THE INTENSITY AND EROSIVITY OF RAINSTORMS IN NIGERIA

BY

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CERTIFICATION

Thesis entitled "The Intensity and Erosivity of Rainstorms in Nigeria" by Commander Stephen O. Aiyepeku, meets the regulations governing the award of Doctor of Philosophy of Ahmadu Bello University, and it is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This work is dedicated to my wife, Mrs. Tayo Aiyepeku and to my children Dupe, Bola and Funke, for their patience during my course in ABU.

DECLARATION

I hereby declare that this thesis has been composed by myself and that it is a record of my own research work. It has not been presented in any previous application for a higher degree. All sources of information are specifically acknowledged by means of references.

S. O. AIYEPEKU
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January 1993

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ABSTRACT

This work is a study of the intensity and erosivity of rainstorms in Nigeria. Intensities and erosivity of 34,288 rainstorms spread throughout the country and over a period of 10 years (1960 to 1970) were quantified from autographic rainfall charts.

The limit of erosive intensities was determined by using the Hudson KE > 25. The spatial variation of intensities showed that the proportion of non-erosive intensities that were less than 25mm hr^{-1} was high in the South and decreased with latitude. Conversely, the proportion of erosive storms increased with latitude northward. The temporal variation of monthly mean intensive rainstorms in most southern stations showed high values at the beginning and at the end of the rainy season, with low values between July and September.

A comparison of the relative performance of the three erosivity indices of Wischemeier's EI_{30} Hudson's KE > 25 and Lai's AI_{10} show that Lai's AI_{10} erosivity index is the most applicable to the Nigerian environment.

From the iso-erodent map constructed for the country using Lai's AI_{10} index, it was noted that the annual erosivity in the country ranges from a maximum of 140cm^2 hr^{-1} in northwestern Nigeria to a maximum of 1,759 cm^2 hr"^{1} in the Niger Delta area. The values decrease with latitude, showing a distribution that suggests a strong influence of the ITD's differentiated weather zones, coupled with local topograhic differences.

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CHAPTER ONE

BACKGROUND TO THE STUDY

1.1 INTRODUCTION.

Soil erosion is the process whereby the surface layer of the whethered rock is loosened and carried away by agents of denudation such as ice, wind and running water. It is a very serious problem in the tropics as it has very serious environmental impacts that are hazardous to life. In Nigeria, many areas are being devastated by soil erosion. Examples of areas seriously affected are Enugu, Imo, Abia and Anambra States in the Eastern part of Nigeria.

In the former Imo State, over 80 erosion sites have been identified in the 21 Local Government Areas of the State (Nigerian Statesman, 22 June, 2985(a), p 3); Daily Times, 26 June, 1985 p 1. With a population density of 474 persons per square kilometre, the implication of the erosion sites on development have been very disastrous to say the least. Various hazards of soil erosion were summarized by Nigerian Ststeman of 3 August (1985 (b), p 7). These include uprooting of economic trees estimated at N103 million; devastation of 60 hectares of crops estimated at N20 million at Orlu - a major town in Imo state.

The former Anambra State (now made up of Anambra and Enugu States) consist of more rugged topography than the other States in the Eastern Nigeria. This has given rise to many more erosion

sites. Here, not only farmlands, but also roads, buildings and even whole communities in the Agulu - Nanka areas of the State have been affected by the menace of soil erosion. It was estimated by Dr. F.O.R Akamigbo, the Chairman of Anambra State Task Force on soil erosion, that to reclaim the 120 sq km erosion- ravaged area of Agulu-Nanka in the Aguata Local Government Area of the State would cost N1 million. This implies that, to reclaim the lands destroyed by erosion in Anambra State alone, there would be a need to sink nothing less than N2 billion (National Concord of 3
January, 1989, p.1).

Similarly, each of the 30 States of Nigeria including the Federal Capital Territory, Abuja, has its own area of very serious erosion hazard. And each of these areas manifests very serious consequences of the soil erosion menace. The estimated cost of controlling erosion in the country is, however, staggering and relatively unaffordable, especially as the national economy keeps dwindling. Yet, Nigeria cannot afford to wait. Waiting in the face of the potential effects of the erosion system in the affected areas could be very dangerous. Very soon, the affected areas will assume such alarming proportions that the present tale of woes would be a child's play. There is, therefore, a need to understand the factors of soil erosion with a view to finding the most cost-effective methods of controlling them in the shortest time possible.

Many factors contribute to the higher rate of soil erosion in the tropical areas than in other parts of the world. In

general, these factors include land management, nature of the soil (soil erodibility), climate and topography (Greenland and Lal, 1977; Morgan, 1979).

In order to conserve the soil against the hazard of soil erosion, the rate of soil erosion and the factors contributing to this rate should be properly understood. The rate of soil erosion is, however, a difficult parameter to measure directly. Consequently,the indirect measures are used to allow for fast determination of the rate of soil erosion. One of the indirect ways of determining the rate of soil erosion is through the use of the index of erosivity.

The use of erosivity as an indirect measure of the rate of soil erosion is, however, fraught with difficulties. First erosivity of rainfall is difficult to measure directly. Secondly, the rainfall records that can be used to estimate the values of erosivity are very scarce. There is, however, a need to estimate values of erosivity from whatever means available. In this study erosivity was measured indirectly from the available rainfall records of about 10 years between 1960 and 1970 at Oshodi Meteorological Station, Lagos.

1.2 AIM AND OBJECTIVES OF STUDY

The general aim of this study is to determined the nature of rainfall intensity and erosivity in Nigeria. Whithin this general aim, the specific objectives are to :

a. Provide data for the nature of rainfall intensity and

erosivity in Nigeria.

b. Determine the intensities of rainstorms at the Meteorological Stations in Nigeria.

c. Determine the erosivity of the rainstorms using their intensities and kinetic energies.

d. Investigate the spatial and temporal variations of the rainstorm characteristics over Nigeria.

e. Determine the erosivity index that best predicts soil erosion in Nigeria savanna, using the savanna area as the study case.

f. Examine the behaviour of the predictor index over space and time for the 10-year period of study.

g. Produce an Iso-erodent map of Nigeria on the basis of the predictor index of erosivity.

1.3 JUSTIFICATION AND SCOPE OF STUDY

Rainfall intensity is one of the three major features of rainfall. The others are the accumulated depth or amount of rainfall and rainstorm duration. The intensity of rainfall describes the rate at which rain falls. It helps to accurately quantify terms such as fine drizzle, light rain and torrential downpour, all which describe the rate at which rain falls.

The rate at which rain falls has many erosional and hydroclimatological consequences. When rain falls at a low intensity, for instance, rainwater gradually seeps into the soil

without doing much damage to the earth's surface. If it falls at a high intensity, however, considerable amount of soil erosion results (Ward, 1967). The first contribution to soil erosion caused by high intensity rainstorm is the mechanical work of raindrops on impact with the surface. Torrential rain with large individual drops can on the one hand, move particles of soil. On the other hand, it can cause compaction on the surface, thus accelerating runoff, and consequently increasing rate of soil erosion. It is through these two processes that high-intensity rainfall often contribute to the increasing rate of soil erosion.

From the general climatological point of view, information on rainfall intensity can be used meaningfully to differentiate the rainfall types prevalent in a given region and season. Likewise, it can help in the determination of the contribution of rainfall to the water-budget in various dormains. This is why information about intensity of rainfall is very vital.

One of the problems with the study of rainfall intensity is high degree of variation, and consequently the difficulty in measurement. Intensity varies considerably over time and space; it also varies among storms and even within a particular storm. The average of all the intensities are often indicated by the term 'mean intensity'. Similarly, the average values of the highest intensities experienced during the storms recorded in each station are termed 'mean peak intensities' of rainstorms. It should be noted that some intensity values are however, much higher than the mean values. It is during the periods of high-

intensity rainfalls that rainstorms do considerable amount of damage which results in soil erosion through the mechanical work of rainsdrops. There is therefore a need to examine the periods of high rainfall intensity.

In the southern part of Nigeria, there is often much more rain than can be profitably utilized. This excess water comes in form of rain and storm water which pose very serious erosion problems. In the northern Nigeria, on the other hand, the rainy season is erratic and often results into drought in some years. This is not to say that there is no erosional problems in the north. In fact the annual rains here consist of large rainfall amounts concetrated into a short rainy season and falling at high intensities. Thus, Nigeria is a land of extremes in terms of rainfall amount and the duration of rainy season. However, erosion is a serious problem not only in the south but all over the country. There is therefore a need to control soil erosion as fast as possible (Leow and Gardiner,1982; Leow and Ologe, 1984). The cost of controlling soil erosion is, however, staggering since all the 30 states of the country are affected by it; even though with unequal intensity. However, assuming that N2 billion was required to solve the menance of soil erosion in each of the 30 states of the Federation as in the case of Anambra State, it would therefore require nothing less than N60 billion to solve erosion problem in the country. This is appromixately Nigeria's annual budget for several years. The solution to erosion problem is, however, not a once-and-for-all affair. This is because as erosion is being solved in one place, it raises its ugly head in

another. Thus, the sum of N60 billion may be required may times over before the problem can be completely eradicated. This is the magnitude of the problem of soil erosion: the seriousness of which necessitiated the need to understand the characteristics of rainfall which are the prime mover of erosion. Meeting this need may contribute to developing techiques to cost-effectively curb erosion menance at the shortest possible time.

The rapid removal of soils resulting in the destruction of valuable land by agents of denudation such as torrential rains and runoff, is one of the enviromental hazards in contemporary Nigeria (Areola, 1978). Although the high rate of erosion occuring in Nigeria is due to high erodibility (Leow and Jaiyeoba, 1982; Leow and Gardiner, 1982) and man, whose activities result in the destabilization of the delicate balance between soils and vegetation (Dunne, 1977; Dunne et al, 1978; Ologe et al, 1982; Usoroh, 1969), one of the most important contributing factors is high erosivity. According to Pauwelyn et al, (1988), the erosivity of rainfall can be split into two components. The first component is the kinetic energy contained in raindrops hitting the soil. The impact of the raindrops detaches and displaces soil particles which are then delivered or taken up by overland flow.

The second component is the erosive power of the runnoff. It is equal to the energy that water generates by taking advantage of the slope gradient. This means that besides the climatic parameters, other information is needed before the erosive power of the runoff can be evaluated.

Bols (1978), has however, observed that in the tropics, kinetic energy of rainstorms is high enough to detach sufficient soil to saturate runoff with sediments. Consequently, the impact of overland flow on detachment was neglected. The detachment of soil particles is related to the kinetic energy of rainstorms while the amount of sediments entrained downslope is determined by the amount of runnoff water. Since runoff depends also on the amount and intensity of rainfall, erosivity can be approximated quite accurately by considering the kinetic energy of rainfall (Pauwelyn et al, 1988). This study has, therefore, concentrated only on the classical indices which associate erosivity with rainstorm activities.

1.4 ORGANIZATION OF STUDY

Chapter one provides the introduction which includes the aim and objectives of the study. Chapter Two reviews the literature on the relevant area of the subject. Chapter three provides a brief summary of rainfall characteristics and the mechanics of rainstorms in Nigeria. The summary is required as a background knowledge for understanding the intensity and erosivity of rainstorms in certain areas of the country.

Of special interest is Chapter Four which deals with the study area, data base and data assembly. Chapter five provides the analytical procedures and investigates which erosivity index is most applicable to the Nigerian Environment.

Chapter Six deals with the spatial and temporal variations

of mean rainfall intensities. Based on the best index considered applicable to the Nigerian environment, Chapter Seven gives the iso-erodent map computed for Nigeria using the index selected. Finally, Chapter Eight presents the summary of findings and conclusions.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Despite the widespread hazard of soil erosion in the tropics, and in Nigeria in particular, only very little progress has been made towards developing effective control techniques in the countries affected. This is because only very few of the countries have the resources required to apply the most widely advocated technique of the Universal Soil Loss Equation (U.S.L.E) developed by the United States Department of Agriculture (Wischmeier and Smith, 1978). The Universal Soil Loss Equation takes many of the factors of soil erosion into consideration. The USLE (Wischmeieier et al, 1958; and Hudson, 1975) incorporates both the land and rainfall factors that one needs to take into account when studying soil erosion. According to Wischmieier and Smith (1978), the USLE is given as:

$$A = R.K.LS.C.P \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

where A = Soil Loss (tonnes ha^{-1})

R = Rainfall erosivity index.

K = Soil erodibility index.

LS = Slope length factor (m); and slope gradient (percent).

C = Crop management factor

P = Erosion control practice factor.

The essence of the equation is to isolate each variable and quantify its erosional effect such that the product of the values of all the variables gives the amount of soil loss in the field

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concerned. The identification of factors of soil erosion led to the development of the USLE (Morgan, (1979); Wischmeier and Smith, 1978: Hudson 1975). Most of the factors are more frequently measured in the developed World than in the tropics where soil erosion is more widespread. The USLE can not therefore be applied easily. In order to utilize a more local data base Elwell and Stocking (1981) developed another framework for predicting soil erosion with the use of a Soil Loss Estimation Model for South Africa (SLEMSA).

The model developed in Tanzania, is given as:

$$Z = KCX \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.2)$$

where K = EF

C = Energy intercepted by crops (per cent)

X = SL

and where E = rainfall energy

F = soil erodibility index obtained by rating all solid from 1 to 10

S = slope steppness in degrees

L = slope length in (m).

Equations 2.1 and 2.2 are equally complex. The criticisms levied against the USLE will, also, therefore, apply to Soil Loss Estimation Model (SLEMSA). This is because very few countries affected by erosion have the resources to quantify all the factors involved in their calculations. What is needed therefore is an approach to soil loss estimation that is less complex and capable of dealing with soil degradation. To this end, rainfall

erosivity, which is the battering effect of raindrops on the soil surface leading to the detachment of soil particles, is often used. Wischmeier and Smith (1958) showed that the weight of water from raindrops falling in a 30-minute duration in a typical rain storm exceeds 250 tonnes per hectare. With an average velocity of about 200m hr^{-1}, the rainfall energy that is expended during a 30-minute period may exceed 1.4 million tonnes per hectare. Therefore, an average rainstorm possesses an energy potential that can lead to the breaking of soil aggregates and also cause compaction and sealing up of soil pores.

Until recently, erosion studies have focussed on runoff rather than rainfall erosivity. For example, Hudson (1971) quoted Bennet as syaing that "... the cutting and abrasive effect of runoff from rains and the melting of snow are of far more importance than raindrop splash". Hudson (1971), however, showed that rain has about 256 times more kinetic energy than surface runoff. This suggests that the primary cause of soil erosion is the impacting raindrops or erosivity that remove soil particles. Erosivity is, therefore, very important and should be accorded a high priority in the study of soil erosion (Elwell and Stocking, 1981). The erosivity of rainfall is a function of the kinetic energy of rainstorm (Ekern 1950). Kinetic energy is a difficult parameter to measure directly as the forces involved are so small that any instrument sufficiently sensitive to record them mechanically is liable to be swamped by wind effects. Thus, KE has been expressed as functions of the various factors. Such

factors are: (a) drop-size distribution of rainfall (b) terminal velocity of raindrops (c) wind velocity and intensity of rainfall (Moore, 1979; and Oladipo, 1984). In order to understand clearly how these factors affect kinetic energy, consideration will be given to the ralationships between kinetic energy and each of the factors.

2.2 FACTORS AFFECTING THE KINETIC ENERGY OF RAINSTORMS

2.2.1 DROPSIZE DISTRIBUTION OF RAINDROPS

Dropsize distribution shows the proportion of large raindrops to small ones. This proportion varies in different kinds of rain. The low intensity rains which last for a long time are often made up of small raindrops, while the high intensity rainstorms from tropical thunderstorm have much larger dropsizes (Hudson, 1971). The dropsize distribution of rainfall affects the kinetic energy because when the proportion of the large to small raindrops is high, rainstorm of high kinetic energy and erosivity results. Consequetly, the understanding of raindrop distribution in different rainstorms is useful for the study of rainfall momentum and enery in relation to erosion (Lal, 1981; Oladipo, 1984).

According to Hudson (1971), the median volume drop diameter D_{50}, is probably the best index for determining drop size distribution of rainfall. The median volume drop diameter, D_{50}, is the drop diameter such that half of a rainstorm falls in the form of drops with smaller diameter and half as bigger drops (Hudson, 1971; Oladipo, 1984). The median volume drop diameter is obtained from the plot of cumulative volume against drop diameter

as illustrated in Fig 2.1.

Some data obtained on dropsize distribution of rainstorms measured at Ibadan have indicated that most erosive rains have a D_{50} ranging between 1.70 and 2.55mm; and that D_{50} above 2.5mm is quite common (Lal, 1977). In another case study of drop size distribution of rainstorms at Samaru, Kowal and Kassam (1977) found that the median volume drop diameter was 3.42 mm with a range of 2.35 to 8.46mm.

Laws (1941) had earlier reported an increase in D_{50} with increase in rainfall intensity. This was confirmed in another independent study of Gunn and Kinzer (1949). In the studies, it was suggested that the relationship between D_{50} and storm intensity (I) is of the form:

$$D_{50} = aI^b \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

where a and b are constants. The Laws and Parson (1943) findings were therefore expressed in an equation as follows:

$$D_{50} = 2.231^{0.102} \quad \ldots\ldots\ldots\ldots (2.4)$$

where D_{50} = median volume drop diameter (mm)

I = intensity of rainstorms

Hudson (1971) pointed out that the relationship between median dropsize of a rainstorm and its intensity may only apply to low intenstiy ranges of temperate rainfall and may not hold true for erosive storms of the humid tropics. Measurements made at the International Institute of Tropical Agriculture (IITA), Ibadan indicated that no correlation existed between the median dropsize and intensity calculated for different time intervals. The median drop size was also found to be unrelated to sand

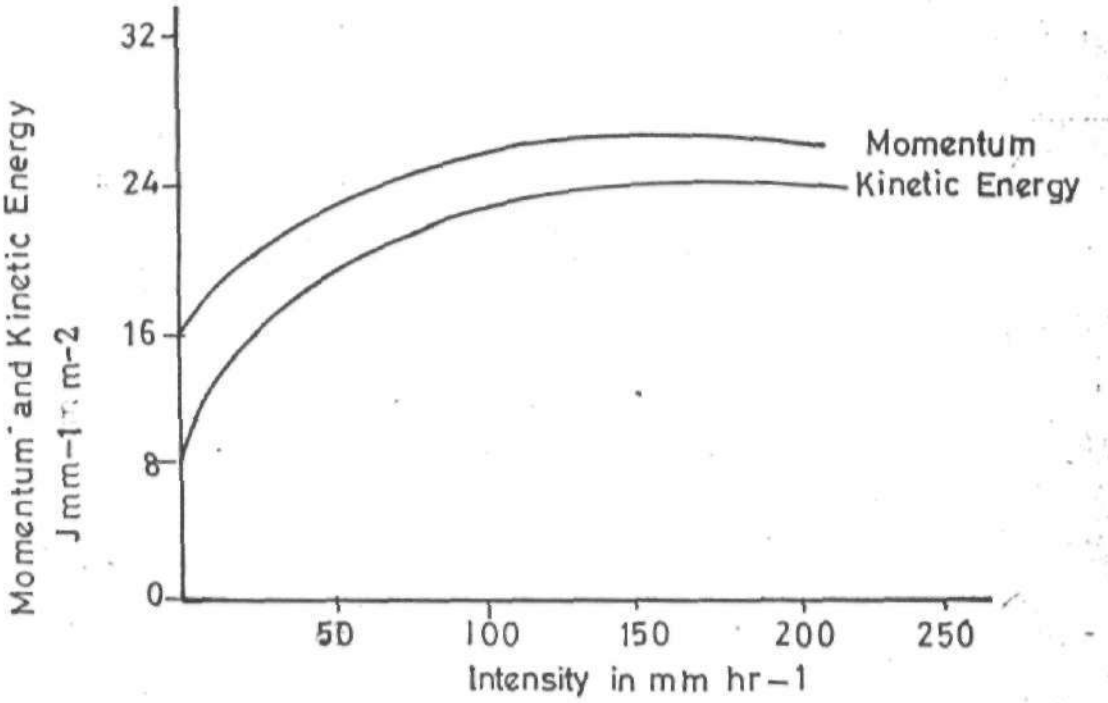


Fig. 2.1. A Comparism of Kinetic energy and momentum as function of intensity (After Hudson, 1971)

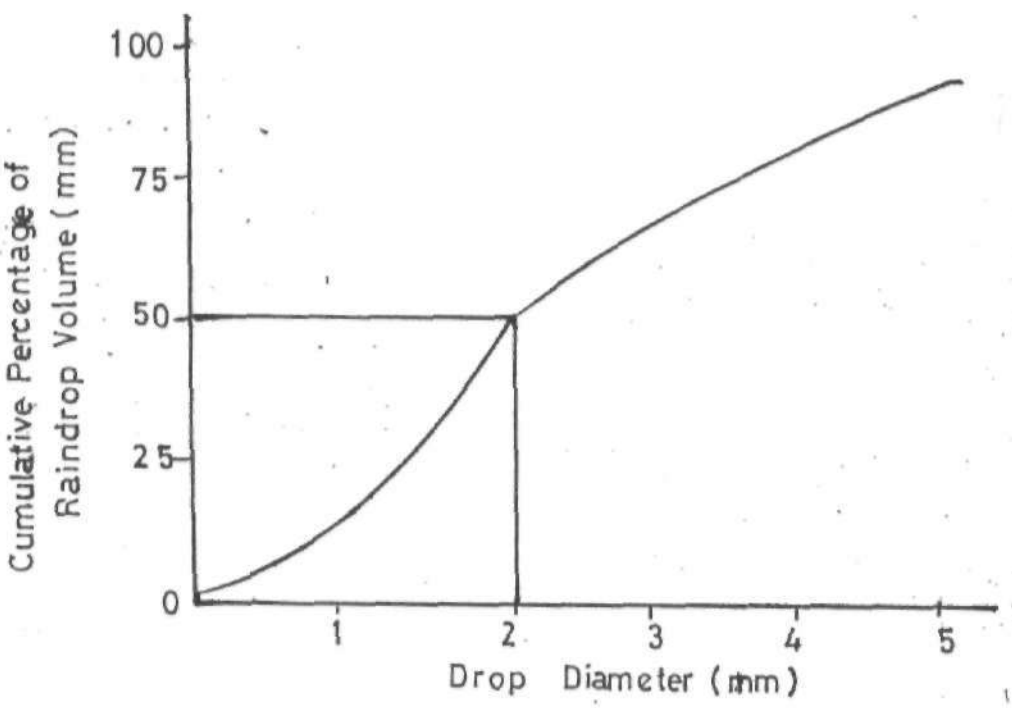


Fig.2.2. Determining the median volume drop diameter (After Hudson, 1971).

splash (Lal, 1981). From theoretical considerations, kinetic energy and momentum are parameters of rainfall which should be significant to erosion. This is because erosion is a work process which entails the expenditure of energy in detaching soil particles. It was assumed by Wischmeier (1958) and Hudson (1965) that soil detachment is dependent only on kinetic energy(i.e 1/2 mass x velocity^2) of rain. However, work by Rose (1960) and Williams (1969) showed that raindrop momentum (mass x velocity) or any other functions of mass and velocity could equally be valid. After detailed experimental work, Rose (1960) argued that the mass of soil detached per unit is more closely related to the momentum than to the kinetic energy of a rainstorm. Consequently, the empirical relationship between momentum and rainfall intensity is given by the Elwell and Stocking (1973) equation:

$$M = 75.3 - 155.2/I \text{ kg mm}^{-1} \text{ m}^{-2} \quad \ldots\ldots\ldots\ldots\ldots \quad (2.5)$$

where M = momentum in kg mm^{-1} m^{-2} and

I = intensity of rainstorms.

Nevertheless, since kinetic energy and momentum have very similar relationship with intensity, as exemplified in Fig. 2.2, the issue of whether momentum can be used instead of kinetic energy is not important.

2.2.2 TERMINAL VELOCITY OF RAINDROPS.

Terminal velocity is the velocity of raindrops usually at the time of impact with the soil. Besides falling freely under the force of gravity, raindrops, like any falling body, often accelerate until the frictional resistance of the air is equal to

the gravitational force; subsequently, the bodies continue to fall at that speed. In the case of raindrops, this speed is termed the terminal velocity, and it is closely related to kinetic energy of a rainstorm. In general, the terminal velocity of raindrop increases as their size increases (Wischmeier and Smith, 1958).

Other published work on the terminal velocity of raindrops include Laws (1941) who used modern high speed photography. His method involved allowing water drops which have been given a slight electric charge to fall through two induction rings. As the waterdrops fell through the measured distance between the two induction rings, the electrical pulse generated is fed through amplifiers to an oscillograph so that the time it takes to fall through the distance between the two induction rings could be measured very accurately. Gunn and Kinzer (1949) also measured very accurately the terminal velocity of water droplets using a similar method. The results differed from those of Laws by less than 3 percent. The relationship between kinetic energy and terminal velocity has been expressed in the form of an equation by Wischmeieir and Smith (1958) as:

$$KE = IV^2/2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.6)$$

where KE = kinetic energy in Watts m^{-2}

I = Intensity in mm sec^{-1}

V = Velocity of rainfall before impact in m sec^{-1}

Similarly, the relationship between soil detached, rainfall intensity, drop diameter and terminal velocity have been established and expressed as:

$$E = KV^{4.22}\ d^{1.6}\ I^{0.65} \ldots\ldots\ldots (2.7)$$

where E = relative amount of soil detached

K = constant of erodibility of soil

V = velocity of raindrops sec^{-1}

d = diameter of raindrop (mm)

i = rainfall intensity (mm hr^{-1})

2.3.3 INTENSITY OF RAINFALL

Rainfall intensity is another parameter found useful in assessing splash erosion of rainstorms. Rainfall intensity is expressed in terms of the amount of rain that occurs during a given time interval. It was defined by Conrad and Pollack (1950) and Buchanan (1974) as the ratio of the total amount of rain to the duration of the rain. As frequently experienced, intensity varies with time during most rainstorms. Severe rainstorms usually last for only a short time (Ward, 1967; Briggs, 1968; Hersfield, 1972; Ofomata, 1981). Thus while rainfall which lasts for several hours may give a large total amount, the average intensity for the whole rainstorm will usually be less than the peak intensity which may result from a short burst experienced during the rainstorm.

