as:

$$Z_1 = \left\{\left[\sum_{i=1}^{N}(X_i - \bar{X})^3/N\right] / \left[\sum_{i=1}^{N}(X_i-\bar{X})^2/N\right]^{3/2}\right\}/(6/N)^{1/2} \qquad (1)$$

and the standardised coefficient of Kurtosis $Z_2$, calculated as:

$$Z_2 = \left\langle\left\{\left[\sum_{i=1}^{N}(X_i-\bar{X})^4/N\right] / \left[\sum_{i=1}^{N}(X_i-\bar{X})^2/N\right]^2\right\} - 3\right\rangle/(24/N)^{1/2} \qquad (2)$$

where $X_i$ is the annual rainfall, $\bar{X}$ is the long-term mean, and N is the number of years in the series. The two statistics were used to test the hypothesis that the series for each station were normally distributed (Brazel, et al., 1986). If the absolute value of $Z_1$ or $Z_2$ is greater than 1.96, a significant deviation from the normal curve is indicated at the 0.95 confidence level.

In addition, the chi-square test using ten equal probability class intervals calculated, according to Walpole (1968) as:

$$\chi^2 = \sum_{i=1}^{k}\frac{(o_i - e_i)^2}{e_i} \qquad (3)$$

was applied to the frequency distribution, where $\chi^2$ is a value of the random variable $\chi^2$ whose sampling distribution is approximated closely by the Chi-square

distribution, $o_i$ and $e_i$ are the observed and expected frequencies respectively for the $i^{th}$ cell, and k is the number of cells. If the computed chi-square is less than the corresponding table value, we conclude that the distribution is uniform (Walpole, 1968).

Table 3.2 shows for each station, the mean $\bar{X}$, standard deviation, number of cases N, standardised coefficients of skewness $Z_1$, standardised coefficient of kurtosis $Z_2$, number of degrees of freedom, computed chi-square and the critical values of chi-square. The absolute values of $Z_1$ and $Z_2$ for thirty-two stations are less than 1.96, indicating that the series for these stations are normally distributed. However, on examination of the series for the remaining eight stations - Ondo, Owerri, Port Harcourt, Enugu, Ogbomosho, Lagos, Offa and Pankshin, it was found that a few high values created unexpected skewness in their frequency distributions. The standardised coefficients of peakedness are equally high for Owerri, Enugu, Ogbomosho, Lagos, Offa and Pankshin.

The chi-square test indicates that the series for thirty four stations are normally distributed, since the computed chi-squares are all less than the table values. The calculated chi-squares for Owerri, Yandev, Lagos, Oyo, Offa, and Pankshin are higher than the table values, indicating a deviation from the normal distribution. Surprisingly, Ondo, Port-Harcourt, Enugu and Ogbomosho are found to be normally distributed by the chi-square test as opposed to the case of the standardised coefficients of skewness and kurtosis $Z_1$ and $Z_2$ above. Probably, the few

TABLE 3.2 DISCRIPTIVE STATISTICS OF THE ANNUAL RAINFALL

| STATION | CASES | MEAN | STANDARD DEVIATION | $z_1$ | $z_2$ | DEGR. OF FREEDOM | COMPUTED CHI-SQUARE | CRITICAL VALUES OF CHI-SQUARE |
|---|---|---|---|---|---|---|---|---|
| BENIN | 79 | 2038.0 | 335.3 | 0.65 | 1.16 | 6 | 4.063 | 12.592 |
| CALABAR | 84 | 2956.8 | 537.8 | 1.49 | 2.35 | 5 | 4.562 | 11.070 |
| ONDO | 79 | 1575.5 | 317.9 | 3.77 | 1.73 | 7 | 6.766 | 14.067 |
| JOS | 63 | 1381.0 | 178.2 | -0.08 | -0.56 | 5 | 5.748 | 11.070 |
| MAIDUGURI | 70 | 634.3 | 150.1 | -0.79 | -0.78 | 6 | 2.672 | 12.592 |
| BIRNIN KEBBI | 62 | 779.9 | 148.4 | -0.84 | -1.19 | 5 | 5.782 | 11.070 |
| YANDEV | 45 | 1317.0 | 197.6 | 0.19 | -1.23 | 3 | 7.893 | 7.815 |
| OWERRI | 66 | 2440.6 | 345.5 | 11.77 | 32.28 | 2 | 8.892 | 5.991 |
| BIDA | 57 | 1212.0 | 177.3 | 0.36 | -0.07 | 4 | 5.453 | 9.488 |
| KADUNA SOUTH | 67 | 1289.3 | 191.9 | 0.86 | -1.07 | 6 | 2.579 | 12.592 |
| MAKURDI | 42 | 1269.2 | 199.7 | -0.08 | -0.20 | 3 | 0.746 | 7.815 |
| PORT-HARCOURT | 71 | 2508.5 | 412.3 | -7.97 | -1.09 | 6 | 6.405 | 12.592 |
| ILORIN | 68 | 1269.2 | 225.9 | 0.40 | -1.34 | 6 | 6.413 | 12.592 |
| KATSINA | 61 | 686.9 | 147.2 | -0.50 | -1.25 | 5 | 3.958 | 11.070 |
| YOLA | 75 | 948.4 | 167.0 | 1.08 | -0.25 | 5 | 4.443 | 11.070 |
| YELWA | 43 | 997.7 | 169.7 | -0.38 | -0.10 | 2 | 0.469 | 5.991 |
| LOKOJA | 69 | 1137.7 | 252.7 | 0.99 | 1.29 | 3 | 6.437 | 7.815 |
| AKURE | 44 | 1412.2 | 252.6 | 1.32 | 0.21 | 1 | 1.390 | 3.841 |
| OTURKPO | 38 | 1431.6 | 375.4 | 0.08 | 1.56 | 1 | 0.650 | 3.841 |
| ENUGU | 56 | 1787.7 | 271.7 | 2.40 | 3.53 | 3 | 4.726 | 7.815 |
| NSUKKA | 43 | 1565.7 | 284.1 | -0.74 | 0.66 | 2 | 0.284 | 5.991 |
| SOKOTO | 71 | 707.1 | 146.3 | 0.58 | -0.53 | 5 | 3.699 | 11.070 |
| MINNA | 69 | 1299.9 | 211.8 | 0.96 | 0.61 | 6 | 11.196 | 12.592 |
| KANO | 80 | 823.8 | 176.4 | 0.20 | -0.62 | 6 | 2.425 | 12.592 |
| POTISKUM | 49 | 719.4 | 207.0 | 0.61 | -0.72 | 3 | 4.129 | 7.815 |
| IBI | 59 | 1134.2 | 164.2 | 0.38 | -0.03 | 5 | 1.721 | 11.070 |
| NGURU | 43 | 500.6 | 127.9 | 0.51 | 0.67 | 1 | 0.998 | 3.841 |
| BAUCHI | 70 | 1086.9 | 156.3 | 0.86 | -0.37 | 5 | 6.183 | 11.070 |
| KABBA | 39 | 1492.7 | 314.9 | 1.80 | 0.10 | 2 | 3.531 | 5.991 |
| OGBOMOSHO | 64 | 1189.1 | 290.2 | 3.51 | 2.88 | 4 | 5.714 | 9.488 |
| LAFIA | 53 | 1280.6 | 237.3 | 1.35 | 0.72 | 3 | 6.218 | 7.815 |
| IBADAN | 78 | 1239.6 | 262.2 | 1.63 | 0.03 | 6 | 2.021 | 12.592 |
| AUCHI | 37 | 1261.3 | 287.8 | 0.23 | 0.74 | 1 | 0.041 | 3.841 |
| LAGOS | 70 | 1833.0 | 386.5 | 2.83 | 2.88 | 3 | 9.033 | 7.815 |
| OYO | 79 | 1168.2 | 258.9 | 0.92 | 0.11 | 6 | 14.368 | 12.592 |
| UYO | 37 | 2464.8 | 348.8 | 1.37 | 0.14 | 1 | 0.932 | 3.841 |
| KWALE | 46 | 2193.6 | 333.0 | 1.25 | 0.57 | 2 | 2.713 | 5.991 |
| OFFA | 60 | 1268.6 | 275.5 | 4.19 | 4.06 | 4 | 11.213 | 9.488 |
| HADEJIA | 55 | 627.7 | 125.2 | 1.29 | 0.43 | 3 | 2.287 | 7.815 |
| PANKSHIN | 53 | 1081.1 | 246.5 | 5.16 | 1.87 | 1 | 10.689 | 3.841 |

stations are not normally distributed as a result of the inherent errors in the data. These results indicate the differences in the power of the two tests. It would appear that the chi-square test is better, since it yields more number of stations which are normally distributed. Since the time series for 85% of the stations are normally distributed, statistical tests which imply normality can be applied to the series.

## 3.4 TEST FOR TREND AND RANDOMNESS

The Mann - Kendall Rank Test was applied to test for trend and randomness of the series. This statistic is determined, following Brazel, et al., (1986) as:

$$T = \left[4\left(\sum_{i=1}^{N-1} n_i\right)/N(N-1)\right] - 1 \qquad (4)$$

Where $n_i$ represents the number of subsequent terms (from $X_{i+1}$ to $X_n$) in the time series that exceed $X_i$ and N the number of years. A test statistic

$$(T)_t = 0 \pm t_g \left[(4N+10)/9N(N-1)\right]^{\frac{1}{2}} \qquad (5)$$

where $t_g$ is the two-tailed probability of the Gaussian distribution which is equal to 1.96 at 0.95 confidence level. If T lies outside the bounds of $(T)_t$, it can be concluded that some form of trend exists in the time series (Brazel, et al., 1986). The statistic T and the critical value $(T)_t$, including the number of cases for each station, are presented in Table 3.3.

The Mann-Kendall Rank test results in Table 3.3 indicate that the time series for 75% (30) of the stations are influenced by random processes since T lies within the critical values $(T)_t$ for each station. This randomness does not exhibit any regional patterns. The remaining 25% (10) of the stations show negative trends which appear to be regional. These stations are Birnin Kebbi, Katsina, Lokoja, Oturkpo, Minna, Kano, Potiskum, Nguru, and Pankshin in the North, and Calabar in the South. The downward trend in these Northern towns could be as a result of the severe drought of 1969-1973. Surprisingly, some northern stations such as Sokoto, Maiduguri and Hadejia show positive trend while Calabar in the South shows a downward trend. These inconsistencies could be as a result of unforeseen data error.

## 3.5 SUMMARISING AND CHARACTERIZING RAINFALL PATTERNS IN NIGERIA

In order to be able to examine the rainfall variation in Nigeria, the descriptive statistics, mean monthly rainfall, standard deviation of the mean monthly rainfall, and the coefficient of variation of the mean monthly rainfall, were calculated for each station over periods between 1901 and 1984. The mean, $\bar{X}$, was computed as:

$$\bar{X} = \frac{\sum_{i=1}^{N} X_i}{N} \qquad (6)$$

where each $X_i$ is the monthly observation in the year and, N is the number of years (sample size).

TABLE 3.3 DETAILS OF MANN-KENDALL RANK TEST FOR TREND AND RANDOMNESS

| STATION | NUMBER OF CASES N | T | $(T)_t$ |
|---|---|---|---|
| BENIN | 79 | 0.132 | 0.150 |
| CALABA | 84 | -0.247* | 0.146 |
| ONDO | 79 | 0.022 | 0.150 |
| JOS | 63 | -0.161 | 0.169 |
| MAIDUGURI | 70 | -0.135 | 0.160 |
| BIRNIN KEBBI | 62 | -0.268* | 0.171 |
| YANDEV | 45 | 0.004 | 0.202 |
| OWERRI | 66 | 0.018 | 0.165 |
| BIDI | 57 | -0.123 | 0.178 |
| KADUNA SOUTH | 67 | -0.048 | 0.164 |
| MAKURDI | 42 | -0.004 | 0.210 |
| PORT-HARCOURT | 71 | -0.043 | 0.159 |
| ILORIN | 68 | -0.055 | 0.163 |
| KATISNA | 61 | -0.236* | 0.172 |
| YOLA | 75 | -0.067 | 0.154 |
| YELWA | 43 | -0.174 | 0.207 |
| LOKOJA | 69 | -0.168* | 0.161 |
| AKURE | 44 | -0.049 | 0.205 |
| OTURKPO | 38 | -0.263* | 0.222 |
| ENUGU | 56 | -0.061 | 0.180 |
| NSUKKA | 43 | -0.012 | 0.207 |
| SOKOTO | 71 | -0.138 | 0.159 |
| MINNA | 69 | -0.250* | 0.161 |
| KANO | 80 | -0.208* | 0.149 |
| POTISKUM | 49 | -0.257* | 0.193 |
| IBI | 59 | -0.068 | 0.175 |
| NGURU | 43 | -0.347* | 0.207 |
| BAUCHI | 70 | -0.132 | 0.160 |
| KABBA | 39 | -0.112 | 0.219 |
| OGBOMOSHO | 64 | -0.126 | 0.168 |
| LAFIA | 53 | -0.093 | 0.185 |
| IBADAN | 78 | -0.031 | 0.151 |
| AUCHI | 37 | -0.051 | 0.225 |
| LAGOS | 70 | -0.042 | 0.160 |
| OYO | 79 | -0.045 | 0.149 |
| UYO | 37 | -0.099 | 0.225 |
| KWALE | 46 | -0.154 | 0.200 |
| OFFA | 60 | -0.009 | 0.174 |
| HADEJIA | 55 | 0.069 | 0.182 |
| PANKSHIN | 53 | -0.208 | 0.185 |

* indicates existence of trend

The standard deviation s was calculated as

$$s = \frac{\sum_{i=1}^{N}(X_i-\bar{X})^2}{N} \qquad (7)$$

where $X_i$ is the month's observation in the year, $\bar{X}$ the mean and, N the number of years.

The coefficient of variation CV, was computed as

$$CV = \frac{s}{\bar{X}}x100 \qquad (8)$$

where s is the standard deviation, and $\bar{X}$ the mean.

The computed values of the mean, the standard deviation, and the coefficient of variation were used in mapping their spatial distributions in Figures 4.2, 4.3, and 4.4 respectively in Chapter Four.

A five-year moving average of annual rainfall for some selected stations were calculated and plotted on the same axes with the original data to show the trend. The rainfall values for the first five years were added and divided by five to obtain the average which is recorded against the mid-point of the cycle. Next the average of next five year's rainfall, ignoring the first year was calculated. This process continues until the data points are exhausted. The trend of the original data and the five-year moving average are shown in Figure 4.5 (Chapter Four).

## 3.6 ANALYTICAL PROCEDURE OF PCA

Generally, the data used in principal component analysis consists of n observations made on p variables.

In this study, forty three annual rainfall values at forty stations are analysed. According to Beaudion and Rousselle (1982), these observations can be represented in a p-dimensional space, where each axis represents a variable. The objective of principal component analysis is to transform the original p - axis system into a new one having the properties that the new principal axes are orthogonal and the principal components are arranged in descending order of importance, such that each component explains the maximum amount of variance of the observations left unexplained by the previous components.

To obtain the principal components, the 40 x 40 inter-station correlation matrix **R** is firstly computed from the original 43x40 data matrix **A**. Each element of **R** is calculated from the general equation:

$$r = \frac{N\Sigma X_1X_2 - \Sigma X_1X_2}{((N\Sigma X_1^2 - (\Sigma X_1)^2)(\Sigma X_2^2 - (\Sigma X_2)^2))^{\frac{1}{2}}} \qquad (9)$$

where $X_1$ and $X_2$ are the respective annual rainfall values at stations one and two, and N the number of observations. The lower triangular of the computed correlation matrix is detailed in Table 5.1, Chapter Five.

Next the forty eigenvalues ($\lambda$) of R are derived following, Kendall, (1975), by solving the characteristic equation

$$|_{40}R_{40} - \lambda_{40}I_{40}| = 0 \qquad (10)$$

where **I** is the 40x40 identity matrix. For, each eigenvalue ($\lambda$) of equation (10), a non-zero vector **e**

can be derived such that

$$ {}_{40}R_{40}e_1 = {}_{40}e_1 \qquad (11) $$

where the vector e is called the characteristic vector or eigenvector of the correlation matrix R associated with the corresponding eigenvalue $\lambda$. The significant eigenvalues calculated, together with the percentage of total variance explained are given in **Table 5.2 Chapter Five** while the calculated eigenvectors are shown in Table 5.3, Chapter Five.

According to Kaiser(1958), only the eigenvalues for which $\lambda_i > 1$ (i=1,...,40) should be retained. In this study, the first thirteen eigenvalues were greater than 1 and are therefore retained for further analysis. The percentage of total variance $V_i$ explained by each principal component is calculated as:

$$ V_i = \frac{100\lambda_i}{\sum_{i=1}^{13}\lambda_i} \quad \text{for } i=1,\ldots,13 \qquad (12) $$

The initial eigenvectors obtained were subjected to orthogonal and oblique rotations in order to improve on the results. The mathematics of the rotation procedure is complicated and is therefore not outlined here. The orthogonally (varimax option) and obliquely (Oblimin option) rotated eigenvectors are shown in Tables 5.4 and 5.5 respectively of Chapter Five.

In pre-computer era, the arithmetic involved in principal component analysis was rigorous. Nowadays, there are many computer-based statistical packages which perform the analysis quickly and accurately.

## 3.7 COMPUTER PROGRAMMING

The preliminary computer analysis to calculate the descriptive statistics, measures of dispersion, including the summary print-out of the monthly rainfall values were done on the Ahmadu Bello University Control Data Corporation Cyber 72 computer system. The Swed and Eisenhart's (1943) runs test, test for normality, Mann-Kendall's Rank test, the moving average and the rainfall trend were carried out on the University of Nigeria - University of Dublin Linkage Facilities on Operations Research and Data Processing. Since the Cyber 72 Computer system of Ahmadu Bello University could not handle the principal component analysis, this was carried out on the Abubakar Tafawa Balewa University Digital Equipment Corporation VAX 11/780 Computer system using SPSS-X. The programs used are shown in Appendices A, B and C.

# CHAPTER 4

## FEATURES OF RAINFALL IN NIGERIA

### 4.1 ORIGINS OF RAINFALL

Rainfall in the tropics is said to be largely associated with the passage of the synoptic scale disturbance (Riehl, 1954). Also local factors such as orography, land and sea breeze effects could influence the properties of the basic currents (La Seur, 1960), and cause changes in the effect of such disturbances. Johnson (1963) associated the rainfall patterns to both lower and upper tropospheric systems while Alaka (1964) pointed out that synoptic systems are associated with meso-scale as well as short-lived mobile convective scale systems which Garnier (1967) and others in West Africa referred to as Line-squalls. Thus rainfall in Nigeria and West Africa is produced by atmospheric processes, convective, and non-convective systems and orographic uplift.

During the rainy season (April - October), a basic feature of the lower atmosphere over West Africa is the thermally-induced low pressure cell over the Sahara with its axis located between latitudes $18^{\circ}N$ and $22^{\circ}N$. At the same time, the sub-tropical high pressure over the south Atlantic intensifies and extends equatorwards. The resulting gradient between the two pressure systems induce a low-level south-westerly air (south-west monsoon) from the south Atlantic. At the surface, this warm, moist and convectively unstable southwesterly airstream can penetrate deep as far inland as the southern fringes of the Sahara desert, reaching altitudes $20^{\circ}$ - $22^{\circ}N$ in August. The depth of this south-west monsoon decrease inland from the Guinea coast.

Above this south-west monsoon at about 3km is a hotter and drier northeasterly airstream from the Sahara. Near the 3km and 12km levels, these easterly winds concentrate into narrow bands of jet streams known respectively as the African Easterly Jet (AEJ) and the Easterly Tropical Jet (ETJ). The position and intensities of the jets influence the formation of synoptic-scale features such as easterly waves, line-squalls and thunderstorms. These move westwards, giving rise to strong surface convergence, enhanced cloud development and rainfall (Okulaja, 1970; Kamara, 1986).

Secondly, large amount of rainfall is generated by convective systems. Kamara (1986) has identified two types of convective systems. They are the local convective rainstorm and the line-squalls. The local convective rainstorm is associated with intense heating of the land surface which results in rapid convection, giving rise to towering cumulus and cumulonimbus. When they occur, large areas have showery weather and many areas experience rainfall. This is highly localised and mostly experienced in the southern coastal towns of Nigeria (Adefolalu, 1983). The line-squalls on the other hand, are associated with the instability phenomena. Eldridge (1957) suggested that they have elongated structure which was confirmed by Forsdyke (1960). Hamilton and Archbold (1945) and Garnier (1967) observed that periods of active line-squall coincide with enhanced easterly wave activity over West Africa. They move from east to west during the night and early morning, with highest frequency at the onset and towards the end of the rainy season (September to October).

Most of them originate from West Central Africa, the highlands of Eastern Nigeria and Western Cameroon. The line-squalls are characterised by high temperatures, low humidity and torrential rain, accompanied by lightning and thunder. These line-squalls are responsible for a high proportion (about 60 - 70%) of the total rainfall received in many parts of the country (Adefolalu, 1983). Okulaja (1970) made a synoptic analysis of weather conditions in West Africa for 26 - 28 July, 1960. He found that the line-squall on the 26, first manifested itself on the surface as line distribution of heavy cloud with heavy rain.

The effect of orography as a rain producer is highly localised. This is associated with mountain barriers which can deflect, block, or enhance air uplift. As the south-westerlies approach these mountain masses, the winds are forced to rise up, and beyond the condensation level, where adiabatic expansion results in cooling, condensation, cloud formation and rainfall. It has been noted that the amount of rainfall is significantly greater on the windward side than on the leeward slopes of mountains. Such variations in rainfall concentration reflect fundamental differences in the distribution and concentration of heat, moisture and general convective instability between the two sides of the mountain (Kamara, 1986). This type of rainfall is experienced in Calabar and Jos.

It is also noteworthy that the non-convective system of rainfall is produced by the low level convergence. This produces air ascent convergence in the horizontal flow of air masses. This means that large-scale surface convergence below the Easterly Tropical Jet promotes widespread instability within

the moist maritime tropical airmass which result in the development of thick and continuous layers of medium-level altostratus and altocumulus clouds and low-level stratus and stratocumulus clouds over very wide area. It occurs in West Africa where there is a marked deepening of the low level south-westerlies between June and September, resulting in widespread and prolonged monsoon rains. This is similar to the type of rainfall found over southeast Asia during summer. The rainfall is characterised by light continuous downpours with occasional spells lasting from a few hours to several days. Generally, the periods of maximum convergence rainfall coincide with minimal thunderstorm activity, which suggests differences in the mechanisms that organise the thunderstorm and massive uplift of the monsoon air.

## 4.2 THE WEATHER SYSTEM IN NIGERIA

The weather conditions in Nigeria have been described by Hamilton and Archbold (1945). The general pattern of weather is similar to those experienced over West Africa. These weather conditions result from the general circulation of the atmosphere and its associated airmass over the globe, modified by local conditions. However, rainfall in Nigeria exhibits a definite alternating wet and dry seasons in response to the pressure belts associated with the apparent movement of the overhead sun (Oguntoyinbo et al.,1978). Belts of distinctive weather have been observed to show pronounced migration across the region. This migration is strongly associated with the north-south movement of a zone of sharp discontinuity between dry cT and the humid mT. This boundary zone is known as the Inter-Tropical Discontinuity in West Africa. The ITD assumes its northernmost position in August

around latitude 20°N and attains its southernmost position in January between latitudes 5°N and 7°N. Generally, places north of the ITD would have little or no rainfall, while rainfall will occur in places some distances south of the position of the ITD. The tropical continental airmass tends to be predominant in the northern part, while the tropical maritime airmass dorminates the south. For this reason, the rainy season is longer in the southern than in the northern part of the country. This relationship of these weather zones to the location of ITD may be perceived by reference to the idealised cross section in Figure 4.1.

In this figure the surface position of the ITD is indicated by a straight line intended to illustrate the way in which humid air exists as a tongue penetrating into the dry air. North of this juncture, lies dry easterly air with generally cloudless skies while to the south of it, there is a mass of moist southwesterly air at the surface and the dry easterly air aloft. The structure of this south-westerly and its contrast with the northeasterly are reflected in the different weather zones. The locations are shown by letters A to D in Figure 4.1 by Walker (1958). Zone A lies north of ITD. It is a region of dry air and little cloud consisting mainly of high cirrus and some medium clouds especially at dawn. The weather type is characterised by strong harmattan conditions during December to early February. It is a rainless zone with relatively cool nights. The north-easterlies bring light and gusty wind in the mornings. There are also periods of a few days of extensive haze caused by fine dust suspended in the atmosphere.

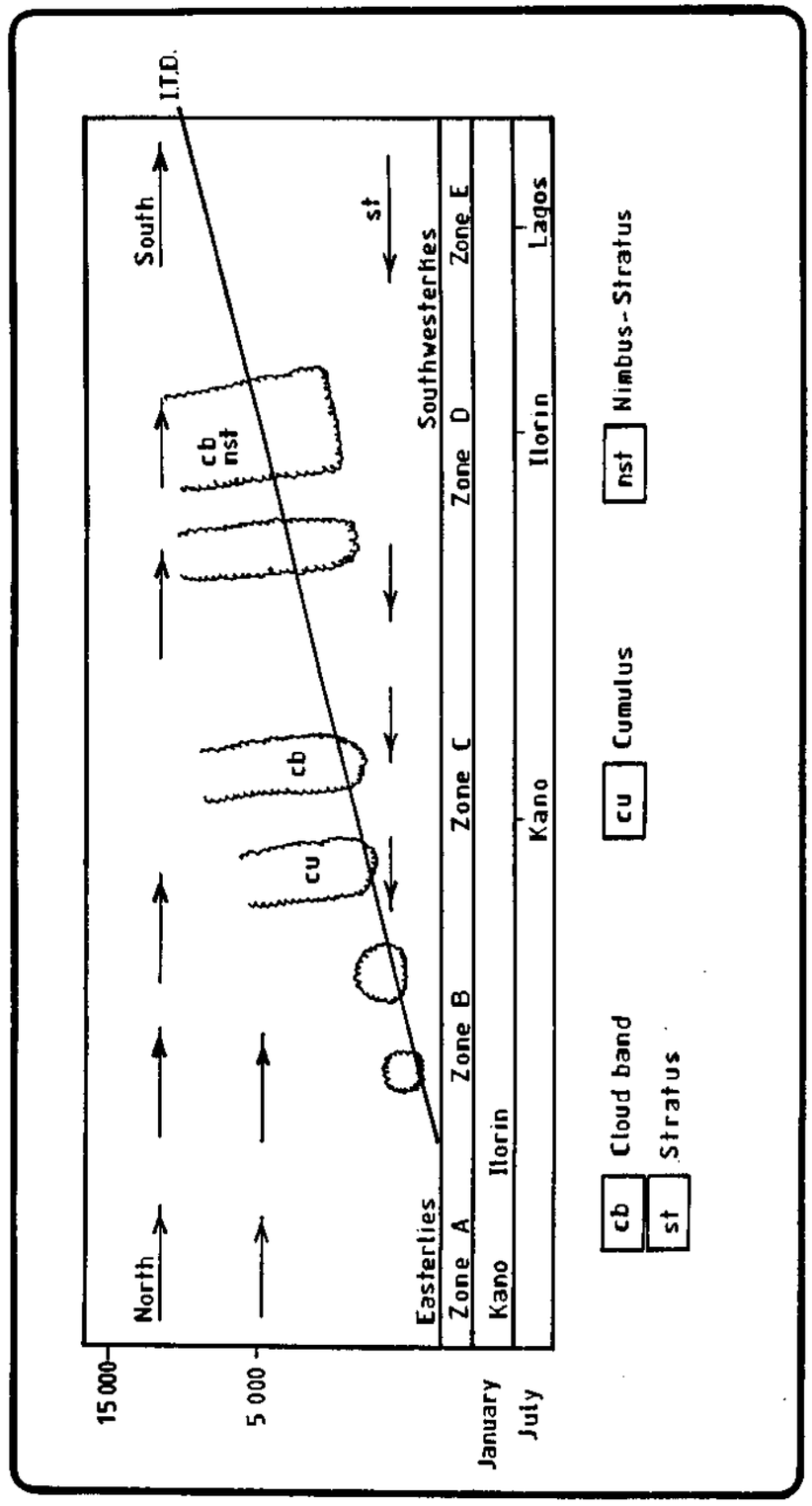



FIG. 4,1 THE ITD AND THE WEATHER ZONES ( WAIKER, 1958 )

Zone B, lying immediately to the south of the ITD extends for some 240 - 320 km. The weather is mainly dry with rather warmer nights and hotter days inland and on the coast. There may be an isolated rain shower or thunderstorm but these are not common. There is usually a marked increase in night temperatures and humidities giving a sense of stickness. This is felt more in the south than in the north. Zone C lies south of zone B and extends southwards for 600 - 800 km. Periods of rain are short and of high intensity. The atmospheric condition is associated with disturbance lines, such as thunderstorms, giving wide - spread but variable and sporadic rainfall. Humidity is generally high and diurnal temperature range is small. Zone D lies to the south of Zone C. It is characterised by high humidity and relatively low and constant temperature. It is a region of much stratus cloud with a base of only 200 - 300 metres in the sky. Above this layer, relatively stable conditions and sometimes temperature inversions are prevalent. These inhibit upward movement, thus reducing the quantity and intensity of the rainfall and is sometimes regarded as responsible for the little dry season. Zone E is the most southerly zone which penetrates a relatively short distance inland in July and August. The weather conditions are similar to those of zone D.