The peak intensity of a rainstorm is the maximum intensity experienced, usually for a short time interval during the rainstorm. It was rightly decribed by Summner (1977) as within - storm maximum intensity. Peak intensities of rainstorms could as indicated above, be very much higher than their average intensities. Therefore, the average intensity values often used

^"tnanm-.i!

for erosion studies which may then be applied for planning purposes could be misleading as there is an obvious possibility of underestimating the value of instantaneous peak intensities that often perpetrate the greatest damage through flood or erosion.

The study of rainfall intensity and peak intensity is important for many reasons. In the analysis of distribution of rainfall in Northern Nigeria, for example, Leow et al (1982) examined briefly the implication of high intensity rainstorms for civil aviation. These include reduction of visibility to between 50 - 500 metres and the distortion of the pilot's perception of distance from the runway. In addition, the effect of high intensity rainfall on stream flows and flooding in catchment areas form the basis of Hewlett's (1970) runoff model. Erosion studies conducted by Kowal (1970), Kowal and Kassam (1977), Leow and Ologe (1981) Leow and Gardiner (1982), and Leow (1982) show that these short-burst, peak intensity rainstorms present serious erosion hazards. As will be seen below, other studies directed towards the identificaiton of rainfall parameters which can be used to predict soil erosion have shown a considerable evidence of a close relationship between peak intensity and soil erosion.

Rainfall intensity appears to be one of the most important factors affecting the kinetic energy of a rainstorm and consequently its erosivity. The total kinetic energy of a rainstorm is the sum total of the kinetic energy of its compenent drops which is related to the amount of rain and obviously to its

intensity. From experimental records of kinetic energy relationship with intensity, it has been possible to calculate the kinetic energy of rainstorm. This is done by summing up the product of mass or dropsize and terminal velocity squared to give the total kinetic energy at a particular intensity (Wischmeier and Smith, 1958).

This indirect method of calculating kinetic energy from its relationship with intensity had given better results than attempts to measure it directly as earlier explained in section 2.3.

Studies have been carried out in various climates by independent researchers using different techiques. The results have been summed up by Hudson (1971) as shown in Fig. 2.3.

The curves were expressed in the form of equations expressing kinetic energy as a function of intensity. For example, Wischmeieir and Smith's (1978) curve gave:

$$KE = 916 + 331 \text{ Log } I \quad \ldots\ldots\ldots\ldots\ldots \quad (2.8)$$

where KE = Kinetic energy in foot - tons per acre per inch of rain,

and I = rainfall intensity (in hr^{1})

In the SI units, the Wischmeier curve was expressed as:

$$KE = 11.9 + 8.73 \text{ Log } I \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.9)$$

where KE = kinetic energy in Joules m^{-2}

and I = intensity in mm hr^{-1} while in metric units

$$KE = 210.3 + 89 \text{ Log } I \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.10)$$

where KE = kinetic energy im metre - tons ha^{-1} cm^{-1}

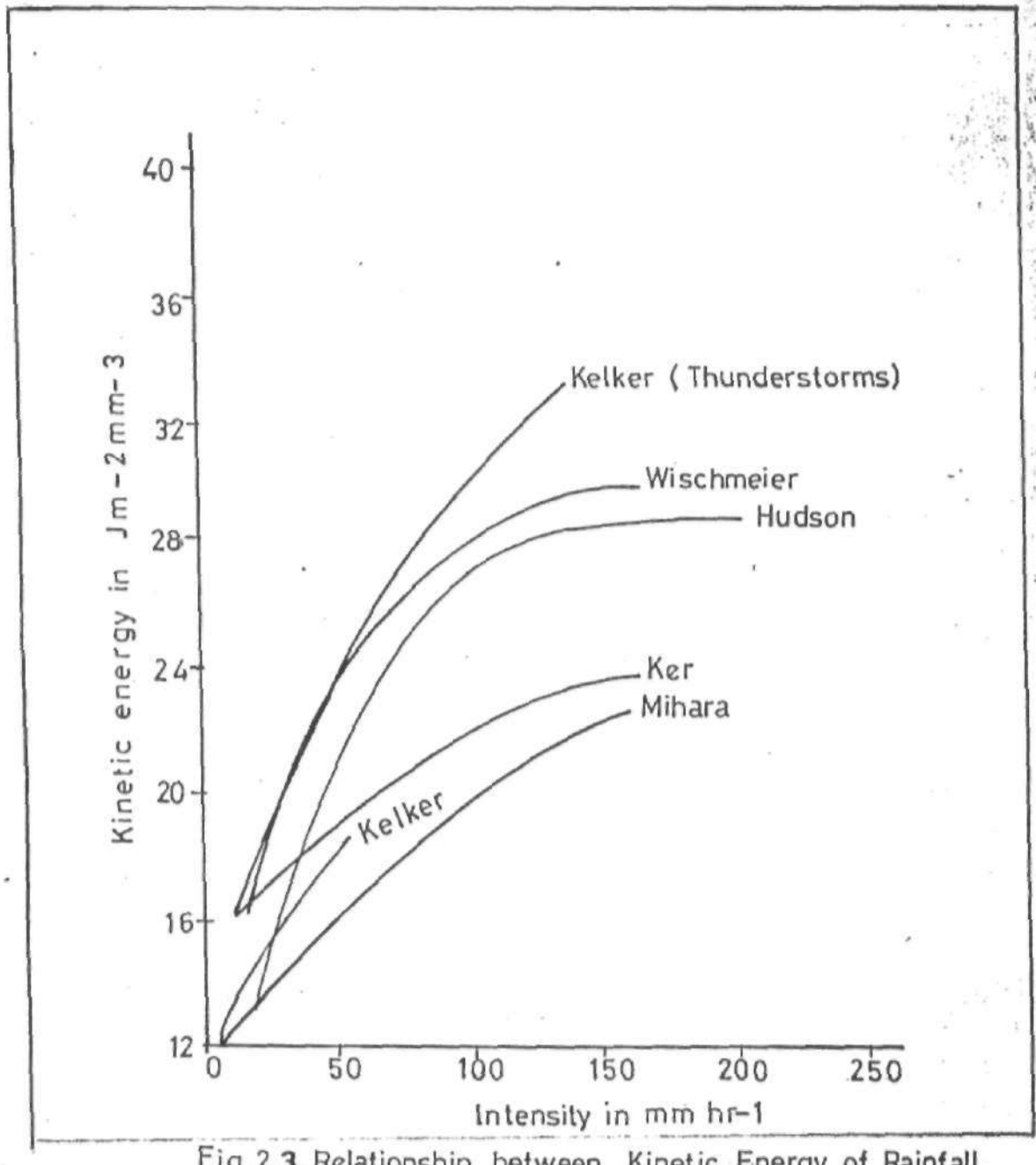


Fig. 2.3. Relationship between Kinetic Energy of Rainfall And intensity (After Hudson 1971)

Hudson's curve on the other hand, has been expressed in equation form by Elwell and Stocking (1973) as:

$$KE = 29.82 - 127.5\ Jm^{-2}\ mm^{-1} \text{ of rainfall} \quad ...(2.11)$$

where KE = kinetic energy in Joules m^{-2} mm^{-1}

I = intensity in mm hr^{-1}.

2.2.4 WIND VELOCITY

Wind is an important characteristic of tropical rainstorms which has also been found to influence the kinetic energy of rainstorms. Lyles et al (1969) found that there was an increase in the solids detached from the soil as wind velocity increases. In an experiment, they demonstrated that about 73 percent more soil was detached at a wind speed of 13.4 sec^{-1} than when there was no wind i.e. in still air. This suggests an increase in kinetic energy as wind velocity increases. This is because when rain is accompanied by wind, there is an added sideways component of velocity and this increases the storms kinetic energy, and consequently the erosive capacity. A horizontal wind increases the terminal velocity by the reciprocal of the angle of inclination of the rain with the vertical. In a heavy wind driven rain with a D_{50} of 3mm and a 30^0 angle of inclination, the velocity will be greater by 17 percent and the kinetic energy increased correspondingly by about 36 percent than when the same rain falls vertically in still air.

Some of the rainstorm characteristics such as dropsize distribution and terminal velocity that could be used to determine kinetic energy considered above, are as difficult to measure as kinetic energy of rainstorm itself. As for wind velocity

accompanying storms, it was argued that wind-driven rain brings about added sideways component of velocity and thereby increasing the storm's kinetic energy and consequently in erosive power (Lyles et al, 1969).

Wind data were, however, not available for inclusion into the erosivity equations. The under-estimation of rainfall erosivity this causes was not significant because wind effect is greater on non-erosive smaller drops falling slowly than on large drops with high velocities (Hudson, 1964). Secondly, it is only when a strong wind blows in a constant direction throughout the rainstorm period that the actual rainfall energy deviates significantly from the computed amount. In practice, the constant changes in wind direction in relative to slope direction tend to neutralize wind effect in many rainstorms (Wischmeier and Smith, 1958). The exclusion of wind data from the computation of erosivity should therefore produce little error.

The most practical and rational way of estimating energy load of rainstorm and consequently erosivity is by using the more easily and freqently measured rainstorm characteristics (Elwell and Stocking, 1975). Consequently, erosivity can be related to easily monitored parameters such as rainfall amount, intensity and kinetic energy of rainstorm derived from its indirect relationship with intensity. This type of easily measurable rainstorm parameters has been combined in various ways to provide soil-loss indices that have been useful in soil loss prediction. Some of the important indices under use include EI_{30} (Wischmeier and Smith, 1958); P_1^2/p (Fournier, 1956: Fournier and

Henin, 1959); KE > than 25 ; (Hudson 1971) and AI_m;(Lal, 1976). Many researchers have attempted to modify these parameters by other factors considered to be important in estimating soil detachment (Lal, 1981). Thus, wide range of rainfall erosivity parameters have been developed. In the section that follows, therefore, some key studies on the indices of erosivity will be reviewed.

2.3 STUDIES IN THE DEVELOPMENT OF INDICES OF RAINFALL EROSIVITY

Indices of rainfall erosivity are parameters derived from rainfall characteristics which sufficiently correlate with surface erosion, and consequently constitute a reliable medium of estimation. It is necessary to develop such indices because neither the rainfall amount nor the intensity has been found to be very highly correlated with soil-loss. Moreover, the kinetic energy of rainstorm is a difficult parameter to measure. Many studies have been directed towards identifying rainfall parameters or characteristics that could be used as indices of rainfall erosivity. Those that will be reviewed in the present work include (a) the Fournier p_1^2/p index (b) the Wischmeier's EI_{30} index (c) Hudson's KE > 25 indes and (b) Lal's AI_m index.

2.3.1 THE FOURNIER (p_1^2/p) INDEX

Fournier (1956) and Fournier and Henin (1959) correlated the suspended lead in 140 rivers with climatic data in Europe, Asia and USA,and derived a rainfall coefficient which significantly correlated with soil loss or degradation, given by the equation:

•NHHMHN iMSftiiifiv i •& ttfUHHfr

$$D = a^c - b \quad \ldots\ldots\ldots\ldots \quad (2.12)$$

where D = degradation or soil loss in tones km^{-2}

c = Fournier's rainfall coefficient = p_1^2/p

where P_1 = mean monthly rainfall in the wettest month of the year (mm).

p = the mean annual rainfall (mm)

and a and b = coefficients whose magnitudes depend upon the orographic coefficient(O) which is in turn given by the equation:

$$O = H/S \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.13)$$

where H = height of terrain above its base level and

S = the projected area of the stream.

Fournier's index was more significantly correlated with erosion in the tropics than in temperate regions and on steeper slopes than gentler ones. The lack of consistency in P_1^2/p index significant correlation with erosion in various land types and the complexity of the equation appear to limit its applicability in relation to soil management (Lal, 1977). That apart, the index is more useful for assessing erosivity on a global and continental scales; it is not very effective for use in more detailed studies (Moore, 1979).

2.3.2 THE WISCHMEIER EI_{30} INDEX

Wischmeier (1958) investigated the interrelationship between soil loss and rainstorm characteristics such as intensity, raindrop impact, raindrop velocity and the combinations of these characteristics. He found that the index that was most highly correlated with soil loss was the product of the kinetic energy

of rainfall and the maximum 30 minute rainfall intensity (I_{30}). The I_{30} is defined as twice the greatest amount of rain falling in any 30 consecutive minutes. The product of kinetic energy and the maximum 30 - minute rainfall intensity (I_{30}) is often indicated by EI or EI_{30}. The sum of the erosity index EI of all storms in one year gives the annual erosivity index R.

The EI index tends to provide a good measure for explaining many energy and intensity conditions of rainstorms. For example, the following conditions are easily explainable in terms of the EI_{30} index:

(a) A storm with average E and low I implies low EI_{30} product which predicts no soil loss.

(b) A storm with low I but average E due to long duration of storm implies gradual decrease in infiltration rate as long as the storm lasts. If the low intensity lasts long enough, the infiltration rate may finally become low enough for runoff to occur. This would show up in the prediction equation by a sufficiently increased EI_{30} product large enough to predict soil loss.

(c) A storm with low E and high I produces comparable soil loss to b above.

(d) Finally, heavy rainfall at high intensity possesses high soil - detaching capacity of raindrops and high soil carrying ability of turbulent flow. These are described by very large EI_{30} product.

Increases in kinetic energy due to wind - driven rains were

not explained by the EI_{30} variables. This probably accounts for some of the standard errors obtained in the estimation of soil losses. As earlier mentioned in section 1,5, the detaching ability of wind driven raindrops is often influenced by the angle of impact. However, changes in wind direction during a rainstorm probably tend to balance out these effects in many storms. But when a strong wind blows constantly in one direction, there would be a significant deviation of the actual soil loss from the computed value. Related wind data are however not available to test the importance of these hypotheses (Wischmeier, 1958.

Stocking and Elwell (1973) found that the derived parameter EI_5 - the product of kinetic energy and the maximum 15-minute rainfall intensity - gave the best assessment of the erosive potential of rainfall when vegetation cover was at a maximum. On poor vegetation cover, EI_{15} was found to be the best predictor of soil erosion while EI_{30} was most applicable on bare soil.

2.3.3 WEST AFRICAN INDICES

The Wischmeier EI_{30} index was developed for the United States of America and it is not widely applied outside the USA mainly because of the limited availability of detailed rainfall data and partly because correlation with soil loss has not been very high (Bergsma, 1981). Several approximations have, therefore, been derived which are more adaptable to areas where less comprehensive data are available.

The first of these approximations is provided by (Wischmeier, 1959) in the form:

$$EI_{30} = (P. I^{r}_{1} . I^{r}_{24}) \ldots\ldots (2.14)$$

energy and the maximum 1'5 minute rainfall intensity - was the

where P = annual precipitation

I^r_1 = one hour maximum rainfall with a return period of 2 years.

I^r_{24} = 24 hour maximum rainfall amount with a return period of 2 years.

The second of these approximations was made during soil erosion studies in Niger and Burkina Fasso and reported by Bergsma (1981) and Oladipo (1984). The studies found that the product of the total rainfall per storm (P_s) and I_{30} showed a linear relationship with EI_{30}. The resultant equation for the two regions is of the form

$$EI_{30} = 0.0158\ P_s.I_{30} - 1.2 \quad \ldots\ldots\ldots \quad (2.15)$$

where EI_{30} = Wischmeier's erosion index

P_s = total rainfall per shower (mm)

I_{30} = maximum 30 minute rainfall intensity

A simple approximation of annual erosivity index R in West Africa is:

$$R = (0.50 - 0.05)Pt. \quad \ldots\ldots\ldots\ldots\ldots \quad (2.16)$$

R = annual sum of the EI values

where Pt = average annual precipitation (mm)

A similar relationship between EI_{30} and rainfall amount or rainfall volume (P_s) was derived for Ivory Coast. The relationship was given in the form:

$$EI_{30} = 0.577P_s - 5.766 \quad \ldots\ldots\ldots\ldots \quad (2.17)$$

Most of the approximations discussed above provide only an average value of annual erosivity index. It should also be noted that most of the formulae are valid in the areas where the paticular sturdies were carried out and not for individual storm as required by this study (Stocking,1978; Oladipo, 1984).

2.4.4 THE HUNDSON KE > 25 INDEX

Another erosivity index was developed by Mudson (1971) while working in Zimbabwe. First he found that the Wischmeier R value appeared less valid in Zimbabwe than in the area of Wischmeier's study. He therefore conducted experiments to evaluate the assumption that erosion occurs when rainfall intensity was more than a threshold value. He suggested a threshold value of 25 mm hr^{-1}. This implies that at intensities greater than this critical value, significant amounts of erosion may be produced; while rains with intensities below the threshold value may not be erosive.

From the experimental records of kinetic energy relationship with intensity, it was possible to express kinetic energy of rain with intensities above the threshold value of 25mm hr^{-1} with Eq. (2.8). After obtaining the cumulative kinetic energy of storms with intensities greater than 25mm hr^{-1}. Hudson correlated the value with soil loss from splash cups. He found that the resultant value was better correlated with soil loss than the Wischmeier EI_{30}.Thus an erosive index, KE >25 was developed and recommended for use in the tropics.

2.4.5 THE LAL AIm INDEX

Experiments in the tropics have indicated a lower correlation coefficient between EI_{30} and soil loss than in the U.S.A. Observations in Ibadan, for example, suggested that neither EI_{30} nor KE >25 was very highly correlated with soil loss in Nigeria (Lal, 1977). Lal, therefore, proposed another index (AI_m) which is the product of rainfall amount (A) in cm and the maximum intensity Im in cm hr^{-1}. The annual AIm index is give by the equation:

$$AI_m = \frac{\frac{12}{\cdots\cdots\cdots}}{\underset{i=1}{\overline{\qquad}}} \; \frac{\overset{n}{\overline{\qquad\qquad}}}{\underset{i=1}{\overline{aim}}} \quad \ldots\ldots\ldots \quad (2.18)$$

where a = total rainfall in any one storm (cm)

Im = maximum storm intensity (cm hr^{-1})

n = rainy days in the month.

The AI_m index shows a higher and more significant correlation with soil loss in southern Nigeria and other areas with high intensity tropical rainfall such as India and Australia than either EI_{30} or KE 25. This is probably because the high intensities of tropical storms are fully reflected in the index. One attractive feature of the index is that it can be more simply computed than either KE > 25 or EI_{30} as it does not make use of rainfall energy.

2.4 ASSESSMENT OF THE EROSIVITY INDICES

Various attempts have been made to measure splash erosion both in the laboratory and in the field, and to evaluate the erosivity indices as good estimators of erosion in small scale laboratory experiments as well as erosion in real field conditions. For example, Ellison (1944), using the Ellison - type splash cups, tried to measure the 'splashability' (erosivity) of rainstorms. In the experiment, Ellison used brass cylinders 77mm in diameter and 50 mm deep with fine wire mesh soldered on one end to form a porous bottom. He placed thin layer of cotton wool on the wire and filled the cylinders with fine sand so that when placed in water, the sand in the cups are maintained at a constant moisture status of near saturation. The cups were ovendried and weighed before and after exposure to rainstorms so that the weight difference would give the splashability or erosivity of the rainstorm.

Hudson (1965) working in South Africa, also used the method since it provides simple but precise and easily reproducible measurements. In their experiments, groups of splash cups were exposed to every storm for two years. The results showed that there was a good correlation between sand splashed and KE > 25 with a coefficient (r) of 0.96.

Free (1952) in a related study in United States of America, collected data on both splash erosion and runoff using pans that are 1m long, 0.3m wide, and 1m deep. The pans were filled with

sieved clay-loam soil set along 5% slope and maintained at constant moisture status. The soils washed off the pans were collected in troughs placed at the lower edge. The pans were also exposed to every storm for two years and the results showed that a good correlation existed between KE > 25 and soil loss at($r = 0.92$).

In a field experiment by Hudson (1973) where most of the variables which occur in nature, such as change in moisture at the beginning of the storm were introduced, the good relationship between KE > 25 and soil loss still holds. In the experiment, the soil was undisturbed except for the minimum amount of weeding to keep the surface free of vegetation and the soil moisture was not controlled. The plot was 27.5m long, 1.5m wide and situated on a 5 percent slope. The soil loss was caught in run-off tanks placed at the bottom of the Ppot. The result showed that the correlation with soil-loss was still high with ($r = 0.94$).

Other methods that have been used in measuring erosivity of rainstorms include installing splash boards with catching troughs attached (Kwaad, 1976); embedding small funnels of about 50mm in diameter in the soil to catch splashed particles (Bolline, 1979) and wash traps designed by Young (1960) and used successfully by Morgan (1979) and Leow (1982). Some of these studies such as those of Ellison (1944), Bisal (1950) and Free (1952) provide for small scale laboratory experiments and may not be very relevant to real field conditions. Although other methods such as that of (Hudson, 1973), which catch run-off from field plots into tanks

at the bottom of the plots may introduce most variables which occur in the field into the experiments, the type of heavy rainstorms that are normally experienced in the tropical environment may produce too much water which may fill the tanks during a single storm. The tanks may thus overflow together with the splashed soil which we want to collect. This would introduce a major source of error into the experiment. Moreover, the method is very cumbersome as it would require the carrying of may tanks of runoff water. And addition, the method does not separate erosion due to splash from erosion due to runoff.

In order to overcome the problems associated with the methods used in previous attempts to measure splash erosion, the Leow (1982) splashtraps were used. The detailed procedure involved in the use of splashtraps is described in chapter Four. Erosivity indices discussed in the proceeding section often give good results only in areas where the particular studies were carried out. They cannot be assumed to be valid for other areas with different climate, vegetation and soil conditions (Stocking, 1978). Therefore, it is pertinent to note that each major ecological zone derives its own model for predicting soil loss due to erosion (Elwell and Stocking, 1981). There is thus the urgent need to determine erosivity values and indices for major ecological zones in Nigeria in order to be able to predict the potential erosion hazards in the regions (Olayile and Filani, 1977).

Despite the acute problem of erosion in Nigeria, very few studies have been carried out on the mechanics of soil erosion (Leow et. al., 1982). However, there is still a dearth of knowledge on rainfall erosivity situation in the Nigerian environment. The present work is an attempt to fill the gap by examining the comparative performance of six erosivity indices with application to Nigeria, and to construct Iso-Erodent map for Nigeria using the best among the indices tested in Nigerian environment.

CHAPTER THREE

RAINFALL IN NIGERIA

3.1 INTRODUCTION

Nigeria has a land area of 913,920 km^2 and measures 1040 km from the North to the South; and 1,120 km from the East to the West. The country experiences different weather conditions. This chapter, which is a weather - related study of intensity and erosivity of rainstorms in Nigeria begins with a look at the overall atmospheric picture.It thus reviews some aspects of the temporal and spatial intensities of rainfall in the country.

3.2 GENERAL RAINFALL CHARACTERISTICS OF NIGERIA

In order to understand the problems of storm erosivity, the nature and development of rain-producing systems and their complex interrelationships should be properly understood. The following account is a summary of the weather systems over Nigeria which act as the causal mechanics of the typical high intensity rainfall characteristics often experienced in the country.

Nigeria's weather conditions are a microcosm of that of the West African region and result from the general atmospheric circulation of air mass over the earth, modified by local conditions. Climatological models of air circulation in West Africa and its effect on the climate have been described by Walter (1940), Ilesanmi (1971), and Ojo (1977).

The principal air - masses affecting the weather are the rain - bearing tropical maritime air - mass (mTs) from the

South and the dry, dusty tropical continental air mass (cTs) from the Sahara Desert. The air - masses flow towards each other from the opposite directions. The belt into which they flow is known as the Inter-Tropical Discontinuity (ITD), and it is an unstable region of ascending air.

The structure of the ITD is such that the dry tropical continental air - mass lies over the humid tropical maritime air-mass and the third air-mass called the Equatorial Easterlies (E.E) blows in the upper atmosphere generally above the two air-masses. The boundary between the two air-masses is important because it marks a sharp discontinuity between two contrasting weather patterns on both sides of the discontinuity.

The weather structure associated with the two sides of the ITD falls into 5 main zones as schematically illustrated by Omotosho (1984) and shown here as Fig.3.1. The distance of each weather zone on either side of the surface of the discountinuity has been studied by Adejokun (1964) and Garnier (1967). Zone A, lies immediately north of the surface discontinuity, Zone B extends for about 3^0 of latitude South of the discontinuity, Zone C from approximately $3\text{-}10^0$ South of the surface discontinuity, Zone D South of C and Zone E further South.

The relationship between the five major West African weather zones and the ITD have been shown in form of the cross section of the atmospheric situation over West Africa by Adejokun (1966) and it is presented in Fig. 3.2. The figure is drawn to scale making use of the January slope of 1:300 (1/91 metre), and the following discussion is taken mainly from Oguntoyinbo(1978).