Not all the five weather types shown in Fig. 4.1 are experienced in all parts of Nigeria. Type A is rarely experienced at the coast while types D and E are confined to the south. Broadly speaking, weather zone A prevails over much of the northern part of the country during the dry season months of November - April. During this period, most of the south enjoy weather zone B, with the weather zone C prevailing

along the coastalareas particularly the Niger-Delta area. From May to October, weather zones, B and C prevail over the north while weather zones C, D, E prevail over the south with varying frequencies. The location of the ITD and its effect in January (Fig. 4.1) is typical of dry season conditions. North of the surface ITD, all areas are continuously under cT air, while south of it, areas are under mT air. This implies that Kano corresponds to zone A while Ilorin corresponds to zone B. As the ITD, moves northwards in July, the mT air dorminates the country. Hence, weather zones B and C prevail in the north while weather zones D and E prevail in the south. And as such, Kano enjoys weather zone C, Ilorin experiences weather zone D and Lagos enjoys weather zone E.

## 4.3 THE RAINFALL PATTERNS

During the preliminary analysis of the data, the mean annual rainfall, mean monthly rainfall and coefficient of variation of mean monthly rainfall were determined. The result of the analysis were used in discussing the variation of rainfall pattern across the country. The resultant maps of the patterns are presented in Figures 4.2, 4.3 and 4.4 respectively.

Figure 4.2 shows the distribution of the mean annual rainfall in Nigeria. The amount of the rainfall decreases from the south to the north. The highest values received in the south are within isohyets 2,400mm and 3,000mm. They vary from 2,441mm in Owerri, through 2,465mm in Uyo and 2,509mm in Port-Harcourt, to 2,957mm in Calabar. These high values could be explained in terms of the orientation of the coast across the wind path, or in terms of the effects of the disturbance lines that are most frequently generated

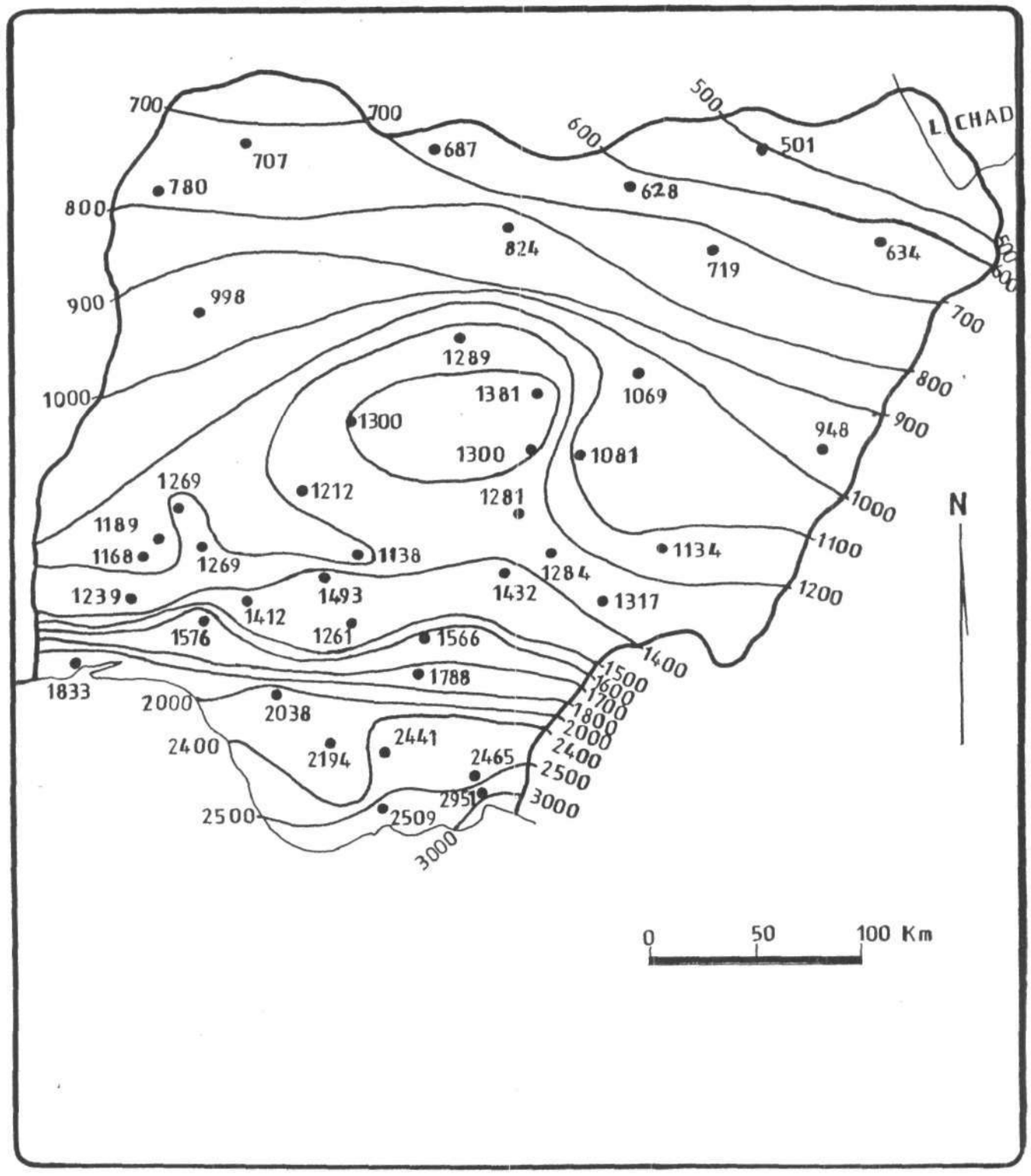



FIG. 4.2. DISTRIBUTION OF MEAN ANNUAL RAINFALL (mm)

to the east of Nigeria (Adedokun, 1978). The very high values in Calabar in the east and Jos in the north are attributable to the altitudinal effects of the Cameroon Mountains and the Jos Plateau. The low amounts, on the other hand, occur in the south-west within isohyets 1,200mm and 1,500mm. They range from 1,168mm in Oyo, through 1,189mm in Ogbomosho, 1,240mm in Ibadan, 1,269mm in Ilorin and Offa, to 1,412mm in Akure. These low values may have resulted from the effects of the easterly extension of the dry belt of Ghana and Togo.

As the rainfall decreases inland, the relatively high values in the north are experienced in Yelwa (998mm) and Yola (948). This may have resulted from the orographic influence of the North-Central Plateau and Mandara Mountains. Low values occur at Nguru (501mm) and Hadejia (628mm). This might be due to the effects of continentality.

The central portion, known as the Middle Belt, which includes the Niger-Benue trough stations, has similar characteristics as the south-western Nigeria. The rainfall amounts range from 1,138mm in Lokoja, 1,281mm in Lafia, 1,212mm in Bida, 1,317mm in Yandev, to 1,432mm in Oturkpo. The low values may be ascribed to the low land nature of the land which runs parallel to the Niger-Benue trough. This may have caused the deflection of the south-westerlies, thus resulting in minimal rainfall in the area.

The rainfall patterns for the mean monthly rainfall are shown in Figures 4.3.1 to 4.3.12. There is a general east-to-west and south-to-north decrease in the monthly rainfall, with the

isohyets running east to west. Figures 4.3.11, 4.3.12, 4.3.1 and 4.3.2 indicate that the greater part of the country is rainless from November to February while the southern coastal stations experience rain to a certain degree. For example, the values of rainfall in November (Fig.4.3.11) are 176mm in Calabar, 132mm in Port-Harcourt, 75mm in Lagos, and 47mm in Ondo, while the amounts in December vary from 43mm in Port-Harcourt to 46mm in Calabar. The decrease in rainfall at this time is due to the southward movement of the ITD. This pattern persists in January (Fig.4.3.1). By February (Fig. 4.3.2) and March (Figure 4.3.3), rainfall has extended a little inland, with Benin receiving 38.8mm, Owerri 47.4mm and Kwale 43.4mm. The amounts are higher in March within which Akure, Enugu and Kabba had 108.8mm, 76mm and 64.5mm respectively. The highest rainfall values from January to March are found in the south-eastern Nigeria. This is because the rain-bearing south-westerlies accompaning the mT air, strike the coast at right angles, coupled with the effects of the Cameroon Mountain (Ojo,1977). Zonal patterns also occur in April and May (Figures 4.3.4 and 4.3.5) with rainfall generally decreasing from the coast inland. The values range between .5mm and 212mm in April and between 23mm and 292mm in May. It is evident from the maps that there are more areas with greater amounts in May than in April. All these reflect the influence of the northward movement of the ITD and the dorminance of the south-westerlies.

June and July (Figures 4.3.6 and 4.3.7) are the periods of the heaviest rainfall, with great variations as well. Rainfall is evenly distributed all over the country as the ITD, is in its northernmost limit. This is in agreement with the general pattern of rainfall in the tropics.

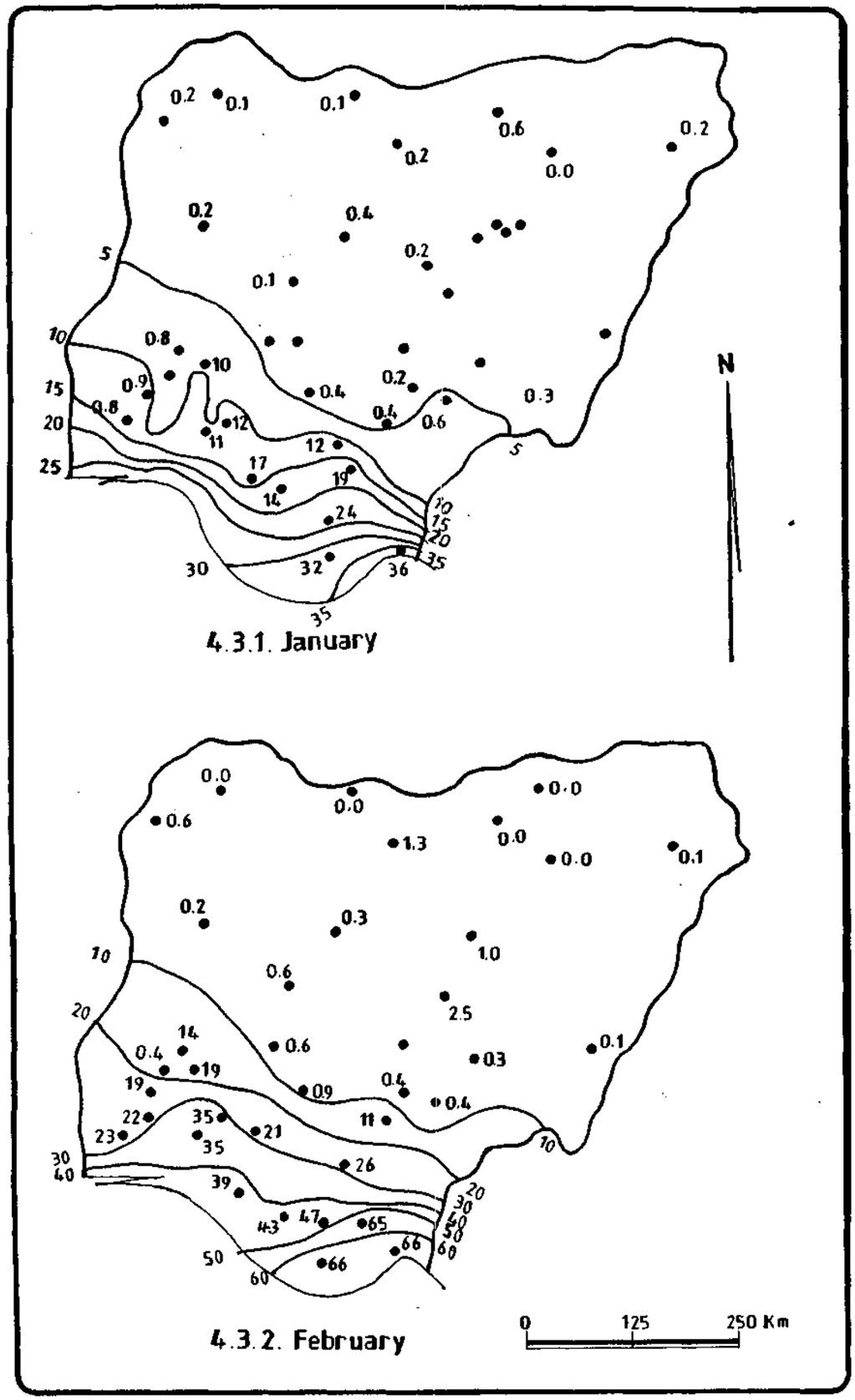



Fig. 4.3.Distribution of mean monthly rainfall
(4.3.1. January ; 4.3.2. February )

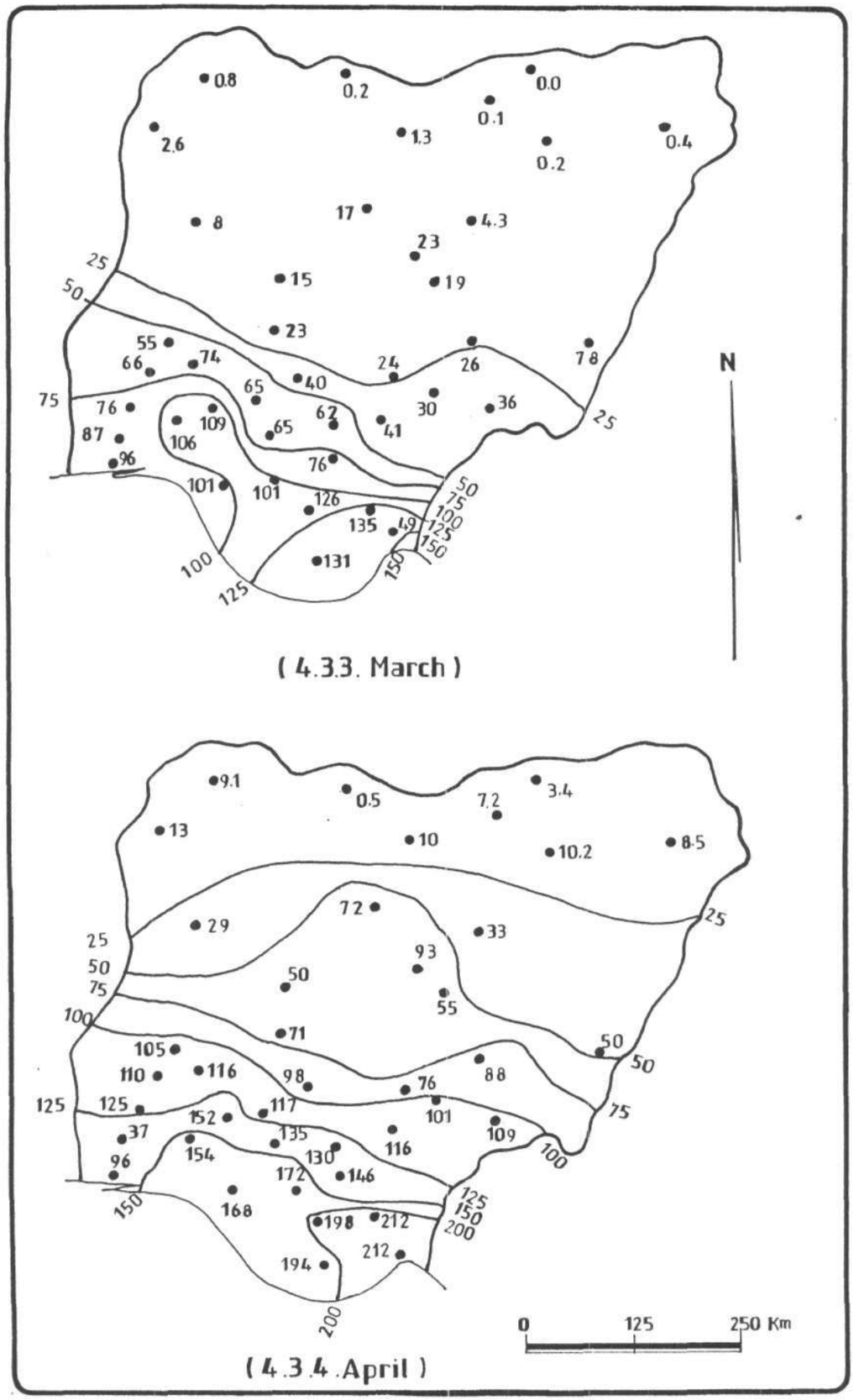



Fig. 4.3. Distribution of mean monthly rainfall
( 4.3.3. March ; 4.3.4. April )

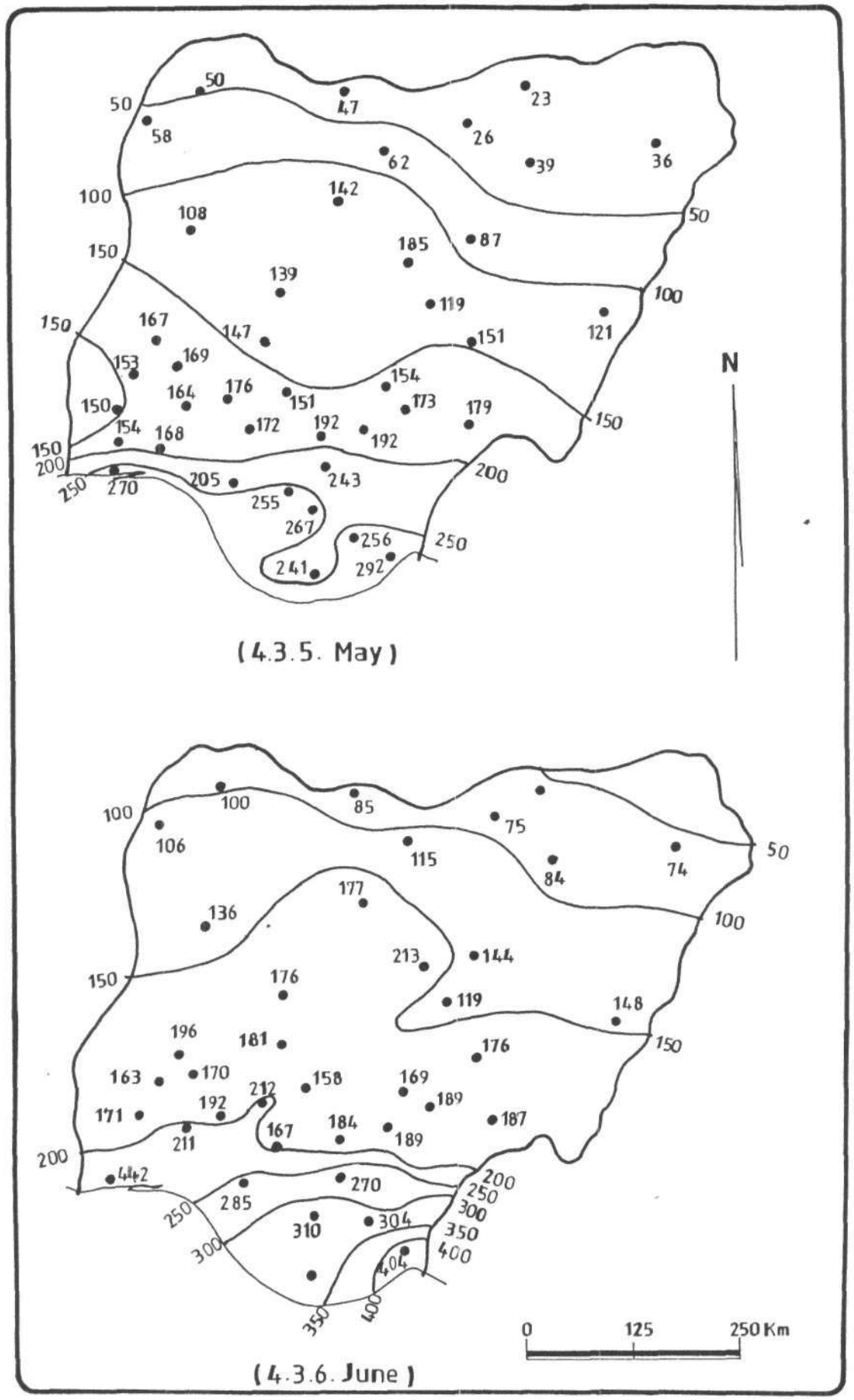



Fig. 4.3. Distribution of mean monthly rainfall
(4.3.5. May ; 4.3.6. June)

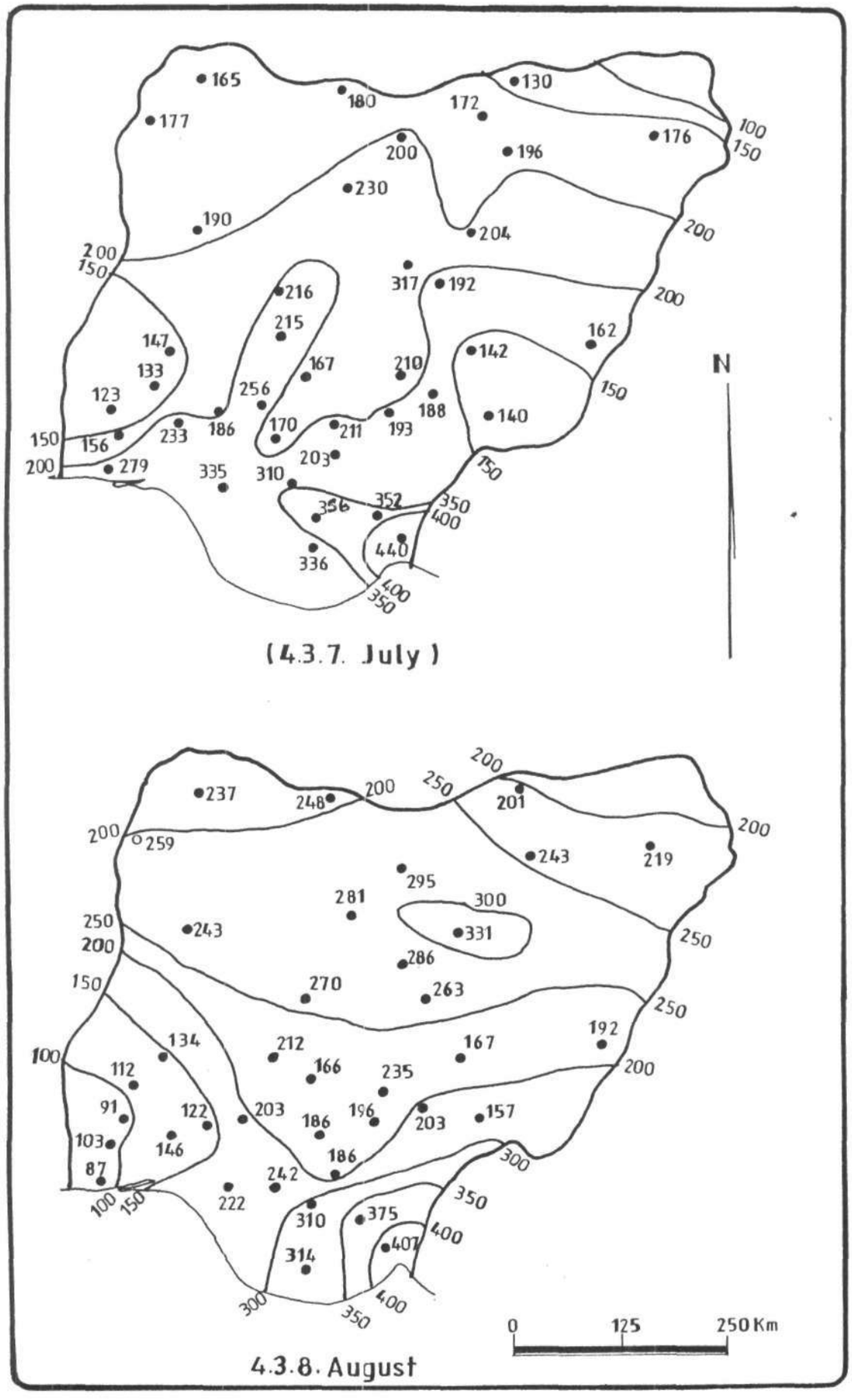



Fig. 4.3 Distribution of mean monthly rainfall
(4.3.7. July ; 4.3.8. August)

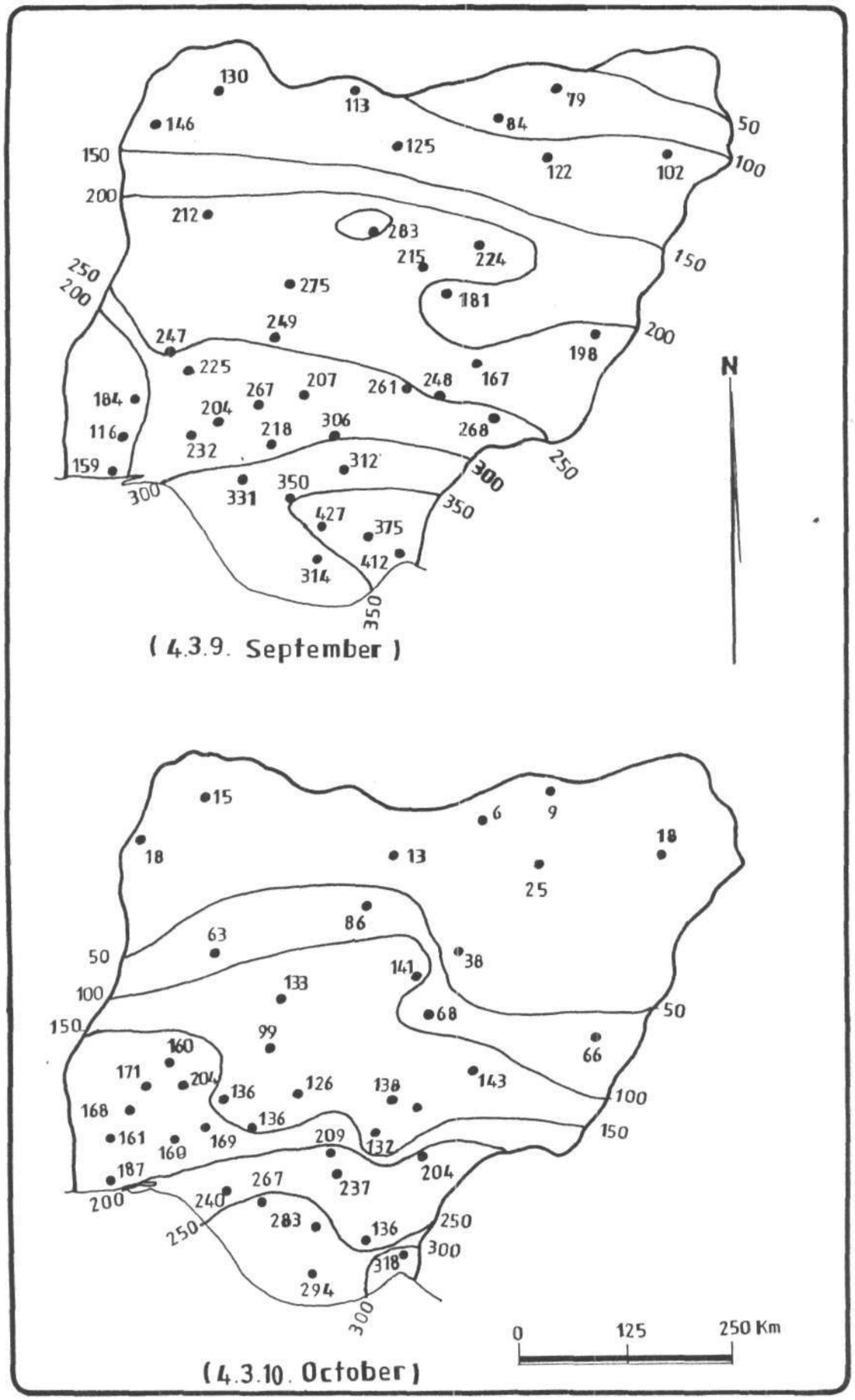



Fig. 4.3. Distribution of mean monthly rainfall
(4.3.9 September ; 4.3.10. October)