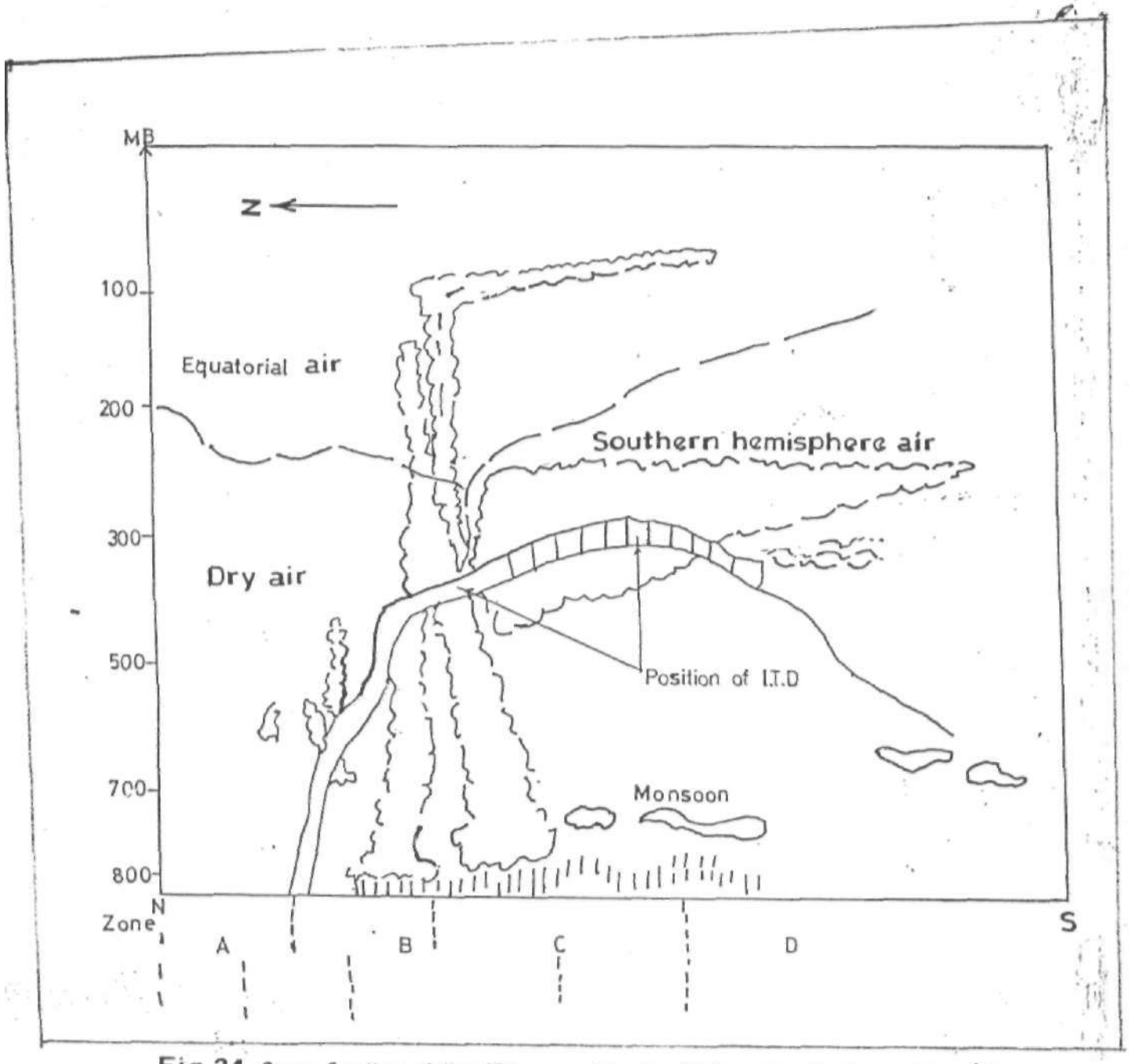


Fig. 3.1. Cross-Section of the I.T.D over Nigeria. (After Omotosho 1984)

Zone A lies 240 - 320 km north of the ITD where the sky is often covered by about 1 - 2/8 cumulus and 2 - 4/8 cirrus types of clouds which normally dissolve in the evenings. The zone is a region of dry air that is dominated by the dusty harmattan wind and pervades most part of Nigeria lying north of latitude 9° N between December and February. The dusty condition often results in early morning mist which persists for an hour or two after sunrise (Oguntoyinbo, 1978).

Just South of zone A is where the ITD comes in contact with the surface. It is identified by the dew point and surface wind. The moist air has a dew point in excess of 14° C with winds exhibiting a southerly or westerly component while the drier air generally has a dew point below 14° C and winds exhibiting northerly or easterly components.

Zone B lies 288 - 320km South of the ITD. As a result of vertical transport of horizontal momentum, winds change direction from light Southwesterly in the mornings to Northeasterlies in the afternoons. Cloud development is diurnal and convective, and is normally of the cumulus type. The zone is characterised by early morning mists or a low stratus cover and by the development of scattered and small cumulus during the late morning and early afternoon. It is more noticeable in the Southern half. This condition is typical of February and part of all March during

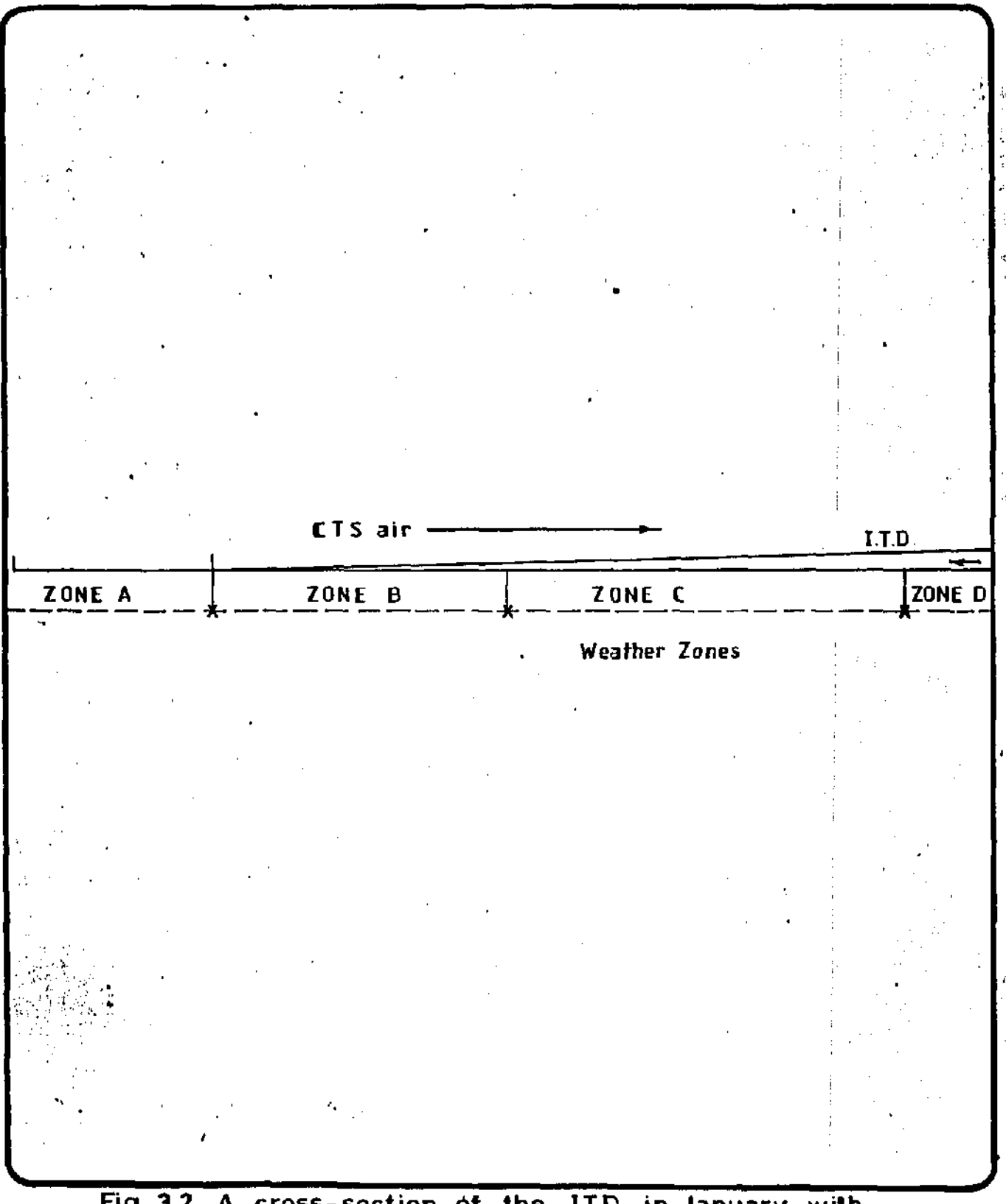


Fig. 3.2. A cross-section of the I.T.D. in January with slope 1:300 (metre) along latitude 5°E (after Adejokun, 1966).

which showers become frequent usually associated with thunderstorms and lightening. Maximum temperature range from 29° C to 35° C, and the minimum, from 18° C to 24° C. Relative humidity is as high as between 60 - 90%. Visibility is good except for frequent early morning fog and mists in the southern part of the country. Zone C can be found between 320 - 1,280 km South of the ITD and covers about 960 km South of Zone B. The zone is characterised by high humidity and highly unstable atmospheric condition and therefore the most rainy zone. Winds are predominantly northWesterly up to 1,515 metres and reaching as high as 2,121 metres especially in the Southern areas of the zone. Low clouds develop in the day and diminish completely at night. Cumulus and cumulo-nimbus clouds with bases ranging from 600 - 900 metres give frequent afternoon showers and thunderstorms; usually associated with squall lines travelling at the speed of 48 km hr^{-1}. An average of 125 - 200 mm of rainfall is common in this zone during the month of August. There is however an average maximum of about 300 mm at about 11°N. The diurnal range in temperature is relatively small, and the maximum temperature is between 27° C - 32° C, while the minimum temperature is between 18° C - 24° C. Relative humidity drops rather sharply from 95% in the early mornings. Visibility is generally good except when the rain falls.

Zone D which lies 1,280 km - 1,600 km south of the ITD has afternoon temperature of 21° C - 27° C and night temperature of 18° C - 21° C. It has a relative humidity of between 95% in the

mornings and 65% in the afternoons; thus the occurrence of mist and sometimes fog is a common phenomenon of this zone. By July and part, or all to August, the ITD has advanced to its northern-most position over Nigeria. The atmosphere in this zone is very stable as temperature inversion conditions exist above the stratus cloud layer. This prevents upward movement, and thus reduces the amount and intensity of rainfall (Oguntoyinbo, 1978). Whenever the zone moves over the SouthWestern part of the country in August, it produces the "ittle - dry season" (Ireland, 1962) or "August break" (Ilesanmi, 1971) in the South, while the north at this time experiences its highest rainfall. The break forms a gap between two periods of heavy rainfall in the south; one in May - July and the other in September - October. In the north, this gap does not exist as the sun returns to the northern latitudes almost as soon as it leaves them (Iloeje, 1976). The two rainfall peaks which follow the sun therefore come so close together that they bmerge to form a single maximum in the northern part of the country.

Zone E (not shown on the diagram) lies South of Zone D. The southern boundary of the zone is not exactly known but probably extends as far as 160 - 320km South of Gulf of Guinea. Garnier (1967) assumed that zone E is a continuation of zone D as it also falls within the area of the little dry season. West of the Delta area, the zone is characterised by drizzle and low rainfall with an average of between 30 -35 mm for the month. East of longitude 10^{o} E, the effect of the little dry season is

negligible as the average rainfall in August is about 500 mm.

The ITD moves north and south with all the 5 zones described above in response to the advance and retreat of the airmasses. Figs 3.3 and 3.4 illustrate how the movement of the zones - a northward retreat in January through March to June; and a southward advance in July through September to December when northward movement resumes again.

The ITD movement is a complex latitudinal process. It neither moves at a steady rate nor in a constant direction for a long time. Rather, it fluctuates in a haphazard manner. The southward movement is, however, faster than the northward advance, and the average rate varies from 1.9^{o} of latitude to as high as 7^{o} of latitude per month. In the years when the rate of southward movement is as high as 7^{0}, the rainy season ends abruptly, since ITD is the large - scale circulation system controlling rainfall in Nigeria. Superimposed on the ITD are other small - scale propagating systems such as linesqualls, thunderstorms, monsoon effect and orographic influence.

Linesqualls or disturbance lines originate from the activities of the Equatorial Easterlies which Equatorial easterlies which normally blow in the upper atmosphere over the ITD. For some unknown reasons, the Equatorial easterlies dive and undercut either the tropical maritime or tropical continental airmass. In either case, the Equatorial easterlies force up the airmass concerned very violently. When the undercut involves the maritime airmass, rapid convection currents are generated. The

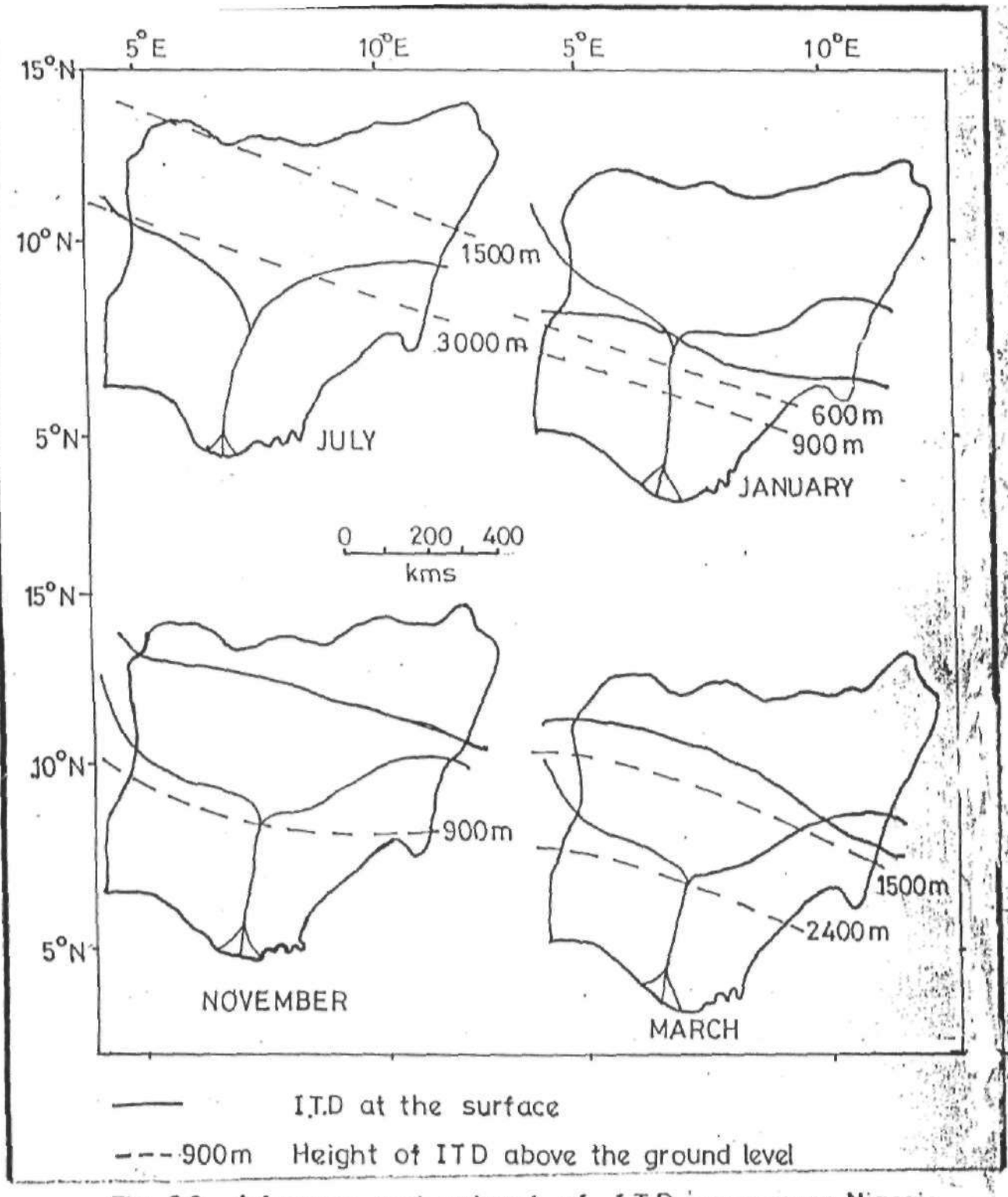


Fig. 3.3. Advance and retreat of I.T.D. zones over Nigeria (After Oguntoyinbo, 1978).

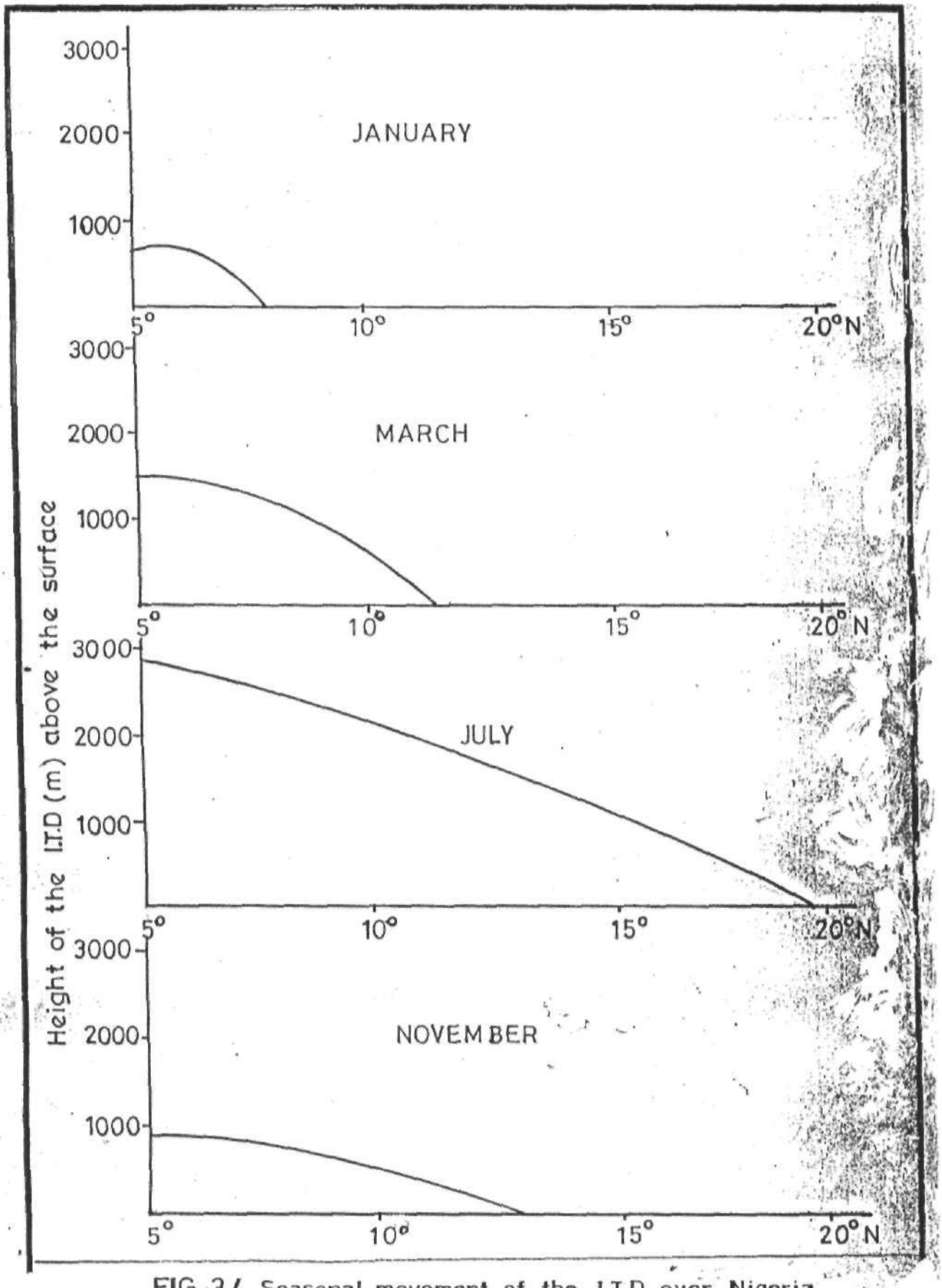


FIG. 3.4. Seasonal movement of the I.T.D. over Nigeria
(AFTER OGUNTOYINBO, 1978).

moisture in the airmass suddenly condenses, and sets free the electrical charges in the atmosphere. This gives rise to thunder, lightening, strong winds and brief but heavy rain. In general, line squalls are propagating meso-scale convective systems with gusts of 30 km hr^{-1} or more. Their appearance in the windfield coincides with the development of lower level disturbances such as the Easterly Tropical Jetstream, easterly waves and vortices (Omotosho, 1984).

According to Omotosho (1984), the Easterly Tropical Jetstream is located at about 650 mb (12 km) where the wind speed exceeds 60 km hr^{-1}. The Jetstream appears two times in the year: first between April and May, and later between October and November. The jetstream is, however, weakened during the inflow of the deep layer of the south west monsoon in August, during which there is a drastic reduction in linesqualls' activities. Linesqualls' precipitation therefore exhibits double maxima for all stations south of latitude 12^0 N. The Easterly Tropical Jet is believed to be very important in the development and continued existence of line squalls. Oguntoyinbo, (1978) who has presented a description of the Easterly waves noted that they originate from East Central Africa between longitudes 15^o E and 30^o E, and south of African Easterly Jet. From this position, the waves move westward across West Africa at a speed of about 30 km hr^{-1}. To the front of the wave trough exist strong surface convergence, enhanced cloud development, thunderstorm and rainfall. To the rear, there is subsidence and fair weather.

Among the lower - level disturbances of the line squalls are

the cyclonic vertices. They occur at about 850 mb or 1.5 km level within the easterly wave trough where the wind is organised into a series of closed cyclonic vertices that are several hundred kilometres wide. To the south east quadrant of the vortex, intense cloud development and and rainfall occur. Clear skies and moderate cloudiness are often the characteristics of the north-west and north-east quadrants.

These three lower-level disturbances (the easterly tropical jetstream, easterly wave and vortices) are generally termed Lines qualls. The characteristic uplift is initiated by the thermal convection over highlands in Eastern Nigeria and Western Cameroun. Over Nigeria, line squalls are usually at maximum at around 9^{o} N and are the most important rain-producing systems in the country. They give rise to about 47.6 percent of the mean total annual precipitation (Omotosho, 1985). Over central and northern parts of West Africa, lines squalls account for over 90 per cent of the annual total rainfall (Kamara, 1986). As the percentage contribution of line squall increases with latitude, precipitation from thunderstorms and monsoons decreases.

In addition to line squalls, thunderstorms also contribute significantly to rainfall in Nigeria. There are two types of rain producing thunderstorms in Nigeria: in - situ and slow-moving thunderstorms. In - situ or local convective thunderstorms result from intense heating in an unstable atmosphere. Thunder and lightening normally accompany the storm, and rainfall is heavy with cloud burst intensity lasting for only 1 - 2 hours.

The convective thunderstorms are often localised as they affect areas of only about 50 sq km. They are largely stationary weather systems.

Slow moving linear thunderstorm consist of gusts less than 30 km hr $^{-1}$ They are predominant in the northern part of West Africa, but also occur with less frequency in the southern parts, especially where there are high grounds (Kamara, 1986). In general, thunderstorm precipitation decreases with increasing latitude. Rainfall from the storms shows a single peak in July-August at stations north of latitude 9^{o}N.

Naturally, where prevailing winds encounter a mountain range, the air layer is either deflected, blocked or forced to rise in order to surmount the mountain barrier. Once the airmass is lifted, it rises on the windward side and cools at the dry adiabatic rate to produce clouds and rainfall. Consequently, the amount of rainfall is significantly greater on the windward than the leeward slopes of the mountain. The type of variations in rainfall is a reflection of differences in distribution of heat, moisture, and general convective instability between the two sides of the mountain (Kamara, 1986).

Following Kamara's (1986) account, orographic rainfall in Nigeria is limited to high land area of the Jos Plateau, Biu Plateau and Adamawa-Cameroun highlands along Nigeria-Cameroun border. While rainfall amount would be expected to increase with altitude, the relationship between rainfall and altitude, in

tropical and subtropical areas is rather complex. This is because orographic elements such as exposure to, or shelter from rain-bearing winds, orientation and steepness of the mountain slope, size of mountain barrier and distance from the source of moisture, all of which are difficult to quantify readily, play significant roles in influencing the distribution of rainfall.

Monsoon rainfall due to coastal convergence also occurs in the South-eastern coast of Nigeria. The mechanism involves moist and potentially unstable onshore monsoon winds from aerodynamically smooth sea surface blowing over a rough landmass. The resulting instability causes convective clouds that stretch for several hundred kilometres along the coastal areas. The coastal cloud band produces light to moderate showers that cause prolonged morning maximum diurnal rainfall. Thunderstorm rains contribute highest to the amount of Nigerian rainfall as line squall precipitation is drastically reduced. Monsoon is common in the Port Harcourt area and other areas South of latitude 8^{o} N. According to Kamara (1986) monsoon precipitation decreases exponentially with increasing altitude. Both monsoon and orographic rain account for only 13.4 percent of the mean total annual precipitation in Nigeria.

One of the explanations for the rather afternoon - evening nature of thunderstorm over continental zone (as those existing in the northern part of Nigeria), offered by Oladipo (1985), is based on thermodynamic process. This principally is the effect of solar radiation on static stability. The explanation is based

on the assumption that increased infrared cooling from the tops of clouds at night causes increase in static lapse rate as the tops of the clouds cool more at night than the cloud base. The increase in lapse rate will then promote convective overturning, and enhance noctural thunderstorms. While the radiation cooling theory cannot solely explain the late afternoon - early evening thunderstorms in Zaria and its environs, this theory no doubt explains the destablizing effect of the atmosphere in the nights.