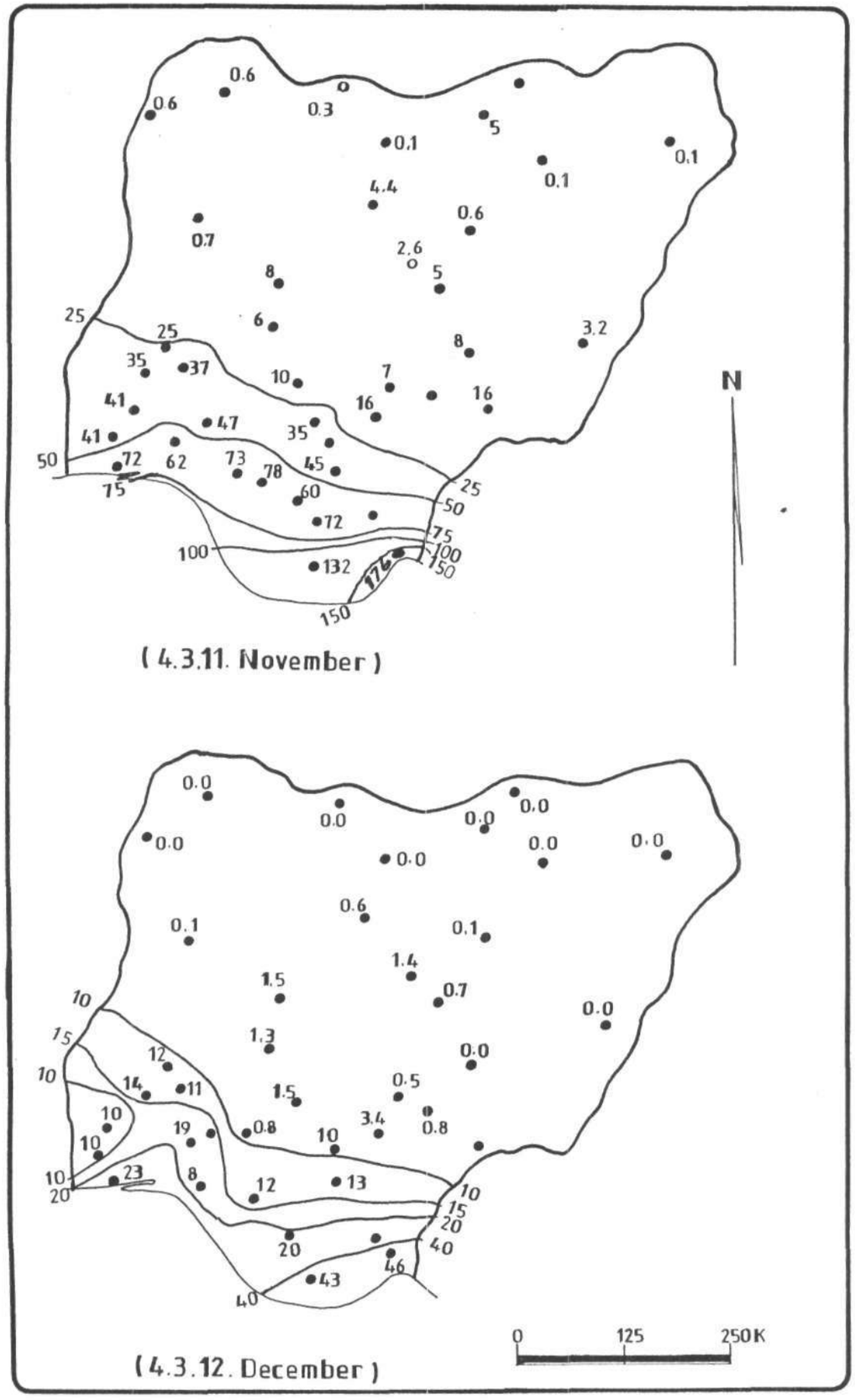



Fig. 4.3. Distribution of mean monthly rainfall
(4.3.11. November ; 4.3.12. December)

The effects of relief are noted in the distribution of rainfall. For example, Jos has highest rainfall values of 213mm in June and 317mm in July in the north, which is much higher than the stations in its surroundings. High values also occur in June and July in the south-western. The values range from 163mm in Ogbomosho through 183mm in Ibadan, 192mm in Akure to 442mm in Lagos in June, while those of July are 133mm in Ogbomosho, 156mm in Ibadan, 186mm in Akure and 279mm in Lagos. This may be due to the curvature effects of the coastline in bringing about convergence. On the other hand, the south-eastern part experiences higher rainfall amounts in July than in June. The values are 440mm in Calabar, 352mm in Uyo and 356mm in Owerri in July, while in June, the amounts are 404mm in Calabar, 304mm in Uyo and 310mm in Owerri. This may be explained in terms of increased moisture content of the mT airmass as the ITD is farthest north. The August (Figure 4.3.8) pattern of rainfall distribution is similar to that of July, with the exception of abnormally low values in the south-west. This is associated with the period of high sun when the ITD is farthest north and the mT air attains its maximum depth. The abnormally low rainfall has been regarded as the little dry season in the south-western Nigeria. It receives lesser amount of rain than other parts of the country at this period. The values range from 91mm in Oyo, 87mm in Lagos through 314mm in Port-Harcourt to 375mm in Uyo. The retreat of the rain-bearing south-westerlies is reflected in the rainfall patterns for September and October (Figures 4.3.9 and 4.3.10). Rainfall is much higher in September than October, although the orientation of the isohyets is similar to what obtains in April and May. As the ITD retreats towards the coast, the

pattern reverts to that of dry season.

Figures 4.4.1 to 4.4.12 represent the mean monthly coefficients of variation (CV) of rainfall which are generally inversely related to the mean monthly values (Udo, 1970). Low CVs are observed over high rainfall areas and high CVs over low rainfall areas. The highest CVs are found mostly in the northern part especially during the dry season (November - February). The values are above 700% in Maiduguri, Katsina, Sokoto and Kano in January to March. The lowest values are found in the south with 42% and 50% in Lagos and Calabar respectively. Similar patterns occur in April to June as could be seen in Figures 4.4.4 and 4.4.6). The CVs are generally low over the country in July (Figure 4.4.7) and August (Figure 4.4.8). The highest values are 69% (Oyo) and 71% (Ilorin) in July and 86% (Offa) and 100% (Ibadan) in August. These are mostly found in the south-west. This is consistent with the fact that rainfall is generally more areally widespread and less variable during this period.

The dissimilarities between the mean monthly rainfall values and CVs lie in the fluctuations of the ITD which alternatively brings the stations under the influences of hot, dry cT air and moist mT air. As a result of this, there is a northward decrease of rainfall variability across Nigeria, and higher variability in the southern part is due to the greater relative frequency of thundershowers there. Secondly, it is due to the fact that Nigeria receives over 70% - 80% of the mean annual rainfall during the rainy season. Thirdly, rainfall in July to August is generally widespread and less variable.

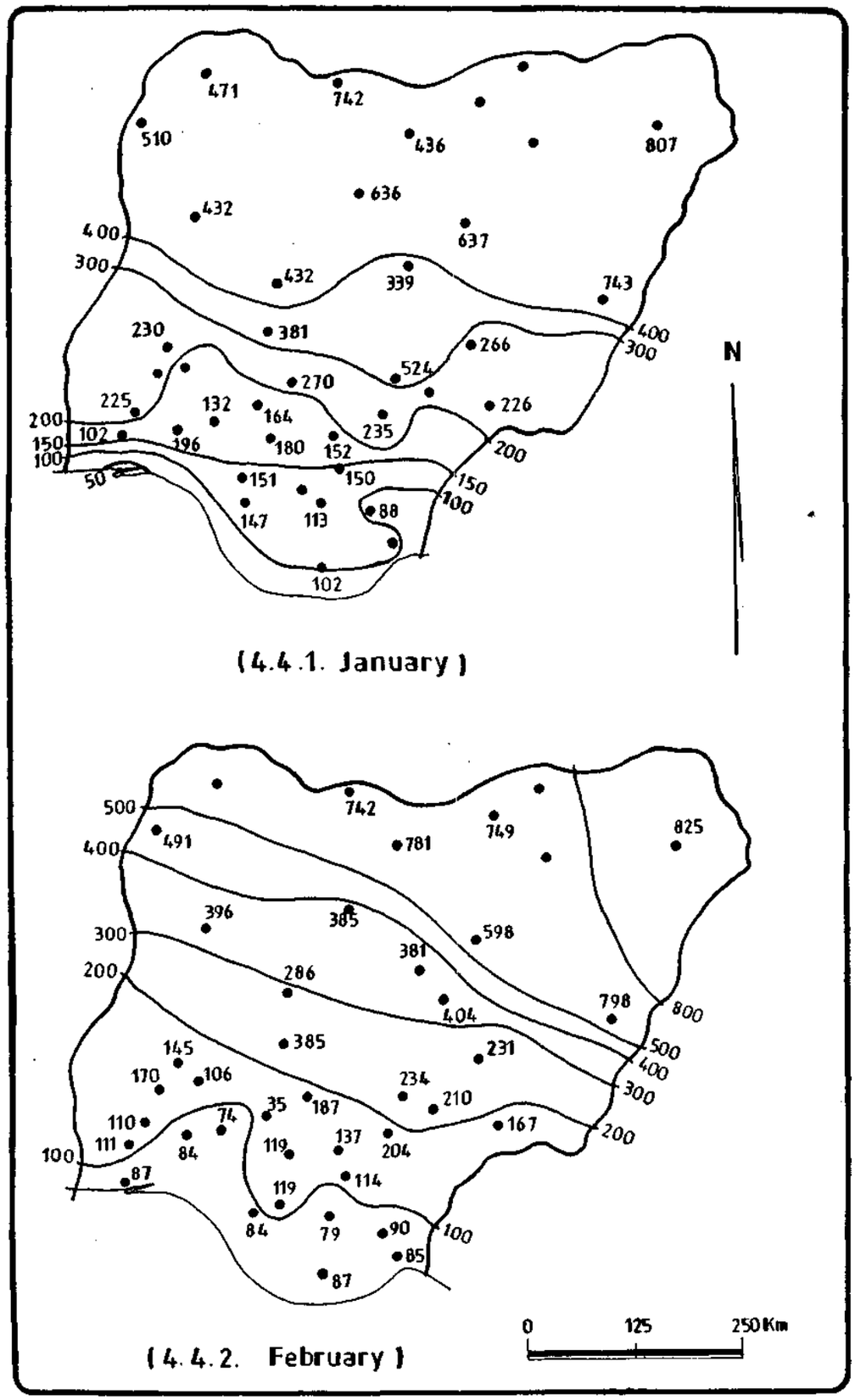



Fig. 4.4. Distribution of coefficient of variation of mean monthly rainfall
(4.4.1. January ; 4.4.2. February).

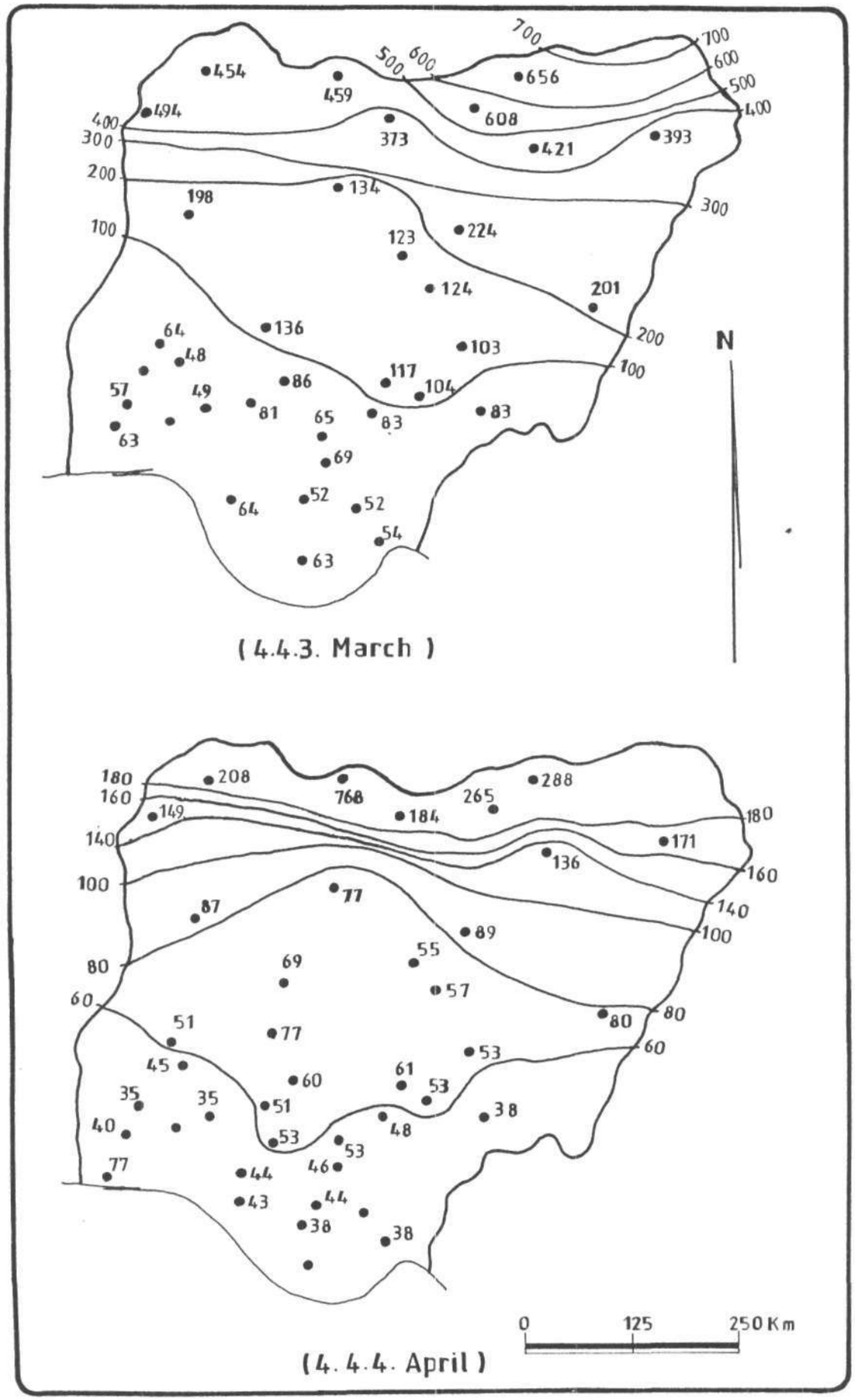
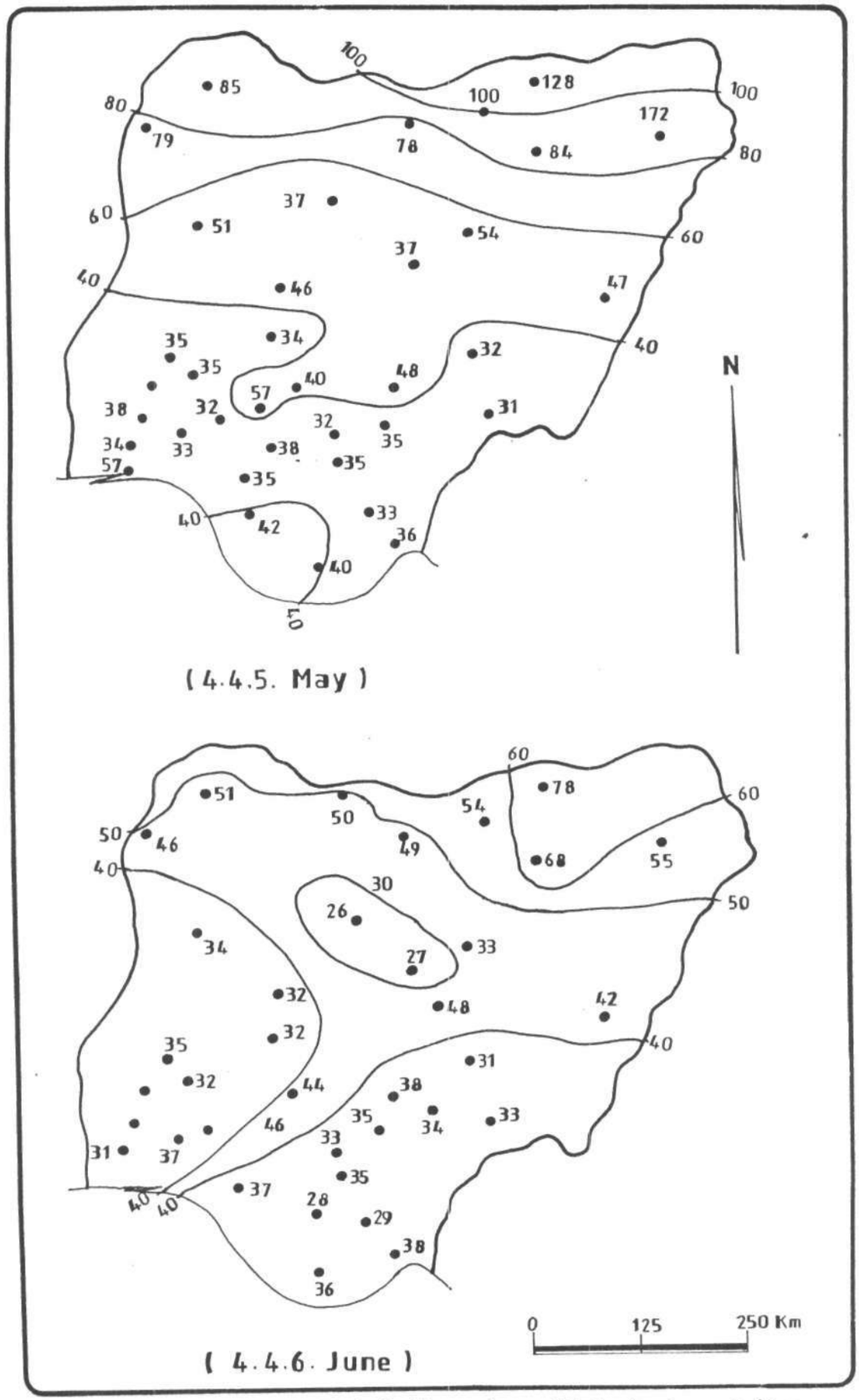



Fig. 4.4.continued: Distribution of coefficient of variation of mean monthly rainfall (4.4.3. March.; 4.4.4. April).




( 4.4.5. May )

( 4.4.6. June )

Fig. 4.4.continued: Distribution of coefficient of variation of mean monthly rainfall ( 4.4.5. May ; 4.4.6. June ) .

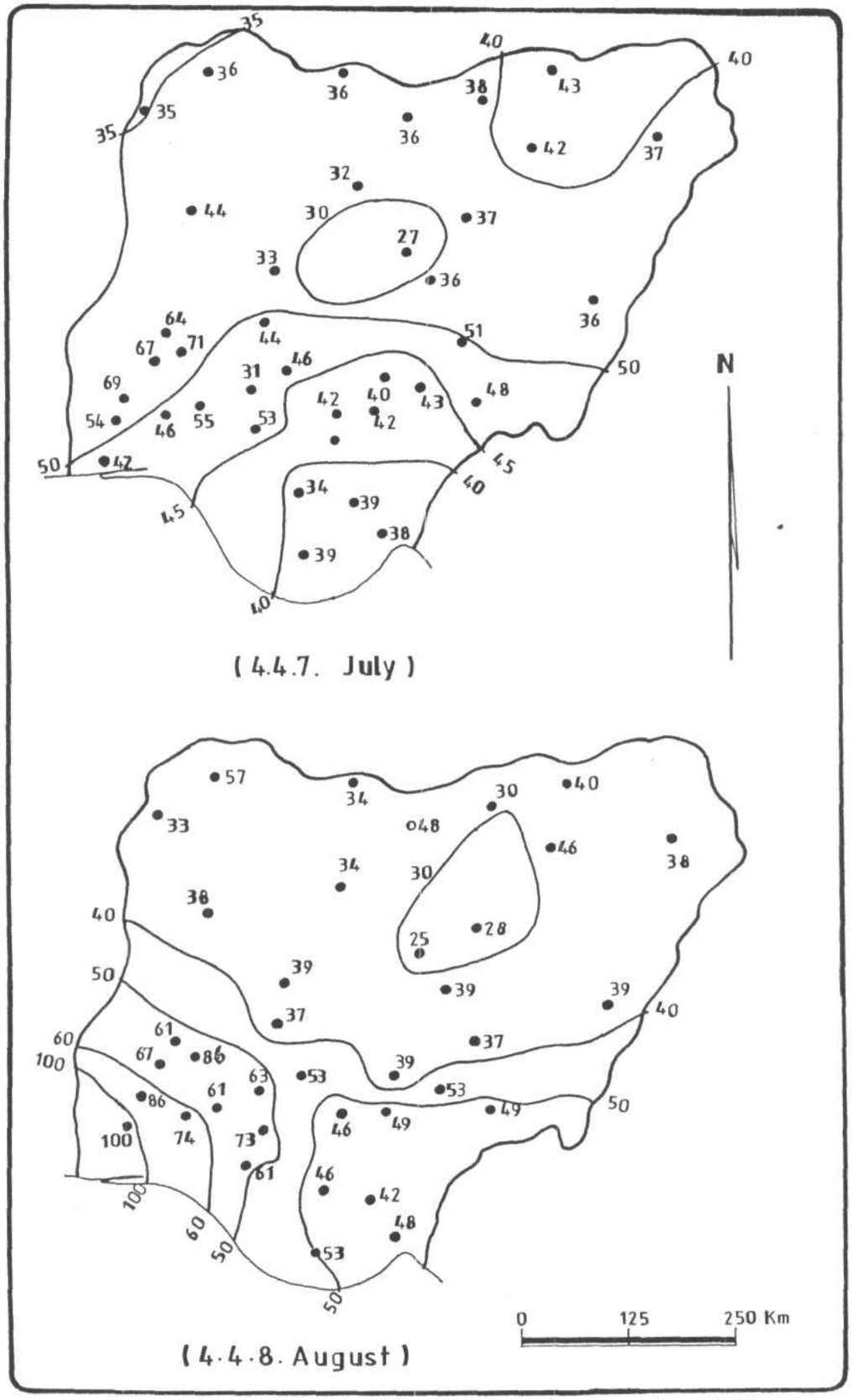



Fig. 4.4 continued: Distribution of coefficient of variation of mean monthly rainfall
( 4.4.7. July ; 4.4.8. August ) .

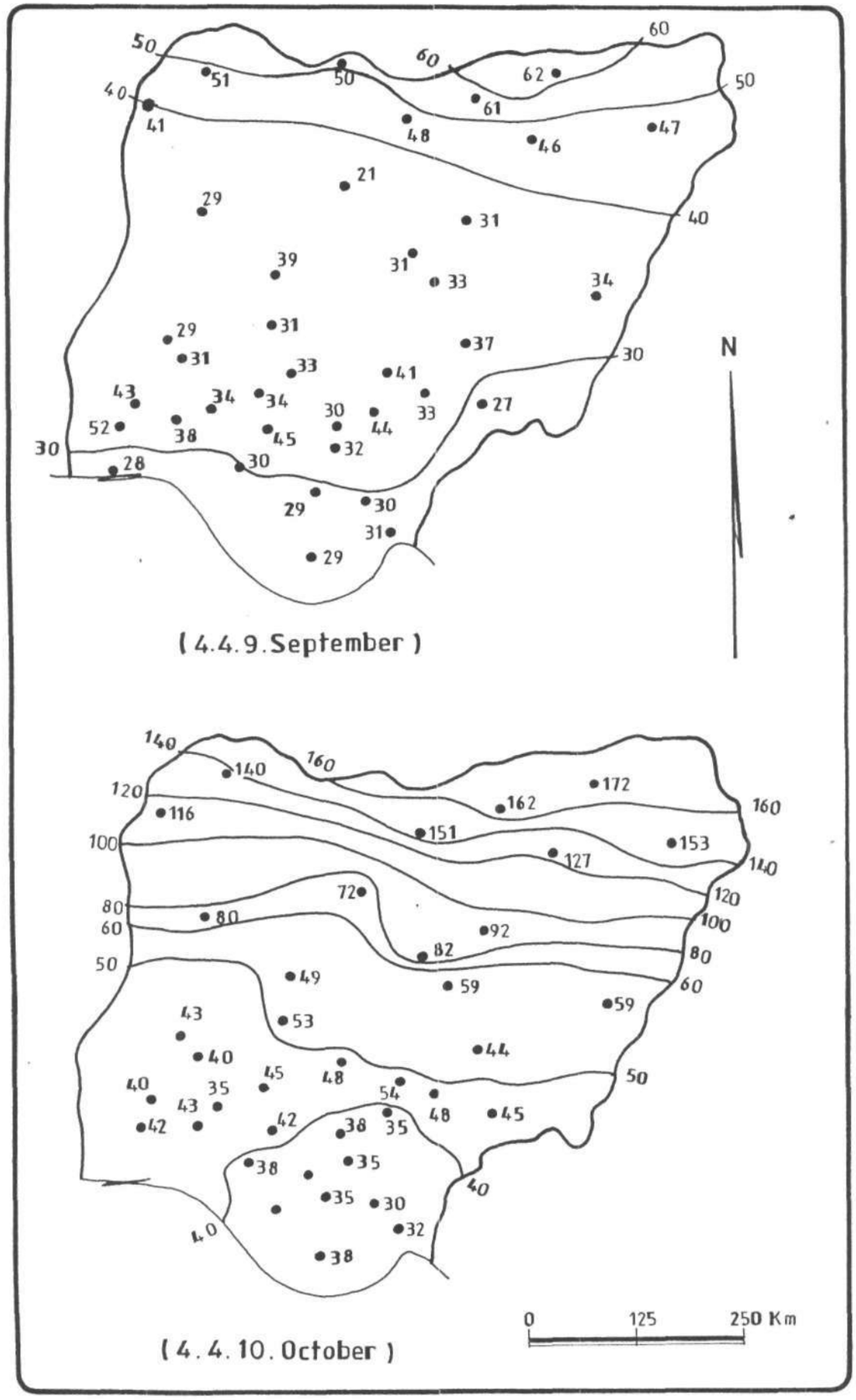



Fig. 4.4. continued : Distribution of coefficient of variation of mean monthly rainfall
( 4.4.9. September ; 4.4.10. October ) .

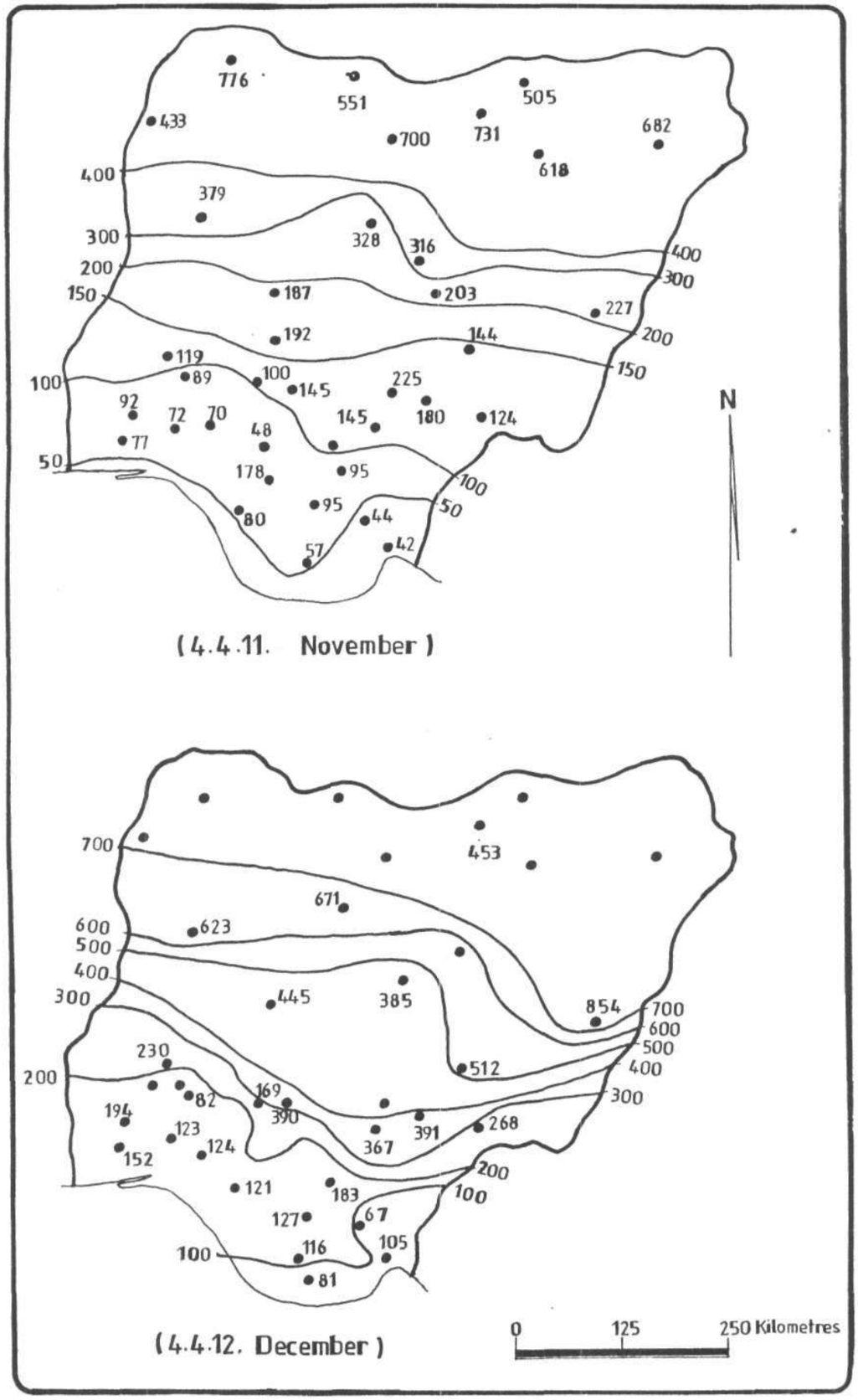



Fig. 4. 4. continued: Distribution of coefficient of variation of mean monthly rainfall
(4.4.11. November; 4.4.12. December).

## 4.4 FLUCTUATIONS IN RAINFALL

The graph of the original rainfall series was smoothed using a five-year moving average over varied number of years (1901 - 1984) for some selected stations to illustrate the changing patterns in the annual rainfall. By using the moving average method, cyclical, seasonal and irregular patterns were eliminated, thus leaving only the trend movements. The representative stations were Calabar, Enugu, Ibadan, Lagos, Port-Harcourt from the south, and Jos, Kano, Kaduna South, Maiduguri and Sokoto from the north. Figures 4.5.1 to 4.5.10 show the graph of the original data and the five-year moving average indicating a broad pattern of the long-term trends from which periodic fluctuations can be deduced.

The southern stations (Lagos, Ibadan, Calabar and Port-Harcourt) experienced below-average rainfall between 1910 and 1920, while Kano and Sokoto had an upward trend of wetter years from 1915-1928, and Kaduna South and Maiduguri from 1923-1928. The wetter years in the north may be as a result of pronounced dry period in the high-sun season (August break) in the south. During this period, a pronounced rainfall minimum occurs in the south. There followed a countrywide period of downward trend from about the mid-1930s to mid-1950s, especially in the north, leading to numerous local famines. The period between 1951 and 1960 showed a pattern of alternating wet and dry years with a general upward trend towards increasing rainfall in the south. This may be attributed to the strenghtening of the moisture bearing south-westerlies during the rainy season. The decade 1961 to 1970 had some years of very heavy rainfall, particularly in the south (Figures 4.5.1 - 4.5.5). In the north, a drier episode