3.3 SPATIAL VARIATION OF RAINFALL IN NIGERIA

The rainfall pattern in Nigeria is a good reflection of the seasonal variation of the ITD. Basically rainfall decreases from the coast to the interior, except where altitudinal effects create islands of higher rainfall. The coastal areas receive over 4,000 mm spread over 8-10 months whilst the extreme north receives less than 250 mm spread over 3 to 4 months (See Fig. 3.5). One of the exceptions to the fairly regular south-north pattern is the Jos Plateau which has much higher rainfall owing to the influence of its high altitude. The annual rainfall on the Jos Plateau ranges from about 1,250 - 1,800 mm per annum. East of the Jos Plateau, along Bauchi - Gombe - Numan axis lies an area of low rainfall that is generally less than 1,000 mm per annum. As a result of the rainshadow effect of the Jos Plateau, the rainfall received here is generally lower than those or the adjoining land, and does not conform to the normal pattern of the south-north gradient of annual rainfall.

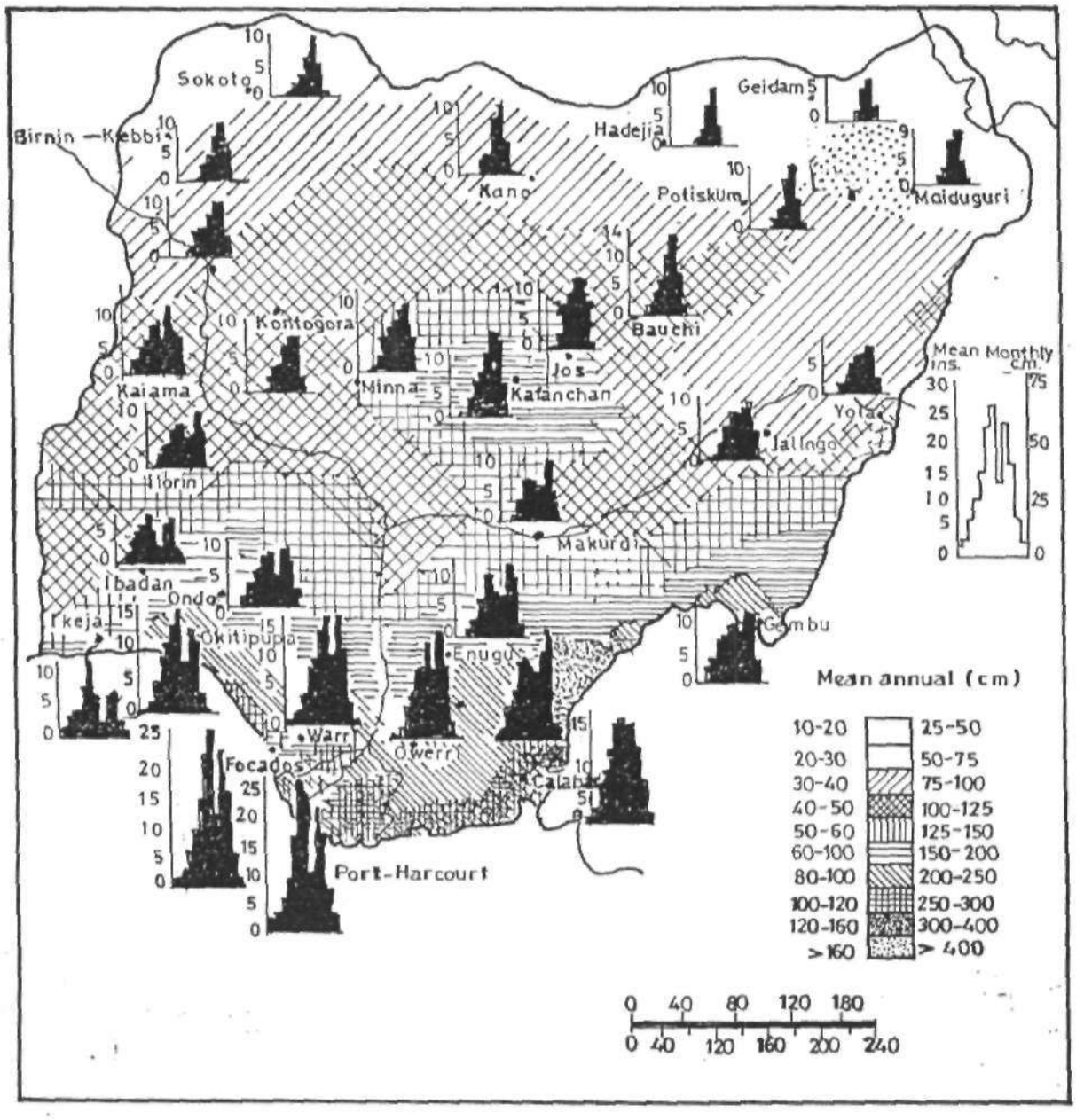


Fig. 3.5. Spatial variation of mean annual rainfall (after Oguntoyinbo, 1978).

The south-north gradient of annual rainfall suggests that the distance from the source of moisture is a dominant factor of rainfall. The rain-bearing southerly airmass gives progressively less total rainfall inland becaseu it looses moisture as it moves along its path northwards and farther away from the source. Secondly, the duration of its influence decreases from south to north. The closeness of the association between the distance from the source of moisture and the amount of annual rainfall has been demonstrated by Kowal and Knabe (1972) who compiled the agroclimatological atlas of Northern States of Nigeria. Their regression equation establishing this relationship is given by Kowal and Knabe (1972) as:

$$Y = 89.3 - 4.7X \quad \text{---------} (r = -0.77) \qquad (3.1)$$

where Y = distance from the coast

and X = rainfall in inches.

This equation indicates that the annual rainfall decreases by 4.7 inches (119.4 mm) for every degree of latitude.

Since a significant relationship exists between annual rainfall and latitude, it is pertinent to also examine the monthly variations of rainfall with latitude. These are depicted in Fig. 3.6. The arrows denote the actual points of the values plotted for the particular month at the relevant latitude by Omotosho (1985). The means of data from pairs of stations were used to obtain the lines except for latitude 4^{o} 30 ' N, where data from only Port Harcourt were used. Total precipitation gave an inverse linear relationship with latitude except in

September. The departures for September was ascribed to the sudden southward retreat of the ITD which normally starts during this month. From the Fig 3.6 it can be seen that there were six months interval (February - August) on the northward trail, whereas, the February position was reached again in just three months on the south - bound retreat. This, therefore, agrees with the finding of Adejokun (1965) that the southward retreat of the ITD is much faster than its northward advance.

Figure 3.6 serves as a useful model for assessing the probable onset and / or cessation of any agriculturally adequate rainfall amount. Without any direct knowledge of the position of the ITD, as in the studies of Ilesanmi (1971) and Adedokun (1979), it is possible to predict, with some accuracy, the month when any desired amount of precipitation, often required for agricultural planning, is to be expected at a given latitude. However, because local influences, such as altitude do have significant effects on the occurrences of line squalls and thunderstorms which are the greatest rainfall contributors, more extensive and longer period data along each latitude are required to improve the reliability of the diagram (Omotosho, 1985).

3.4 TEMPORAL VARIATION OF RAINFALL IN NIGERIA.

For all practical purposes, especially for the planning of hydrological and agricultural projects, it is not only necessary to know what quantities of rainfall are experienced at a given place and during what season, but also its charateristics over time. The quantity, although significant, is an incomplete description of rainfall. The duration and intensity of rainfall,

the seasonal onset and cessation of rainfall, and the long term trends are also needed as additional information.

3.4.1 Duration and Intensity of Rainfall in Nigeria

The duration of rainfall in Nigeria was analysed by Ilesanmi (1972) when working on the amounts and duration characteristics of rainfall in Nigeria. The spatial distribution of rainfall periods illustrated in Fig. 3.5 reflects the spatial distribution of annual rainfall amounts. The heavy rainfall in the Niger Delta east of longitude 5^{o} E is matched by long duration of rainfall hours recorded here. While the rainfall hours in this part of the country amount to over 500 a year, the duration for west of the Niger Delta (between longitude 4^{o} E and 6^{o} E and between latitudes 6^{o} - 7^{o} N) decreases to 400 - 500. These two areas, however, record the highest number of rainfall hours in the country, and also coincide with the high rainfall zone identified earlier.

In the moderate rainfall zone covering the sections of the country within latitudes 7^{o} - 9^{o} N, the rainfall hours average 250 - 300 a year. The least rainfall hours, however, occur in the low rainfall zone far north of latitude 9^{o} N. The rainfall hours here are between 150 and 250 a year.

Ilesanmi (1972) further showed he similarity in the distribution patterns of annual rainfall amounts (Y) and annual rainfall hours (X) in the form;

$$Y_c = -3.7 + 5.2\,X \qquad (r = 0.972) \ldots\ldots\ldots\ldots\ldots \quad (3.2)$$

with a standard error SEy of 34.6 rainfall hours.

The intensity patterns of rainfall in Nigeria was also evaluated by Kowal and Knabe (1972) and Ilesanmi (1972). The values of intensities were obtained by dividing the rainfall amount by four hours because the intensities were derived at 4 - hourly intervals. The result of the analysis showed that rainfall intensity is highest during the afternoon and evening hours at most Nigeria stations. Those times correspond with the times of maximum thunderstorm activities in most parts of the country. The coincidence is therefore suggestive of the inherent thunderstorm characteristics of rainfall in Nigeria (Ilesanmi,1972).

When rainfall intensities were compared with their duration, Ilesanmi (1972) found that the highest intensities of between 6.4 to 12.7mm were associated with rainfall duration of 0.2 hour. The rainfall lasting 0.4 - 1.0 hour shows moderate rates of fall and the rainfall of 2.0 and 3.0 hours duration have rather low intensities . The least rates of fall are associated with rainfall duration of 6 - 24 hours. In general, the rainfall intensities are similar spatially over the country. This homogeneous distribution suggest that all sections of the country are exposed to similar atmospheric dynamics. However, further analysis of duration and frequency of rainfall gave an indication of the perturbations and the modifying role of surface terrain.

3.4.2 Seasonal Onset and Cessation of Rainfall

As earlier illustrated in Fig. 3.6 there is a pronounced south - north movement in the spread of rainfall and corresponding north - south pattern in its termination. The major rainfall peaks occur during June - July and September in areas south of latitude 9^{o} N. Northwards of the latitude, the peaks gradually converge to give a single wet season peak in August. The first fall in the season are variable in amount and irregular in frequency.

The southern stations have an early start, on the average, from the middle of March. Conversely, the northern stations show a late start beginning in June. There is, therefore, a difference of about 3 months in the start of rains between the extreme north and southern parts of Nigeria. The relationship between the time of start of rain and latitude is described by the regression equation of Kowal and Knabe (1972) as:

$$y = 1.43\ x - 1.32 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

where y = coded time of start of rains,

x = latitude.

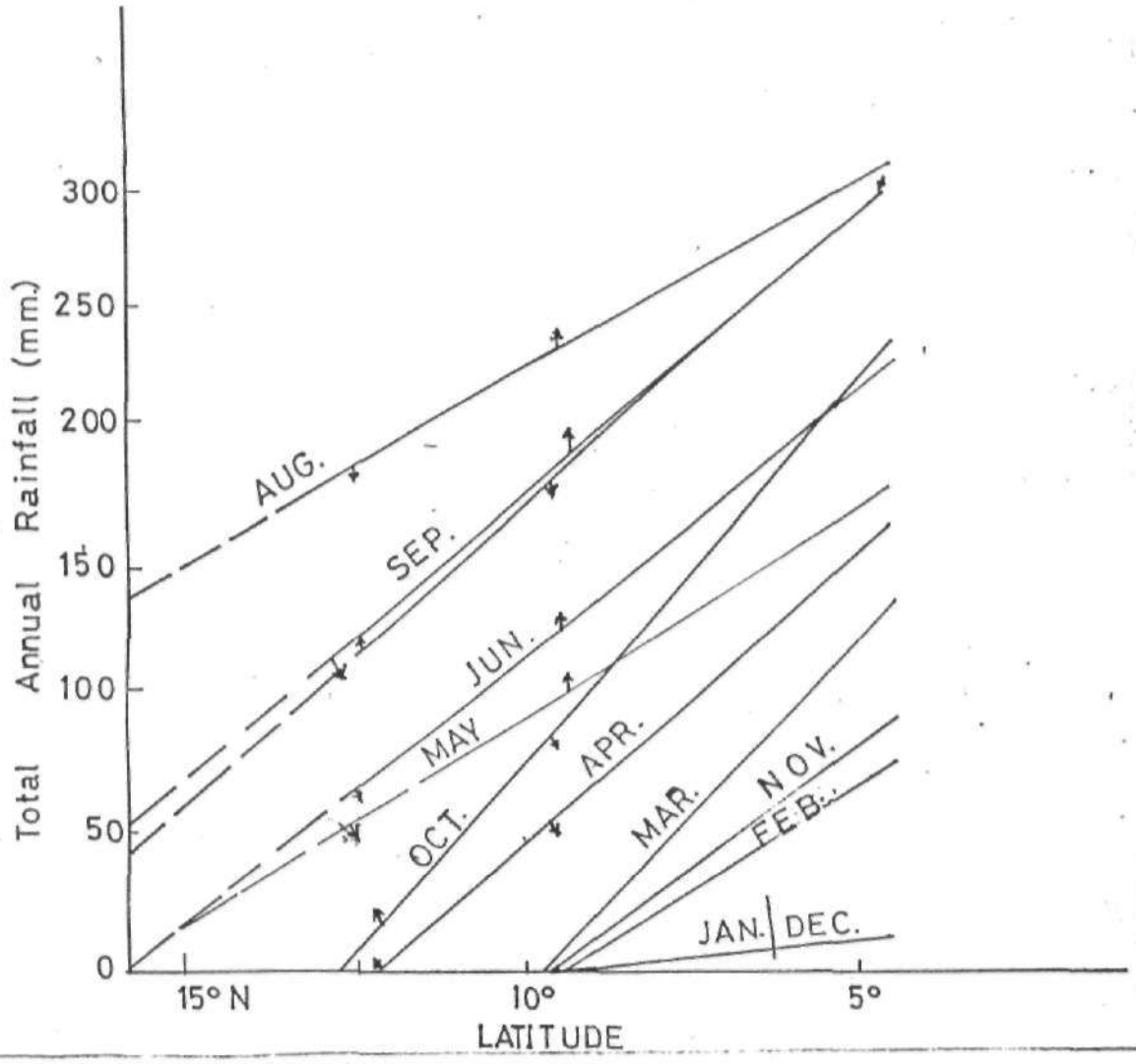


Fig. 2·6 Monthly variation of total rainfall with latitude
(After Omotosho, 1985).

The regression equation indicates that the rain belt advances at a mean rate of about 14 days per latitude which is equivalent to 8km per day.

The retreat of rainfall signals the end of the rainy season and the beginning of the dry season. The dry season begins earlier in the year around September in the northern parts and around October in the southern parts of the country. The difference between the two extremes is about 45days. According to Kowal and Knabe(1973) the relationship between Latitude and end of rain is:

$$y = 35.13 - 0.6X \qquad (r = 0.832) \ldots\ldots\ldots\ldots (2.4)$$

where y = coded time of end of rains in 10-day period.

X = latitude.

and this suggests that the retreat of the rains is much faster than their northward advance, averaging 6.7 days per degree of latitude or about 1.6 km per day.

The length of the rainy season ranges from about 80 days in the north of latitude 13° N to about 200 days in the south of latitude 7° N. The regression equation between latitude and end of the rainy season for 1951 and 1965 by Kowal and Knabe (1972) is:

$$y = 36.48 - 2.103X \qquad (r = 0.910) \ldots\ldots\ldots\ldots\ldots\ldots (2.5)$$

where x = degree of latitude x

and y = length of rainy period in 10-day period.

The equation suggests that the rainy period increases in length from the north to the south by about 21.0days per degree of latitude or for 1 day for every 3.4 miles or 5.4km.

3.4.3 Long Term Trends of Rainfall in Nigeria

Oguntoyinbo et al (1978) have made some general statements about the rainfall trends in Nigeria within the present century.A summary of the observations is presented in Fig 3.7. From the figure, there appears to have been a period of low rainfall in the later part of the last century when drought condition swept over most of West Africa. This pattern conforms with the fluctuations in the low water level of Lake Chad termed 'Little Chad'. (Sikes, 1969). This condition continued into the early part of the 20th century when the north-western part of Nigeria suffered drought conditions in the first and second decades and the Sahara started its encroachment on the Sudan. The year 1913 was particularly dry (Oguntoyinbo et al, 1978).

The period between 1915 was known to have been generally one of lower than average rainfall in the south. The north however experienced better rainfall conditions. There was a period of low rainfall and drought from about the mid 1930s to mid 1950s causing many famines (Mortimore, 1973). The drought of the

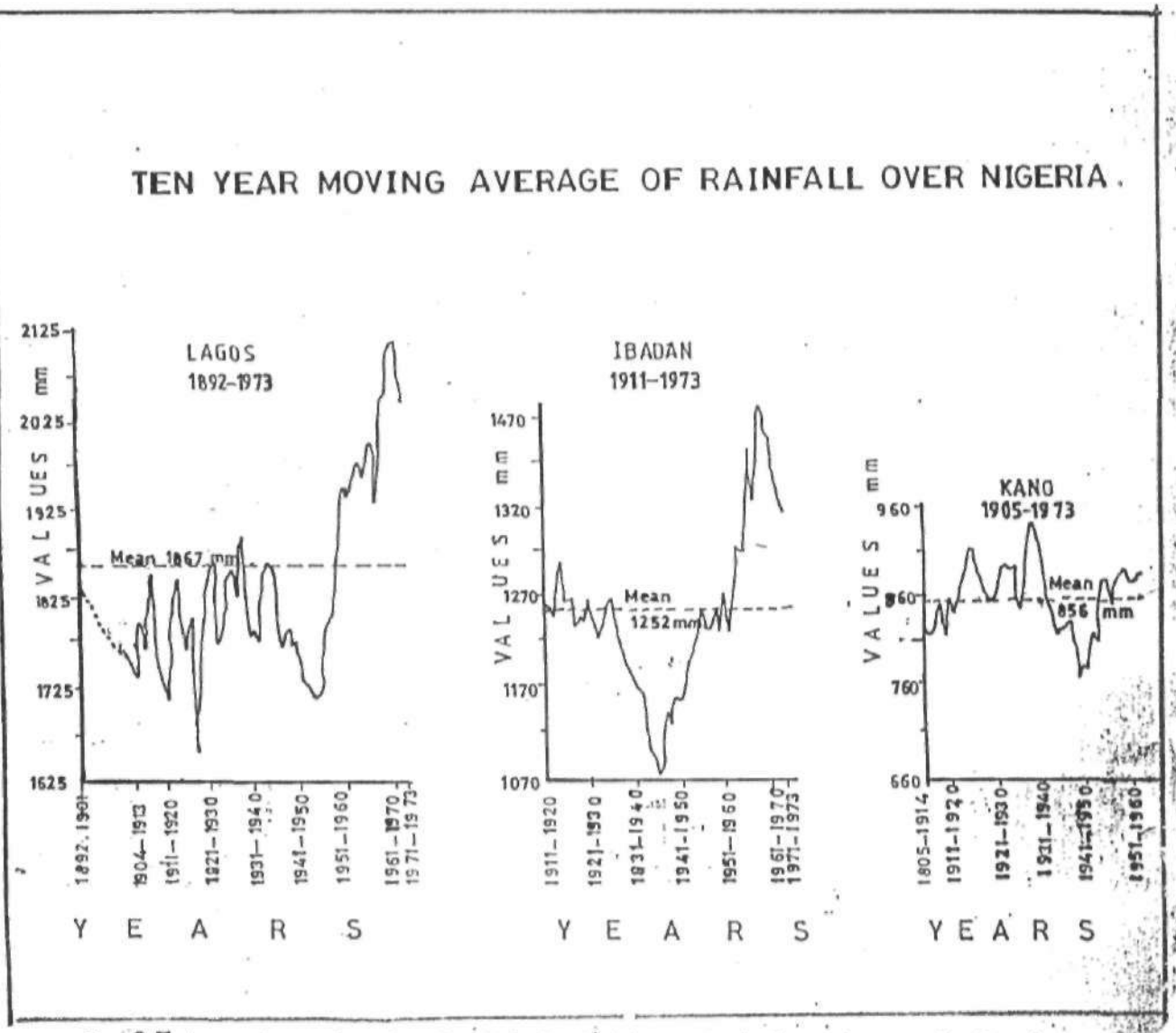


Fig. 3.7. Long term trends of rainfall at selected stations: Lagos, Ibadan, and Kano.

(Oguntoyibo, 1978)

1940s was perhaps the most serious in the southern parts of the country. Ibadan, for instance, received only about 60% of its annual rainfall.

The period between 1951 and 1960 showed evidence of alternating wet and dry years, but with a general upward trend. The decade 1961 - 1970 was marked by notably heavy rainfall, especially in the south. From then onward, there occurred a rapid decline in rainfall such that by the end of that decade Kano received only about 40% of its mean annual rainfall. In 1973, it received only about 40% of its mean annual rainfall - the lowest annual total on record. On the whole, the south received heavier rainfall throughout the period 1951 - 1969.

Between 1969 and 1973, the whole country received from 90 percent of the mean in the wettest part of the country to only about 50 percent in the far north east. Within the long term trend, the 5 years' (1969 - 1973) deficit, has been more severe than those of about 30 t0 60 years ago. If considered over 2 or 3 years trend, the drought of 1972 - 73 was more acute than that of 1913 - 1914 (Oguntoyinbo et al, 1978).

The periodic fluctuations of rainfall in Nigeria has been ascribed to the fluctuations of the ITD. Whenever the ITD advances far inland, the whole country enjoyed heavy rainfall as the ITD dragged along the tropical maritime airmass (mTs) far inland. However, if the ITD failed to advance far inland, the air would be restricted in depth and to the lower latitudes. This would lead to a reduction in rainfall amounts in the north,

and drought conditions might prevail in the interior, while at the same time, the areas south of the ITD might enjoy excessive rain. The whole of the shifting pattern cannot be viewed in isolation, but rather, as part of the fluctuations in the global atmospheric circulation systems (Oladipo, 1985).

The foregoing account of general rainfall charateristics in Nigeria depicts the nature and development of rain-producing systems. The weather systems over Nigeria showed that the two principal air masses affecting the weather flow into the ITD.

The pattern should not be considered in isolation, but as part of the fluctuations in the global atmospheric circulation systems. Having reviewed the causal mechanics of the high intensity rainfall in Nigeria, it is now pertinent to take a look at the position of high intensity rainstorms within the context of factors of soil erosion.

CHAPTER FOUR

4. THE STUDY AREA, DATA BASE AND DATA ASSEMBLY

4.1 THE STUDY AREA

The study area is made up of the whole Nigeria with an area of 923, 768.00 sq kilometres. It lies between latitude 4^0 and 14^0 It is therefore entirely within the tropical zone. A conspicuous feature of the northern area is the Jos Plateau which rises as a steep ascarpment from the Niger-Benue Basins to an average height of 606 metres. The plateau culminates into ranges of hills between 1,515 and 1818 metres in the Shere Hills around Jos. The plateau descends gently northward in the direction of Lake Chad in the North-East and more sharply towards Zaria in Kaduna State.

Although, Nigeria is wholly within the tropics, it is a land of extremes in terms of rainfall amount and the duration of the rainy season. In the southern part for example, there is often much more rain than can be profitably utilised. The excess water not utilised constitute storm water which causes very serious erosion problems. In the northern belt on the other hand, the rainy season is short. This is not to say that there is no erosional problems in the north. The rainy seasons in the north are made up of fewer rainstorms which are of shorter duration but fall at higher intensities. Consequently, erosion problems are widely experienced not only in the south but also in the north.

4.2 DATA BASE

Twenty-seven Synoptic stations with autographic raingauges were selected for analysis on the basis that they have autographic records for at least 10 years, between 1960 and 1970. Even though the stations were not evenly spread throughout the country, they were thought to be fairly representative of the different rainfall zones in Nigeria (Fig 4.1).Rainfall records measured on autographic charts in the imperial units during the period were converted to their metric equivalents.

4.3 DATA ASSEMBLY

4.3.1 GENERAL

The data assembly for this study was carried out in 3 phases:

(a) Phase 1 involved the determination of rainfall characteristics on autographic charts that were stored in Nigerian Meteorological offices at Oshodi, Lagos;

(b) Phase 2 was the field investigation carried out in Samaru - Zaria for the purpose of identifying the best erosivity index for savannah evironment; and

(c) Phase 3 was the laboratory work involving the drying and weighing of soil loss collected in (b) above at the Institute of Agricultural Research (IAR) laboratory also in Samaru - Zaria.

In this study, rainstorm is defined after Bergsma (1981) as a period of sustained rainfall ending when there is a period of 6 hours with less than 13 mm (or 0.5 inch) of rain. In general rainstorms of high intensity last for short periods and cover



Fig. 4.1. Location of meteorological stations used in this analysis.

Source: Oguntoyinbo (1978)

small areas. Infrequent combination of relatively short duration, high intensity and long duration, low intensity storms give large total amounts of rainfall capable of causing much damage. The probability of intense rainstorms varies with locality, and it is important to determine the probability of occurrence of rainstorms using different intensity segment method (Oladipo, 1984).

4.3.2 INTENSITY SEGMENT ANALYSIS

The method of intensity segment analysis is suitable for individual rainstorm equal to or greater than 1 mm in the case of computer scanning, and 5 mm in the case of manual analysis. For the manual analysis the following procedure applies.

a. Mark all the distinct intensity (slope) changes of the autographic recorder trace. In general it is impossible to detect differences between closely space intensity intervals by eye, especially on charts with curvilinear scale, and it is necessary, therefore, to abstract all discernible intensity changes.

b. Tabulate all the time co-ordinate of selected intensity change points to obtain the following for each intensity segment.