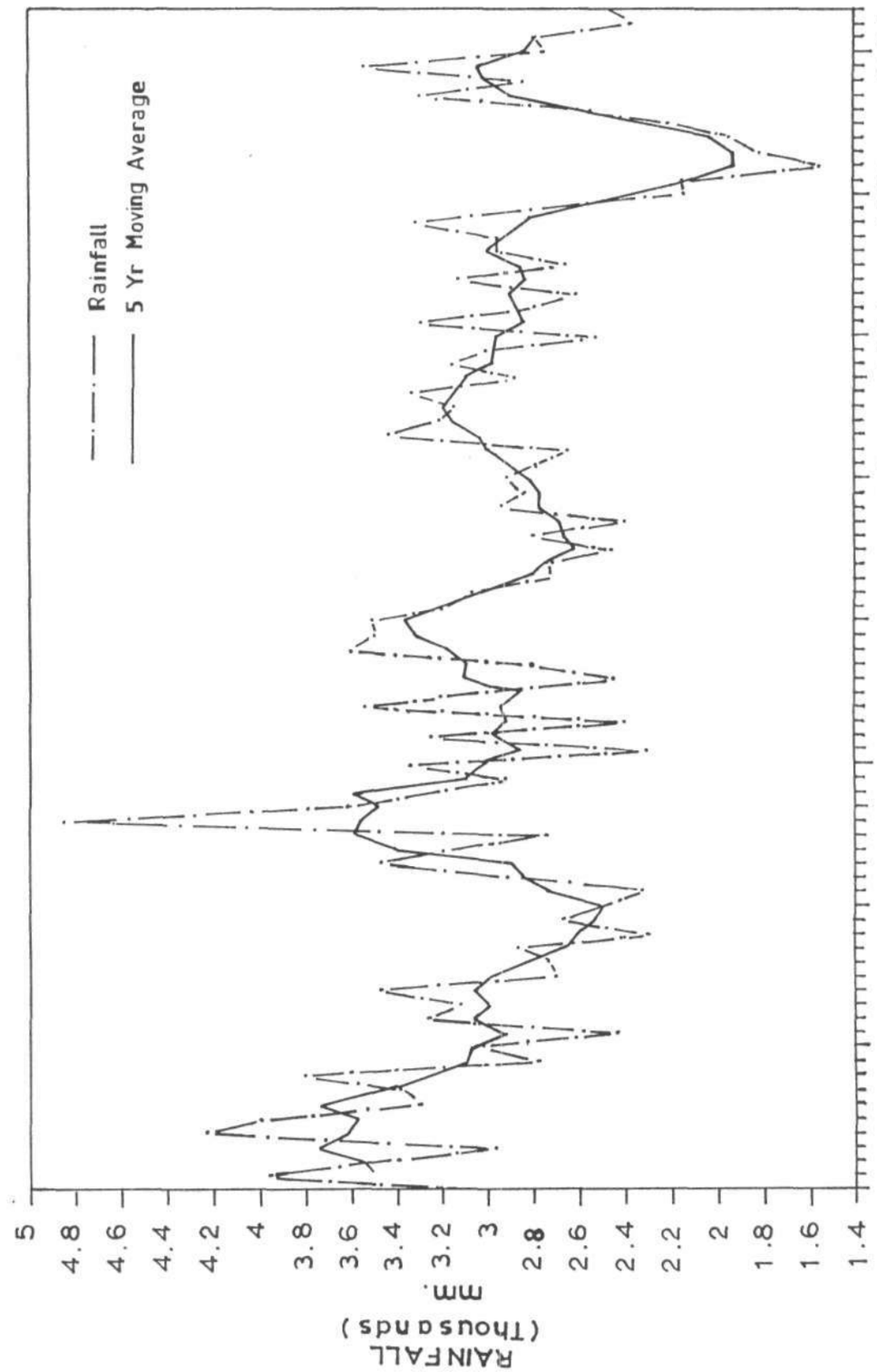



FIG. 4.5. TREND OF RAINFALL AND FIVE YEAR MOVING AVERAGES

4.5.1. TREND OF CALABAR RAINFALL

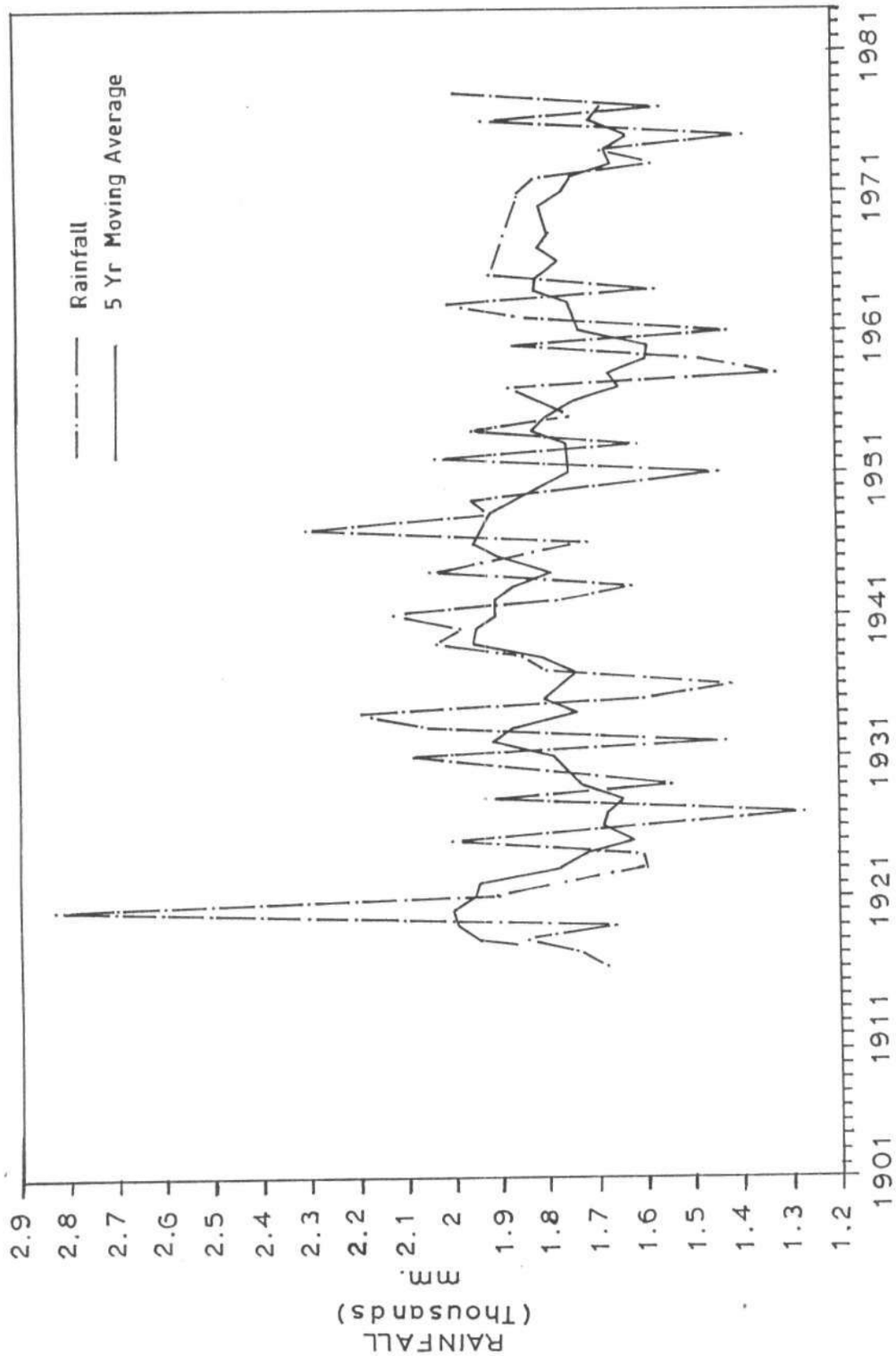



FIG. 4.5. TREND OF RAINFALL AND FIVE YEAR MOVING AVERAGES

4.5.2. TREND OF ENUGU RAINFALL

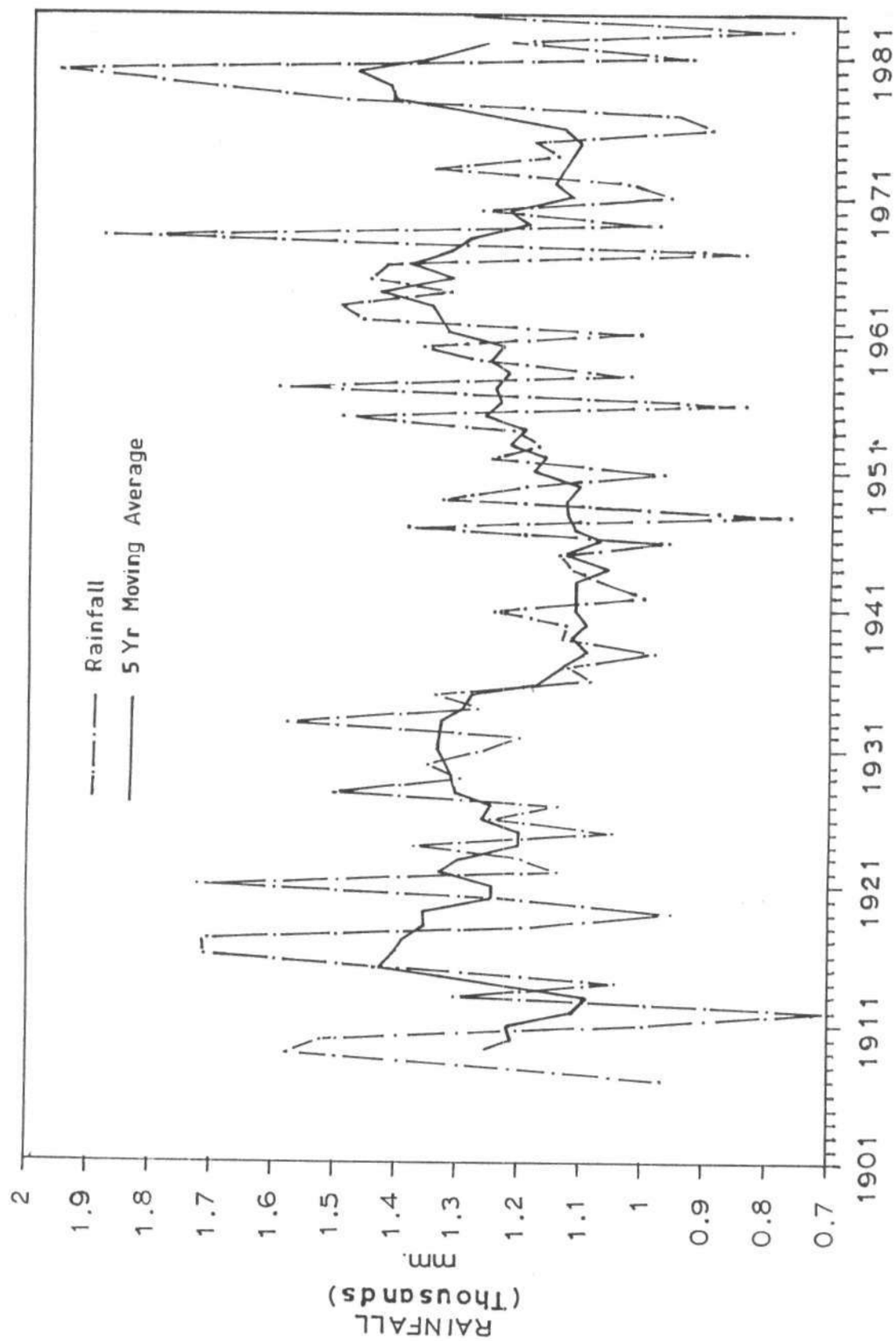



FIG. 4.5. TREND OF RAINFALL AND FIVE YEAR MOVING AVERAGES

4.5.3. TREND OF IBADAN RAINFALL

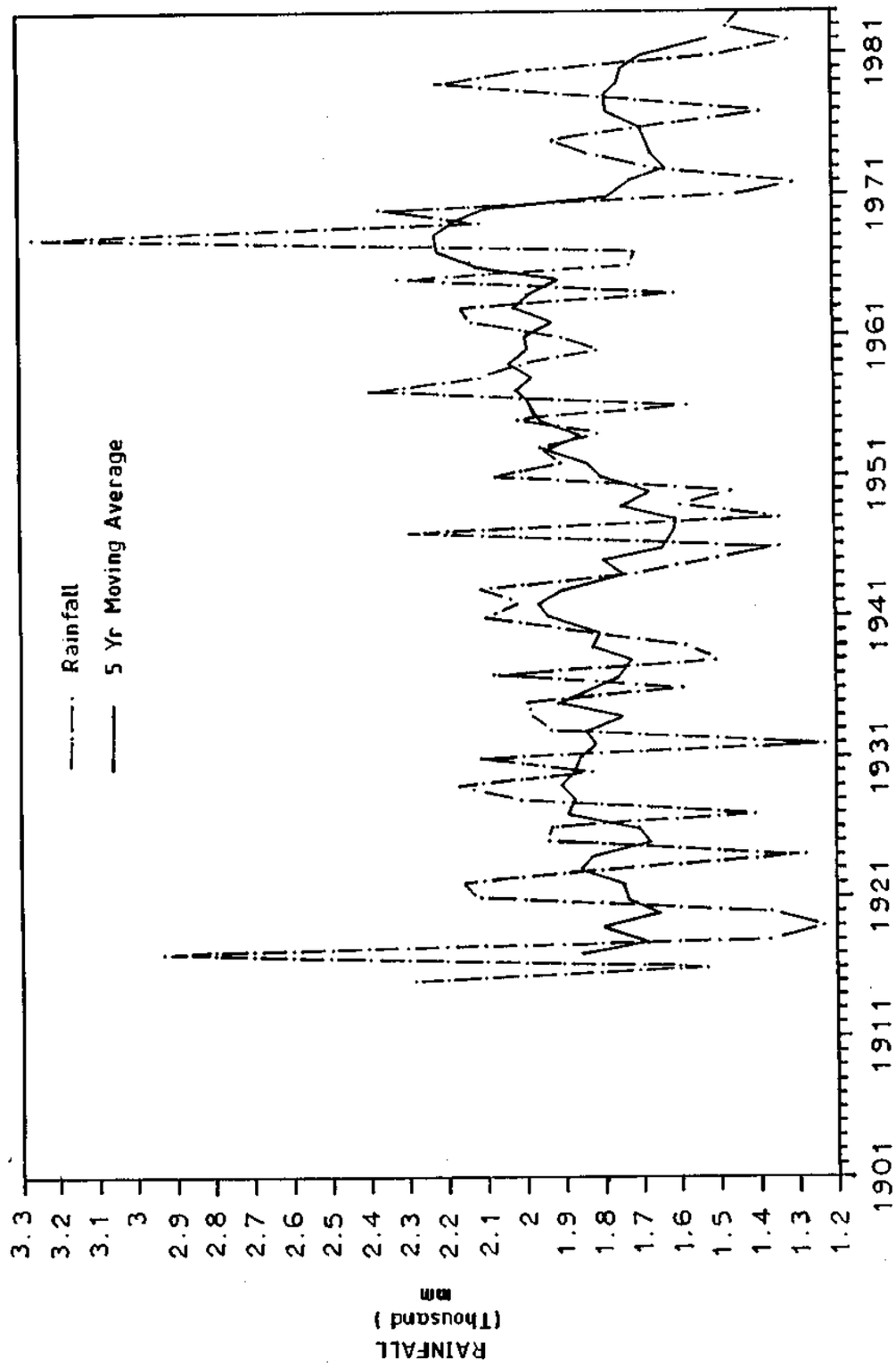



**FIG. 4.5. TREND OF RAINFALL AND FIVE YEAR MOVING AVERAGES**

**4.5.4. TREND OF LAGOS RAINFALL**

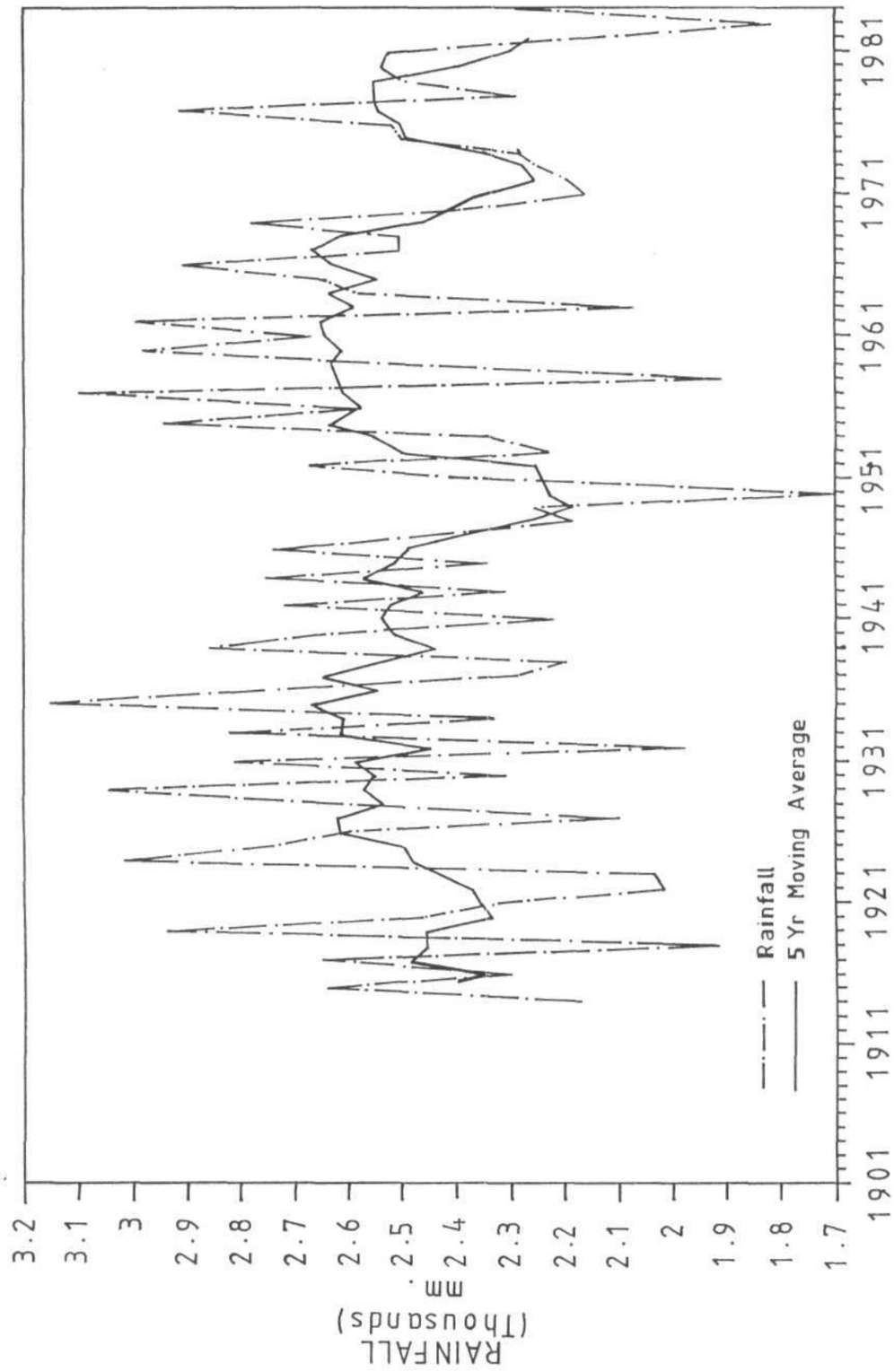



FIG. 4.5. TREND OF RAINFALL AND FIVE YEAR MOVING AVERAGES

4.5.5. TREND OF PORTHARCOURT RAINFALL

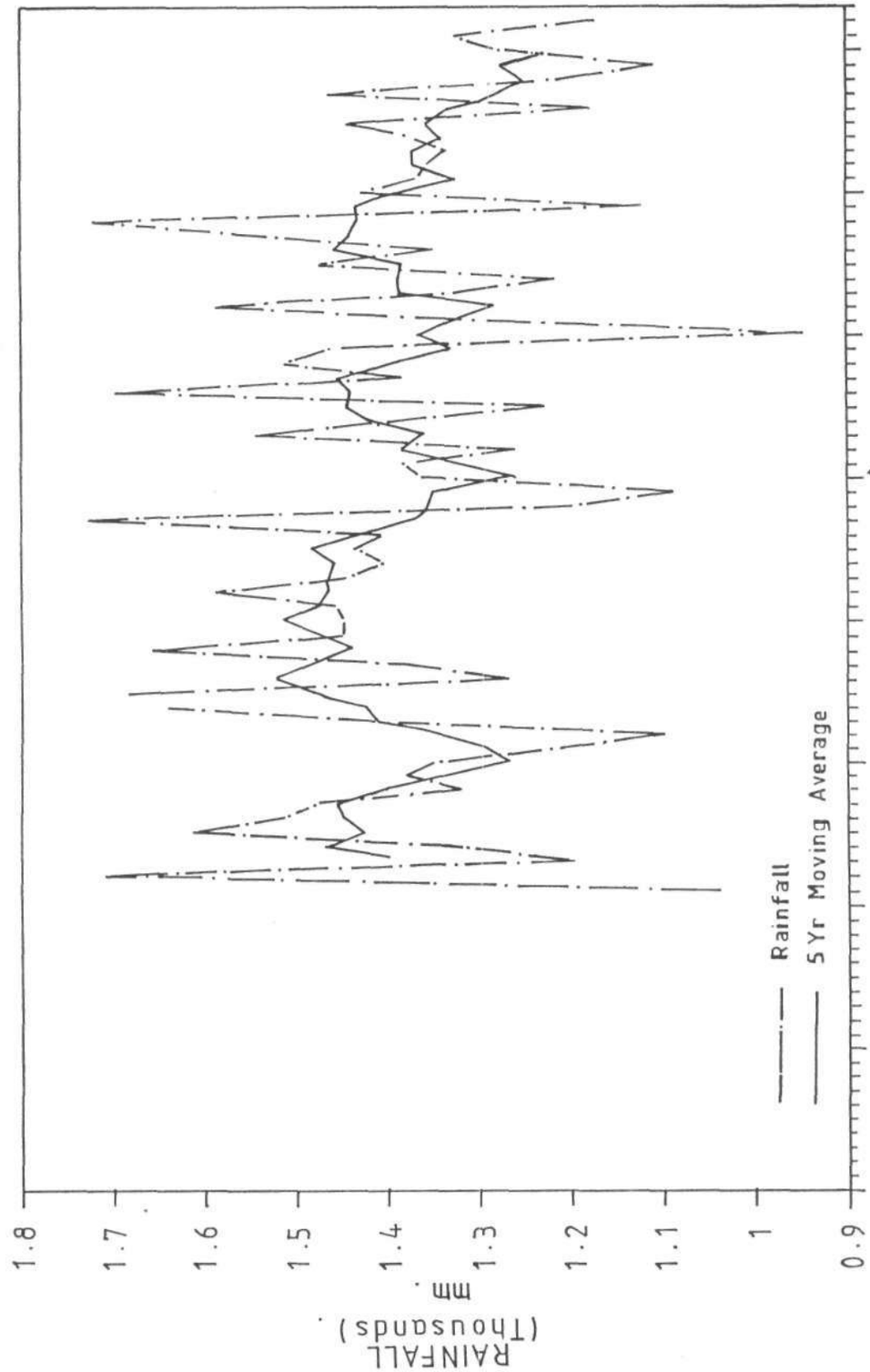



FIG. 4.5. TREND OF RAINFALL AND FIVE YEAR MOVING AVERGES

4.5.6. TREND OF JOS RAINFALL

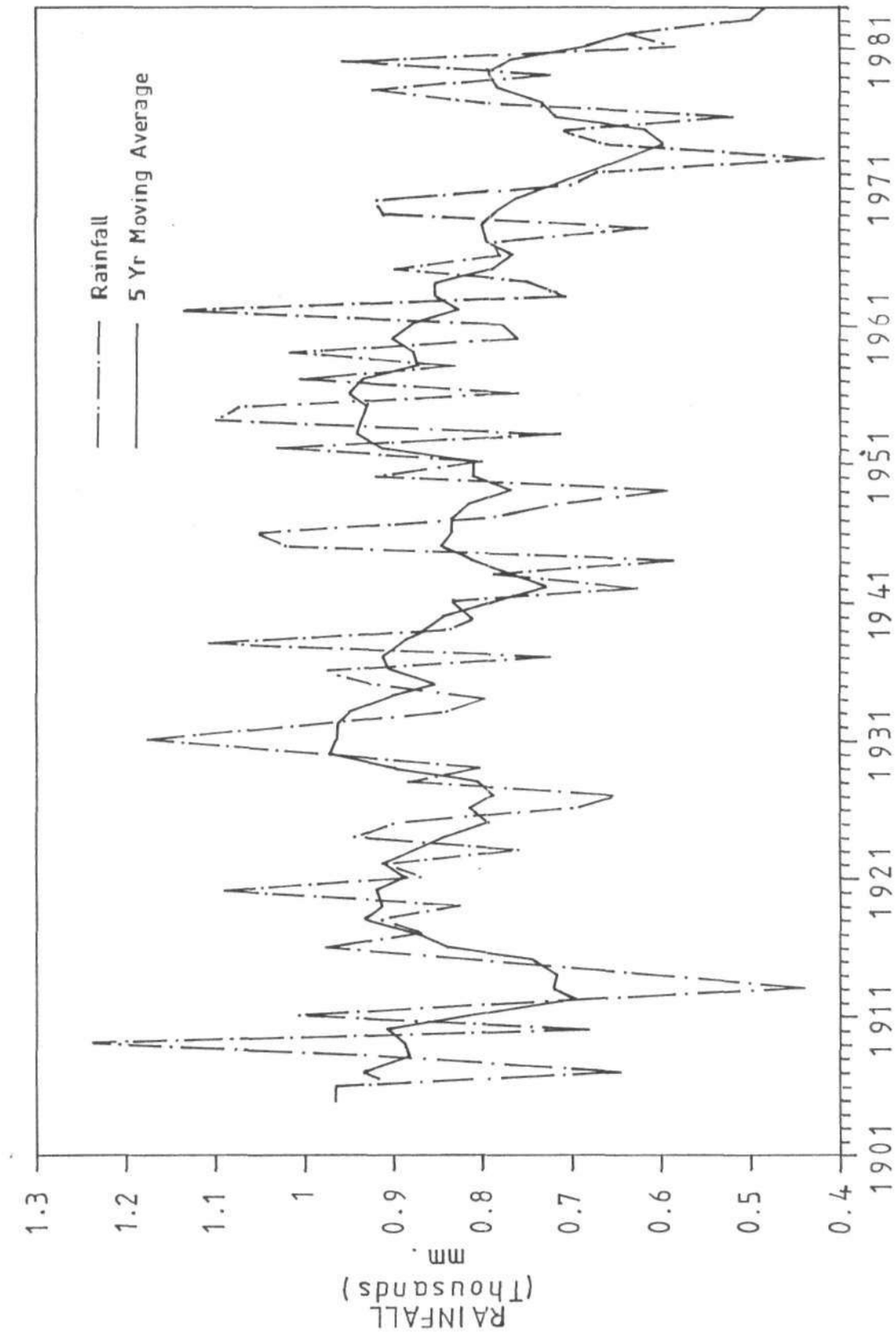



FIG 4.5. TREND OF RAINFALL AND FIVE YEAR MOVING AVERAGES

4.5.7. TREND OF KANO RAINFALL

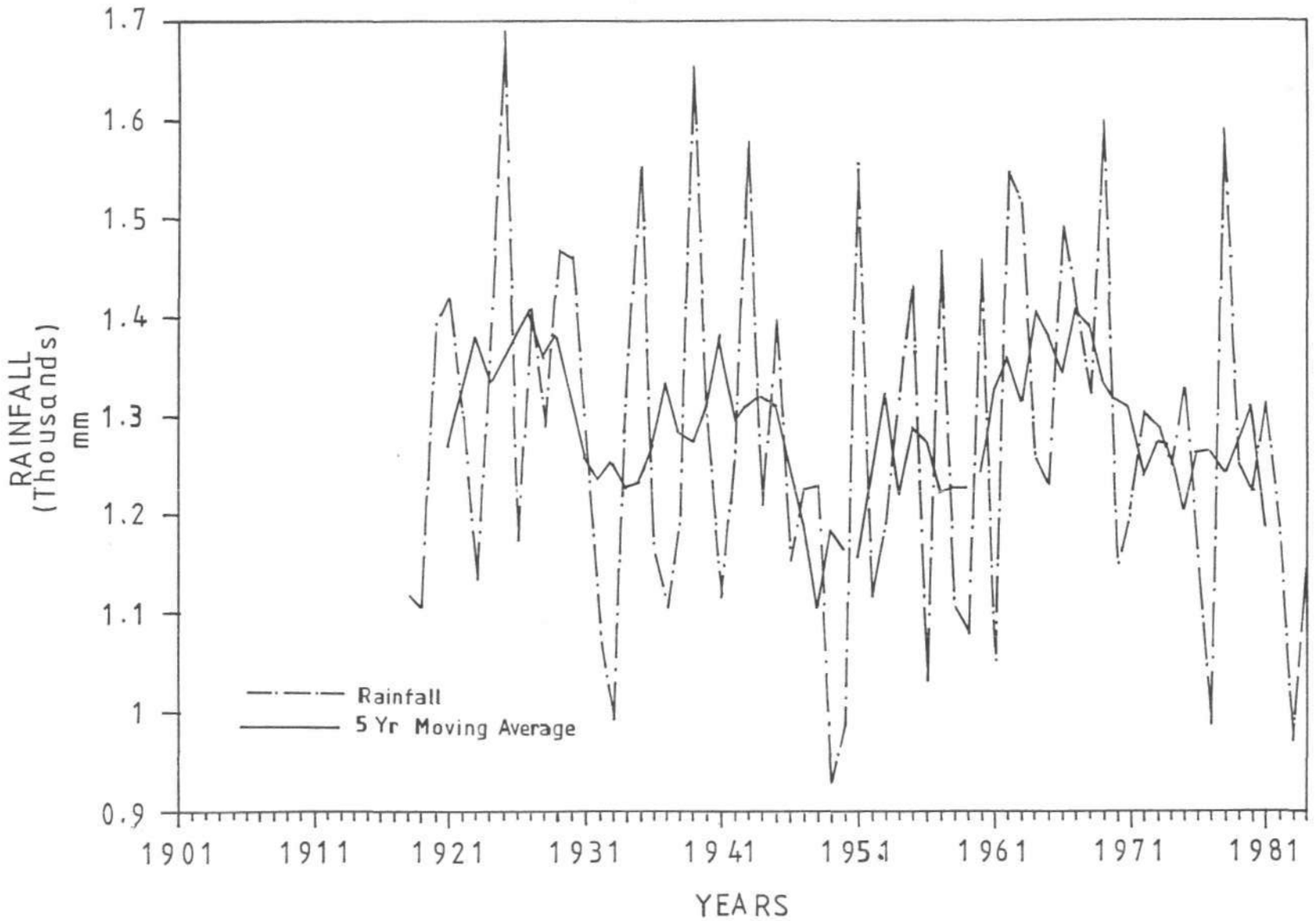



FIG. 4.5. TREND OF RAINFALL AND FIVE YEAR MOVING AVERAGES

4.5.8. TREND OF KADUNA SOUTH RAINFALL

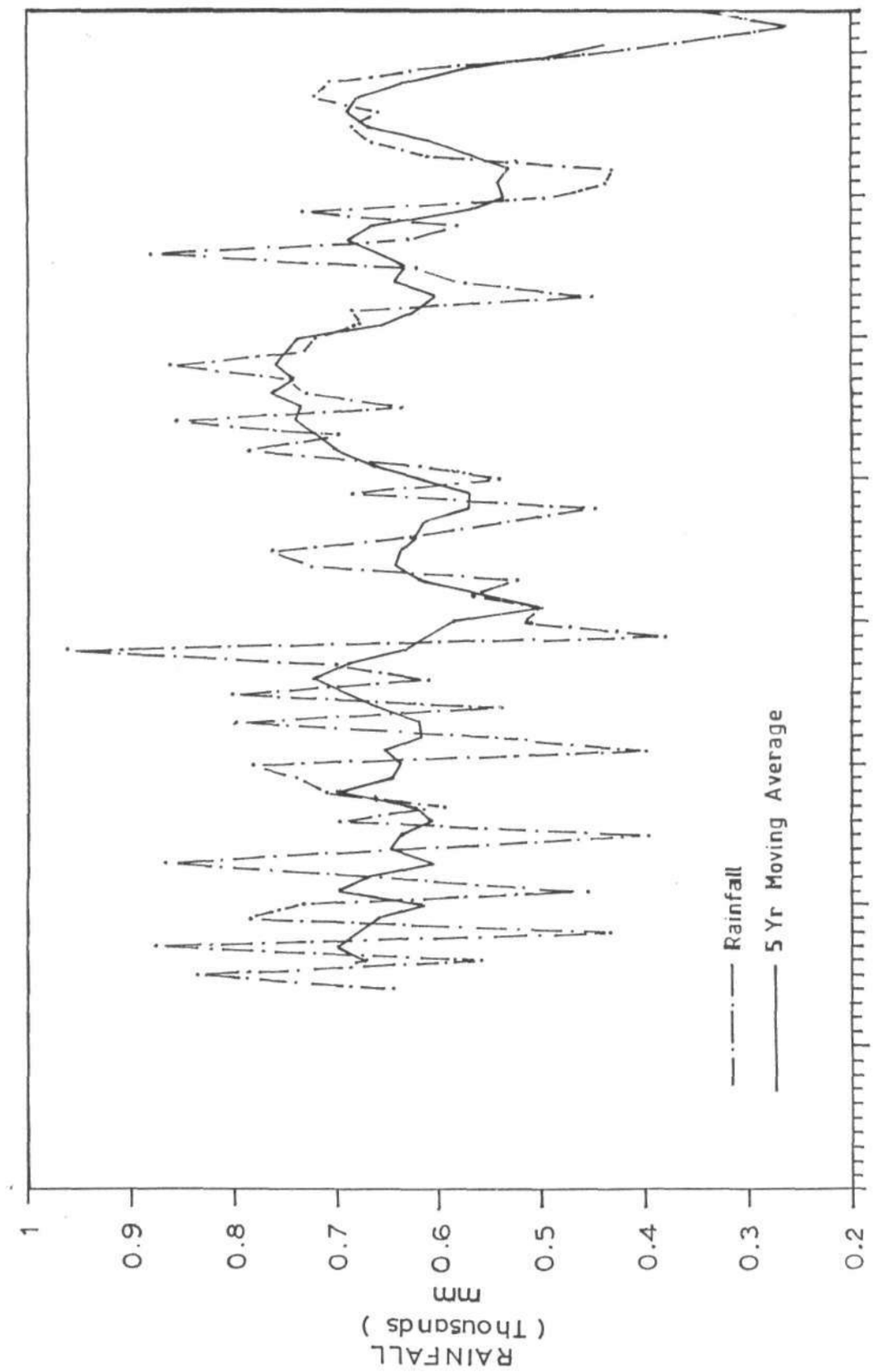



FIG. 4.5. TREND OF RAINFALL AND FIVE YEAR MOVING AVERAGES

4.5.9. TREND OF MAIDUGURI RAINFALL

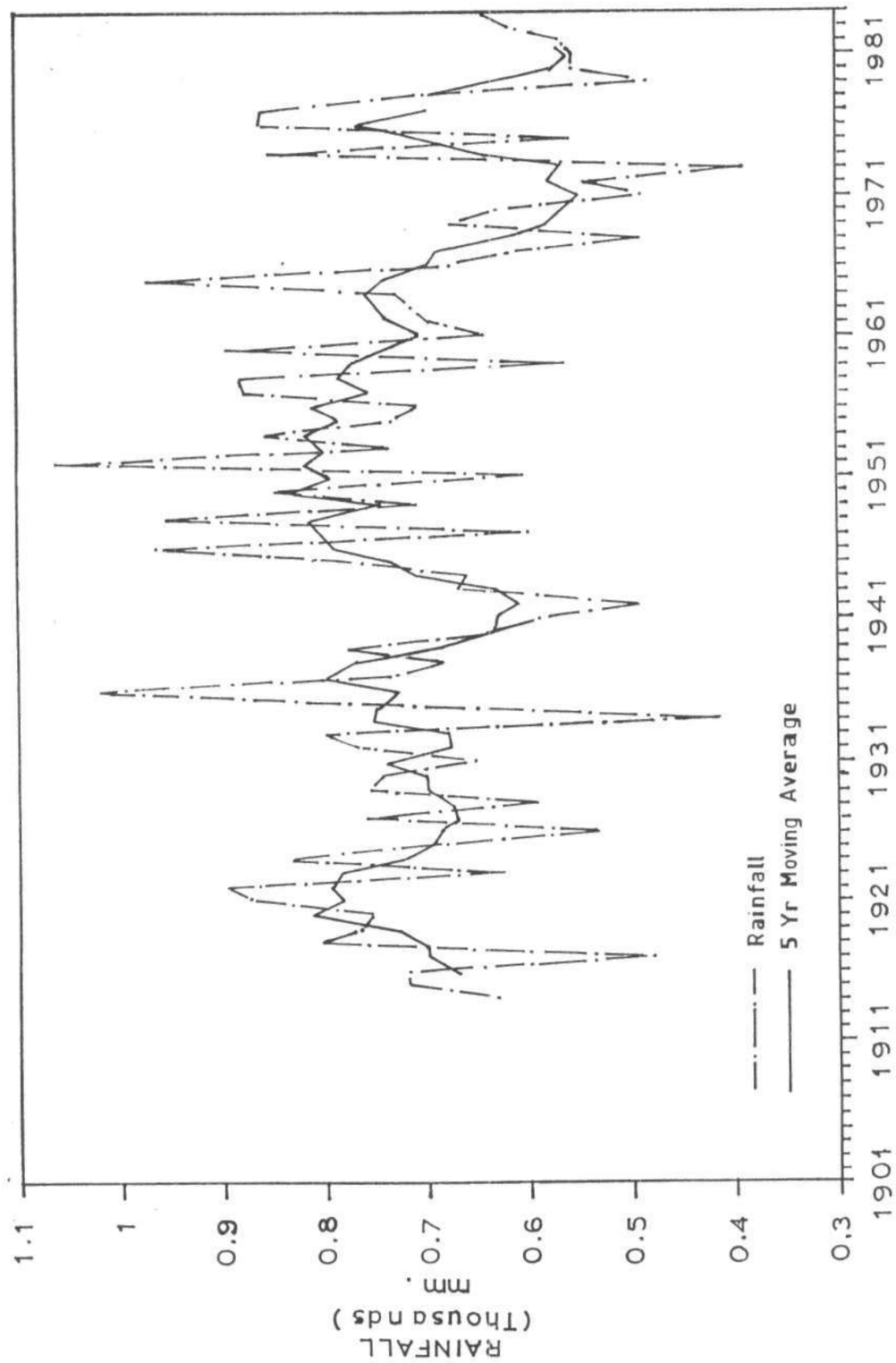



FIG. 4.5. TREND OF RAINFALL AND FIVE YEAR MOVING AVERAGES

4.5.10. TREND OF SOKOTO RAINFALL

set in, in the mid-1960s, then progressed and turned to severe drought, which spread to other parts of the country between 1969 and 1973. On the whole, the south experienced above average rainfall in the period 1951 to 1970 and the peak in the decade 1960 to 1969.

The period 1969 to 1973 was marked by severe drought conditions. These conditions might be due to the southward shift of the subtropical high pressure belt and the Easterly Tropical Jet causing an increased subsidence and low-level convergence over West Africa and a decrease of moisture flux and upper level easterly flow into Nigeria (Ojo,1977).

Generally, over the years, there has been alternating downward and upward trends, indicating no significant trend in the annual rainfall.

# CHAPTER 5

## RESULTS AND DISCUSSION OF PRINCIPAL COMPONENT ANALYSIS

The annual rainfall values at forty stations for forty three years (1941 - 1983) were subjected to an S-mode principal component analysis. According to (Richman and Lamb, 1985) an S-mode PCA seeks associations among stations over a set of time periods for a fixed parameter. The inter-station correlation matrix, an input into the next stage of the PCA procedure was first generated. This symmetric matrix is detailed in Table 5.1.

From the Table, it is evident that the correlation coefficients between stations are generally low, the highest being 0.76 for Akure against Ondo. Stations nearer to each other displayed higher coefficients than those which are farther apart. For example, Ondo has significant correlations with Akure (0.76), Ibadan (0.71), Lagos (0.63) and so on. Similarly, Jos correlates with Kaduna South (0.58), Lafia (0.46), Bauchi (0.41) and so on, while Kano relates with Katsina (0.59), Hadejia (0.36) and Potiskum (0.33). On the other hand, Maiduguri in the northeast has low correlation with Oyo (-0.07), Owerri (0.13), Lafia (0.16), and so on. This is in agreement with Pandzic (1986) in his factor analysis of temperature field in a relatively small area. The results indicate that stations which are under the influence of common physical factors appear to have significant correlations with each other and they follow regional patterns. This presupposes that the results of the principal component analysis will probably follow the same pattern since it is based on inter-station correlation.

| STATION | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SEMIN | 1 | 1.00 | | | | | | | | | | | | | | | | | | | |
| CALABAR | 2 | 0.33 | 1.00 | | | | | | | | | | | | | | | | | | |
| ONDO | 3 | 0.57 | 0.39 | 1.00 | | | | | | | | | | | | | | | | | |
| JOS | 4 | 0.04 | 0.14 | 0.33 | 1.00 | | | | | | | | | | | | | | | | |
| MAIDUGURI | 5 | 0.13 | 0.26 | 0.14 | 0.07 | 1.00 | | | | | | | | | | | | | | | |
| ILORIN | 6 | 0.04 | 0.39 | -0.04 | 0.23 | 0.16 | 1.00 | | | | | | | | | | | | | | |
| YANDEV | 7 | 0.35 | 0.22 | 0.30 | 0.13 | -0.05 | -0.08 | 1.00 | | | | | | | | | | | | | |
| OWERRI | 8 | 0.54 | 0.34 | 0.48 | 0.19 | 0.13 | 0.23 | 0.33 | 1.00 | | | | | | | | | | | | |
| BIDA | 9 | 0.19 | 0.14 | 0.39 | 0.36 | 0.30 | 0.12 | 0.42 | 0.13 | 1.00 | | | | | | | | | | | |
| KAD SOUTH | 10 | 0.21 | 0.23 | 0.38 | 0.58 | 0.17 | 0.09 | 0.50 | 0.36 | 0.58 | 1.00 | | | | | | | | | | |
| MAKURDI | 11 | 0.35 | 0.26 | 0.50 | 0.19 | 0.13 | 0.16 | 0.40 | 0.31 | 0.34 | 0.20 | 1.00 | | | | | | | | | |
| PH | 12 | 0.29 | 0.06 | 0.01 | 0.17 | 0.27 | 0.09 | 0.30 | 0.33 | 0.13 | 0.17 | 0.20 | 1.00 | | | | | | | | |
| ILORIN | 13 | 0.33 | 0.26 | 0.49 | 0.26 | 0.00 | 0.21 | 0.25 | 0.23 | 0.31 | 0.32 | 0.45 | 0.02 | 1.00 | | | | | | | |
| KATSINA | 14 | 0.05 | 0.32 | 0.05 | 0.01 | 0.51 | 0.35 | 0.03 | 0.13 | 0.12 | 0.04 | 0.09 | 0.03 | -0.21 | 1.00 | | | | | | |
| YOLA | 15 | 0.23 | 0.30 | 0.45 | 0.47 | 0.07 | 0.07 | 0.17 | 0.16 | 0.21 | 0.40 | 0.21 | 0.11 | 0.13 | 0.10 | 1.00 | | | | | |
| YELWA | 16 | 0.23 | 0.30 | 0.29 | 0.07 | 0.32 | 0.14 | 0.42 | 0.38 | 0.30 | 0.28 | 0.33 | 0.12 | 0.36 | 0.23 | 0.04 | 1.00 | | | | |
| LOKOJA | 17 | 0.27 | -0.02 | 0.16 | 0.19 | 0.23 | 0.21 | 0.09 | 0.24 | 0.39 | 0.25 | 0.30 | -0.05 | 0.04 | 0.14 | 0.10 | 0.09 | 1.00 | | | |
| AKURE | 18 | 0.46 | 0.27 | 0.76 | 0.32 | -0.05 | -0.03 | 0.32 | 0.49 | 0.27 | 0.35 | 0.32 | 0.00 | 0.51 | -0.16 | 0.24 | 0.08 | 0.03 | 1.00 | | |
| OTURKPO | 19 | 0.27 | 0.19 | 0.16 | 0.18 | -0.13 | 0.02 | 0.36 | 0.11 | 0.20 | 0.36 | 0.12 | -0.19 | 0.13 | 0.33 | 0.14 | 0.08 | 0.27 | 0.11 | 1.00 | |
| ENUGU | 20 | 0.20 | 0.29 | 0.30 | 0.26 | -0.15 | 0.06 | 0.22 | 0.20 | 0.01 | 0.07 | 0.45 | 0.12 | 0.26 | -0.16 | 0.10 | -0.19 | 0.09 | 0.32 | 0.11 | 1.00 |
| NSUKKA | 21 | 0.48 | 0.29 | 0.43 | 0.24 | 0.08 | 0.14 | 0.28 | 0.59 | 0.24 | 0.23 | 0.40 | 0.03 | 0.46 | -0.02 | 0.19 | 0.29 | 0.40 | 0.40 | 0.23 | 0.42 |
| SOKOTO | 22 | 0.05 | 0.09 | -0.13 | 0.14 | 0.32 | 0.53 | -0.02 | 0.05 | 0.04 | -0.10 | 0.11 | 0.22 | -0.10 | 0.45 | 0.07 | -0.04 | 0.26 | -0.16 | 0.06 | 0.13 |
| MINNA | 23 | 0.23 | 0.37 | 0.36 | 0.22 | 0.21 | 0.14 | 0.52 | 0.39 | 0.30 | 0.37 | 0.35 | 0.21 | 0.10 | 0.17 | 0.16 | 0.19 | 0.15 | 0.36 | 0.21 | 0.23 |
| KANO | 24 | 0.13 | 0.59 | 0.20 | 0.11 | 0.59 | 0.43 | 0.11 | 0.26 | 0.19 | 0.23 | 0.23 | 0.06 | 0.02 | 0.59 | 0.14 | 0.28 | 0.13 | 0.08 | 0.16 | 0.05 |
| POTISKUM | 25 | -0.24 | 0.12 | -0.15 | -0.03 | 0.28 | 0.22 | -0.02 | -0.02 | -0.04 | -0.01 | -0.02 | 0.02 | -0.07 | 0.55 | 0.06 | 0.22 | -0.04 | -0.37 | 0.20 | -0.13 |
| IBI | 26 | 0.18 | 0.27 | 0.36 | 0.42 | 0.25 | 0.10 | 0.30 | 0.26 | 0.38 | 0.39 | 0.49 | 0.18 | 0.19 | 0.17 | 0.23 | 0.25 | 0.17 | 0.30 | 0.21 | 0.28 |
| NGURU | 27 | -0.11 | 0.20 | 0.06 | -0.02 | 0.37 | 0.16 | 0.01 | 0.00 | -0.01 | 0.07 | -0.02 | -0.01 | -0.09 | 0.46 | 0.07 | 0.13 | 0.04 | -0.01 | 0.11 | -0.10 |
| BAUCHI | 28 | 0.07 | 0.16 | 0.03 | 0.41 | 0.11 | 0.23 | 0.27 | -0.02 | 0.25 | 0.24 | 0.04 | 0.14 | -0.00 | 0.25 | 0.12 | -0.01 | 0.15 | 0.03 | 0.39 | 0.07 |
| KABBA | 29 | 0.35 | 0.38 | 0.47 | 0.29 | 0.11 | 0.13 | 0.34 | 0.51 | 0.33 | 0.45 | 0.33 | 0.14 | 0.21 | 0.15 | 0.09 | 0.10 | 0.23 | 0.40 | 0.30 | 0.32 |
| OGBOMOSHO | 30 | 0.52 | 0.30 | 0.62 | 0.34 | 0.37 | 0.13 | 0.22 | 0.43 | 0.47 | 0.35 | 0.48 | 0.22 | 0.66 | 0.10 | 0.23 | 0.46 | 0.15 | 0.58 | 0.04 | 0.18 |
| LAFIA | 31 | 0.03 | 0.20 | 0.28 | 0.46 | 0.16 | 0.19 | 0.21 | 0.29 | 0.40 | 0.46 | 0.30 | 0.24 | 0.13 | 0.12 | 0.31 | 0.24 | 0.21 | 0.30 | -0.01 | -0.01 |
| IBADAN | 32 | 0.51 | 0.36 | 0.71 | -0.00 | 0.20 | -0.06 | 0.36 | 0.43 | 0.34 | 0.25 | 0.38 | 0.05 | 0.47 | 0.16 | 0.16 | 0.25 | 0.07 | 0.57 | 0.15 | 0.21 |
| AUCHI | 33 | 0.51 | 0.37 | 0.61 | 0.31 | 0.05 | 0.13 | 0.33 | 0.50 | 0.31 | 0.39 | 0.41 | 0.09 | 0.51 | 0.18 | 0.25 | 0.28 | 0.33 | 0.51 | 0.45 | 0.30 |
| LAGOS | 34 | 0.49 | 0.39 | 0.63 | 0.19 | 0.32 | -0.08 | 0.29 | 0.38 | 0.34 | 0.27 | 0.22 | 0.10 | 0.38 | 0.11 | 0.27 | 0.22 | -0.11 | 0.63 | 0.05 | 0.05 |
| OYO | 35 | 0.05 | 0.02 | 0.38 | 0.19 | -0.07 | -0.04 | -0.01 | 0.17 | 0.08 | 0.20 | 0.13 | -0.04 | 0.46 | -0.21 | 0.19 | 0.08 | -0.03 | 0.40 | -1.10 | 0.11 |
| OYO | 36 | 0.27 | 0.22 | -0.02 | -0.09 | 0.01 | -0.09 | 0.12 | 0.26 | -0.03 | -0.05 | 0.14 | 0.06 | -0.01 | -0.10 | -0.15 | 0.15 | 0.12 | 0.07 | 0.14 | 0.22 |
| KWALE | 37 | 0.39 | 0.10 | 0.22 | 0.36 | -0.00 | 0.11 | 0.17 | 0.42 | 0.06 | 0.15 | 0.09 | 0.51 | 0.23 | 0.00 | 0.42 | 0.09 | 0.09 | 0.11 | 0.17 | 0.32 |
| OFFA | 38 | 0.45 | 0.37 | 0.52 | 0.17 | 0.11 | 0.09 | 0.19 | 0.36 | 0.40 | 0.32 | 0.35 | 0.28 | 0.46 | 0.07 | 0.19 | 0.20 | 0.16 | 0.41 | 0.14 | 0.19 |
| HADEJIA | 39 | -0.25 | -0.06 | -0.13 | 0.01 | 0.31 | 0.22 | -0.33 | -0.27 | -0.12 | -0.08 | -0.11 | -0.11 | -0.20 | 0.42 | 0.12 | -0.06 | -0.08 | -0.40 | -0.02 | -0.22 |
| PANKSHIN | 40 | 0.11 | 0.23 | 0.33 | -0.06 | 0.13 | -0.06 | 0.05 | 0.02 | 0.32 | 0.10 | 0.29 | 0.12 | 0.07 | 0.16 | 0.24 | 0.09 | 0.07 | 0.15 | 0.00 | -0.06 |

TABLE 5.1: INTER-STATION CORRELATION MATRIX

| STATION | | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NSUKKA | 21 | 1.00 | | | | | | | | | | | | | | | | | | | |
| SOKOTO | 22 | 0.00 | 1.00 | | | | | | | | | | | | | | | | | | |
| MINNA | 23 | 0.21 | -0.01 | 1.00 | | | | | | | | | | | | | | | | | |
| KANO | 24 | 0.10 | 0.43 | 0.43 | 1.00 | | | | | | | | | | | | | | | | |
| POTISKUM | 25 | -0.05 | 0.33 | -0.07 | 0.33 | 1.00 | | | | | | | | | | | | | | | |
| IBI | 26 | 0.31 | 0.10 | 0.59 | 0.43 | -0.18 | 1.00 | | | | | | | | | | | | | | |
| NGURU | 27 | -0.09 | 0.29 | 0.02 | 0.33 | 0.57 | -0.28 | 1.00 | | | | | | | | | | | | | |
| BAUCHI | 28 | 0.06 | 0.40 | 0.19 | 0.19 | 0.37 | 0.18 | 0.29 | 1.00 | | | | | | | | | | | | |
| KABBA | 29 | 0.51 | -0.00 | 0.32 | 0.24 | -0.12 | 0.34 | 0.08 | 0.09 | 1.00 | | | | | | | | | | | |
| OGBOMOSHO | 30 | 0.40 | 0.10 | 0.21 | 0.23 | -0.11 | 0.48 | -0.09 | 0.07 | 0.24 | 1.00 | | | | | | | | | | |
| LAFIA | 31 | 0.03 | 0.19 | 0.30 | 0.28 | -0.06 | 0.39 | 0.04 | 0.30 | 0.16 | 0.44 | 1.00 | | | | | | | | | |
| IBADAN | 32 | 0.35 | -0.16 | 0.29 | 0.25 | -0.15 | 0.21 | -0.05 | -0.18 | 0.40 | 0.48 | -0.01 | 1.00 | | | | | | | | |
| AUCHI | 33 | 0.55 | 0.02 | 0.20 | 0.18 | 0.12 | 0.24 | 0.11 | 0.35 | 0.44 | 0.49 | 0.15 | 0.44 | 1.00 | | | | | | | |
| LAGOS | 34 | 0.20 | -0.14 | 0.22 | 0.19 | -0.18 | 0.25 | -0.04 | 0.07 | 0.34 | 0.60 | 0.16 | 0.59 | 0.35 | 1.00 | | | | | | |
| OYO | 35 | 0.26 | -0.39 | -0.08 | -0.26 | 0.12 | -0.28 | 0.27 | -0.26 | 0.21 | 0.22 | -0.06 | 0.34 | 0.22 | 0.17 | 1.00 | | | | | |
| UYO | 36 | 0.24 | 0.09 | 0.02 | 0.15 | -0.34 | 0.36 | -0.40 | -0.10 | 0.15 | 0.19 | 0.03 | 0.12 | 0.06 | 0.17 | -0.41 | 1.00 | | | | |
| KWALE | 37 | 0.43 | 0.06 | 0.16 | -0.06 | 0.03 | 0.30 | -0.26 | 0.13 | 0.18 | 0.28 | -0.01 | 0.14 | 0.36 | 0.14 | 0.07 | 0.12 | 1.00 | | | |
| OFFA | 38 | 0.43 | -0.12 | 0.21 | 0.16 | 0.03 | 0.28 | -0.20 | 0.06 | 0.38 | 0.52 | 0.17 | 0.52 | 0.62 | 0.27 | 0.29 | -0.03 | 0.38 | 1.00 | | |
| HADEJIA | 39 | -0.24 | 0.39 | -0.05 | 0.36 | 0.50 | -0.08 | 0.37 | 0.10 | -0.12 | -0.19 | -0.11 | -0.23 | -0.23 | -0.17 | -0.18 | -0.43 | -0.12 | -0.13 | 1.00 | |
| PANKSHIN | 40 | 0.09 | 0.03 | 0.13 | 0.24 | -0.05 | 0.28 | 0.07 | -0.10 | 0.13 | 0.26 | 0.39 | 0.33 | 0.04 | 0.01 | 0.05 | 0.11 | -0.06 | 0.41 | 0.06 | 1.00 |

TABLE 5.1 CONTINUED

The application of the PCA procedure on the 40x40 correlation matrix reduced the forty stations (variables) to thirteen principal components (PCs). The variance extracted by each of the PCs and their eigenvalues are presented in Table 5.2.

TABLE 5.2 EIGENVALUES AND VARIANCES EXTRACTED BY EACH PC

| PC | EIGENVALUE | % OF VARIANCE | CUM % OF VARIANCE |
|---|---|---|---|
| 1 | 9.72 | 24.3 | 24.3 |
| 2 | 4.49 | 11.2 | 35.5 |
| 3 | 2.67 | 6.7 | 42.2 |
| 4 | 2.38 | 5.9 | 48.2 |
| 5 | 2.17 | 5.4 | 53.6 |
| 6 | 1.85 | 4.6 | 58.2 |
| 7 | 1.58 | 4.0 | 62.2 |
| 8 | 1.55 | 3.9 | 66.0 |
| 9 | 1.39 | 3.5 | 69.5 |
| 10 | 1.32 | 3.3 | 72.8 |
| 11 | 1.23 | 3.1 | 75.9 |
| 12 | 1.13 | 2.8 | 78.7 |
| 13 | 1.05 | 2.6 | 81.3 |

Table 5.2 shows that the thirteen PCs account for 81.3% of the total variance of the annual rainfall of which 24.3% was extracted by the first PC. The first three PCs together account for 42.2% of the total variance, indicating that these components can account for most of the variances of the annual rainfall in Nigeria. In similar studies, Gregory (1975) noted that the first three components could account for 68% of the total variance of the annual rainfall over United Kingdom, while Dyer (1975) observed that only 47.2% of the total variance of the South African annual rainfall could be extracted by the first three components with the first accounting for 27.95%. Thus the results of this study is in line with their findings.

The principal component loadings (unrotated) of the thirteen PCs on the forty stations are detailed in Table 5.3. It is evident from this Table that there are too many stations (28) in PC1 with component loadings greater than the absolute value of 0.30. Harris (1967) recommended absolute value of 0.30 as the minimum loading for interpretation when the input is based on correlation matrix. The PC1 shows no definite grouping of stations. Many northern stations such as Kano (0.40), Minna (0.53), Yelwa (0.44), Yola (0.42), Bida (0.57) and Jos (0.47) are grouped with the southern stations - Benin (0.64), Calabar (0.55), Ondo (0.80), Nsukka (0.64), Owerri (0.67), Ibadan (0.66), Lagos (0.60), and Enugu (0.38) as being influenced by the same physical processes. This is clearly not in agreement with the earlier discussion on rainfall patterns in Nigeria. Almost all the stations (Ondo, Minna, Kano, Ibadan, Auchi, Kabba and Oyo) loading on PC3 also have significant loadings on PC1. Thus, the result do not exhibit any regional patterns and therefore uninterpretable.

To improve the principal component interpretation, the eigenvectors were subjected to orthogonal (varimax option) and oblique (oblimin option) rotations. Anyadike (1987) observed that rotation has the effect of repartitioning and shifting of the variances towards higher factors, while Richman (1986) noted that it attempts to isolate subgroups of stations which covary similarly, thereby ensuring the usefulness of S-mode analysis for regionalization. The orthogonally and obliquely rotated PCs are presented in Tables 5.4 and 5.5 respectively.

The results indicate that the varimax rotation isolated three distinct, significant and interpretable principal components

| STATION | | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 | PC7 | PC8 | PC9 | PC10 | PC11 | PC12 | PC13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BENIN | 1 | 0.64 | -0.19 | -0.07 | -0.13 | 0.33 | 0.05 | -0.18 | 0.01 | 0.15 | -0.24 | -0.13 | 0.19 | 0.04 |
| CALABAR | 2 | 0.55 | 0.25 | 0.05 | -0.23 | 0.21 | -0.05 | 0.14 | -0.33 | -0.11 | 0.09 | 0.16 | -0.17 | 0.33 |
| ONDO | 3 | 0.80 | -0.19 | 0.31 | -0.07 | -0.06 | -0.03 | 0.16 | -0.15 | 0.10 | -0.10 | -0.04 | 0.09 | -0.03 |
| JOS | 4 | 0.47 | 0.13 | -0.12 | 0.57 | -0.35 | 0.19 | 0.11 | -0.15 | -0.15 | -0.15 | -0.04 | -0.18 | -0.05 |
| MAIDUGURI | 5 | 0.28 | 0.56 | 0.13 | -0.41 | -0.08 | 0.19 | -0.16 | 0.08 | -0.04 | -0.13 | -0.23 | -0.02 | -0.32 |
| B/KEBBI | 6 | 0.21 | 0.50 | -0.06 | 0.13 | 0.18 | 0.32 | 0.25 | 0.07 | -0.37 | 0.06 | 0.01 | -0.19 | 0.14 |
| YANOFV | 7 | 0.54 | -0.05 | -0.19 | 0.10 | -0.06 | -0.41 | -0.41 | -0.02 | -0.04 | 0.32 | 0.15 | 0.19 | -0.06 |
| OWERRI | 8 | 0.67 | -0.06 | -0.08 | -0.06 | 0.28 | 0.12 | -0.23 | -0.03 | -0.15 | 0.12 | -0.37 | -0.15 | 0.19 |
| BIDA | 9 | 0.57 | 0.14 | 0.01 | 0.05 | 0.44 | -0.16 | -0.01 | 0.35 | -0.09 | -0.08 | -0.03 | 0.05 | -0.20 |
| KAD/SOUTH | 10 | 0.61 | 0.09 | 0.01 | 0.31 | -0.40 | -0.24 | -0.17 | 0.03 | -0.03 | 0.02 | -0.14 | -0.24 | 0.01 |
| MAKURDI | 11 | 0.62 | 0.00 | -0.08 | -0.09 | -0.00 | 0.05 | 0.25 | 0.21 | -0.02 | 0.33 | 0.21 | 0.24 | -0.18 |
| PH | 12 | 0.28 | 0.10 | -0.26 | 0.01 | -0.06 | 0.51 | -0.53 | -0.07 | 0.14 | 0.28 | -0.11 | 0.28 | -0.01 |
| ILORIN | 13 | 0.59 | -0.27 | 0.29 | 0.11 | 0.04 | 0.16 | 0.10 | 0.22 | -0.28 | -0.04 | 0.41 | -0.03 | -0.10 |
| KATSINA | 14 | 0.19 | 0.77 | 0.11 | -0.20 | 0.20 | -0.12 | -0.05 | -0.04 | 0.17 | -0.10 | -0.03 | -0.03 | 0.01 |
| YOLA | 15 | 0.42 | 0.12 | 0.12 | 0.29 | -0.24 | 0.21 | 0.04 | -0.30 | 0.34 | -0.13 | 0.01 | -0.14 | 0.18 |
| YELWA | 16 | 0.44 | 0.17 | 0.12 | -0.26 | -0.02 | -0.06 | -0.41 | 0.38 | -0.26 | 0.13 | 0.25 | -0.25 | 0.09 |
| LOKOJA | 17 | 0.32 | 0.18 | -0.22 | 0.18 | 0.09 | -0.11 | 0.24 | 0.57 | -0.08 | -0.10 | -0.45 | 0.03 | -0.08 |
| AKURE | 18 | 0.69 | -0.38 | 0.19 | -0.00 | -0.10 | -0.07 | 0.15 | -0.26 | -0.21 | -0.11 | -0.11 | 0.19 | 0.06 |
| OTUKPO | 19 | 0.33 | 0.18 | -0.13 | 0.33 | 0.26 | -0.60 | 0.00 | 0.04 | 0.23 | -0.19 | 0.17 | -0.07 | 0.08 |
| ENUGU | 20 | 0.38 | -0.20 | -0.26 | 0.23 | 0.31 | 0.12 | 0.38 | -0.26 | -0.05 | 0.29 | 0.12 | 0.20 | -0.21 |
| NSUKKA | 21 | 0.64 | -0.17 | -0.06 | 0.15 | 0.40 | 0.06 | 0.12 | 0.24 | 0.01 | 0.07 | -0.11 | -0.18 | -0.05 |
| SOKOTO | 22 | 0.06 | 0.67 | -0.05 | -0.28 | 0.05 | 0.19 | 0.17 | 0.04 | -0.11 | -0.13 | -0.03 | 0.35 | -0.01 |
| MINNA | 23 | 0.53 | 0.16 | 0.24 | -0.08 | -0.16 | -0.23 | -0.05 | -0.29 | -0.02 | 0.37 | -0.06 | -0.08 | -0.22 |
| KANO | 24 | 0.40 | 0.68 | -0.05 | -0.37 | 0.06 | -0.05 | 0.16 | -0.18 | -0.07 | 0.05 | 0.02 | -0.16 | 0.01 |
| POTISKUM | 25 | -0.07 | 0.68 | 0.37 | 0.20 | 0.25 | 0.00 | -0.20 | 0.08 | 0.07 | 0.14 | 0.24 | 0.02 | 0.02 |
| IBI | 26 | 0.59 | 0.12 | -0.50 | -0.14 | -0.27 | -0.10 | 0.14 | -0.08 | 0.08 | 0.04 | 0.18 | -0.19 | -0.22 |
| NGURU | 27 | 0.00 | 0.59 | 0.52 | 0.09 | 0.11 | -0.17 | -0.04 | -0.09 | -0.14 | 0.17 | -0.20 | 0.27 | 0.10 |
| BAUCHI | 28 | 0.22 | 0.48 | -0.20 | -0.48 | -0.03 | -0.18 | -0.12 | -0.08 | -0.08 | -0.22 | 0.16 | 0.35 | 0.06 |
| KABBA | 29 | 0.61 | -0.02 | -0.03 | 0.07 | 0.16 | -0.20 | 0.13 | -0.10 | 0.03 | 0.16 | -0.37 | -0.11 | -0.05 |
| OGBOMOSHO | 30 | 0.76 | -0.07 | 0.09 | -0.19 | -0.15 | 0.28 | -0.02 | 0.17 | -0.17 | -0.26 | 0.17 | 0.10 | -0.05 |
| LAFIA | 31 | 0.44 | 0.23 | -0.218 | 0.04 | -0.59 | 0.10 | 0.06 | -0.17 | 0.05 | 0.04 | -0.09 | 0.12 | 0.40 |
| IBADAN | 32 | 0.66 | -0.23 | 0.31 | -0.36 | 0.13 | -0.12 | 0.03 | -0.07 | 0.16 | -0.01 | -0.01 | 0.05 | -0.13 |
| AUCHI | 33 | 0.72 | -0.02 | 0.13 | 0.27 | 0.31 | -0.12 | -0.01 | 0.12 | 0.05 | -0.17 | 0.09 | 0.09 | 0.10 |
| LAGOS | 34 | 0.60 | -0.16 | 0.21 | -0.28 | -0.08 | -0.04 | -0.19 | -0.34 | -0.16 | -0.41 | -0.02 | 0.07 | -0.14 |
| OYO | 35 | 0.24 | -0.33 | 0.73 | 0.27 | 0.00 | 0.14 | 0.04 | 0.06 | -0.08 | 0.30 | -0.13 | -0.06 | 0.01 |
| UYO | 36 | 0.19 | -0.20 | -0.63 | -0.41 | 0.23 | -0.09 | 0.03 | 0.07 | -0.09 | -0.16 | 0.05 | -0.06 | 0.19 |
| KWALE | 37 | 0.41 | -0.10 | -0.24 | 0.34 | 0.26 | 0.47 | -0.31 | -0.11 | 0.32 | -0.06 | 0.07 | -0.20 | -0.05 |
| OPEA | 38 | 0.65 | -0.13 | 0.17 | -0.01 | 0.06 | 0.19 | 0.02 | 0.17 | 0.37 | 0.04 | 0.14 | -0.03 | 0.10 |
| HADEJIA | 39 | -0.24 | 0.66 | 0.26 | 0.01 | -0.05 | 0.14 | 0.15 | -0.09 | 0.23 | -0.07 | 0.06 | -0.14 | -0.30 |
| PANKSHIN | 40 | 0.30 | 0.09 | 0.09 | -0.37 | -0.32 | 0.06 | 0.28 | 0.15 | 0.52 | 0.20 | 0.06 | 0.15 | 0.36 |

TABLE 5.3: UNROTATED PRINCIPAL COMPONENTS 1 - 13

PC1, PC2 and PC3, while the oblimin identified two, namely, PC1 and PC2. Considering component loadings greater than or equal to 0.30, it could be observed that the PC1 and PC2 in both cases are similar. However, as many as thirteen stations are loaded on PC1 in the varimax option, while only seven load on it in the oblimin option. Similarly, eight stations load on the varimax PC2, while six load on the oblimin PC2. The PC3 in the oblique rotation does not represent any definite pattern, since the northern stations Potiskum (0.43), Nguru (0.69) and Ibi (-0.53) are mixed up with the southern stations Oyo (0.75) and Uyo (-0.76). Thus, the orthogonal varimax components best represent the input data and are used to describe the spatial patterns of PC1, PC2 and PC3. The various stations loading on each of the three principal components, both unrotated and varimax rotated are detailed in Table 5.6, while their spatial patterns are presented in Figure 5.1. The PC1 accounts for 24.4% of the total variance in the rainfall data. The unrotated PC1 (Fig,5.1.1) does not exhibit any regional pattern, and is totally uninterpretable.

It is evident from Figures 5.1.2, 5.1.4, 5.1.6 that the PCA has identified three distinct geographical rainfall regions Owing to their locations, the PC1, PC2, and PC3 respectively, may be named Southern component, Northern component and Middle-Belt component. It should be noted that lines separating the different dominant regions are by no means sharp frontiers, they simply indicate the locations where the influence changes from one component to another (Ehrendorfer, 1987).

The varimax rotated PC1 (Southern component, Figure 5.1.2) is associated with the stations (towns) of southern Nigeria (considering the cut-off eigenvalues of 0.30 and above).

| STATION | | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 | PC7 | PC8 | PC9 | PC10 | PC11 | PC12 | PC13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BENIN | 1 | 0.65 | -0.02 | -0.13 | 0.06 | -0.18 | 0.40 | 0.04 | 0.17 | 0.24 | 0.02 | 0.05 | 0.10 | 0.11 |
| CALABAR | 2 | 0.34 | 0.32 | 0.10 | 0.14 | -0.10 | -0.01 | 0.13 | 0.19 | -0.18 | 0.17 | 0.18 | -0.01 | 0.62 |
| ONDO | 3 | 0.80 | 0.02 | 0.24 | 0.13 | 0.12 | 0.03 | 0.07 | 0.09 | 0.09 | 0.19 | 0.25 | -0.09 | 0.06 |
| JOS | 4 | 0.11 | -0.01 | 0.85 | 0.06 | 0.05 | 0.13 | 0.05 | 0.04 | 0.12 | 0.17 | -0.13 | 0.15 | 0.04 |
| MAIDUGURI | 5 | 0.25 | 0.74 | 0.02 | 0.12 | -0.03 | 0.08 | 0.15 | -0.31 | 0.19 | -0.18 | -0.02 | 0.06 | -0.08 |
| B/KEBBI | 6 | -0.15 | 0.39 | 0.26 | -0.18 | 0.03 | 0.01 | 0.25 | -0.08 | 0.16 | 0.26 | -0.10 | 0.21 | 0.48 |
| YANDEV | 7 | 0.20 | -0.14 | 0.00 | 0.77 | -0.02 | 0.15 | 0.24 | 0.27 | 0.01 | 0.07 | 0.03 | 0.18 | -0.01 |
| OWERRI | 8 | 0.41 | -0.00 | 0.05 | 0.27 | -0.02 | -0.39 | 0.12 | -0.05 | 0.33 | -0.02 | -0.06 | -0.04 | 0.55 |
| PIDA | 9 | 0.27 | 0.13 | 0.38 | 0.32 | -0.02 | -0.07 | 0.31 | 0.06 | 0.37 | -0.05 | 0.24 | 0.08 | -0.31 |
| KAD SOUTH | 10 | 0.21 | -0.01 | 0.62 | 0.47 | 0.10 | 0.03 | 0.18 | 0.18 | 0.23 | -0.16 | 0.04 | -0.03 | 0.05 |
| MARKURDI | 11 | 0.26 | 0.06 | 0.02 | 0.29 | -0.04 | 0.02 | 0.35 | -0.03 | 0.21 | 0.56 | 0.31 | 0.10 | -0.02 |
| OH | 12 | 0.02 | 0.04 | 0.01 | 0.33 | 0.00 | 0.75 | 0.04 | -0.35 | -0.02 | -0.00 | 0.11 | 0.30 | 0.00 |
| ILORIN | 13 | 0.46 | -0.16 | 0.19 | -0.09 | 0.13 | 0.02 | 0.65 | 0.07 | 0.01 | 0.36 | -0.01 | -0.05 | 0.01 |
| KATSINA | 14 | 0.04 | 0.79 | -0.06 | 0.07 | 0.04 | 0.02 | -0.01 | 0.25 | 0.07 | -0.14 | 0.11 | 0.14 | 0.15 |
| YOLA | 15 | 0.23 | 0.11 | 0.59 | -0.04 | 0.13 | 0.30 | -0.14 | 0.17 | -0.11 | -0.00 | 0.28 | -0.03 | 0.07 |
| YELWA | 16 | 0.13 | 0.18 | -0.03 | 0.29 | -0.03 | 0.07 | 0.78 | 0.03 | 0.05 | -0.23 | 0.04 | -0.05 | 0.19 |
| LOKOJA | 17 | 0.00 | 0.09 | 0.11 | 0.01 | -0.07 | -0.01 | 0.03 | 0.12 | 0.88 | 0.05 | 0.08 | 0.11 | -0.03 |
| AKURE | 18 | 0.79 | -0.27 | 0.24 | 0.16 | 0.07 | -0.10 | 0.01 | -0.03 | 0.04 | 0.19 | 0.05 | 0.06 | 0.18 |
| OTURKPO | 19 | 0.08 | 0.08 | 0.10 | 0.19 | -0.08 | 0.04 | -0.01 | 0.85 | 0.17 | 0.02 | -0.02 | 0.08 | 0.02 |
| ENUGU | 20 | 0.17 | -0.14 | 0.04 | 0.14 | -0.06 | 0.15 | -0.13 | 0.06 | 0.04 | 0.82 | -0.06 | 0.06 | 0.13 |
| NSUKKA | 21 | 0.31 | -0.07 | 0.06 | 0.04 | -0.03 | 0.28 | 0.24 | 0.21 | 0.49 | 0.34 | -0.03 | -0.18 | 0.26 |
| SOKOTO | 22 | -0.14 | 0.53 | 0.02 | -0.16 | -0.12 | 0.11 | -0.06 | -0.06 | 0.19 | 0.23 | -0.02 | 0.61 | 0.09 |
| MINNA | 23 | 0.17 | 0.21 | 0.22 | 0.72 | -0.13 | 0.04 | -0.03 | -0.00 | 0.02 | 0.23 | 0.04 | -0.08 | 0.13 |
| KANO | 24 | 0.14 | 0.76 | 0.10 | 0.21 | -0.18 | 0.12 | 0.08 | 0.02 | 0.00 | 0.09 | 0.14 | 0.05 | 0.35 |
| POTISKUM | 25 | -0.29 | 0.56 | -0.08 | -0.03 | 0.47 | 0.13 | 0.23 | 0.32 | -0.12 | -0.04 | -0.02 | 0.17 | 0.06 |
| IBI | 26 | 0.16 | 0.21 | 0.43 | 0.38 | -0.55 | 0.08 | 0.15 | 0.01 | 0.07 | 0.30 | 0.17 | -0.07 | -0.04 |
| NGURU | 27 | 0.02 | 0.45 | -0.11 | 0.12 | 0.65 | 0.19 | -0.08 | 0.06 | 0.02 | -0.10 | 0.00 | 0.32 | 0.20 |
| BAUCHI | 28 | -0.02 | 0.18 | 0.30 | 0.15 | 0.04 | 0.06 | -0.01 | 0.41 | 0.00 | 0.04 | -0.12 | 0.69 | -0.07 |
| KABBA | 29 | 0.37 | 0.06 | 0.15 | 0.36 | 0.05 | 0.06 | -0.13 | 0.14 | 0.40 | 0.19 | 0.01 | -0.15 | 0.30 |
| OGBOMOSHO | 30 | 0.66 | 0.08 | 0.25 | -0.02 | -0.15 | 0.14 | 0.51 | -0.14 | 0.11 | 0.10 | 0.15 | 0.15 | -0.02 |
| LAFIA | 31 | 0.08 | -0.02 | 0.55 | 0.23 | -0.09 | -0.08 | 0.16 | -0.22 | 0.12 | -0.13 | 0.41 | 0.42 | 0.21 |
| IBADAN | 32 | 0.75 | 0.09 | -0.13 | 0.19 | 0.04 | 0.05 | 0.13 | 0.08 | 0.07 | 0.13 | 0.22 | -0.27 | 0.03 |
| AUCHI | 33 | 0.51 | -0.01 | 0.12 | 0.04 | 0.12 | 0.22 | 0.25 | 0.49 | 0.27 | 0.18 | 0.04 | 0.15 | 0.16 |
| LAGOS | 34 | 0.87 | 0.10 | 0.14 | 0.13 | -0.12 | 0.03 | 0.08 | -0.04 | -0.16 | -0.13 | -0.14 | 0.01 | -0.01 |
| OYO | 35 | 0.31 | -0.26 | 0.10 | -0.08 | 0.75 | 0.02 | 0.18 | -0.10 | 0.07 | 0.10 | 0.03 | -0.28 | 0.10 |
| UYO | 36 | 0.12 | -0.14 | -0.21 | 0.04 | -0.78 | 0.04 | 0.07 | 0.05 | 0.12 | 0.03 | 0.03 | 0.04 | 0.27 |
| KHALE | 37 | 0.11 | -0.03 | 0.26 | -0.04 | -0.10 | 0.86 | 0.04 | 0.16 | 0.03 | 0.17 | -0.09 | -0.09 | 0.05 |
| OFFA | 38 | 0.41 | 0.01 | 0.12 | -0.01 | 0.07 | 0.37 | 0.28 | 0.19 | 0.15 | 0.17 | 0.44 | -0.16 | 0.02 |
| HADEJIA | 39 | -0.25 | 0.73 | 0.13 | -0.19 | 0.22 | -0.05 | -0.12 | 0.01 | -0.10 | 0.03 | 0.02 | -0.08 | -0.23 |
| PANKSHIN | 40 | 0.13 | 0.11 | 0.03 | 0.04 | -0.05 | -0.02 | 0.01 | -0.05 | 0.04 | 0.00 | 0.93 | 0.04 | 0.01 |

TABLE 5.4: VARIMAX ROTATED PRINCIPAL COMPONENTS 1 - 13

| STATION | | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 | PC7 | PC8 | PC9 | PC10 | PC11 | PC12 | PC13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BENIN | 1 | 0.54 | -0.07 | -0.15 | -0.02 | 0.22 | -0.18 | -0.32 | 0.26 | 0.10 | -0.00 | -0.01 | 0.13 | 0.07 |
| CALABAR | 2 | 0.18 | 0.02 | -0.07 | 0.07 | -0.03 | -0.09 | 0.08 | -0.17 | 0.19 | 0.09 | 0.12 | -0.12 | 0.72 |
| ONDO | 3 | 0.63 | 0.01 | 0.16 | 0.16 | 0.02 | -0.01 | 0.07 | 0.10 | 0.28 | 0.17 | 0.01 | -0.08 | 0.04 |
| JOS | 4 | 0.07 | 0.02 | 0.05 | 0.66 | -0.41 | -0.09 | 0.03 | 0.13 | -0.23 | 0.14 | 0.03 | -0.12 | -0.02 |
| MAIDUGURI | 5 | 0.28 | 0.79 | 0.02 | -0.12 | -0.07 | 0.16 | -0.20 | 0.17 | -0.05 | -0.15 | 0.13 | -0.06 | -0.02 |
| B/KEBBI | 6 | -0.24 | 0.22 | 0.04 | 0.13 | -0.30 | 0.04 | 0.02 | 0.17 | -0.18 | 0.22 | 0.21 | 0.19 | 0.51 |
| YANDEV | 7 | 0.05 | -0.26 | 0.02 | -0.18 | 0.01 | -0.39 | -0.26 | -0.06 | 0.02 | 0.10 | 0.24 | -0.61 | -0.11 |
| ONERRI | 8 | 0.21 | -0.17 | 0.04 | 0.05 | 0.02 | 0.15 | 0.38 | 0.38 | -0.08 | -0.11 | 0.10 | -0.17 | 0.45 |
| SIDA | 9 | 0.15 | 0.21 | 0.00 | 0.09 | -0.24 | -0.13 | 0.07 | 0.33 | 0.20 | -0.02 | 0.27 | -0.24 | -0.40 |
| KAD SOUTH | 10 | 0.07 | -0.07 | 0.12 | 0.38 | -0.25 | -0.13 | 0.05 | 0.24 | -0.02 | -0.21 | 0.20 | -0.48 | -0.05 |
| MAKURDI | 11 | 0.00 | 0.06 | -0.00 | -0.18 | -0.07 | -0.01 | -0.06 | 0.13 | 0.29 | 0.61 | 0.25 | -0.17 | -0.08 |
| PH | 12 | -0.06 | 0.03 | 0.04 | 0.05 | -0.11 | 0.07 | -0.93 | -0.09 | 0.07 | 0.05 | -0.01 | -0.12 | -0.09 |
| ILORIN | 13 | 0.28 | -0.13 | 0.12 | 0.12 | 0.00 | -0.00 | 0.14 | -0.04 | -0.02 | 0.40 | 0.63 | 0.16 | -0.04 |
| KATSINA | 14 | 0.01 | 0.60 | 0.04 | -0.07 | 0.10 | -0.32 | -0.02 | 0.07 | 0.14 | -0.18 | -0.01 | -0.03 | 0.30 |
| YOLA | 15 | 0.13 | 0.05 | 0.11 | 0.67 | -0.10 | -0.11 | -0.08 | -0.09 | 0.27 | -0.07 | -0.15 | -0.01 | 0.10 |
| YELWA | 16 | -0.05 | 0.04 | -0.03 | -0.14 | -0.03 | -0.00 | -0.10 | -0.00 | 0.02 | -0.22 | 0.84 | -0.16 | 0.17 |
| LOKOJA | 17 | -0.15 | 0.11 | -0.05 | -0.07 | -0.11 | -0.08 | 0.05 | 0.93 | 0.05 | 0.00 | -0.05 | 0.06 | -0.06 |
| AKURE | 18 | 0.72 | -0.28 | 0.14 | 0.05 | -0.19 | 0.02 | 0.09 | 0.05 | 0.04 | 0.20 | -0.06 | -0.09 | 0.10 |
| OTURKPO | 19 | -0.03 | -0.10 | -0.13 | 0.13 | 0.26 | -0.74 | 0.28 | 0.21 | 0.04 | -0.07 | 0.02 | -0.18 | 0.06 |
| ENUGU | 20 | 0.02 | -0.13 | -0.02 | 0.04 | 0.12 | -0.03 | -0.07 | 0.02 | -0.07 | 0.82 | -0.22 | -0.14 | 0.11 |
| NSUKKA | 21 | 0.02 | -0.11 | -0.02 | 0.14 | 0.25 | 0.03 | -0.05 | 0.54 | -0.01 | 0.25 | 0.21 | -0.01 | 0.19 |
| SOKOTO | 22 | -0.07 | 0.43 | -0.10 | -0.14 | -0.31 | -0.30 | -0.24 | 0.14 | -0.07 | 0.28 | -0.17 | 0.32 | 0.15 |
| MINNA | 23 | 0.03 | 0.15 | -0.06 | 0.02 | -0.04 | 0.02 | -0.10 | -0.02 | 0.00 | 0.21 | -0.04 | -0.75 | 0.12 |
| KANO | 24 | 0.06 | 0.57 | -0.14 | -0.05 | -0.10 | -0.04 | 0.09 | -0.01 | 0.12 | 0.04 | 0.06 | -0.22 | 0.50 |
| POTISKUM | 25 | 0.34 | 0.35 | 0.43 | -0.01 | 0.16 | -0.39 | -0.10 | -0.14 | 0.01 | -0.04 | 0.27 | 0.07 | 0.18 |
| IBI | 26 | 0.02 | 0.27 | -0.53 | 0.27 | -0.12 | 0.02 | 0.03 | 0.02 | 0.12 | 0.27 | 0.13 | -0.42 | -0.02 |
| NGURU | 27 | 0.05 | 0.23 | 0.69 | -0.30 | -0.15 | -0.25 | -0.03 | 0.02 | 0.00 | -0.07 | -0.12 | -0.05 | 0.24 |
| GAUCHI | 28 | 0.05 | 0.03 | 0.03 | 0.08 | -0.31 | -0.79 | -0.11 | -0.04 | -0.16 | 0.09 | -0.06 | 0.02 | -0.07 |
| KABBA | 29 | 0.17 | -0.03 | 0.11 | 0.07 | 0.10 | 0.04 | 0.01 | 0.46 | 0.01 | 0.10 | -0.16 | -0.40 | 0.24 |
| OGBOMOSHO | 30 | 0.55 | 0.13 | -0.13 | 0.09 | -0.22 | 0.27 | -0.11 | 0.05 | 0.11 | 0.15 | 0.45 | 0.20 | -0.06 |
| LAFIA | 31 | 0.01 | -0.15 | -0.04 | 0.13 | -0.81 | -0.04 | -0.10 | 0.06 | 0.29 | -0.10 | 0.08 | -0.09 | 0.10 |
| IBADAN | 32 | 0.57 | 0.09 | 0.07 | -0.10 | 0.31 | 0.08 | 0.03 | 0.07 | 0.29 | 0.11 | 0.11 | -0.15 | 0.04 |
| AUCHI | 33 | 0.30 | -0.16 | 0.12 | 0.13 | 0.14 | -0.45 | -0.02 | 0.29 | -0.08 | 0.14 | 0.21 | 0.11 | 0.12 |
| LAGOS | 34 | 0.95 | 0.16 | -0.07 | -0.06 | 0.00 | -0.03 | -0.01 | -0.16 | -0.13 | -0.10 | 0.08 | -0.07 | 0.02 |
| OYO | 35 | 0.14 | -0.25 | 0.75 | 0.14 | 0.09 | 0.30 | 0.04 | 0.11 | 0.05 | 0.09 | 0.19 | 0.03 | 0.01 |
| OYO | 36 | 0.09 | -0.20 | -0.76 | -0.20 | 0.01 | -0.02 | -0.03 | 0.12 | 0.03 | -0.01 | 0.05 | 0.05 | 0.26 |
| KWALE | 37 | -0.05 | -0.02 | -0.15 | 0.62 | 0.33 | -0.06 | -0.55 | 0.06 | -0.08 | 0.08 | 0.06 | 0.07 | 0.03 |
| UFFA | 38 | 0.11 | -0.04 | 0.05 | 0.27 | 0.20 | -0.03 | -0.16 | 0.14 | 0.49 | 0.12 | 0.24 | 0.10 | 0.00 |
| HADEJIA | 39 | -0.18 | 0.78 | 0.19 | 0.19 | 0.12 | -0.02 | 0.13 | -0.11 | 0.03 | 0.02 | -0.10 | 0.05 | -0.05 |
| PANKSHIN | 40 | -0.10 | 0.02 | -0.03 | -0.02 | -0.16 | 0.09 | -0.01 | -0.00 | 0.97 | -0.01 | -0.08 | 0.04 | 0.03 |