(1) Time of beginning of rain = t_1

(2) Time of end of rain = t_2

(3) Depth of rain at beginning = d_1

(4) Depth of rain at end = d_2

(5) Duration of rainfall event = $t = t_2 - t_1$

(6) Depth of rain in rainfall event $d = d_2 - d_1$

(7) Intensity of rainfall d/t (mm/hr).

4.3.3 DETERMINATION OF MEAN VALUES OF INTENSITY AND EROSIVITY OF RAINSTORMS

One of the basic requirements in the hydrological study of an area is the determination of an accurate value of the average rate of precipitation over that area in a given period from the average value of a rainfall station which is only a point in the area. Several methods are often used to extrapolate the result obtained in a rainfall station to other inter-station areas. These are arithmetic mean, Thiessen polygons; Height-balanced polygons and isohyetal method (Ward, 1967).

In order to extrapolate the calculated intensity and erosivity values over each meteorological station to the other parts of Nigeria, isohyetal method was used because the method provides the most accurate determination of average precipitation, since it enables a large number of factors, such as relief, aspect and direction of storm movement to be taken into account, even though rather subjectively.

4.3.4 DETERMINATION OF RAINFALL CHARACTERISTICS ON AUTOGRAPHIC CHARTS

For each rainfall that recurred during the 10 year period, the station, date and time of rainstorm were recorded. After that, the distinct intensity changes on the autographic recorder trace were marked out as illustrated in Fig. 4.2. All discernible intensity changes were carefully marked out on the chart.The storm amount falling in each segment and the duration of each

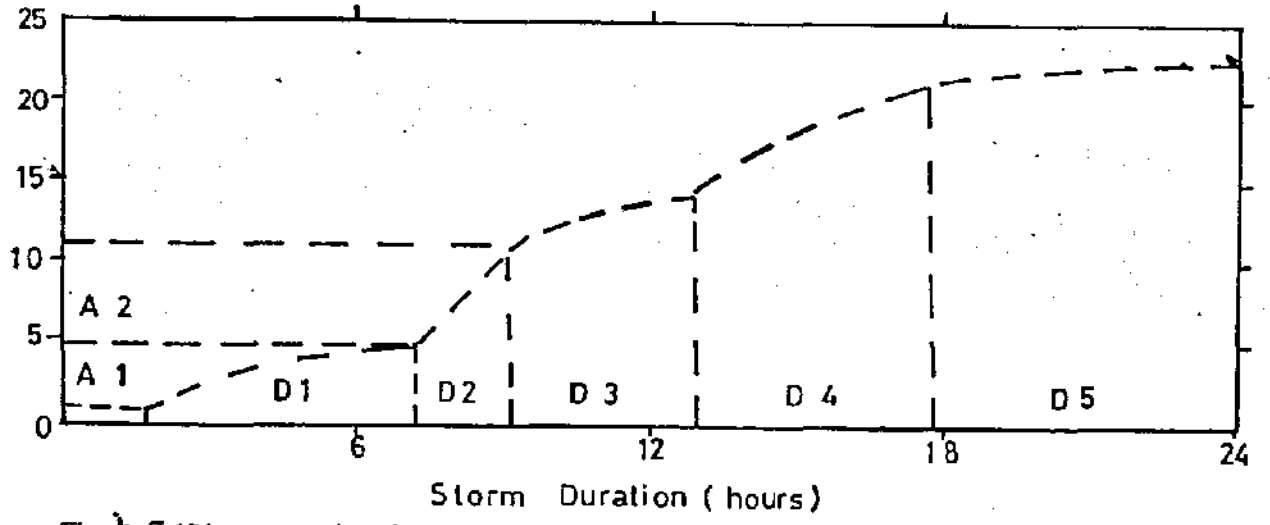


Fig. 4.2 Diagram showing the computation of different intensity segments within a storm
Source: Ward, 1967

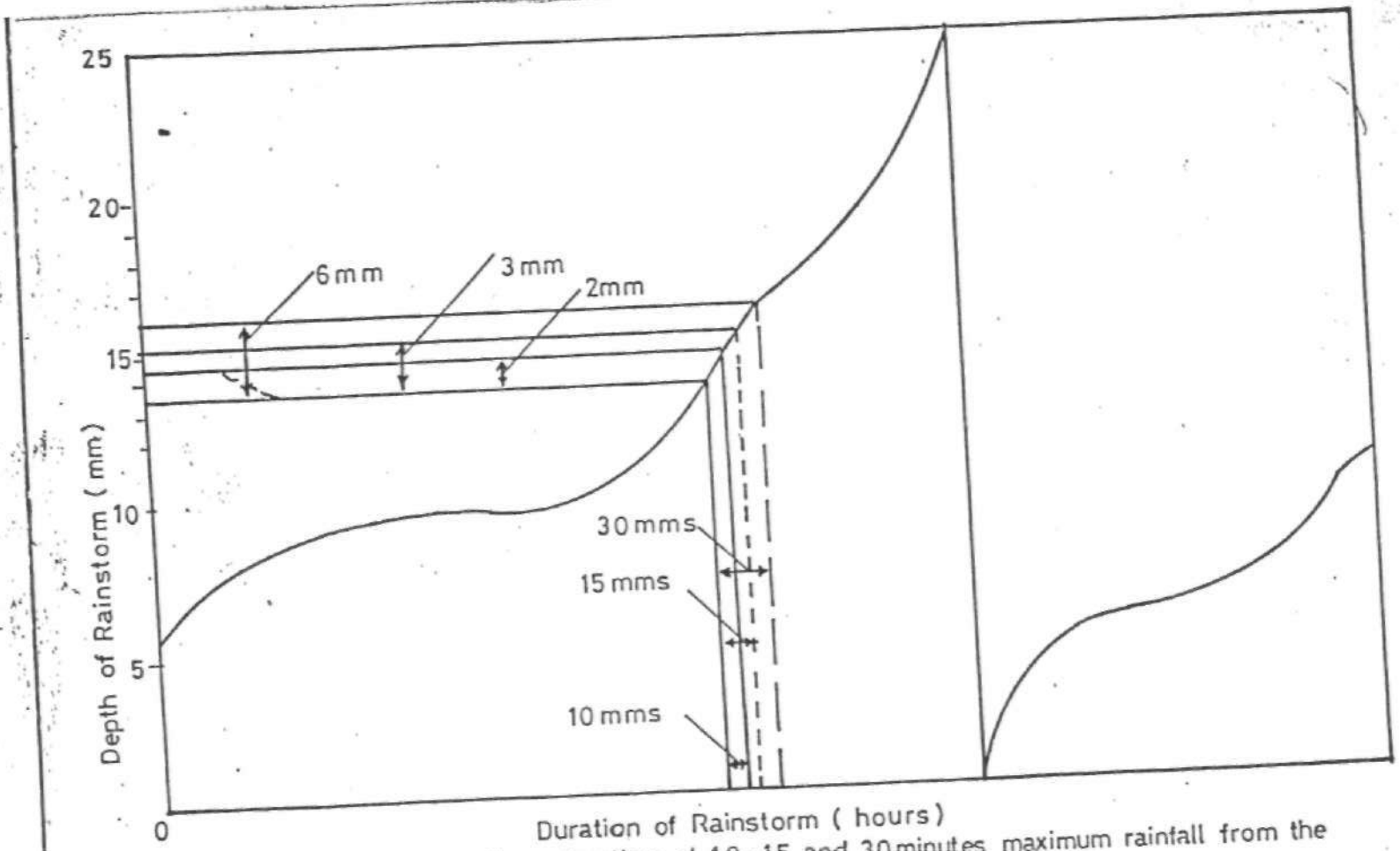


Fig 4.3. Diagram to illustrate the extraction of 10, 15 and 30 minutes maximum rainfall from the Autographic Raingauge Trace of Rainfall during a storm.
Source: Ward, 1967

segment were determined as shown in Fig. 4.3. The result was recorded as shown in Table 4.1. The intensity of the first intensity-segment shown in Fig. 4.3 can be determined by the following simple equation (Ward, 1967)

$$I_1 = A_1/D_1 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 4.1$$

where A_1 = Rainfall amount of the segment
D_1 = Duration of the segment
I_1 = Intensity of the segment.

This process was carried out for all intensity segments for the 34,288 rainstorms analysed (see Table 4.2)

Table 4.2 LATITUDE, LONGITUDE AND ALTITUDE OF SYNOPTIC STATIONS AND NUMBER OF YEARS WITH 'GOOD' RAINFALL RECORDS

STATIONS	LATITUDE	LONGITUDE	ALTITUDE (m)	NUMBER OF YEARS	NUMBER OF STORMS
PORT-HARCOURT	4.85	7.02	18	9	1865
CALABAR	4.97	8.35	63	10	2259
WARRI	5.52	5.73	1	12	3102
BENIN	6.32	5.60	79	10	1942
IKEJA	6.58	3.33	40	13	1393
ENUGU	6.43	7.35	142	10	1414
OSHOGBO	7.75	4.60	305	11	1564
ONDO	7.10	4.83	287	11	1803
IBADAN	7.43	3.90	228	10	1157
ILORIN	8.50	4.58	287	12	1357
MAKURDI	7.68	8.62	97	11	1087
LOKOJA	7.80	6.73	44	19	1587
IBI	8.18	9.25	111	8	749
BIDA	9.10	6.02	144	11	1191
MINNA	9.62	6.53	260	12	1338
JOS	8.87	8.90	1285	11	1699
YOLA	9.23	12.47	175	10	855
YELWA	10.88	4.75	244	12	1095
POTISKUM	11.70	11.03	144	11	830
BAUCHI	10.28	9.82	609	9	917
KADUNA	10.60	7.45	649	8	833
MAIDUGURI	11.85	13.08	354	12	537
GUSAU	12.16	6.70	464	14	1137
KANO	12.05	8.53	476	13	934
KATSINA	13.02	7.68	517	11	695
NGURU	12.88	10.47	344	10	443
SOKOTO	13.02	5.25	351	13	511
TOTAL					34,288

4.3.5 DETERMINATION OF I_{10} I_{15} AND I_{30}

Discussion of the variation of precipitation with time has been largely concerned with the comparatively long-term totals of precipitation for individual years, seasons or months. However to the rainfall intensity in relation to erosivity or surface run-off, the hydrologist has to consider the short-term variation of rainfall intensity during the course of an individual storm. Even, daily rainfall totals may be very misleading. During storms of very short duration variations of intensity may be very important (Ward, 1967). These variations may be described with the aid of intensity duration curves in which rainfall intensity is plotted against the duration of rainfall. An important property of these curves is that the curves of individual storms of similar length tend to resemble each other very closely.

In order to determine the peak intensity of rainstorms, especially the short burst of very high intensity rainstorms the greatest amount of rain falling in any 10, 15 and 30-minute periods were determined from the charts. This involved locating the period when rain fell at highest intensity during a storm. This was given by the area with the steepest slope of the autographic recorder trace. From the charts, the various amounts of rain which the steepest slopes gave at 10, 15 and 30 minutes were read and converted to intensity in mm hr^{-1} and denoted as I_{10}, I_{15} and I_{30} respectively. Figure 4.3 for example, shows how the amount falling at the highest 10 minute - intensity was obtained by tracing the 10 - minute interval lines marked with dotted vertical lines until they touched the curve given by the

autographic recorder trace. These 10 minute interval lines were again traced horizontally to the vertical axis; then, the amount of rainstorm falling during the 10 minute duration was read. In this case, the amount of rain falling at the 10 minute maximum intensity was 1 mm in 10 minutes. This rate of fall was then converted to mm hr^{-1} which in this case was 6 mm hr^{-1}.

In order to facilitate the measurements of I_{10}, I_{15} and I_{30} from the rainguage charts, a piece of transparent paper with 10, 15 and 30 minutes duration marks exactly equal to the scale of the rainguage charts was superimposed on the rainguage charts. It was then possible to determine very quickly the amounts of rainfalls which fell within the 10, 15 and 30 minute periods. The I_{10}, I_{15} and I_{30} were then determined using the process for the 34,288 rainstorm which occurred during the approximately 10 - year period in all the 27 synoptic stations.

4.3.6 DETERMINATION OF KINETIC ENERGY AND EROSIVITY OF RAINFALL

The data obtained from the procedures described in sections 4.3.4 and 4.3.5 were fed into the Ahmadu Bello University Computer. Using the University of Minnesota Fortran Compiler version 5.1 - 27/03/240, the computer was programmed to compute the respective values of the kinetic energies from various intensities of rainfall using the equation in 2.10. Using the 3 erosivity indices of the Wischmeier and Smith (1958) EI_{30}, the Hndson KE>25 and Lal's AIm, the respective values of erosivity of rainfall were calculated as demonstrated in Table 4.3.

TABLE 4.3

AN EXAMPLE OF EI_{30} CALCULATION AFTER OLADIPO, 1984

RAINFALL DURATION (min)	DEPTH (mm)	INTENSITY (mm/hr)	ENERGY PER mm (e_i) xx	ENERGY PER mm OF RAIN (E_i)	TOTAL ENERGY PER STORM (E)	I_{30} (mm/hr)	$R = EI_{30}/685$
15	18.3	73.2	28.2	516.1			
16	2.0	7.5	19.5	39.0			
14	17.2	73.7	28.2	485.0			
15	4.5	18.0	22.9	103.1			98.1J-mm/M^2- hr
27	8.6	19.1	23.1	198.7		44.0	
25	8.0	19.2	23.1	184.8	I,526.7		

* I_{30} directly from the chart = 41.6mm/hr

** $e_i = 11.9 + 8.73 \log I$ or $e_i = 29.82 - 127.5 I \frac{-2}{Jm}$ (not good for every low intensity values).

I

4.3.6.1 DETERMINATION OF THE WISCHMEIER AND SMITH EI_{30} EROSIVITY

Applying the Wischmeier and Smith (1958) EI_{30} index, the values of rainfall erosivity were given by the product of the kinetic energy E, which was calculated using the equation in 2.10 and the maximum 30 minute intensity. This process gave the EI_{30} erosivity value of each intensity segment determined from the rainguage charts.

4.3.6.2 OTHER EI MEASURES

The other Wischmeier and Smith (1958) EI measures analysed are EI_{10} and EI_{15}. Using the 2 indices, their respective values of rainfall erosivity were given by the products of Kinetic energy, E, and the 10 and 15 minute maximum intensities respectively.

TABLE 4.1 SAMPLE RECORD SHEET OF AMOUNTS AND DURATIONS OF VARIOUS INTENSITY SEGMENTS OF RAINSTORMS IN NIGERIA

BIDA 1965

sheet 2 out of

date / /

ST	YE	MO	DA	T	I_{30}	I_{10}	A_1	D_1	A_2	D_2	A_3	D_3	A_4	D_4	A_5	D_5	A_6	D_6	A_7	D_7	A_8	D_8	A_9	D_9
BD	65	06	15	3	1.0	0.1	0.09	0.2																
			16	3	1.0	0.1	0.07	3.5																
			21	3	7.0	5.0	0.43	1.9																
	65		23	3	3.0	2.5	0.27	0.9																
				2	16.0	9.5	0.24	0.3	1.01	2.5														
			26	3	4.0	4.0	0.13	0.1	0.08	0.2														
	65			1	1.0	1.0	0.11	0.3																
				3	0.1	0.1	0.01	0.2																
			28	3	0.5	0.5	0.19	1.1																
			29	3	0.2	0.2	0.03	1.1																
	65	07	02	2	9.0	7.0	0.53	0.4	0.16	2.5														
			05	3	5.3	4.0	0.28	0.4																
			06	3	0.4	0.4	0.13	1.7																
	65			3	1.0	1.0	0.49	0.4	0.07	0.6														
			10	2	1.0	0.8	0.05	0.4																
			17	3	7.0	0.5	0.07	9.6	0.02	1.0	0.35													
	65		13	3	1.0		0.25	1.4																
				2	18.0	1.4	1.03	1.6	0.19	2.3														
			16	0	7.0	0.5	0.36	0.3	0.5	2.6														
			23	1	0.1	0.1	0.01	0.2																
	65		24	2	0.5	0.5	0.04	1.0																
			25	2	0.1	0.1	0.01	0.1																
				2	0.3	0.3	0.04	1.0																
	65		26	3	0.2	0.2	0.02	1.1																
				2	0.1	0.1	0.01	0.1																

LEGEND

ST - Station

DB - Bida

YE - Year of Rainstorm

Da - Date of Rainstorm

T - Time codes (1,2,3)

where 1 = (morning) 0000 to 1200
2 = Afternoon 1200 - 1800
3 = Evening 1800 - 0000

I_{30} - Amount of rainstorm falling during 30-minutes maximum intensity.

I_{10} - Amount of rainstorm falling during 10-minutes maximum intensity.

I_{15} - Amount of rainstorm falling during 15-minutes maximum intensity.

A_1 - A_9 - Various amounts of rainstorm falling at 9 intensity segments.

D_1 - D_9 - Various durations of 9 intensity segments.

4.3.6.3 THE HUNDSON KE > 25

After the Kinetic energies of all the rainfall recorded have been calculated, the computer was programmed to select the energies of those rainfall that fell at intensities above 25 mm hr^{-1}. The values obtained gave the Hudson KE > 25. There was no need to consider the only other variance of Hundson's index of KE < 25 because it has been explained in section 2.3.3 that the rains falling at intensities below the threshold value of 25 mm hr^{-1}, do so at such low intensities that cannot possibly be erosive. (Pauwelyn et al, 1988).

4.3.6.4 LAL's AI_M

High intensity storms last for only very short period. Thus the Im of Lal's AI_m index is purposely meant to quantify the short duration peak intensities experienced during the storm. Consequently, only 2 forms of Lal's AIm were examined: AI_{10}, and AI_{15}. The AI_{10} was obtained by finding the product of the rainfall amount, A and the 10 minute maximum intensities of that rainfall. AI_{15} on the other hand was obtained by finding the product of the rainfall amount, A and the 15 minute maximum intensities, I_{15}, of that rainfall. AI_{30} was not considered because 30-minute-duration is a fairly long period in the life of a storm that could introduce low variations into the values of peak intensities. (Bergsma, 1981, Pauwelyn et al, 1988).

4.3.6.5 WEST AFRICAN INDICES

The West African Indices considered in section 2.3.3 were approximations of R which are annual values of Wischemeier's EI index in West Africa where less comprehensive data are often

available. The values obtained from the approximations provide average values of annual erosivity consequently, the approximations could not possibly provide data for the monthly temporal analysis as required by this study. The West African indices were, therefore, not used in this study.

4.4 FIELD INVESTIGATIONS

A field investigation was carried out in Samaru, Kaduna State, Nigeria as a case study to assess the applicability of 6 erosivity indices and 4 rainstorm characteristics in the northern part of Nigeria. The various methods often used in the assessment of erosivity indices and the difficulties the methods were often faced were earlier reviewed in section 2.4. Leow's (1982) splash trap also known as wash trap was adopted in order to overcome the problems associated with the methods used in those previous attempts to measure splash erosion.

4.4.1 SPLASH-TRAP MATERIALS

The materials used for splash-traps consisted of tins of motor engine-oil which measured 42cm long, 25.4cm wide and 61cm high (see Fig 4.4). Each half was then used as a splash-trap measuring 42cm long, 25.4cm wide and 30.5cm high as illustrated in Figure 4.5.

4.4.2 PROCEDURE OF FIELD INVESTIGATION

Measuring soil loss on the erosion plots on which the splash-traps were installed involved embedding the splash-traps on the plots which measured 9 square metres each. In this investigation, 20 splash-traps were installed in the splash plots

index in West Africa where less comprehensive data are often available. The values obtained from the approximations provide average values of annual erosivity consequently, the approximations could not possibly provide data for the monthly temporal analysis as required by this study. The West African indices were, therefore, not used in this study.

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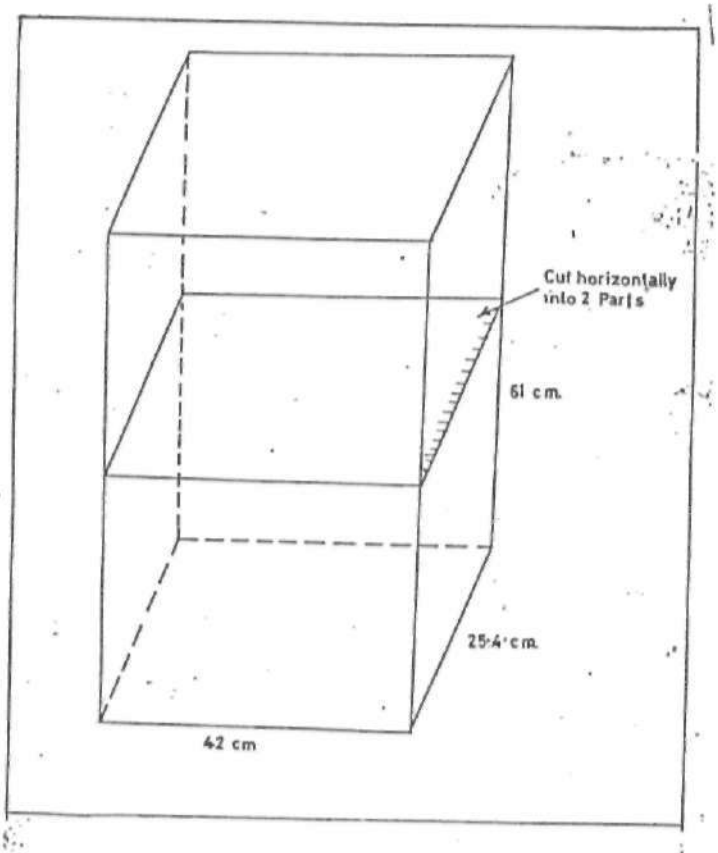


Fig. 4.4. Cross Section View of a sample Washtrap

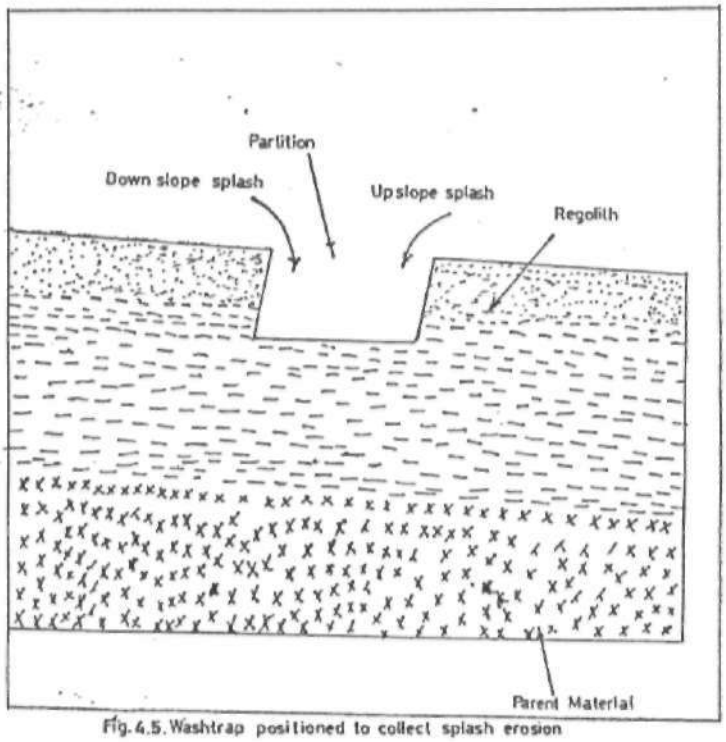


Fig. 4.5. Washtrap positioned to collect splash erosion

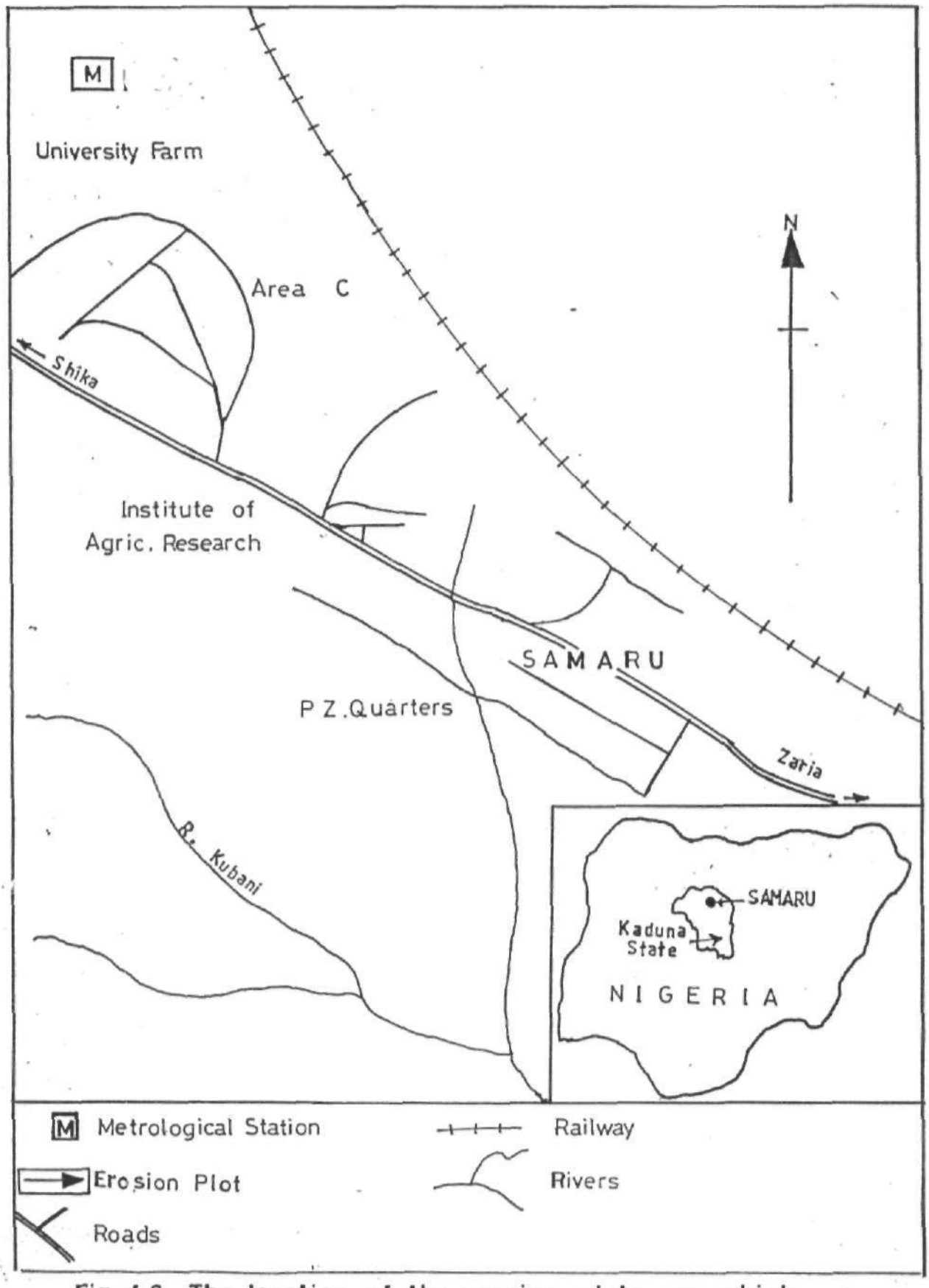
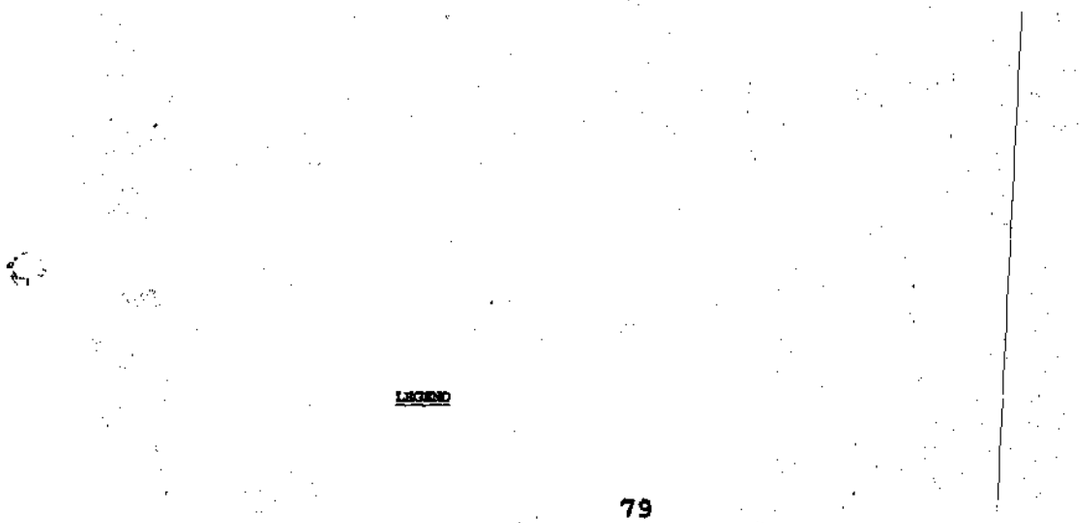