TABLE 5.5: OBLIQUELY ROTATED PRINCIPAL COMPONENTS 1 - 13

TABLE 5.6: STATIONS LOADING ON THE THREE SIGNIFICANT PCs - UNROTATED AND ROTATED EIGENVECTORS

| | STATION | UNROTATED EIGENVECTOR | VARIMAX ROTATED EIGENVECTOR |
|---|---|---|---|
| PC1 | | | |
| | ONDO | 0.80 | 0.80 * |
| | OGBOMOSHO | 0.76 | 0.65 * |
| | AUCHI | 0.72 | 0.51 * |
| | AKURE | 0.69 | 0.79 * |
| | OWERRI | 0.67 | 0.41 * |
| | IBADAN | 0.66 | 0.75 * |
| | OFFA | 0.65 | 0.41 * |
| | NSUKKA | 0.64 | 0.31 * |
| | BENIN | 0.64 | 0.65 * |
| | MAKURDI | 0.62 | 0.26 |
| | KADUNA SOUTH | 0.61 | 0.21 |
| | KABBA | 0.61 | 0.37 * |
| | LAGOS | 0.60 | 0.87 * |
| | ILORIN | 0.59 | 0.46 * |
| | IBI | 0.59 | 0.16 |
| | BIDA | 0.57 | 0.27 |
| | CALABAR | 0.55 | 0.34 * |
| | YANDEV | 0.54 | 0.20 |
| | MINNA | 0.53 | 0.17 |
| | JOS | 0.47 | 0.11 |
| | YELWA | 0.44 | 0.13 |
| | LAFIA | 0.44 | 0.08 |
| | YOLA | 0.42 | 0.23 |
| | KWALE | 0.41 | 0.11 |
| | KANO | 0.40 | 0.14 |
| | ENUGU | 0.38 | 0.17 |
| | OTURKPO | 0.33 | 0.08 |
| | PANKSHIN | 0.30 | 0.13 |
| PC2 | | | |
| | KATSINA | 0.77 | 0.79 * |
| | KANO | 0.68 | 0.76 * |
| | POTISKUM | 0.68 | 0.56 * |
| | SOKOTO | 0.64 | 0.53 * |
| | HADEJIA | 0.66 | 0.73 * |
| | NGURU | 0.59 | 0.45 * |
| | MAIDUGURI | 0.56 | 0.74 * |
| | BIRNIN KEBBI | 0.50 | 0.39 * |
| | BAUCHI | 0.48 | 0.18 |
| | AKURE | 0.38 | -0.27 |
| | OYO | -0.33 | -0.26 |
| PC3 | | | |
| | OYO | 0.73 | 0.10 |
| | UYO | -0.63 | -0.21 |
| | IBI | -0.50 | 0.43 * |
| | IBADAN | 0.31 | -0.13 |
| | ONDO | 0.31 | 0.24 |
| | BAUCHI | -0.20 | 0.30 * |
| | LAFIA | -0.18 | 0.55 * |
| | JOS | -0.12 | 0.85 * |
| | YOLA | 0.12 | 0.59 * |
| | KADUNA SOUTH | 0.11 | 0.62 * |
| | BIDA | 0.01 | 0.38 * |

* indicates significant component loadings ($\geq 0.30$)

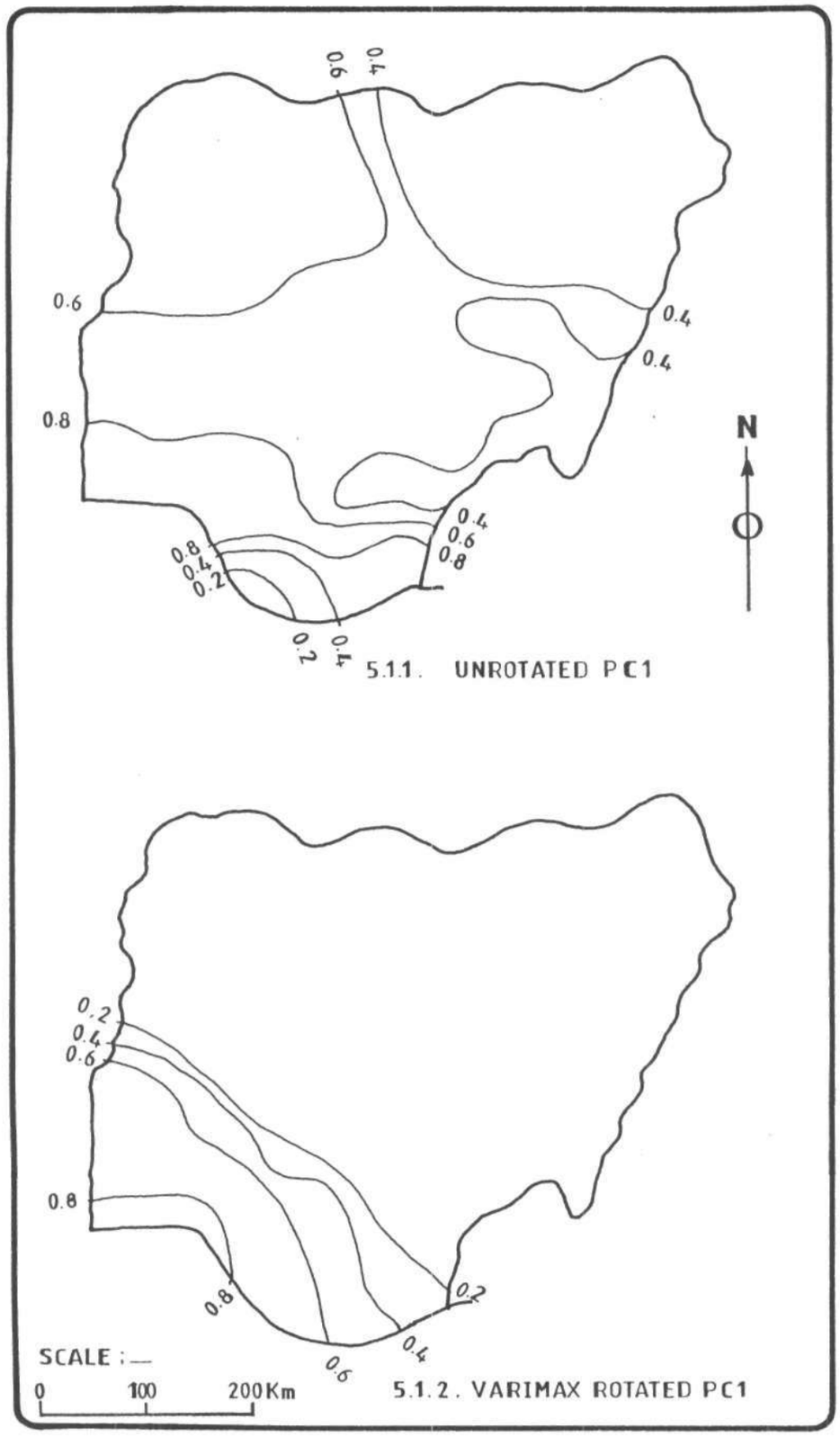



Fig. 5.1. Spatial distribution of the loadings on PC1 (unrotated and rotated).

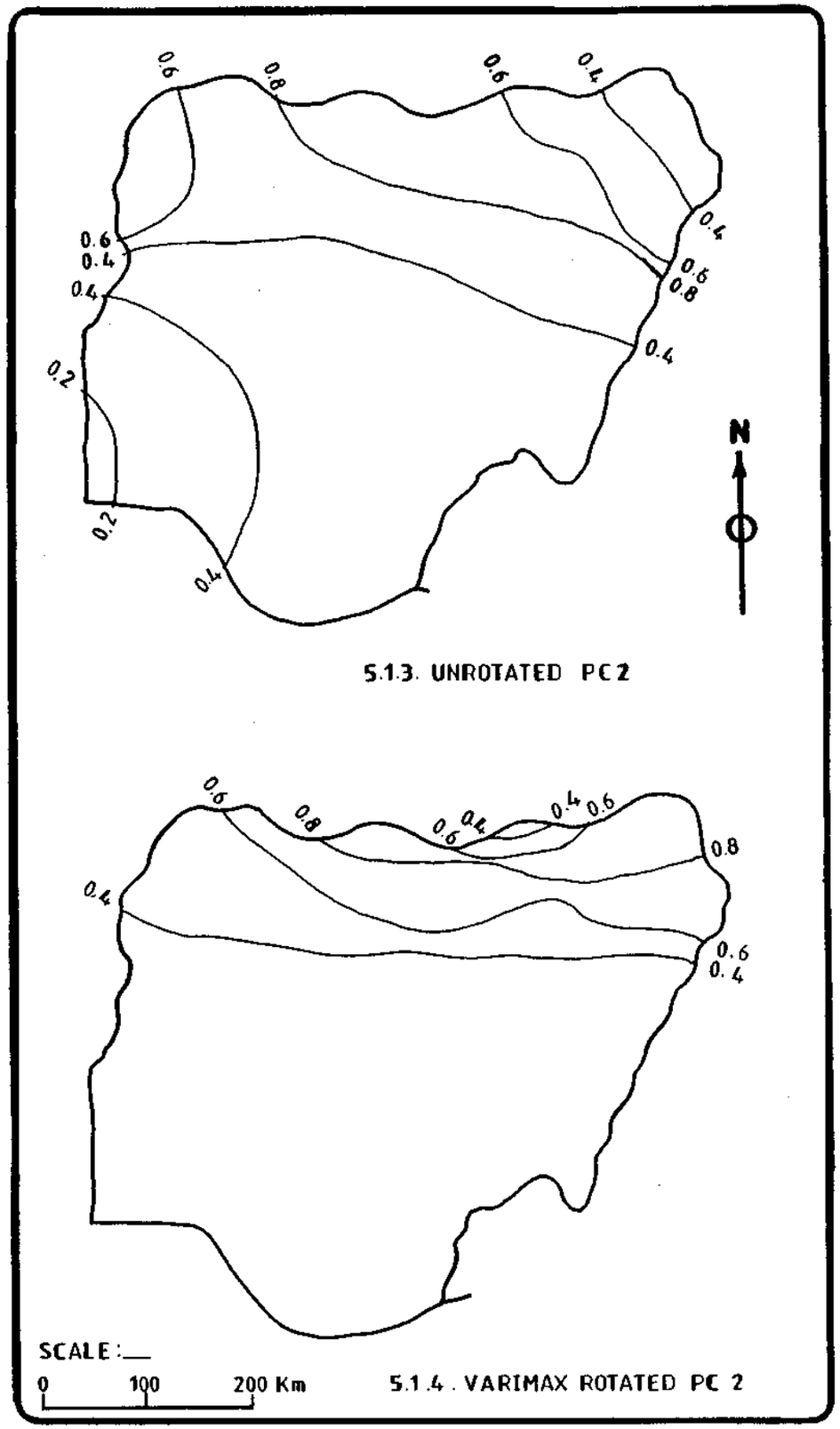



Fig. 5.1 continued : Spatial distribution of the loadings on PC2 (unrotated and rotated ).

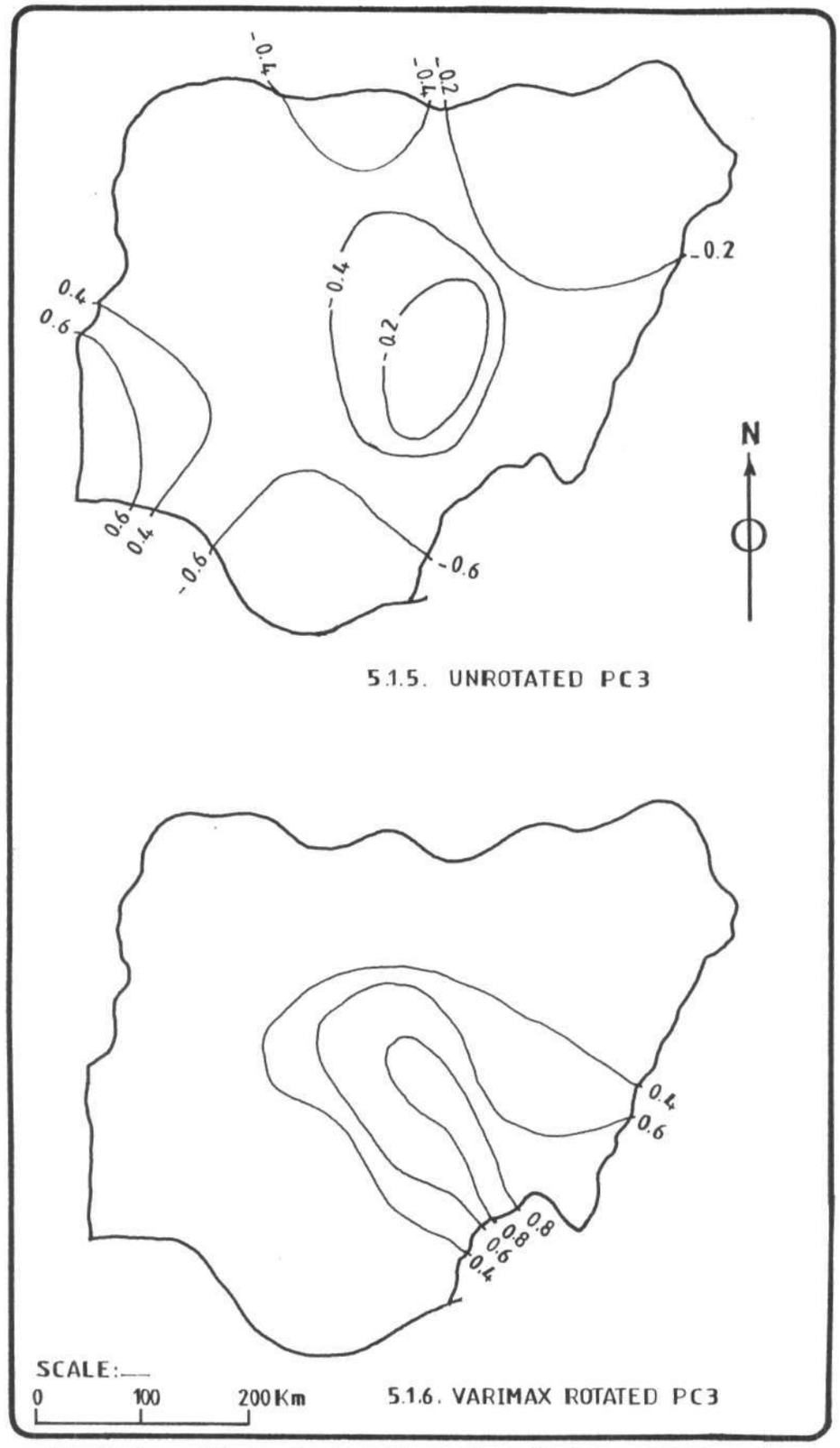



Fig. 5.1. continued : Spatial distribution of the loadings on PC 3 (unrotated and rotated).

The examination of the variable loadings shows that high values (≥0.60) occur mainly in the south-western stations, Lagos, Ondo, Akure, Ibadan, Ogbomosho and Benin, while low ones are experienced in the south-eastern stations Calabar, Nsukka and Owerri. Thus the Southern component explains rainfall variation most frequently found in the south and portrays the degree to which stations covary with the seasonal duration and intensity of rainfall across the region. Rainfall in Nigeria, as in most tropical regions, is generally convective in origin, causing large spatial variation in the rainfall patterns. The significant PC1 stations are highly influenced by the warm moist mT from the Atlantic ocean, orographic effects of the Cameroon Mountains and nearness to the sea. These physical processes generate high amounts of rainfall. The region described by PC1 is the wettest part of the country, and the rainy season (April- October) is particularly long.

The second component, that is the Northern Component (Fig.5.1.4) explains 11.2% of the total variance and is correlated with the far north. The high loadings appear in Katsina (0.79), Kano (0.76), Maiduguri (0.74) and Hadejia (0.73), while Birnin Kebbi (0.39), Nguru (0.45) and Sokoto (0.53) have low values. This region is characterised by low amounts of rainfall as discussed in Chapter Four. The long-term mean varies from 501 mm in Nguru to 824 mm in Kano. The PC2 stations are predominantly influenced by the dry cT air from the Sahara desert and their continentality. Due to these physical factors, the Northern Component region has a shorter period of rainy season (May-September), longer dry season (October-April), and long, dry, cold, and dusty harmattan (generally from November to March).

The PC3 (Middle Belt Component, Fig.5.1.6) is correlated with the Middle Belt and extends into the windward side of the Adamawa Highlands in the north-east. It explains 6.7% of the total variance. The high loadings appear in Jos (0.85), Kaduna South (0.62) and Yola (0.59), while low ones occur in Ibi (0.43), Bida (0.38) and Bauchi (0.30). This region is influenced by the low-lying nature of the area and the altitudinal effects of the Jos Plateau and Adamawa Highlands. The PC3 stations experience moderate amounts of rainfall due to the above physical factors.

In order to classify the rainfall stations into homogeneous regional groups, the significant component loadings of PC1 were plotted against PC2, then PC2 against PC3, and PC1 against PC3 (Pandzic, 1986; Atwoki, 1975). The graphs which show the clusters among stations are presented in Figures 5.2.1, 5.2.2 and 5.2.3. In Figure 5.2.1, five major groups of stations labelled A,B,C,D and E are identified. Similarly, in Figures 5.2.2, four groups of stations F, G, H and I are separated. However, F in Figure 5.2.2 fairly corresponds to D in Fig.5.2.1, while G in Fig.5.2.2 corresponds to E in Fig.5.2.1, M in Fig.5.2.3 corresponds to I in Fig.5.2.2 and C in Fig.5.2.1 stands alone. Thus, seven distinct Groups A,C,D,E,K,L and M adjudged to be the best in accordance with the clustering of the stations are selected as the homogeneous rainfall regional groups of Nigeria. The spatial distribution of the identified groups of stations is shown in Figures 5.3 and labelled I, II, III, IV, V, VI and VII respectively.

Two of the seven recognised groups have only one member each, Calabar (II) on the Cross River and Jos (V) on the Jos Plateau. Both have higher rainfall amounts than their surroundings. This reflects the effects of Cameroon Mountains and Jos Plateau.

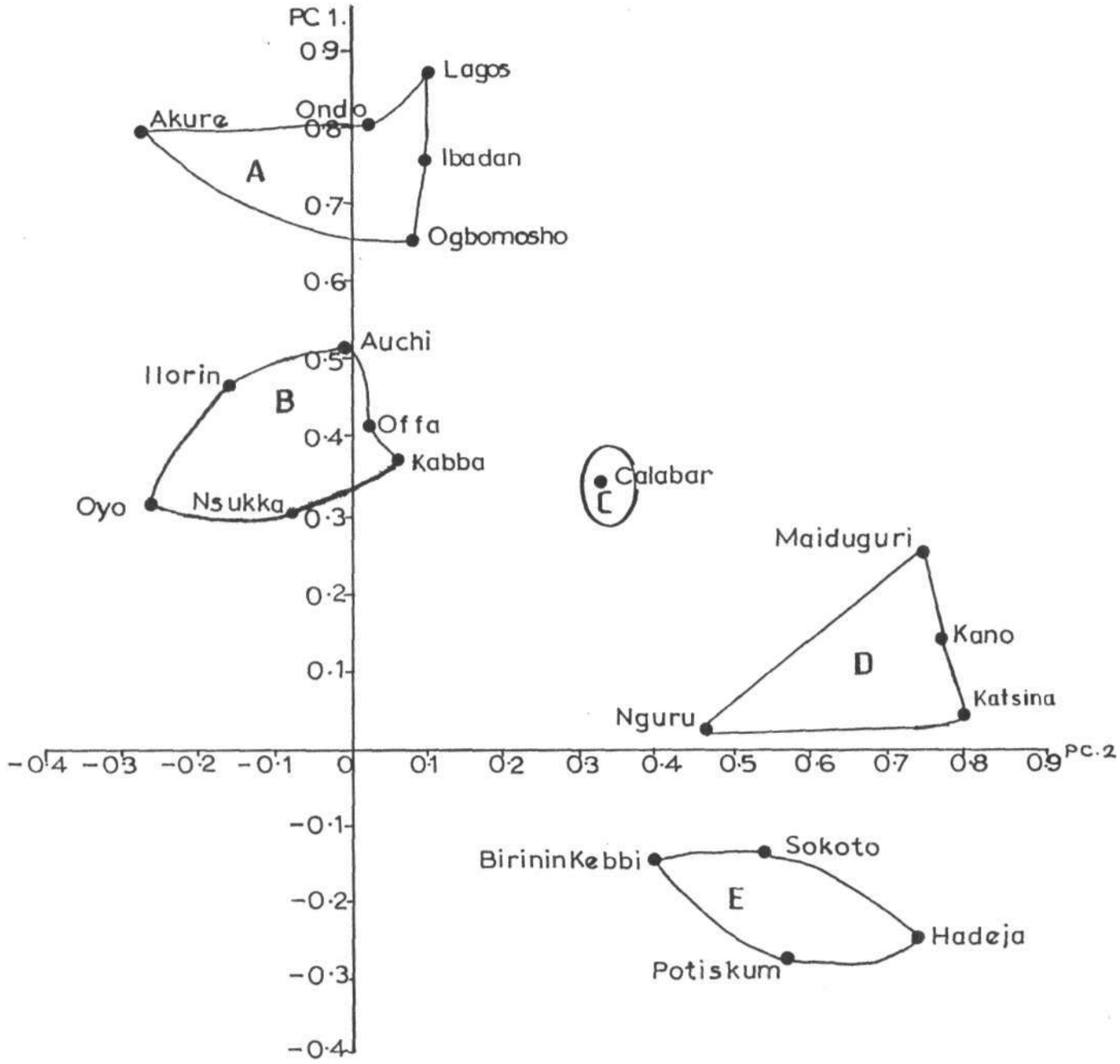



FIG. 5.2. VARIMAX ROTATED PC STRUCTURE INDICATING ASSOCIATIONS BETWEEN STATIONS IN THE COORDINATE SYSTEM 5.2.1: PC1-PC2

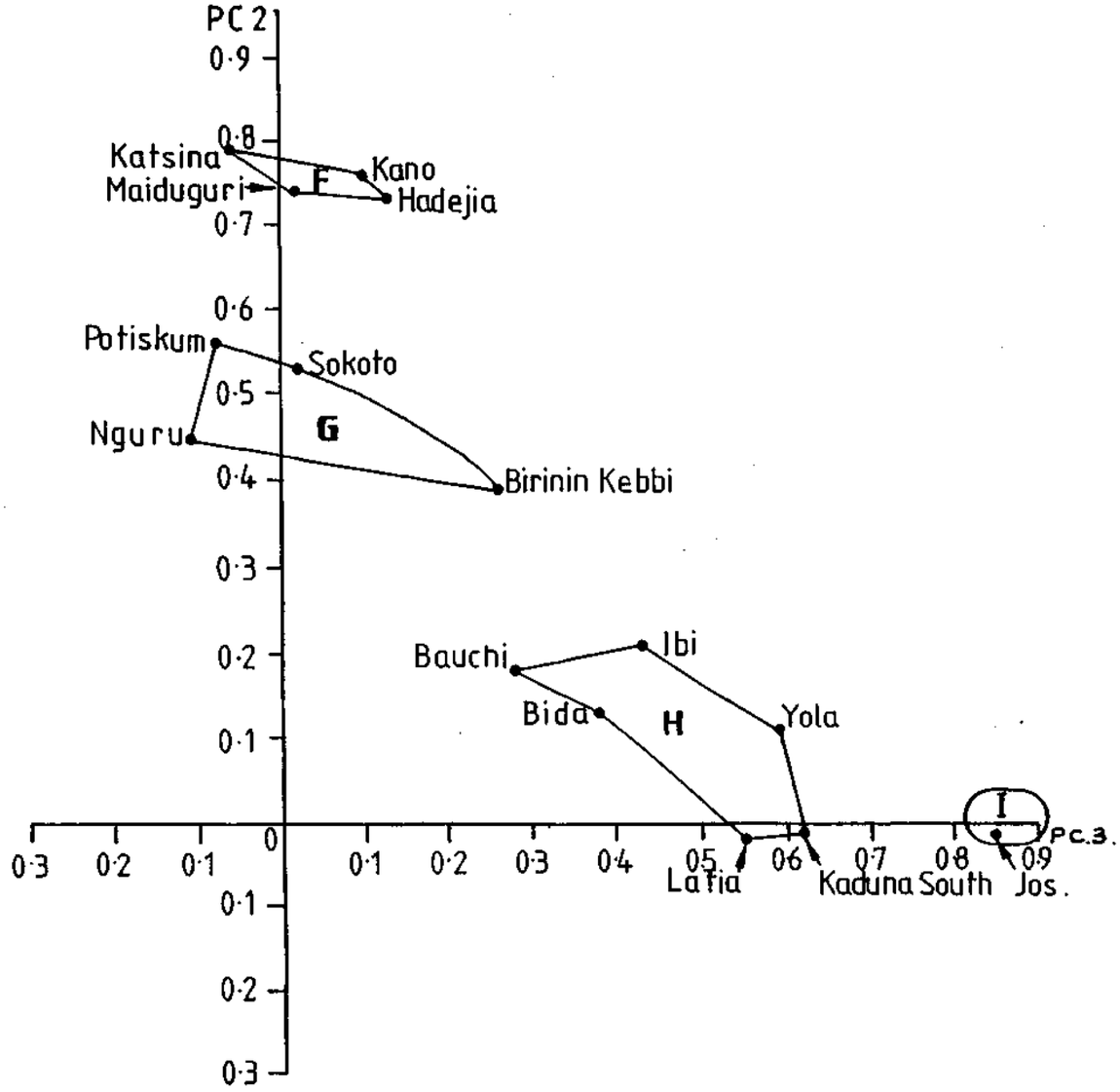



FIG. 5.2. VARIMAX ROTATED PC STRUCTURE INDICATING ASSOCIATIONS BETWEEN STATIONS IN THE COORDINATE SYSTEM 5.2.2: PC2-PC3

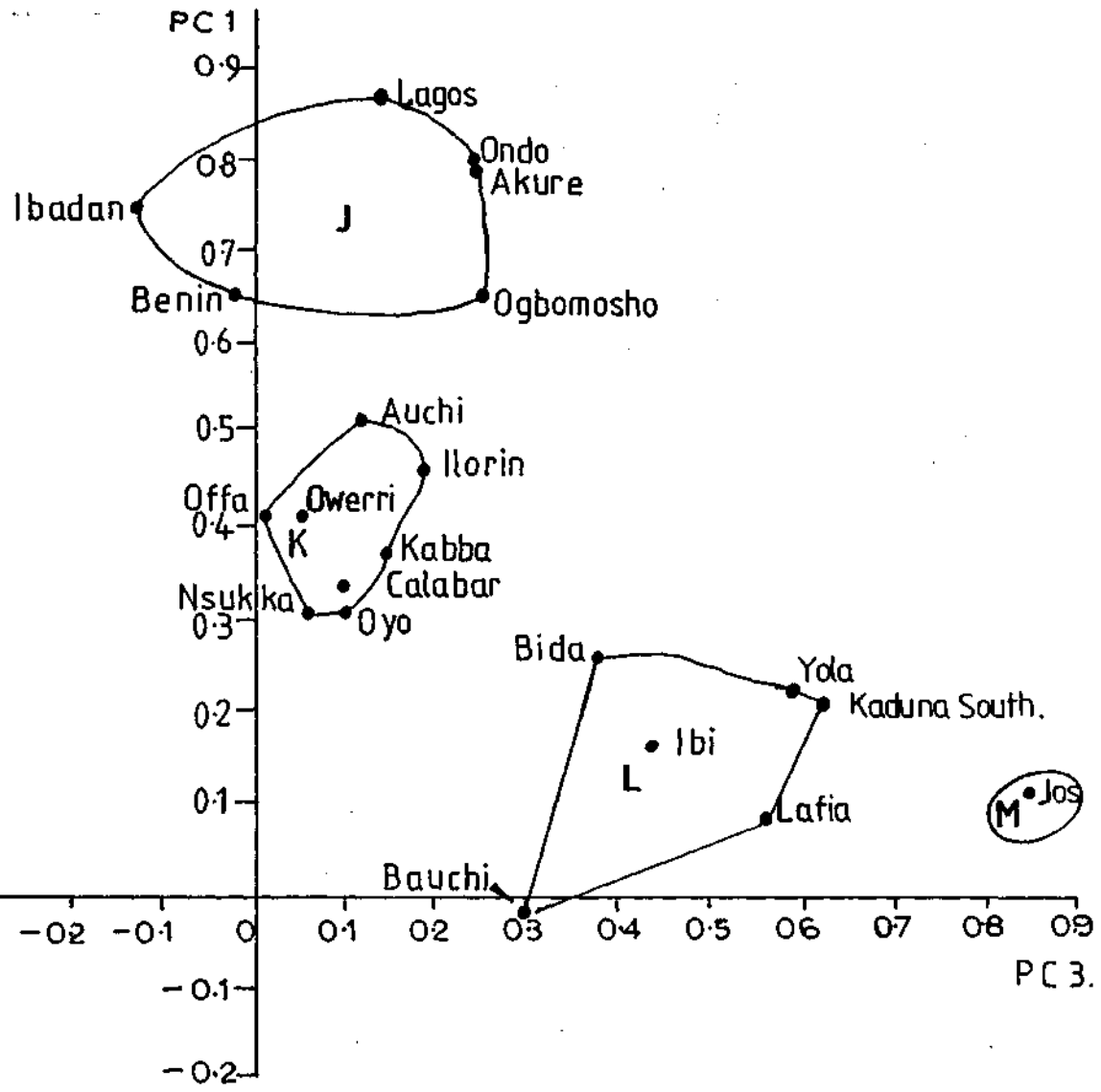



FIG. 5.2. VARIMAX ROTATED PC STRUCTURE INDICATING ASSOCIATIONS BETWEEN STATIONS IN THE COORDINATE SYSTEM 5.2.3 : PC1 - PC3

Group I, which may be referred to as the Southern Coastal Area includes Lagos, Benin, Ondo, Kwale, Owerri and, Port-Harcourt. Group III designated the Southern Upland stretches from south-west to south-east comprising of Ogbomosho, Oyo, Ilorin, Offa, Ibadan, Akure, Auchi, Nsukka and Enugu. These three Groups (I, II, and III) are described by PC1. Generally, they are influenced by the moist mT air mass and their nearness to the sea. These groups experience high rainfall and long rainy season, but Calabar experiences the highest rainfall amounts due to effects of relief. The south-west (Ilorin, Akure, Ibadan, Kabba and others) experiences little dry season for two to three weeks. Group IV, called the Middle Belt includes Lafia, Yola, Ibi, Bida and Kaduna South. This is described by PC3. Most of the stations lie within the Niger-Benue trough and receive moderate amounts of rainfall as a result of the low-lying nature of the trough. Group VI referred to as North-West comprises Sokoto, Birnin Kebbi and Yelwa while Group VII designated North-East is made up of Katsina, Kano, Hadejia, Potiskum, Maiduguri and Nguru. Both, described by PC2 are greatly influenced by the north-easterlies from the Sahara desert and their continentality. The two Groups (VI and VII) experience the least amount of rainfall, although Group VII is usually drier than Group VI because of the rain-shadow effects of the North Central Plateau. Generally, Groups III,IV,V,VI and VII have shorter periods of rainy season (May - October) and longer periods of dry season (November-April). They also experience minimum rainfall peak in August when the ITD is in its northernmost limit.

Perhaps, the only study of this nature in Nigeria was that of Ayoade (1977). He used three classification procedures, namely, Factor Analysis, Elementary Linkage Analysis, and

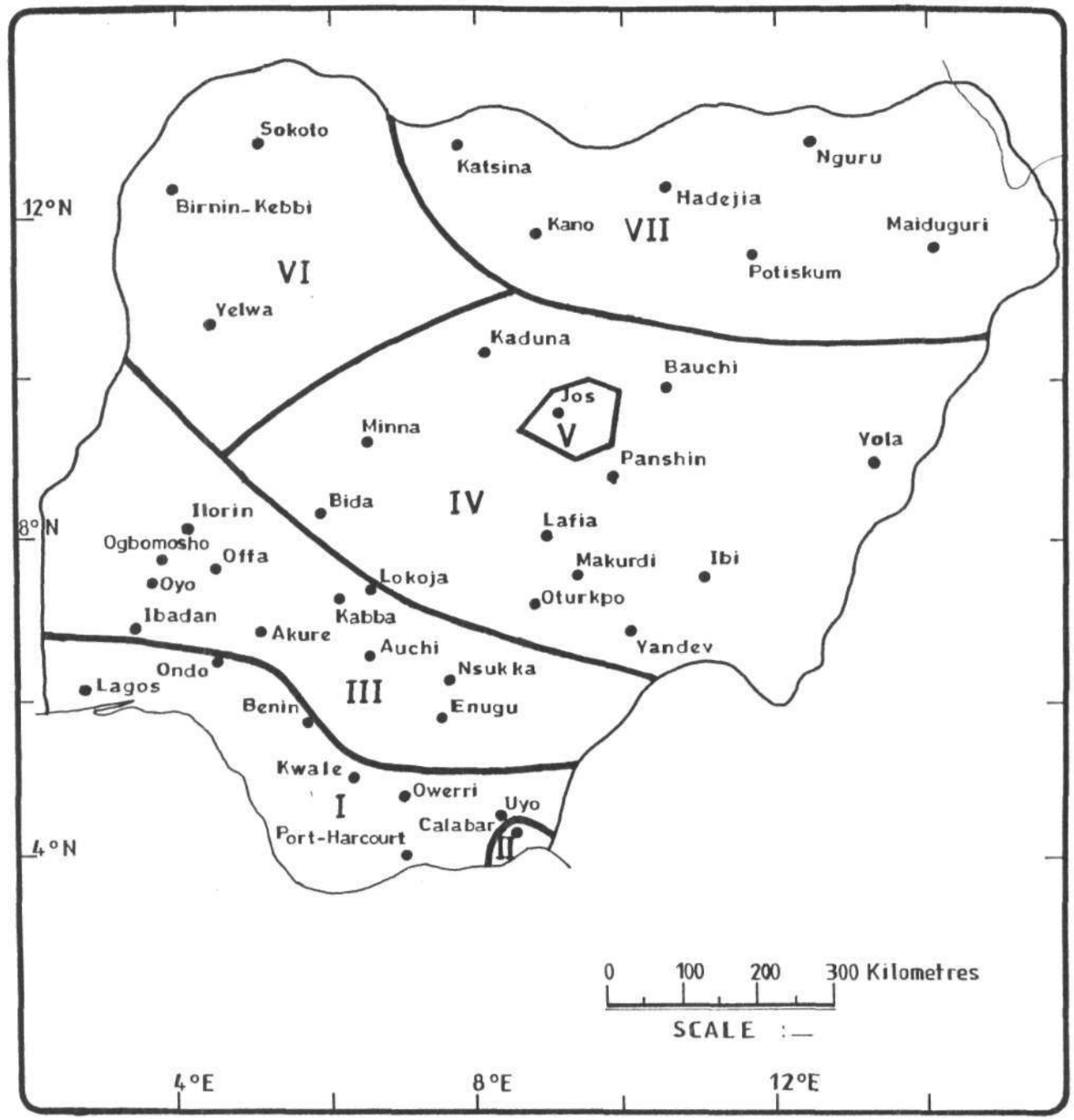



Fig. 5.3. Spatial distribution of homogeneous regional groups of Nigeria obtained by PCA .

Hierarchical Grouping Method to divide Nigeria into seven rainfall regions. His result does not generally agree with the seven regional groups obtained in this study. Only his groups I, and III have some similarity with groups V, VI and VII of this study. The apparent dissimilarity could be attributed to the method and variables employed in each case. His study used ten rainfall variables (mean annual rainfall, rainfall seasonality index, run-off coefficients and so on) which were collapsed into two factors, while this study was based on annual rainfall only. From the results, it is clear that for a more effective regionalization to be obtained, over one hundred stations should be used as opposed to Ayoade's thirty-two and forty in this study.

# CHAPTER 6

## SUMMARY AND CONCLUSIONS

### 6.1 OVERVIEW OF THE STUDY

Rainfall in Nigeria is the most important source of water supply and is therefore the principal controlling element in agriculture. The amount of rainfall received determines which types of farming could be carried out. However, the rainfall variability from year to year is the main factor responsible for the agricultural yields and total agricultural production. Either a deficiency or a surplus of rain can cause crop failure. Consequently there is the need to characterize the country's rainfall in order to understand the availability of water resources and shed some light on the spatial and temporal factors that cause changes in the rainfall distribution. Such a characterization would help in the planning of agricultural activities.

In the Literature Review some of the methods employed in rainfall classification and regionalization were examined. These included the Elementary Linkage Analysis, Map-pattern or Correlation Technique, Factor Analysis and Principal Component Analysis. Because of the tremendous amount of data involved (46,152 observations) it was necessary to employ an analysis procedure that permitted a large reduction in the amount of data, but still providing little or no loss of information about the spatial variability of rainfall in the country. The Principal Component Analysis was adjudged most suitable and modern, taking the advantage of high speed electronic computers.

The data for the study were obtained from the Nigerian Meteorological Services, Oshodi, Lagos. The data set comprised daily rainfall records of sixty-nine stations for the period between 1901 and 1984. The rainfall stations, which represent the best available network of climatological stations were randomly selected, ensuring even distribution all over the country. Since the validity of a study of this nature depended on the quality of the input data and the hypothesis, the annual rainfall data for each of the forty stations selected for PCA were subjected to initial statistical tests. These tests included test for homogeneity and randomness, test for normality and test for trends against randomness. The trend of the original rainfall series was smoothed using a five-year moving average between the period 1901 - 1984 for some selected representative stations to illustrate the changing patterns in the annual rainfall.

## 6.2 RESULTS OF THE STUDY

### 6.2.1 Initial Statistical Tests

The results of the initial statistical tests were revealing. The Swed and Eisenhart's (1943) runs test for homogeneity and randomness showed that with the exception of Ibi, the series for each of the stations were homogeneous and random at 5% significance level. There were too many runs for Ibi which suggested oscillations in the series. In the test for normality, it was discovered that the series for 85% of the stations were normally distributed. This implied that statistical tests (such as correlation) which imply normality could be applied to the series. The Mann-Kendall Rank

test for trends against randomness showed that the series for 75% (30) of the stations were influenced by random processes. The randomness did not exhibit any regional patterns. However, the remaining 25% (Birnin Kebbi, Katsina, Lokoja, Oturkpo, Minna, Kano, Potiskum, Nguru, Pankshin and Calabar) showed negative trends which appeared to be regional.

6.2.2 General Characteristics Of Nigerian Rainfall

The spatial patterns of the mean annual rainfall, mean monthly rainfall, and the coefficient of variations of mean monthly rainfall were mapped using the descriptive statistics generated during the preliminary analysis.

The results showed that in the case of mean annual rainfall, the rainfall decreased both in duration and amount from the coast to the interior except where orographic effects produced higher rainfall amounts, for instance, the Jos Plateau. The coastal areas received amounts between 2000mm and 3000mm, spread over 8 - 10 months while the extreme north received less than 500mm spread over 3 - 4 months. The results also indicated that Nigeria appeared to have high, medium and low rainfall zones. The rainfall during the rainy season accounted for over 80% of the mean annual rainfall.

However, considering the mean monthly rainfall, there is a general east-to-west and north-to-south decrease in the amounts with the isohyets running east to west. The dry season rainfall was experienced only at the coasts while the rainfall from July to August was generally widespread and less variable

across the country. The 'Little' dry season appeared to be most marked in the south-western Nigeria.

The coefficient of variation of mean monthly rainfall was found to be generally inversely related to the mean monthly values. Low CVs were observed over high rainfall areas and high CVs over low rainfall areas.

The trend of a five-year moving average for some selected representative stations showed that the country had wetter years in the decade 1951 - 1960, particularly in the south. The drier episode occurred in the mid-1930s and 1940s. Rainfall in 1969 - 1973 was scanty, resulting in the historic drought of that period, especially in the north. Generally, there has been alternating upward and downward trends over the years in the country's annual rainfall.

### 6.2.3 The Characterization Problem

The Principal Component Analysis reduced the original data set, which contained forty variables (stations) down to thirteen uncorrelated variables (the principal components) which explained 81.3% of the total variance. The first three components which accounted for 42.2% of the total variance were considered significant after applying the varimax orthogonal rotation. Owing to their location, the first component is named the Southern Component, the second, the Northern Component and the third, the Middle-Belt Component.

The Southern Component which accounted for 24.3% of the total variance explained rainfall variations most frequently found in the south and portrays the degree to which stations covary with the seasonal duration and intensity of rainfall across the region. The Northern Component explained 11.2% of the total variance and is correlated with the far north. The region described by this component is characterised by low amounts of rainfall. The Middle-Belt Component is correlated with the Middle-Belt and extends into the windward side of the Adamawa Highlands in the north-east. It explained 6.7% of the total variance and is characterised by moderate amounts of rainfall.

In order to classify the rainfall stations into homogeneous regional groups, the significant component loadings of PC1 (Southern Component) were plotted against PC2 (Northern Component), then, PC2 against PC3 (Middle-Belt Component). PC1 against PC3 and the resulting distinct cluster of stations mapped. From the spatial distributions, seven rainfall regional groups could be identified, namely the Southern Coastal Area, Calabar, Southern Upland, Middle-Belt, Jos, North-west and North-east.

The result of this study was found to be slightly in agreement with a similar study by Ayoade (1977), who classified Nigeria into seven regional groups. Only his groups I (far north) and III (Jos) had some similarities with groups VI (North-west), VII (North-east) and V (Jos) in this study. The apparent

dissimilarities could be attributed to the method and variables employed in each case. His study was based on ten rainfall variables which were collapsed into two factors, while this study was based on annual rainfall only.

## 6.3 A CRITIQUE OF THE STUDY

The overall purpose of this study was to investigate the characteristics of rainfall in Nigeria with a view to grouping the country into homogeneous rainfall regional groups based on the technique of principal component analysis. Seven such rainfall regional groups were identified, namely, the Southern Coastal Area, Calabar, the Southern Upland, the Middle-Belt, Jos, the North-west and the North-east.

The result obtained is important for agro-climatological purposes, especially with regards to planting dates for different seasonal crops. Periods of moisture can easily be determined in each regional group and appropriate schedules for supplementary irrigation and effective drainage system can be designed to minimize risks of prolonged spells and stabilize farming. These regional groups may be used in developing a network of representative observatory stations.

The result of the study could be said to be reasonable within some constraints and limitations. With hindsight, at least one hundred rainfall stations as opposed to Ayoade's thirty-two and forty in this study should have been used to obtain a better characterization. Sixty-nine rainfall stations were selected for the study but only two-thirds could be used since the other one-third contained many years of missing values.

Certain analyses, such as the temporal analysis and regression analysis could not be done because of time constraint. Also further analyses could not be done due to inadequate computer facilities occasioned by the present economic circumstances in the country.

## 6.4 SUGGESTIONS FOR FURTHER RESEARCH

It should be noted that the results of this study were based on annual rainfall and no attempts were made to examine the seasonal data, mean monthly values, runoff coefficients, coefficient of variation of annual rainfall, and rainfall seasonality index. Consequently, it will be interesting to repeat the principal component analysis using the standardised annual rainfall totals, April - October totals, the standardised April - October total and natural logarithmic transformations of annual rainfall and April - October totals. Further more, temporal analysis could also be done on each of the above mentioned data.

It is however, hoped that this characterization study could serve as a starting point for further studies of the regional differences in rain-generating processes.

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APPENDIX A: COMPUTER PROGRAM (IN FORTRAN IV) FOR COMPUTING THE DESCRIPTIVE STATISTICS/MEASURES OF DISPERSION AND SUMMERIZATION OF THE RAINFALL DATA, STATION BY STATION

```
0001          PROGRAM CLIMATE
0002          DIMENSION RAIN(90,15),YSUM(15),YMEAN(15),MISS(15),N(15),IYEAR(90)
0003         1SUMSD(15),SD(15),IS(90),COEFF(15),MFLG(90)
0004          COMMON IPAGE,SNAME(7)
0005          OPEN(UNIT=5,FILE='INDATA.DAT',STATUS='OLD')
0006          OPEN(UNIT=2,FILE='INSET.DAT',STATUS='OLD')
0007          OPEN(UNIT=6,FILE='MEAN_INTERANNUAL.LIS',STATUS='NEW')
0008          OPEN(UNIT=7,FILE='APROCT_TOT.DAT',STATUS='NEW')
0009          OPEN(UNIT=8,FILE='OUTFILE.LIS',STATUS='NEW')
0010          OPEN(UNIT=9,FILE='STANDARD_TOT.DAT',STATUS='NEW')
0011          IPAGE=0
0012          IST=0
0013          WRITE(6,7778)
0014     7778 FORMAT(10X,'STATION',28X,'MEAN-INTER',9X,'N')
0015     11   LNCT=0
0016          DO 20 K=1,15
0017          YSUM(K)=0.0
0018          YMEAN(K)=0.0
0019          MISS(K)=0
0020          N(K)=0
0021          SUMSD(K)=0.0
0022          SD(K)=0.0
0023          COEFF(K)=0.0
0024     20   CONTINUE
0025          READ(2,21,END=99)NYEAR,YRANGE1,YRANGE2,YREST,(SNAME(I),I=1,7)
0026     21   FORMAT(I2,1X,2A4,A1,1X,7A4)
0027          DO 22 I=1,NYEAR
0028          MFLG(I)=0
0029          DO 22 J=1,15
0030          RAIN(I,J)=0.0
0031     22   CONTINUE
0032          DO 23 I=1,NYEAR
0033          READ(5,24)IYEAR(I),(RAIN(I,J),J=1,12),IS(I)
0034     23   CONTINUE
0035     24   FORMAT(I4,12F6.1,1X,I2)
0036          DO 26 I=1,NYEAR
0037          DO 26 J=1,12
0038          IF (RAIN(I,J).EQ.9999.9)GO TO 25
0039          YSUM(J)=YSUM(J)+RAIN(I,J)
0040          N(J)=N(J)+1
0041          GO TO 26
0042     25   MISS(J)=MISS(J)+1
0043     26   CONTINUE
0044          DO 27 J=1,12
0045          YMEAN(J)=YSUM(J)/N(J)
0046     27   CONTINUE
0047          DO 28 I=1,NYEAR
0048          DO 28 J=1,12
0049          IF (MISS(J).LE.5.AND.RAIN(I,J).EQ.9999.9)RAIN(I,J)=YMEAN(J)
0050     28   CONTINUE
0051          DO 33 J=1,14
0052          N(J)=0
0053          YMEAN(J)=0.0
0054          YSUM(J)=0.0
0055     33   CONTINUE
0056          DO 34 I=1,NYEAR
0057          DO 34 J=1,12
```

```
0058            IF(RAIN(I,J).EQ.9999.9)GO TO 5
0059            N(J)=N(J)+1
0060            RAIN(I,13)=RAIN(I,13)+RAIN(I,J)
0061            IF(J.GT.3.AND.J.LT.11)RAIN(I,14)=RAIN(I,14)+RAIN(I,J)
0062            IF(J.GT.3.AND.J.LT.11)N(14)=N(14)+1
0063            YSUM(J)=YSUM(J)+RAIN(I,J)
0064            GO TO 34
0065    5       MFLG(I)=1
0066    34      CONTINUE
0067            N(13)=0
0068            N(14)=0
0069            DO 9 I=1,NYEAR
0070            IF(RAIN(I,13).EQ.0.0.OR.MFLG(I).EQ.1) GO TO 8
0071            YSUM(13)=YSUM(13)+RAIN(I,13)
0072            N(13)=N(13)+1
0073            GO TO 9
0074    8       RAIN(I,13)=9999.9
0075    9       CONTINUE
0076            DO 1111 I=1,NYEAR
0077            IF(RAIN(I,14).EQ.0.0.OR.MFLG(I).EQ.1) GO TO 1112
0078            YSUM(14)=YSUM(14)+RAIN(I,14)
0079            N(14)=N(14)+1
0080            GO TO 1111
0081    1112    RAIN(I,14)=9999.9
0082    1111    CONTINUE
0083            DO 1113 I=1,NYEAR
0084            IF(RAIN(I,13).EQ.9999.9.OR.RAIN(I,14).EQ.9999.9)GO TO 1113
0085            RAIN(I,15)=(RAIN(I,14)/RAIN(I,13))*100
0086            YSUM(15)=YSUM(15)+RAIN(I,15)
0087            N(15)=N(15)+1
0088    1113    CONTINUE
0089            DO 38 J=1,15
0090            YMEAN(J)=YSUM(J)/N(J)
0091    38      CONTINUE
0092            DO 41 I=1,NYEAR
0093            DO 41 J=1,15
0094            IF (RAIN(I,J).EQ.9999.9) GO TO 41
0095            SUMSD(J)=SUMSD(J)+(RAIN(I,J)-YMEAN(J))**2
0096    41      CONTINUE
0097            DO 42 J=1,15
0098            SD(J)=SQRT(SUMSD(J)/FLOAT(N(J)-1))
0099            IF(YMEAN(J).EQ.0) GO TO 13
0100            COEFF(J)=(SD(J)/YMEAN(J))*100.0
0101            GO TO 42
0102    13      COEFF(J)=9999.9
0103    42      CONTINUE
0104            DO 45 I=1,NYEAR
0105            WRITE(7,46)IYEAR(I),RAIN(I,14),IS(I)
0106    45      CONTINUE
0107    46      FORMAT(I4,1X,F7.1,1X,I2)
0108            N1=NYEAR-1
0109            AINTER=0.0
0110            N2=0
0111            DO 7777 I=1,N1
0112            IF(RAIN(I+1,14).EQ.9999.9.OR.RAIN(I,14).EQ.9999.9)GO TO 7777
0113            N2=N2+1
0114            AINTER=AINTER+ABS(RAIN(I+1,14)-RAIN(I,14))
```

```
0115     7777  CONTINUE
0116           IST=IST+1
0117           AINTER=AINTER/FLOAT(N2-1)
0118           N2=N2+1
0119           WRITE(6,7780)IST,(SNAME(J),J=1,7),AINTER,N2
0120     7780  FORMAT(9X,I2,1X,7A4,2X,F12.4,8X,I3)
0121           WRITE(8,9930)(SNAME(J),J=1,7)
0122     9930  FORMAT(40X,'STATION: ',7A4/20X,'YEAR',2X,'APRIL-OCT',3X,'STANDARD'
0123          1,13X,'MEAN DEVIATION')
0124           DO 9931 I=1,NYEAR
0125           IF(RAIN(I,14).EQ.9999.9)GO TO 9932
0126           PDEV=(RAIN(I,14)-YMEAN(14))
0127           ST=(RAIN(I,14)-YMEAN(14))/SD(14)
0128           GO TO 9933
0129     9932  PDEV=9999.9
0130           ST=9999.9
0131     9933  WRITE(6,9934)IYEAR(I),RAIN(I,14),ST,PDEV
0132     9934  FORMAT(20X,I4,2X,F8.1,4X,F7.2,13X,F12.2)
0133           WRITE(9,9935)IYEAR(I),ST,IS(I)
0134     9935  FORMAT(I4,1X,F7.2,1X,I2)
0135     9931  CONTINUE
0136           GO TO 11
0137     99    STOP
0138           END
```

PROGRAM SECTIONS

| | Name | Bytes | Attributes |
|---|---|---|---|
| 0 | $CODE | 1403 | PIC CON REL LCL SHR EXE F |
| 1 | $PDATA | 280 | PIC CON REL LCL SHR NOEXE F |
| 2 | $LOCAL | 7116 | PIC CON REL LCL NOSHR NOEXE F |
| 3 | $BLANK | 32 | PIC OVR REL GBL SHR NOEXE |
| | Total Space Allocated | 8831 | |

ENTRY POINTS

| Address | Type | Name |
|---|---|---|
| 0-00000000 | | CLIMATE |

VARIABLES

| Address | Type | Name | Address | Type | Name | Address |
|---|---|---|---|---|---|---|
| ** | R*4 | AINTER | 2-00001B04 | I*4 | I | 3-00000000 |
| ** | I*4 | J | ** | I*4 | K | ** |
| ** | I*4 | N2 | 2-00001AF4 | I*4 | NYEAR | ** |
| 2-00001AF8 | R*4 | YRANGE1 | 2-00001AFC | R*4 | YRANGE2 | 2-00001B00 |

```
0001           SUBROUTINE PAGER(YRANGE1,YRANGE2,YREST)
0002           COMMON IPAGE,SNAME(7)
0003           IPAGE=IPAGE+1
0004           WRITE(6,29)IPAGE
0005     29    FORMAT(1H1,30X,'MONTHLY RAINFALL TOTALS FOR SYNOPTIC STATIONS IN
0006          1NIGERIA',32X,'PAGE ',I3)
0007           WRITE(6,30)YRANGE1,YRANGE2,YREST
0008     30    FORMAT(/46X,'PERIOD COVERED: ',2A4,A1)
0009           WRITE(6,31)(SNAME(I),I=1,7)
0010     31    FORMAT(/46X,'STATION: ',7A4)
0011           WRITE(6,32)
0012     32    FORMAT(/02X,'YEAR      JAN      FEB    MARCH    APRIL      MAY     JUNE
0013          1    JULY      AUG     SEPT      OCT      NOV      DEC   TOTAL APR-OCT
0014          2SEA-ANN'/)
0015           RETURN
0016           END
```

PROGRAM SECTIONS

| | Name | Bytes | Attributes |
|---|---|---|---|
| 0 | $CODE | 163 | PIC CON REL LCL SHR EXE RD |
| 1 | $PDATA | 255 | PIC CON REL LCL SHR NOEXE RD |
| 3 | $BLANK | 32 | PIC OVR REL GBL SHR NOEXE RD |
| | Total Space Allocated | 450 | |

ENTRY POINTS

| Address | Type | Name |
|---|---|---|
| 0-00000000 | | PAGER |

VARIABLES

| Address | Type | Name | Address | Type | Name | Address | Ty |
|---|---|---|---|---|---|---|---|
| ** | I*4 | I | 3-00000000 | I*4 | IPAGE | AP-00000004@ | R |
| AP-0000000C@ | R*4 | YREST | | | | | |

ARRAYS

| Address | Type | Name | Bytes | Dimensions |
|---|---|---|---|---|
| 3-00000004 | R*4 | SNAME | 28 | (7) |

APPENDIX B: COMPUTER PROGRAM (IN DBASE IV) FOR MANN-KENDALL RANK TEST FOR EACH OF THE FORTY STATIONS

```
set talk off
clear all
clear
set decimals to 4
select c
use stations
declare a[53], b[53]
i = 1
n = 53
do while i <= n
   a[i] = 0
   b[i] = 0
   i = i + 1
enddo
set print on
i = 1
select c
Do while .not. eof()
   b[i] = c->aproct
   i = i + 1
   skip
enddo
i = 1
k = 1
do while i <= n
   j = i + 1
   do while j <= n
      if b[i] < b[j]
         a[k] = a[k] + 1
       endif
       j = j + 1
    enddo
    k = k + 1
    i = i + 1
 enddo
tot = 0
l = 1
Do while .not. l > n
   tot = tot + a[l]
   l = l + 1
enddo
t = ((4 * tot) / (n * (n - 1))) - 1
temp1 = (4*n+10) / (9*n*(n-1))
tt1 = 1.96 * sqrt(temp1)
tt2 = -tt1
? [X40: ], n, tot, t, tt1, tt2
close databases
close all
set prin off
Return
```

## APPENDIX C: COMPUTER PROGRAM FOR PRINCIPAL COMPONENT ANALYSIS (IN SPSS-X)

```
SET LENGTH = NONE WIDTH = 132
TITLE         PRINCIPAL COMPONENT ANALYSIS OF RAINFALL
FILE HANDLE   ANNM / NAME = 'ANNTOT.DAT'
DATA LIST FILE = ANNM RECORDS = 4
   /1 BENIN,CALABAR,ONDO,JOS,MAIDUGUR,BKEBBI,YANDEV,OWERI,BIDA,
      KADSOUTH
      (4X,10(1X,F6.1))
   /2 MAKURDI,PH,ILORIN,KATSINA,YOLA,YELWA,LOKOJA,AKURE,
      OTURKPO,ENUGU
      (4X,10(1X,F6.1))
   /3 NSUKA,SOKOTO,MINNA,KANO,POTISKUM,IBI,NGURU,
      BAUCHI,KABBA,OGBOMOSH
      (4X,10(1X,F6.1))
   /4 LAFIA,IBADAN,AUCHI,LAGOS,OYO,UYO,KWALE,
      OFFA,HADEJIA,PANSHIN
      (4X,10(1X,F6.1))
   FACTOR VARIABLES=BENIN TO PANSHIN/
       ANALYSIS=BENIN TO PANSHIN/
   CRITERIA=ITERATION(90)/
   EXTRACTION=PC/
   PRINT=CORRELATION SIG KMO EXTRACTION ROTATION/
   ROTATION=VARIMAX/
   ROTATION=OBLIMIN/
   ROTATION=EQUIMAX/
   ROTATION=QUARTIMAX
```