Fig. 4.6. The location of the erosion plots on which washtraps were installed.

along first and second valley slopes ranging from 7 to 9 percent located in Samaru (see Fig 4.6). The splash-traps were arranged in four rows, of 5 each, down the slope. The plots were then weeded frequently to keep them bare of vegetation throughout the rainy season. After each of the 42 rainstorms recorded between July and October, 1983, the splashed sediments collected in the compartments of the splash-traps were oven-dried and weighed. After every storms the maximum 10, 15 and 30 minutes intensities were determined from autographic charts from the Institute for Agricultural Research (IAR) meteorological station, Samaru. The calculated erosivities, and some other storm parameters were then correlated with weights of splash material.

The main problem encountered while carrying out the field investigation was that the livestock grazing in the area strayed into the plots and knocked off some of the splash-traps on four different occasions. Sediments collected during the occasions have to be discarded. Thus during the period of study, 46 storms occurred but only 42 could be used for the analysis. The data obtained from the investigation was recorded in Table 5.1.



CHAPTER FIVE

5. ANALYTICAL PROCEDURES

5.1 INTRODUCTION

Two categories of data were obtained for the thesis. The first was the data obtained from soil loss investigation that was carried out in Samaru. The second category was the data on amounts and durations of rainstorms in the 27 synoptic stations in Nigeria.

The data obtained from the soil loss investigation consisted of intensities and erosivities of 43 rainstorms which occured between June and October 1984 in Samaru and the resultant splashed materials from the erosion plots. The data are shown in Table 5.1.

From the data on amounts and durations of rainstorms for the 27 synoptic stations for the 10 year period, the computer was programmed to calculate the intensities and erosivities of the rainstorms in the form of monthly mean intensities, monthly mean peak intensities, the monthly mean erosivities and the monthly total erosivities. The results are shown as Tables in annexes A1, A2, A3, A4 and A5.

5.2 CHARACTERISTICS OF SPLASHED MATERIALS

Table 5.2 illustrates the mean and standard deviations of the values of 6 rainstorm characteristics observed during the investigation. The Table also shows the mean values of the sediments collected in the wash-traps during the period of study in Samaru.

TABLE 5.1

TOTAL SEDIMENTS DETACHED AND EROSIVITY INDICES

S/N	TOTAL SEDIMENTS (gm)	STORM DURATION (min)	STORM AMOUNT	PEAK INTENSITY (mm)	AVERAGE INTENSITY ($mm\ hr^{-1}$)	AI_{10} ($cm^2 hr^{-1}$)	AI_{15} ($cm^2 hr^{-1}$)	EI_{15} ($J\ mm^{-1}\ m^{-2}$)	EI_{30} ($J\ mm^{-1}\ m^{-2}$)	EI_{10} ($J\ mm^{-1}\ m^{-2}$)	KE 25 ($J\ mm^{-1}\ m^{-2}$)
1.	21	40	6	24	8	122	110	-	-	-	-
2.	176	40	12	112	26	1366	1107	-	-	-	-
3.	265	210	30	216	8	6372	5860	27237	25645	28779	24880
4.	115	25	5	120	12	588	518	-	-	-	-
5.	44	30	3	48	6	159	112	-	-	-	-
6.	119	60	9	8	8	70	48	-	-	-	-
7.	26	60	4	40	4	140	80	-	-	-	-
8.	136	60	7	37	7	237	175	-	-	-	-
9.	33	240	9	24	2	200	150	-	-	-	-
10.	319	40	10	130	15	1636	1200	10350	901	11850	7934
11.	110	31	5	77	7	156	140	-	-	-	-
12.	138	40	9	24	11	170	120	-	-	-	-
13.	585	12	28	320	19	9296	7800	23688	17613	29722	-
14.	146	20	6	40	17	220	170	-	-	-	-
15.	113	60	9	8	8	70	48	-	-	-	-
16.	115	25	5	120	12	588	518	-	-	-	-
17.	338	240	27	104	7	2776	2586	9866	9384	87536	7783
18.	161	15	3	40	10	100	97	-	-	-	-
19.	596	135	52	240	23	9880	2950	36017	33721	50519	33017
20.	132	40	9	24	11	170	120	-	-	-	-
21.	112	20	9	12	26	105	96	-	-	-	-
22.	95	25	2	72	5	144	111	-	-	-	-
23.	329	45	12	136	17	1686	1225	10516	9412	11900	7984
24.	461	168	39	200	13	7996	7010	3798	2762	4760	20560
25.	167	75	19	120	15	243	180	11515	8484	17176	-
26.	615	12	28	320	9	9296	7800	226	113	339	-
27.	103	20	8	120	23	924	650	-	-	-	-
28.	164	15	3	40	10	100	97	-	-	-	-
29.	67	15	5	40	20	200	170	-	-	-	-
30.	615	150	56	220	24	9905	8005	36800	33030	50610	33617
31.	103	24	16	110	22	925	666	579	298	869	-
32.	155	18	5	45	16	150	110	-	-	-	-
33.	61	13	4	34	15	192	160	-	-	-	-
34.	322	230	26	100	6	2200	2206	9806	7605	81053	7703
35.	169	35	11	102	24	1306	1056	-	-	-	-
36.	260	200	30	200	8	6302	5060	22007	25045	28009	24008
37.	115	36	17	115	13	1920	500	12006	20100	25116	12220
38.	107	58	10	7	7	69	56	-	-	-	-
39.	239	351	10	90	26	1601	501	-	-	-	-
40.	167	72	10	125	13	223	170	-	-	-	-
41.	313	160	37	210	10	6900	6505	3110	2173	4130	21210
42.	319	15	30	260	16	8605	7602	1933	2900	3867	-
43.	210.2	75.5	15.5	105.8	13.3	1945.5	1681.9	13970.9	12329.8	22630.4	10265.1
SD	1642	81.5	13.3	85.3	6.7	3150.1	2631.1	12270.4	11012.3	20152.3	10071.7
CV	70.1	107.9	86.0	80.6	50.6	162.3	156.4	87.0	95.0	101.9	55.1

During the investigation, rainstorm amounts recorded ranged from 3mm to 56mm. The mean rainstorm amount was 15,5mm with a high coefficient of variation of 86 percent reflecting the extreme intraseasonal variation in rainstorm amount.

The storm duration on the other hand ranges from 12 minutes to about 6 hrs. The mean storm duration during the period was 1 hr 15 minutes, but with high coefficient of variation of 108 percent.

The average intensity for the storms that fell during the period was 13.3mm hr^{-1} with a standard deviation of 6.7mm hr^{-1} with a coefficient of variation of 50.6 percent.

TABLE 5.2

STORM CHARACTERISTICS AND AMOUNT OF SEDIMENTS COLLECTED

S/N	VARIABLES	NO. OF SAMPLES	MEAN	SD	CV
1.	Rainstorm Amount	43	15.5	13.3mm	86.0
2.	Rainstorm Duration	43	75.5	81.5mins	107.9
3.	Average Intensity	43	13.3	6.7mm hr^{-1}	50.6
4.	10min Peak Intensity	43	105.8	85.3mm hr^{-1}	80.6
5.	15min Peak Intensity	43	99.4	81.1mm hr^{-1}	76.0
6.	Total Splash Detachment	43	210.2	164.2gm	78.1

Values of 10 minute peak intensity vary considerably during the study period. The values ranged between 34 and 320mm hr^{-1}. The mean of the 10 minute peak intensity of all the 43 rainstorm recorded during the period was 105.8 mm hr^{-1} with a standard deviation of 85.3 mm hr^{-1}.

The mean and standard deviation of the 15 minute peak intensity of the storms on the other hand were 99.4 and 81.1mm

hr^{-1} respectively. The 15 minute peak intensity ranged from 32.3 to 260mm hr^{-1}.

The weight of the sediments detached during the study period ranged from 61 to 331gm with a mean of 210.2 gm and a standard deviation of 164.2 gm. The high standard deviation was an indication of very high variability of erosivity resulting from various degrees of intensity of rainstorms ranging from 5 to 320 mm hr^{-1}.

5.3 RELATIONSHIP BETWEEN TOTAL SEMDIENTS DETACHED AND RAINSTORM CHARACTERISTICS.

The relationships existing between total sediments detached and 10 rainstorms characteristics were examined using regression and correlation analysis.Regression,as that branch of statistical theory, is concerned with the objective assessment of the association between two or more variables Spiegel (1980) and Rahman (1978). The general aim of regression analysis, therefore, is to derive a mathematical description of the relationship between the variables and, also, an assessment of the inevitable uncertainty of the relationship found. More specifically, one is mainly interested in the relationship of dependence of one variable, say, Y; or other non-random variable(s) say X or X_i (i= 1, 2 ,3,...,n) Oladele (1992). In general, the dependence of Y (the dependent variable on X (the independent or explanatory variables) means that the distribution of Y depends on X. In other words, the movements of Y are functions of X. This relationship can be written mathematically as:

$$Y = f(x) = Bo + BiX \ldots\ldots\ldots 5.1$$

This is the equation of the line that best fit into the data when plotted as the scatter-diagram. It is normally drawn to pass closest to all points, since all the points often cluster around the line but do not always lie on the line. The objective is to minimise the total divergence of the points from the line, that is, minimising the total squared deviation. Common among the methods used to obtain the estimate of Bo is the least square method. Bi or bi is referred to as the regression coefficient that is the value of the gradient or slope of line. Bo, on the other hand, is the constant value or the Y intercept. Similarly, if we have more than one independent variable, say k variables, we have a model of the form:

$$Yi = Bo + B_1Xi_2 + B_2Xi_2 \ldots\ B_kX_{ik} \ldots\ldots 5.2$$

To measure or test the goodness of fit of the regression line, a convinient statistic for this purpose may be developed from the analysis of variance table:

Total variation = Explained variation + unexplained variation

We can therefore define the measure of goodness of fit as

$$R^2 = \frac{\text{variations of Y explained by the fitted line}}{\text{Total Variation}} \ldots\ldots\ldots 5.3$$

R^2 is referred to as multiple correlation coefficient or coefficient of determination. It is the degree of association between the dependent variable and the others.

The assumptions of multiple correlation analysis are similar to those of simple correlation analysis involving only one independent variable. They are:

a. Variables involved are random

b. They have linear relationship

c. Conditional variance are equal (homoscedasticity).

d. Conditional distribution are all normal.

The conditions are quite strigent but they are not usually completely satisfied on real data situation. At any rate, multiple regression analysis is quite robust in the sense that some of these assumptions can be violated without serious consequencies in terms of validity of the result. (Rahman, 1977; Oladele, 1992).

The correlations between total sediments detached and rainstorm characteristics were first examined using regression and correlation analysis. Table 5.3 shows the degree of correlation between pairs of rainstorm characteristics. The first line which shows the correlations between total sediments detached and rainstorm characteristics is the one of utmost importance to us. Generally speaking, it can be observed that there exist some relationship between each of rainstorm characteristics and the sediments detached and AI_{10} erosivity, ($r = 0.89$). This was followed by rainstorm amount and peak intensity of rainstorm where each had a correlation of $r = 0.84$ while the coefficient with AI15 was about 0.82

TABLE 5.3 CORRELATION MATRIX OF TOTAL SEDIMENTS DETACHED AND RAINSTORM CHARACTERISTICS

	SED	DUR	AMO	PINT	AINT	AI_{10}	AI_{15}	EI_{15}	EI_{30}	EI_{10}	KE>25
SED	1.00	0.29	0.84	0.84	0.27	0.89	0.82	0.70	0.61	0.54	0.60
DUR		1.00	0.53	0.19	0.13	0.31	0.29	0.39	0.39	0.55	0.51
AMT			1.00	0.77	0.24	0.90	0.82	0.76	0.75	0.61	0.81
PINT				1.00	0.24	0.91	0.88	0.61	0.57	0.36	0.53
AINT					1.00	0.20	0.10	0.20	0.17	0.30	0.10
AI_{10}						1.00	0.95	0.69	0.67	0.43	0.69
AI_{15}							1.00	0.57	0.52	0.37	0.57
EI_{15}								1.00	0.93	0.67	0.81
EI_{30}									1.00	0.68	0.84
EI_{10}										1.00	0.56
KE > 25											1.00

SED - Weight of sediments collected after each rainstorm (gm)

DUR - Duration of rainstorms (minutes)

AMO - Amount of rainstorms (mm)

PINT - 10-minute peak intensity of rainstorms (mm hr^{-1}).

AINT - Average intensity of rainstorms (mm hr^{-1})

Furthermore, the partial regression analysis was employed to study the extent to which each rainstorm characteristics contributed to sediment detachment from the soil. Table 5.4 illustrates the partial regression analysis of total sediments detached on the rainstorm characteristics. The regression models fitted for each of the 10 rainstorm characteristics are shown in Table 5.4. The table also shows the coefficients of determination, R^2, F, Beta and T-statistic values.

TABLE 5.4 PARTIAL REGRESSION OF TOTAL SEDIMENTS DETACHED ON TEN RAINSTORM CHARACTERISTICS

Rainstorm Characteristics	Regression Equations	R^2	F	Beta	T
Duration	Y = 163.8 + 0.6 X	0.08	3.79	0.29	2.00
Amount	Y = 49.4 + 10.3 X	0.71	101.50	0.84	10.10
Peak Intensity	Y = 39.4 + 1.6 X	0.70	95.16	0.84	9.80
Average Inten.	Y = 122.5 + 6.4 X	0.07	3.15	0.27	1.78
AI_{10}	Y = 109.2 + 0.4 X	0.80	160.20	0.89	12.66
AI_{15}	Y = 121.8 + 0.1 X	0.68	86.10	0.82	9.28
EI_{15}	Y = 149.4 + 0.01X	0.49	39.10	0.70	6.25
EI_{30}	Y = 156.8 + 0.01X	0.37	24.10	0.61	4.91
EI_{10}	Y = 164.5 + 0.004X	0.29	16.90	0.54	4.11
KE > 25	Y = 157.1 + 0.01X	0.36	23.41	0.60	4.84

The value of R^2 associated with AI_{10} erosivity was 0.80 which implies that 80% of the variation of erosivity was explained by the AI_{10} regression model; while the remaining 20% was due to some other factors. Likewise, the values of F, Beta and T associated with AI_{10} were the largest. Therefore, by simple comparison, we can deduce that of all the 6 erosivity indices and the other 4 rainstorm characteristics, AI_{10} erosivity index had the strongest relationship with sediments detached.

Finally multiple regression analysis was employed to investigate which of the 10 rainstorm variables best predicts soil loss. With the Spiegel (1980) multiple regression technique, it was possible to estimate each variable in turn from the 10 erosivity variables. A generalised multiple regression equation used was:

$$Y = Bo + B_1 X_1 + B_2 X_2 \ldots\ldots B_n X_n \quad ..5.4$$

wtere Y = Dependent variable

$X_1 \ldots . X_1$ = Independent variable

$B_o \ldots . B_n$ = Constants.

For the each of the equations, the multiple R, R square, Adjusted R squaare and the standard errors were computed and shown in Table 5.5.

TABLE 5.5 MULTIPLE REGRESSION OF TEN EROSIVITY VARIABLES

Equations	Dependent variable	Multiple R	R square	Adjusted R square	Standard error
1	Total sediment	.94	.89	.55	61.5
2.	Rainstorm Duration	.73	.55	.40	60.9
3.	Raimstorm amount	.97	.93	.91	3.9
4.	Peak intensity	.93	.86	.81	36.2
5.	Average intensity	.58	.34	.13	6.2
6.	AI_{10}	.99	.97	.97	597.1
7.	AI_{15}	.97	.94	.92	763.0
8.	EI_{15}	.95	.91	.88	3456.9
9.	EI_{30}	.97	.93	.90	2908.9
10.	EI_{10}	.85	.72	.63	12772.2
11.	KE > 25	.91	.83	.78	4570.0

From Table 5.5 it can be seen that the multiple R, the R square and the adjusted R are highest for AI_{10} index. This indicates that the AI_{10} is the best erosivity index for Nigerian Environment. This is followed by AI_{15} and rainstorm amount which

gave multiple R of .97 and .97 respectively. The high correlation of AI_{10} obtained here is in agreement with the good linear relationhip earlier observed for Samaru (Kowal and Kassam, 1979) and in Ibadan by Lal (1981). The observation in the present study suggests that rainfall amount related indices such as AI_{10} and AI_{15} are better predictors of the erosion hazard than the energy parameters of EI_{10}, EI_{15} and EI_{30} which Wischmeier and Smith (1958) suggested. The difference could be due the different types of rainstorms occurring in the environment where the observation were made. While Wischmeier and Smith (1958) observation was under low intensity rainstorms in USA, this present study was carried out under high intensity rainstorms in Nigeria.

5.4 CHARACTERISTICS OF INTENSITIES AND EROSIVITIES OF RAINSTORM IN NIGERIA

In order to show the empirical behaviour of intensities and erosivities of the rainstorms over Nigeria during the 10-year period, the percentage frequency distribtions were calculated. The results for both intensities and erosivities are presented in Chapter Six and Chapter Seven respectively.

5.5 RELATIONSHIP BETWEEN RAINSTORM INTENSITIES, EROSIVITIES AND GEOGRAPHICAL FACTORS

In order to facilitate the estimation of the values of the rainstorm variables for most areas of Nigeria without rainfall records, the annual and monthly mean, and the annual and monthly maxima of each of intensity and erosivity in all the 27 synoptic stations were correlated with the three selected geographic factors which are known to influence rainfall producing

mechanisms in Nigeria. The first of these geographic factors is moonsonal-air factor which was interpreted as distance from the ocean. It was measured along the approximate path of the moonsonal air which approaches the Nigerian coast, at an angle of about 45^{o} to the parallel drawn at the most southerly point of the Nigerian coast. The moonsonal air factor was considered with the inference that the moisture content of the westerlies decreases as its ocean source is left farther behind.

Secondly, the disturbance line factor was interpreted as the longitude of the meteorological stations used in this analysis because disturbance lines are intense linear pressure systems which travel from the east to the west bringing along with them heavy rainfalls which decrease westwards in frequency and intensity; and therefore, exhibiting a longitudinal relationship (Kamara, 1986).

Lastly among the geographic factors is the relief factor which was interpreted as the height of the meteorological station concerned. This factor was considered because orographic rainfall is best developed when a deep layer of moist air is forced to rise over a range of hills or mountains; and also, other forms of uplift may be intensified or triggered off in mountanous areas by forced uplift (Ward, 1967). The relief factor, therefore, assumes that the values of intensity and erosivity in increase with height as the orographic lifting mechanism of the air/mass intensities.

The approach used in investigating the relationships between the mean values of the rainstorm variables assembled and the 3 geographical factors was based on the Pearson product moment multiple correlation coefficients (Spiegel, 1980) which was earlier used by Miller and Khan (1963) to investigate the relationship between precipitation and the 3 geographical factors in Sierra Leone, West Africa. The objective of the investigation was to develop multivariate equations involving the three geographical factors as independent variables (X_1, Y_2, Z_3) for the purpose of estimating each of the storm variables including erosivity as dependent variables (Y) for any part of Nigeria. The result of the analysis formed the subject of Chapter Six and Seven.

CHAPTER SIX

RAINFALL INTENSITIES IN NIGERIA

6.1 INTRODUCTION

The parameters of the rainfall intensities used in our present study are, mean intensities and maximum intensities of rainstorms in Nigeria. Their spatial and temporal characteristics are examined in the following sections.

6.2 MEAN INTENSITIES OF RAINSTORMS IN NIGERIA

In general, rainfall intensity can be expressed by dividing the rainfall amount by the given duration of the rainstorm. As the duration over which intensity can be calculated varies, the term 'mean intensity' can take various forms. Thus, it can take the form of annual mean intensity, monthly mean intensity and daily mean intensity. Their various values, for instance, can be calculated by dividing the total amount of rainfall by the number of raindays during which the data was collected. Similarly, hourly mean intensity can be calculated by dividing the total rainfall in a given period by the number of hours over which rain falls. Mean intensity was used in that, it can be computed faster and more easily than peak intensity. Mean intensity can also at the same time serve as an approximate indicator of storm erosiveness and can be an important variable in the study of rainfall erosivity. The spatial and temporal variation of intensities is thus considered an invaluable step towards the understanding of rainfall erosivity in Nigeria. When the mean intensities of rainstorms were analysed in the present work (see Annex 1), it was found that a few stations recorded rainstorms

during the dry season between November and March. These are rare occurrences, especially at stations north of Latitude 9°N. For example, 4mm hr^{-1} of rain was recorded in Kano meteorological station in January 1961 and 8mm hr^{-1} in February 1976. Some of the rare dry-season rainstorms resulted in high intensity rainfall such as the one of 47.0mm hr^{-1} that fell also in Kano in March 1962. Even though the intensities of the rainstorms were sometimes high, they would not be considered to be very important at this dry period when the ground is dry and hard, and when the rate of evaporation is high. Kowal and Knabe (1972) rightly assumed that any rainfall less than 1.27mm in 10 days during this period is ineffective as it is almost entirely lost to evapotranspiration. They also assumed that the first 10.3mm of rain goes in to soil moisture recharge. However, during the few occasions when the dry season rainstorms occurred, it was observed that only a few rainstorms were involved. The rainstorms were neither preceeded nor immediately followed by other storms. These type of rainstorms, according to Kowal and Knabe (1972) are ineffective from the erosional point of view, as the soil requires considerable amounts of rain that should exceed infiltration capacity before any substantial erosion can take place. The erosiveness of such rainstorms were minimal, and can, therefore, be disregarded. Hence, all such rainstorms were not considered in our study of the spatial and temporal variations of mean and peak intensities of rainstorms in Nigeria.

Table 6.1 shows the percentage frequency distribution of mean intensity of rainstorms in Nigeria. It can be seen that the

TABLE 6.1 PERCENTAGE FREQUENCY DISTRIBUTION OF MEAN INTENSITY OF RAINSTORMS IN NIGERIA (mm hr^{-1})

STATIONS	LATITUDE	5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	55 (mm hr^{-1})
PORT-HARCOURT	04.85	71.5	14.9	6.2	3.1	1.4	1.0	0.6	0.1	0.3	0.2	0.1	0.5
CALABAR	04.97	68.0	16.3	6.9	3.3	2.1	1.4	0.7	0.4	0.3	0.1	0.1	0.4
WARRI	05.52	60.9	20.1	7.9	3.7	2.5	1.5	1.2	0.8	0.4	0.1	0.3	0.6
BENIN	06.32	63.5	18.5	6.7	4.1	3.2	1.5	0.9	0.7	0.4	0.2	0.1	0.3
ENUGU	06.43	63.6	17.6	7.6	4.4	2.2	1.1	1.1	0.5	0.4	0.2	0.5	0.7
IKEJA	06.58	60.3	20.3	7.8	4.5	3.1	1.1	0.7	0.4	0.8	0.2	0.3	0.5
ONDO	07.10	62.1	18.8	8.5	4.2	1.9	1.1	1.1	0.6	0.4	0.3	0.3	0.7
IBADAN	07.43	60.6	18.8	7.3	4.6	3.3	1.6	0.9	0.5	0.5	0.5	0.3	1.6
MAKURDI	07.68	67.4	17.2	6.3	4.1	1.9	0.8	0.7	0.5	0.2	0.2	0.2	0.5
OSHOGBO	07.75	61.2	18.3	8.8	4.8	2.9	1.3	0.7	1.2	0.3	0.1	0.0	0.6
LOKOJA	07.80	49.9	19.8	9.4	3.6	2.6	1.6	1.1	1.3	0.8	0.4	0.5	9.1
IBI	08.18	65.3	18.4	8.1	3.1	2.5	1.1	0.5	0.5	0.9	0.0	0.0	0.4
ILORIN	08.50	59.2	20.3	8.0	4.1	2.8	1.0	1.0	0.8	0.5	0.3	0.3	0.7
BIDA	09.10	57.2	22.3	8.0	4.1	2.4	1.4	1.0	0.8	0.5	0.2	0.2	0.9
YOLA	09.23	89.4	19.2	8.3	4.3	3.0	1.1	1.4	0.8	0.6	0.5	0.1	1.4
MINNA	09.62	58.0	20.6	8.0	4.6	3.6	1.1	1.0	0.8	1.1	0.0	0.4	1.0
JOS	09.87	57.9	21.2	8.8	4.6	2.9	1.5	1.1	0.7	0.5	0.1	0.2	0.4
BAUCHI	10.28	60.9	19.3	8.1	4.5	4.0	1.3	1.0	0.8	0.2	0.7	0.4	0.4
KADUNA	10.60	58.6	21.4	7.0	4.7	4.3	1.0	1.0	0.3	0.1	0.5	0.6	0.4
YELMA	10.89	58.1	20.5	8.0	4.1	2.9	1.3	1.6	0.7	0.7	0.2	0.3	0.7
POTISKUN	11.70	54.5	22.4	8.7	5.7	3.0	1.7	1.0	1.2	1.0	0.0	0.3	0.5
MAIDUGURI	11.85	52.7	20.5	10.4	4.8	1.7	2.4	1.5	1.7	0.2	1.1	0.7	2.2
KANO	12.05	50.2	22.4	9.4	6.5	3.6	2.1	1.2	1.1	0.9	0.6	0.2	1.0
GUSAU	12.15	54.0	21.0	10.2	4.1	3.4	1.0	1.4	0.9	0.9	0.2	0.5	0.7
NGURU	12.98	50.9	20.0	14.3	5.7	2.0	3.0	1.0	0.4	0.6	0.3	0.6	0.6
KATSINA	13.02	46.3	20.6	12.7	6.9	4.6	2.3	1.9	0.7	1.0	0.9	0.1	2.0
SOKOTO	13.02	51.3	21.7	10.3	5.5	2.5	4.5	2.5	2.2	0.2	0.4	0.4	0.8

values of annual mean intensity of rainstorms in Nigeria were often about 5mm hr^{-1} or lower. The low values is due to the fact that the averaging technique, which takes into account all values, smoothes out the intensity fluctuations during and between storms. About 70% of storms that fell at average intensity of 5mm hr^{-1} or below in areas south of latitude 9°N was about 70%. This proportion decreased with latitude to about 50 percent in stations located north of latitude 9°N. Conversely, the proportion of rainstorms of mean intensity higher than 5mm hr^{-1} increased from the coastal areas northwards.

In order to facilitate the description of spatial variation of the storm variables analysed in this thesis, Nigeria was derived into 12 geographical zones as shown in Fig 6.1. The zones are are extreme northwest, extreme northeast, northwest, north central and northeast. Others are western middle-belt, central middle-belt, eastern middle-belt, western, Eastern and Niger Delta. The classification above is for ease of reference, brevity and accuracy.

Fig 6.2 illustrates the spatial distribution of annual mean intensity of rainstorms in Nigeria. The Figure shows that larger area of the country experienced annual mean rainfall intensities of less than 10 mm hr^{-1}. The annual average intensity values were lower in the southern, middle-belt and northern parts of Nigeria than the extreme northern parts where values are generally higher than 10mm hr^{-1} were observed. This is due to the fact that

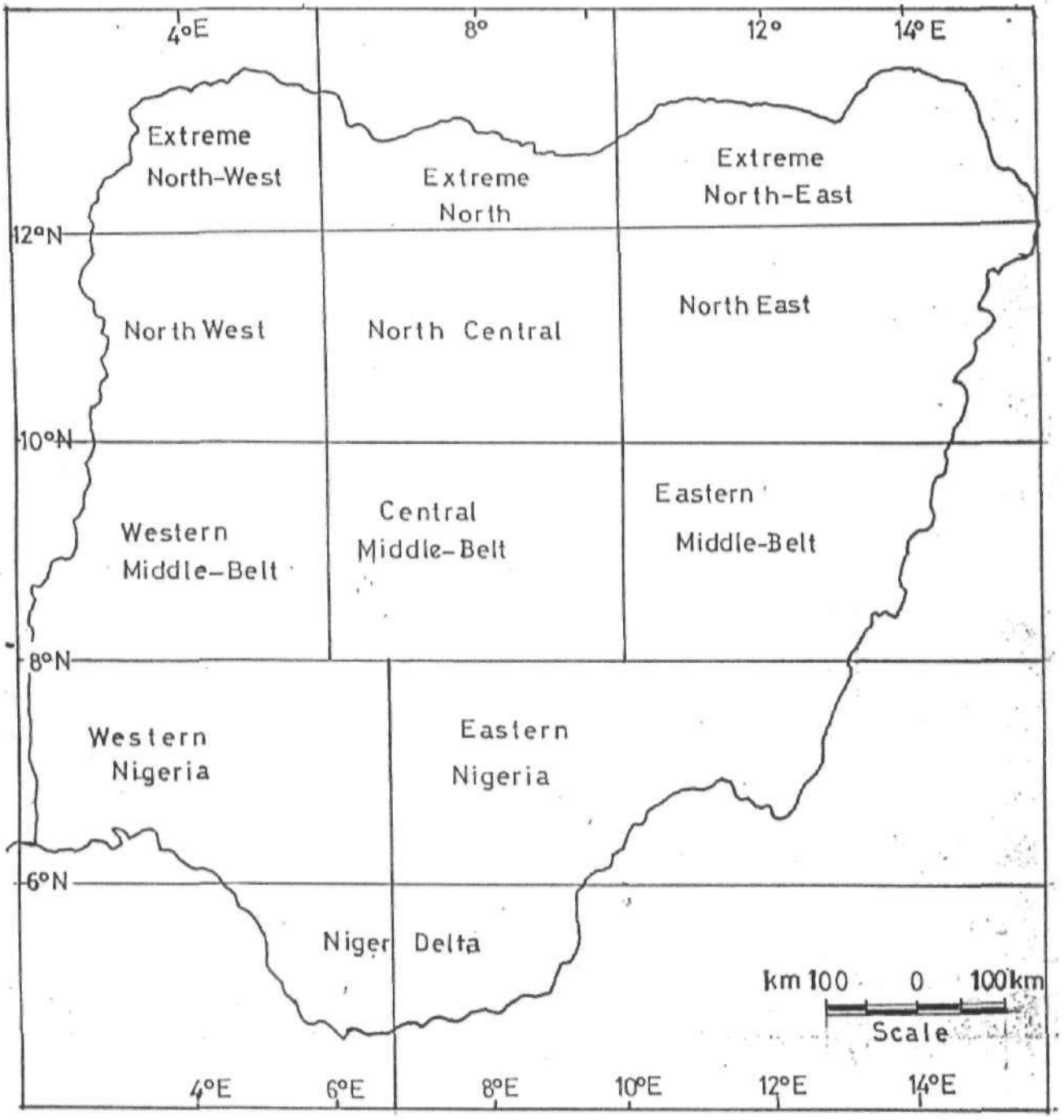


Fig **6.1.** Classication of Nigeria into Geographical Zones.

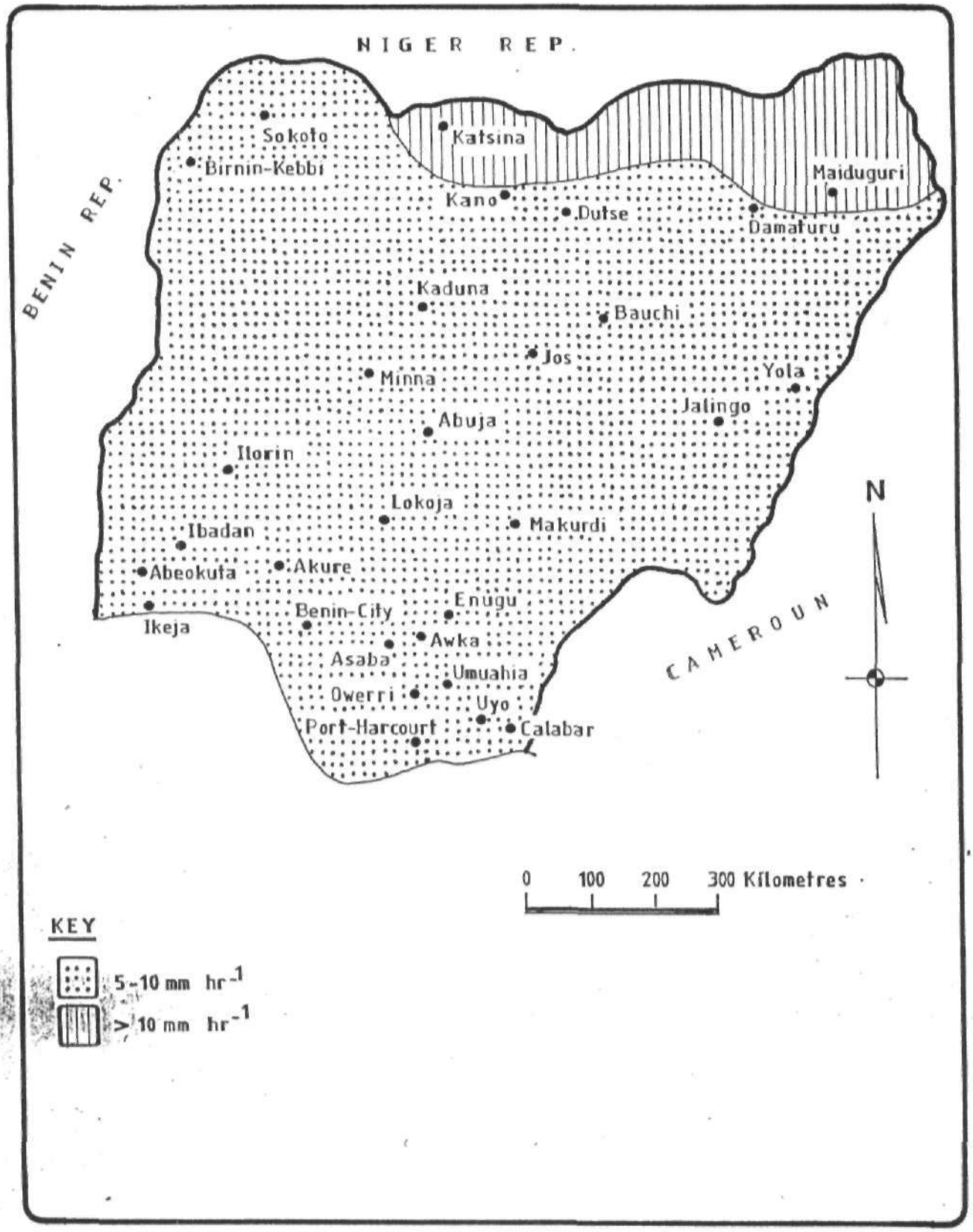


Fig. 6.2. Spatial distribution of mean annual intensity of storms in Nigeria.

SOURCE: Analysis of data

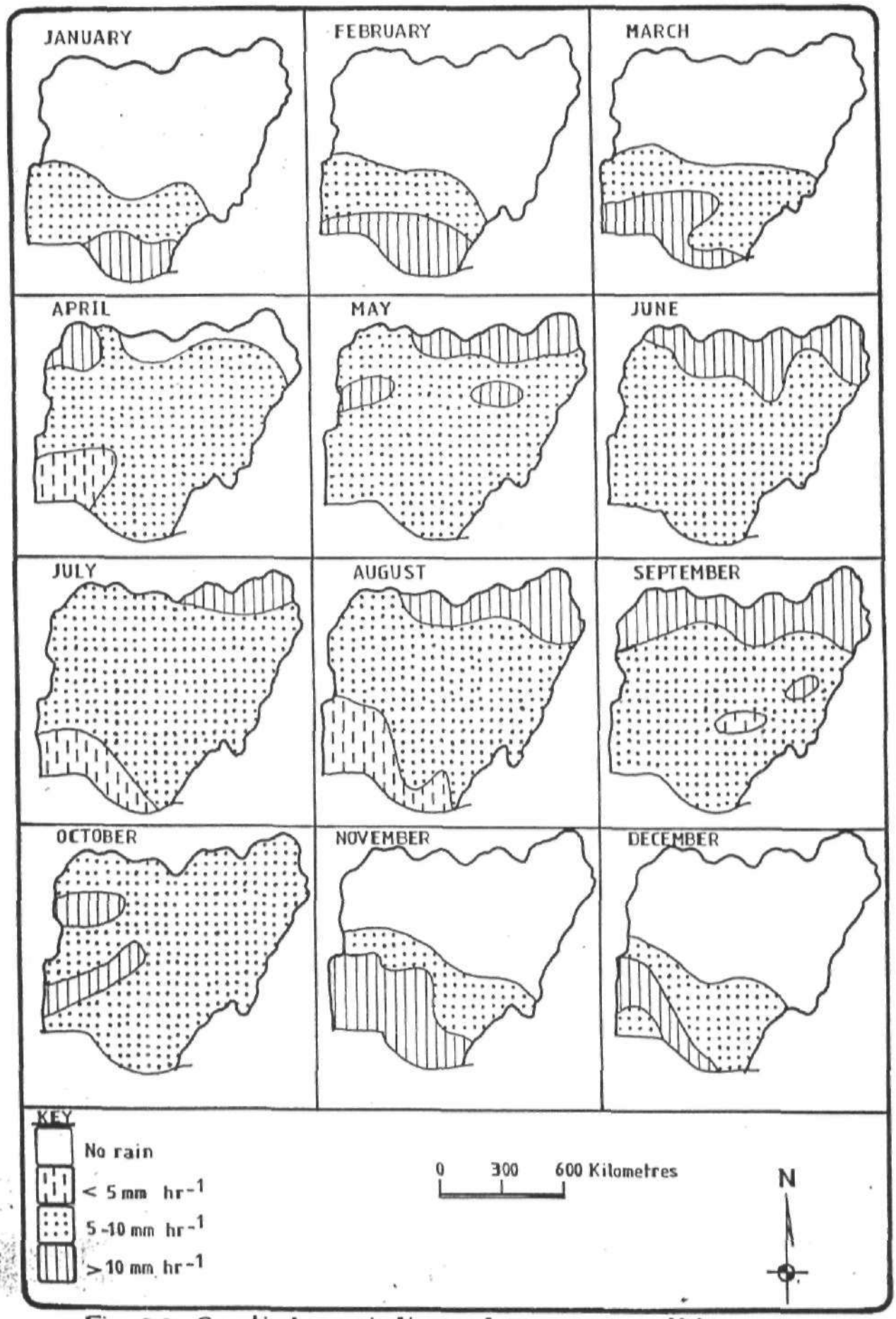


Fig. 6.3. Spatial variation of mean monthly intensity of rainstorms in Nigeria.

SOURCE: Analysis of data

higher rainstorm intensities are often more commonly recorded in drier than the wetter areas (Torrance, 1978).

Figure 6.3 shows the spatial variation of monthly mean intensities. Between November and April, the mean monthly intensities decrease from the coastal areas inland. Values of 10mm hr^{-1} and above were experienced at the coastal areas. The zone between 8^{o} and $9^{o}N$ recorded intensities of 5 - 10mm hr^{-1}, while the remaining parts of the country, north of latitude $9^{o}N$, were rainless. However, most parts of the country experienced mean monthly intensities of 5 - 10mm hr^{-1} for most part of the rainy season between April and October.

The intensity distribution illustrated in Fig 6.3 shows that values of intensities are fairly uniform over most parts of the country. It was only some limited areas at the extreme northern parts of the country that experienced monthly mean intensities higher than 10mm hr^{-1} between May and September. The similarity in intensity values recorded in most stations points to the fact that the causal mechanics of rainstorms that were discussed earlier had fairly uniform effects on the intensities of rainstorms in the country.

The temporal variations of monthly mean intensities of rainstorms in Nigeria are shown in Fig. 6.4. Most of the stations south of latitude $9^{o}N$ exhibited two high mean intensities each at the beginning and at the end of the rainy season with a minimum usually in July or August. The monthly mean intensities are similar for all the months,

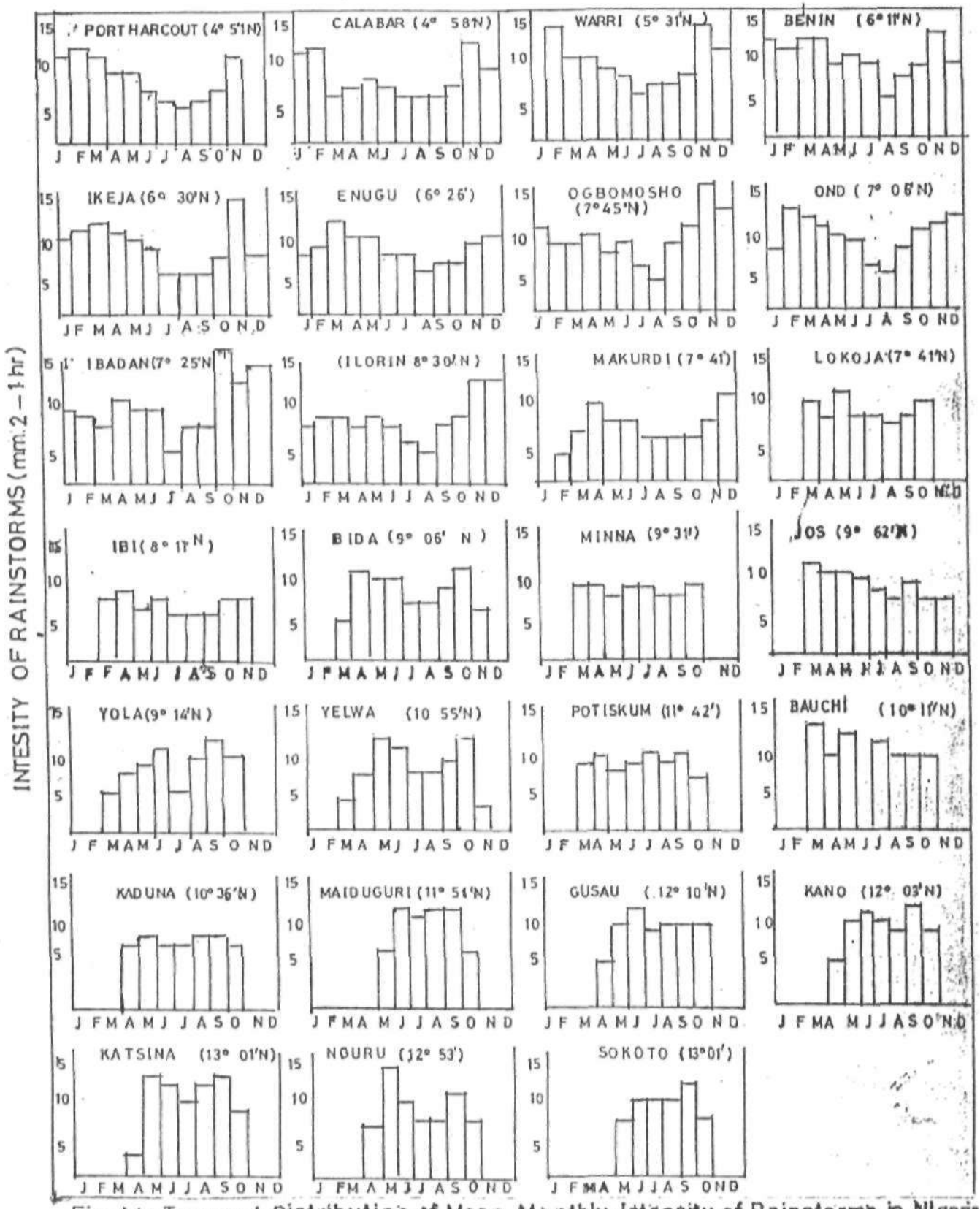


Fig. 4·4: Temporal Distribution of Mean Monthly Intensity of Rainstorms in Nigeria

except in July and August when the 'August break' is normally experienc in the south. This result is consistent with the movement of the ITD and the relevant zone C in which the mesoscale thunderstorm-propagating systems are found. The passage of the ITD thus brings about the meso-scale system that tends to have similar effects on the country. The coastal regions and areas south of latitude 9°N thus have a double period of high, though fairly uniform rainfall intensity at the beginning and towards the end of the rainy season. This is due to the fact that these areas are affected twice by the ITD's zones.

In contrast, the temporal variation of mean monthly rainfall intensity for the stations north of latitude 9°N showed that high intensity rainstorms were concentrated over a shorter time period usually between April/May to September/October. Again there is little intra-seasonal variation in values of mean intensity in these areas. The meso-scale propagating systems responsible for the fairly uniform intensities are line squalls which attain maximum intensity at the onset and towards the end of the rainy season. Also included in the meso-scale propagating systems of rainstorms are the thunderstorms which reach a single maximum around July/August. The fact that both the ITD and thunderstorms yielded fairly similar intensities further points to the fact that the systems have similar effects on the mean intensity of rainstorms in the country within the period under consideration.

6.3 PEAK INTENSITY OF RAINSTORMS IN NIGERIA

Peak intensity was computed as the storms highest intensity during a 10-minute interval. It measures the highest potential of storm erosiveness. Peak intensities are, however more difficult to compute than mean intensity but it is more relevant to erosion prediction. The value of peak intensity just as those of mean intensity vary from rainstorm to rain storn over time and space (Ward, 1967). There is therefore a need to compute the 10-minute peak intensity of the rainstorms that occurred within the approximate 10-year period under consideration. The values as computed are given in Annex 2 The frequency distribution of the values and the spatial and temporal distributions are discussed herewith.

First, the frequency distribution of the rainstorms which occurred within selected intervals of intensities in mm hr^{-1} were also computed. The result is given in Table 6.2. It was found that more than 30% of the peak intensities of the rainstorms were below 12.5mm hr^{-1}. For instance, the stations within the Niger Delta area had 59.0 and 62.7 percent of their peak intensities below 12.5mm hr^{-1} respectively. Ilorin and Ibi situated at the central and eastern middle-belts respectively had 50.3 and 53.4 percent of their peak intensities of the storms below 12.5mm hr^{-1}. Sokoto and Katsina situated in the extreme north-west and extreme-north had 37.0% and 34.0% of their peak intensities for the rainstorms below 12.5mm hr^{-1} respectively. In general, the percentage of erosive rainstorms tends to decrease from the coastal areas inland.

TABLE 6.2 PERCENTAGE DISTRIBUTION OF 10-MIN PEAK INTENSITY OF RAINSTORM IN NIGERIA

STATION	LATITUDE	≤ 12.5	12.5 - 25	25.1- 37.5	37.6 - 50	50.1 62-5	62.6 75.0	75.1 87.5	87.6- 100.0	> 100	NON EROSIVE	EROSIVE
PORT-HARCOURT	04.85	59.0	15.1	5.4	8.2	3.6	1.5	2.2	1.1	4.0	74.1	25.9
CALABAR	04.97	62.7	15.1	5.9	6.5	2.5	1.5	2.5	0.7	3.3	77.8	22.2
WARRI	05.52	56.4	19.0	4.9	7.9	3.5	1.5	2.3	1.2	3.2	75.4	24.6
BENIN	06.32	56.1	16.8	6.2	8.8	3.6	1.8	2.7	1.1	2.8	72.9	27.1
ENUGU	06.43	51.4	16.2	6.9	8.4	4.8	1.5	4.4	1.6	4.7	67.6	22.4
IKEJA	06.58	59.6	16.4	6.1	9.3	4.5	2.3	2.5	4.4	4.8	76.0	24.0
ONDO	07.10	55.3	17.0	6.2	7.8	3.9	1.9	3.4	1.1	4.4	72.3	27.7
IBADAN	07.43	47.2	17.5	5.7	11.3	3.7	2.1	5.4	2.0	6.1	64.7	35.3
MAKURDI	09.68	52.7	19.9	6.4	8.6	3.9	1.0	2.4	1.3	3.8	72.6	27.4
OSHOGBO	07.75	56.0	17.2	5.8	8.3	4.2	1.5	2.6	1.3	3.0	73.2	26.8
LOKOJA	07.80	44.0	17.3	7.2	10.2	4.0	2.5	3.7	1.8	9.3	61.3	38.7
IBI	08.18	53.4	15.9	6.4	8.1	3.3	1.2	3.7	2.0	5.9	69.3	30.7
ILORIN	08.50	50.3	17.0	8.4	8.0	3.4	1.2	3.0	2.9	5.7	67.3	32.7
BIDA	09.10	50.6	19.6	6.9	9.8	4.9	1.3	3.0	1.4	2.4	70.2	29.8
YOLA	09.23	50.6	20.9	5.0	8.9	2.9	1.4	2.7	1.2	6.3	71.5	28.5
MINNA	09.62	49.0	19.0	9.1	9.8	4.0	3.2	3.0	1.8	2.0	68.0	32.0
JOS	09.87	53.8	20.1	5.2	8.4	5.1	1.5	2.8	0.8	2.2	73.9	26.1
BAUCHI	10.28	48.2	22.0	5.7	8.0	5.5	1.3	3.0	1.0	2.0	70.2	29.8
KADUNA	10.60	46.6	20.7	8.1	9.6	5.2	2.8	3.5	1.5	2.5	66.7	33.3
YELWA	10.88	50.3	21.5	6.9	8.9	4.3	0.7	2.6	1.0	3.7	71.8	28.2
POTISKUM	11.70	46.1	24.8	8.3	9.5	7.7	1.9	4.3	2.2	5.1	60.9	39.1
MAIDUGURI	11.84	38.7	20.1	7.8	8.9	7.1	2.8	4.1	2.2	8.2	58.8	41.2
KANO	12.05	35.9	19.6	10.3	12.4	6.5	4.4	4.2	2.2	4.5	55.5	44.5
GUSAU	12.16	40.0	24.7	18.4	9.4	3.8	0.9	1.4	9.0	2.5	64.7	35.3
NGURU	12.88	44.7	21.2	7.7	10.4	3.6	1.8	5.0	0.9	0.7	65.9	34.1
KATSINA	13.02	34.0	22.4	9.4	10.4	5.6	2.7	4.7	2.7	8.1	54.4	45.6
SOKOTO	13.02	37.0	24.7	11.4	11.4	6.9	0.8	1.6	0.8	2.5	61.7	38.3

The rainstorms were further analysed by separating them into erosive and non-erosive rainstorms. The threshold value of 25mm hr^{-1} was taken as the value above which rainstorms become erosive (Hudson, 1971). The result is shown in the last two columns of Annex 2. The erosive peak intensities of rainstorms that fell above 25mm hr^{-1} increase from about 22 - 25 percent for stations within the Niger Delta area to as high as 40 percent for the station situated in the extreme northern areas. For example, only about 20% of the peak intensities of rainstorms in Port-Harcourt (Niger Delta) are erosive. On the other hand about 38% and 45.6 of the peak peak intensities of storm in Sokoto and Katsina respectively are erosive. In other words, the percentage of non-erosive peak intensities decreased from about 75% for stations in the Niger Delta to about 60 percent for stations in the extreme northern parts of the country. Consequently, the proportion of erosive to non-erosive rainstorms tend to be lower in the southern than in the northern parts of the country. This, however, does not mean that there are more erosive rainstorms in the northern than in the southern areas. In essence, there exist large numbers of short-duration, high-intensity rainstorms in the south. These high intensity erosive rainstorms have, however, been masked by much greater numbers of rainstorms of low intensity. Thus, even though, the erosive rainstorms were higher in the south, the proportion of erosive to non-erosive rainstorms was higher in the north than in the south. This result is similar to what Torrance (1978) observed for the spatial variation of rainstorms in Zimbabwe. In the study, he noted that the highest intensities are more frequently recorded in the drier

areas than in the wettest regions. This is because, while it does not rain frequently, or as long as in the drier region, whenever it does, the rainstorms are usually of very high intensities.

The spatial variation of the annual mean 10-minute peak intensities of rainstorms in Nigeria is shown in Fig 6.5. One striking feature of the variation of rainstorm intensity shown in the figure is that there are higher intensity rainstorms in the north than in the south. The annual mean 10-minute peak intensities of 30-35mm hr^{-1} tend to occur most frequently in the northern and north-eastern parts of the country. Apart from this, there is no specific trend that is readily observable in Figure 6.5. Other peak intensities of between 25 and 30 mm hr^{-1} and between 30 and 35 mm hr^{-1} and those less than 25 mm hr^{-1} occurred in the extreme north-west, north-central and north-eastern parts as well as in the western and eastern Nigeria.

The values of annual mean peak intensities were correlated with the geographical factors of longitude, latitude and altitude. The result showed an inverse relationship of annual mean 10-minute peak intensity with latitude with a correlation coefficient of - 0.40 significant at 0.05 percent level (Table 6.5). Similarly, longitude also showed a significant inverse correlation with annual mean peak intensity of rainstorms (r = 0.36). The relationship of annual mean intensities with altitude is not significant at 0.05 level. The results of the analysis

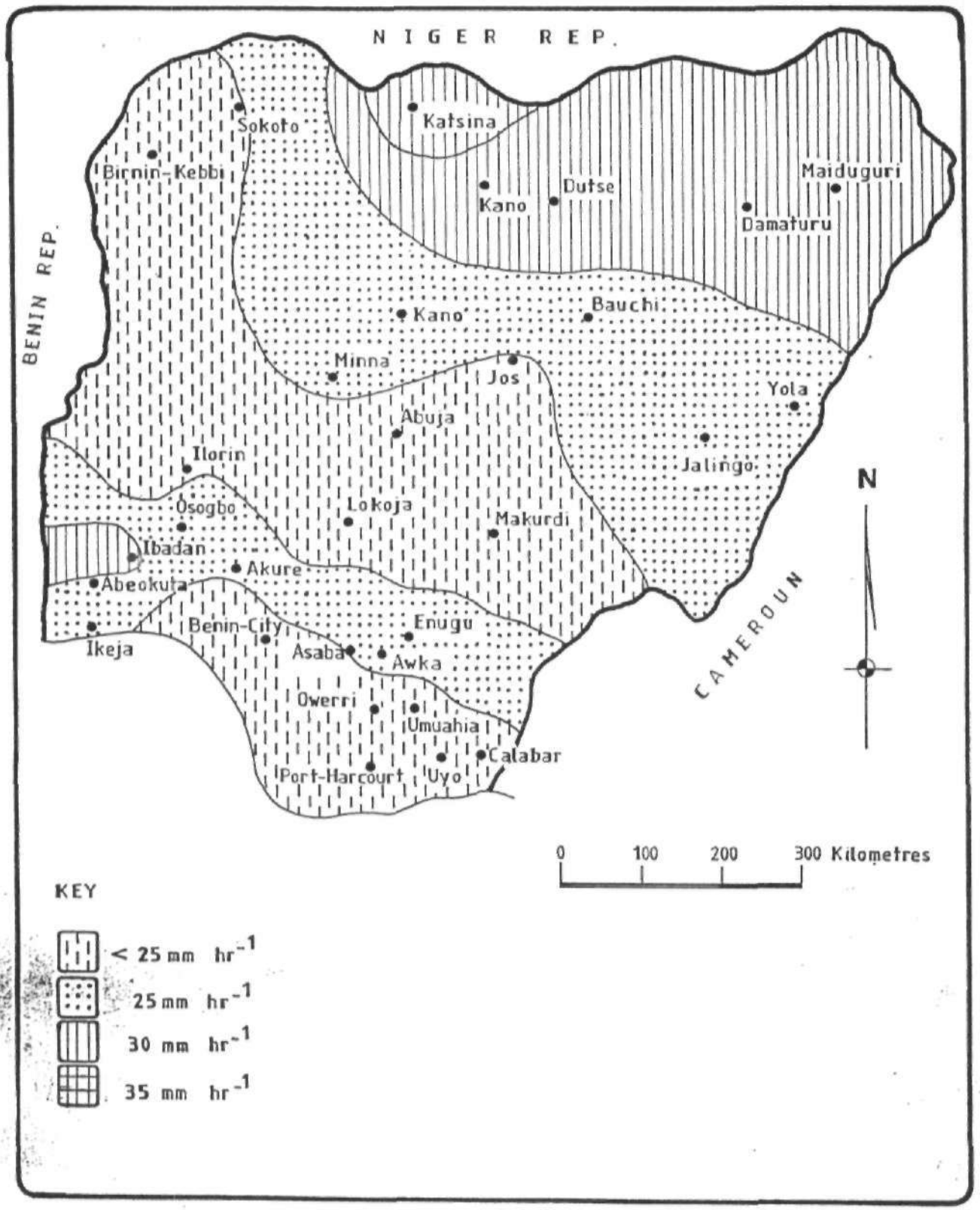


Fig. 6.5. Spatial variation of annual mean 10 mins. peak intensity of rainstorms in Nigeria.

SOURCE: Analysis of data

imply that on an annual basis, there are higher rainfall intensities in the northern than in the southern part of the country. This result is consistent with the earlier observation on percentage frequency of peak intensities by Torrance (1978) who noted that the highest peak intensities of rainstorms are more frequently recorded in the drier areas than in the wettest regions. As the Niger Delta, the Eastern and Western parts of Nigeria constitute the wettest parts of the country, these areas invariably experienced lower annual mean rainstorms intensities than the relatively drier middle-belt and northern parts of the country.

The spatial variations of mean monthly 10 - minute peak intensity of rainstorms in Nigeria are illustrated in Fig. 6.6. The maps do not show any specific trend. All the class intervals in which the 10-minute peak intensities were grouped showed incoherent spatial variations in many months of the year. In general, however, it can be said that intensities of 15 - 30mm hr^{-1} and 30 - 45mm hr^{-1} were experienced in the southern parts of the country including the Niger Delta, the western and the Eastern Nigeria between November and March. During the period, areas in the extreme north, north and middle-belt are rainless. In November and December, maximum intensities of 45mm hr^{-1} and above are experienced in the Niger Delta and western Nigeria. In July, August and September, few stations in the extreme north and extreme northeast experienced high mean peak intensities of 35 - 45mm hr^{-1}.

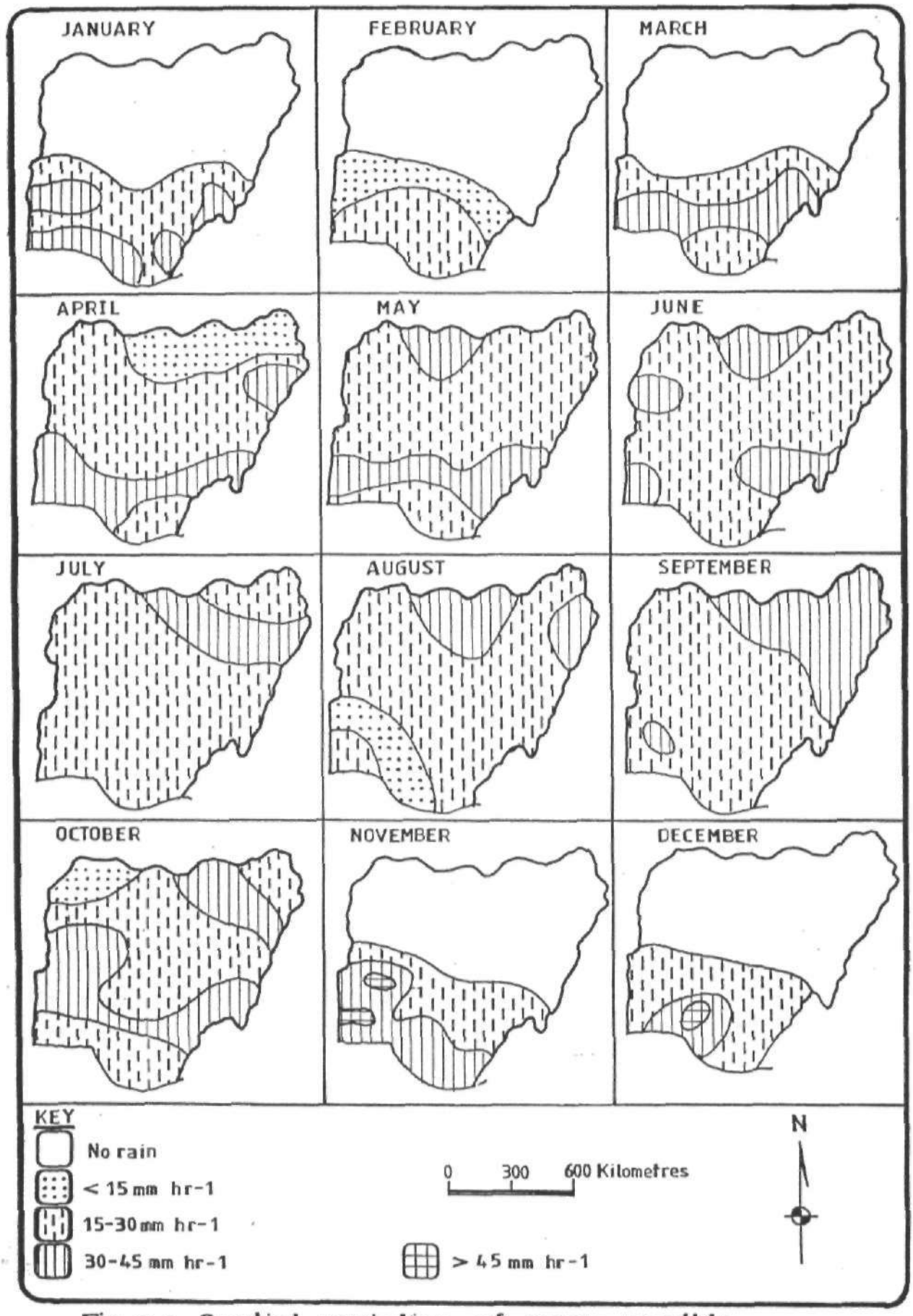


Fig.6.6. Spatial variation of mean monthly intensity of rainstorms in Nigeria.

TABLE 6.3 CORRELATION COEFFICIENTS BETWEEN MEAN MONTHLY PEAK INTENSITY AND GEOGRAPHICAL FACTORS

FACTORS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Longitude	-.57	-.50	-.33	-.25	0.33	.07	.54	.64	.48	-.28	-.54	-.37	-.36
Latitude	-.38	-.38	-.50	-.42	.31	.05	.39	.61	.35	.62	-.45	-.41	-.40
Altitude	.05	.03	.24	-.16	.23	.02	-.22	.17	-.11	.05	.02	.07	-.12

The values of monthly mean peak intensities were also correlated with the three geographical factors of longitude, latitude and altitude. The results are shown in Table 6.5. Significant correlations of between - 0.28 and - 0.57 were obtained between monthly mean peak intensities and longitude between October and May. This result implies a decrease of mean peak intensities with longitude; that is, higher mean peak intensities in the western than in the eastern part of the country during this time. In June, the correlation coefficient of 0.07 recorded was not significant at .05 level. In July, August and September, however, the respective correlation coefficients of 0.54, 0.64 and 0.48 obtained were significant at 0.05 level. These results indicate higher intensities in the eastern than in the western parts of the country during July to Sept. The higher intensities in the eastern than the western part of the country can be ascribed to the fact that the stations in the Niger Delta and eastern Nigeria do not experience August break because its coast line run at right angle to the wind direction; the coast is washed by the warm Guinea Current and also covered by swamps - all the conditions which constantly favour the propagation of rainstorms in the area (Iloeje, 1976); and can also be due to the monsoon rainfall that is often experienced in the Niger Delta (Kamara, 1986) at the time.

Peak intensities of rainstorms showed inverse relationships with latitude throughout the country between November and April. The correlation coefficients obtained ranged from - 0.38 to - 0.45 and they were significant at .05 level. This result shows a

distrubution that is similar to that of the dry season when only the coastal areas have rain while all the middle-belt and the northern parts are rainless. No significant relationship existed in June. In July, August, September and October, significant correlation of 0.39, 0.61, 0.35 and 0.62 were obtained respectively. The implications of these results is that higher mean peak intensities occurred more in the northern parts than in the southern parts of the country. This trend may be attributed to the migration of the ITD together with its meso-scale precipitation propagation systems to the northern most position of the country in August. Thus, the maximum rainfall intensities in the north, coupled with minimum rainfall intensities arising from the August break in the south-western part of Nigeria, explain the significant positive correlation coefficient observed during the months of July to October.

The 10 - minute peak intensities of rainstorms showed no coherent relationship with altitude. The correlation coefficient obtained for the months between September and February, and in June were not significant at .05 level. In March, April, May, July and August, the correlation coefficients of 0.24, - 0.16, 0.23, - 0.22 and - 0.17 were obtained respectively. The lack of any systematic significant relationship of 10 - minute peak intensities with longitude, latitude and altitude is due to the unpredictable behaviour that often characterised high intensity rainfall which have neither been properly studied nor understood (Oladipo, 1984).

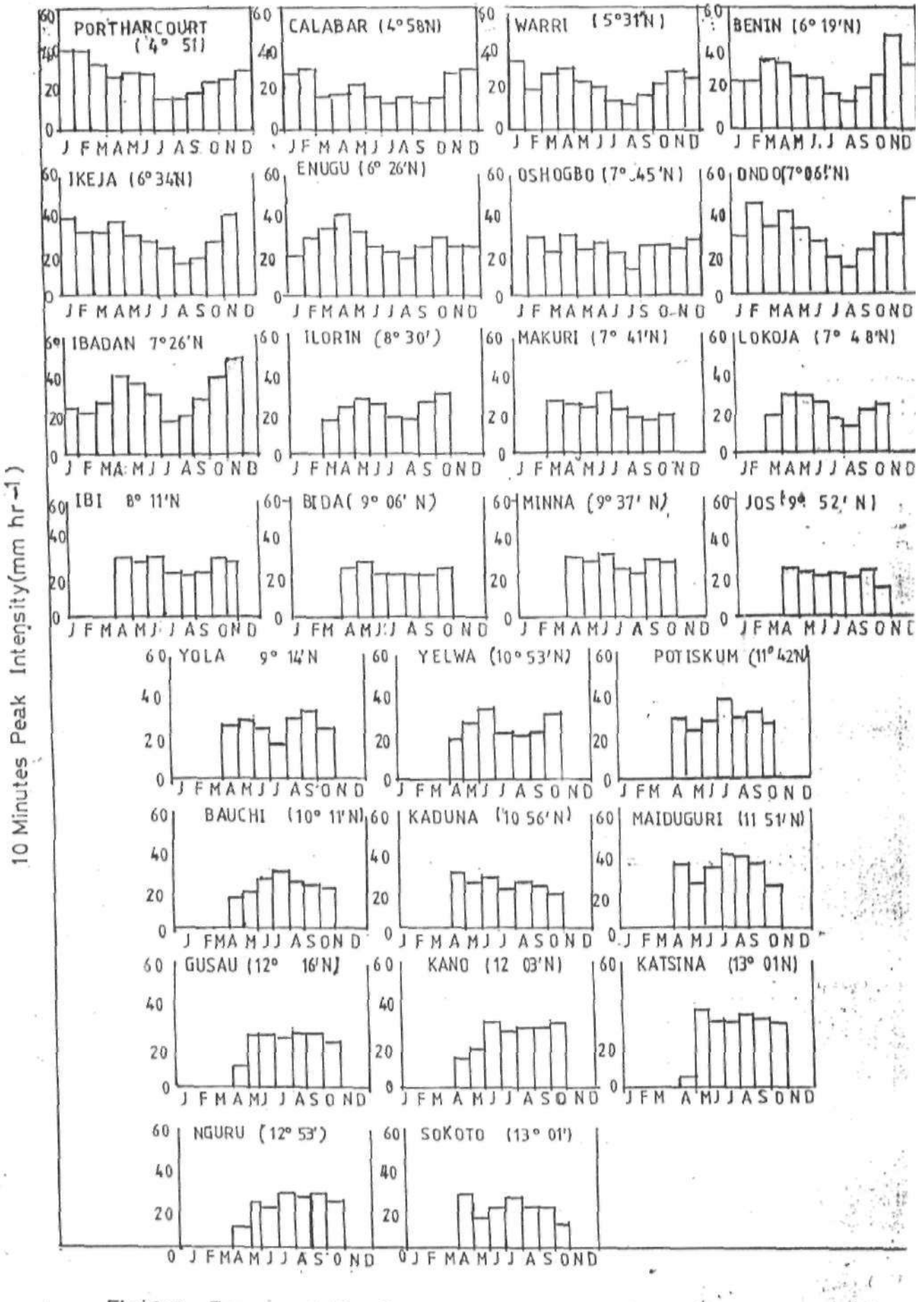


Fig. 6.7. Temporal Distribution of Mean Monthly 10 Minutes Peak Intensity of Rainstorms in Nigeria.

The temporal variation of mean monthly 10 - minute peak intensities of rainstorms in Nigeria is illustrated in Fig. 6.7. The southern stations shows that the values of 10 - minute mean peak intensities are usually higher at the beginning and at the end of the rainy season than during the months of July and August. In the northern areas, on the other hand, the mean peak intensities are higher for the months of July, August and September than other months of the year. These temporal variations may be attributed to the migratory movements of the ITD. Consequently, the two periods when rainfall intensities are highest are at the beginning and at the end of the rainy season. In the northern parts of the country, the effects of the ITD, coupled with the small scale thunderstorm propagating systems, explained the consistently high intensities between May and September.

6.4 MAXIMUM 10-MINUTE PEAK INTENSITIES OF RAINSTORMS IN NIGERIA

The highest values of the 10-minutes peak intensities of rainstorms which occurred in each month of the 1960 to 1970 10-year period of study are presented in Annex 3.

The spatial variation of the annual maximum 10 - minute peak intensity of rainstorms in Nigeria is shown in Fig. 6.8. It does not reveal any coherent spatial trend in terms of the relationship with either longitude, latitude or altitude. When the annual values of maximum 10-minutes peak intensities were correlated with the selected controlling factors correlation

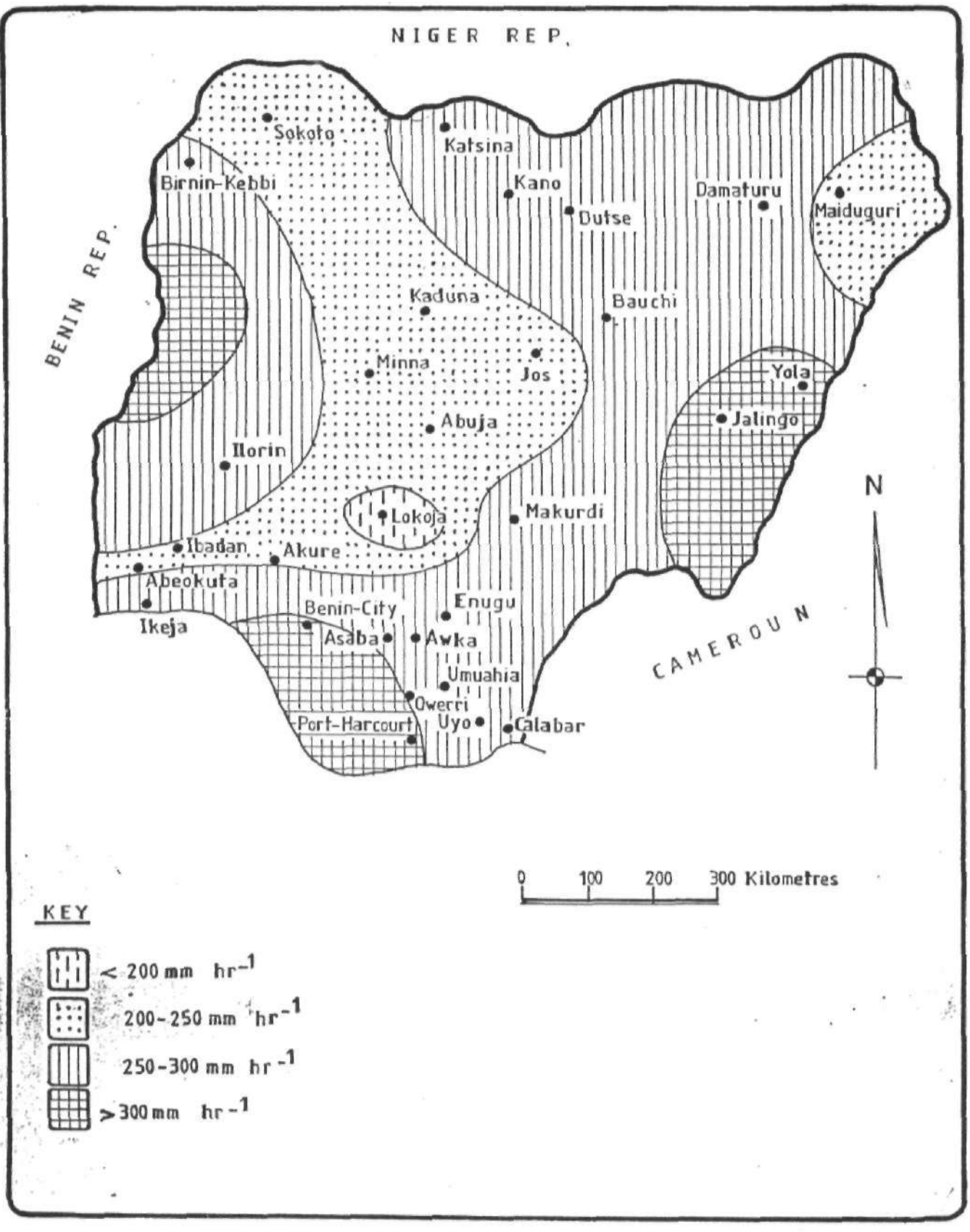


Fig. 6.8. Spatial variation of annual maximum 10 mins. peak intensity of rainstorms in Nigeria .

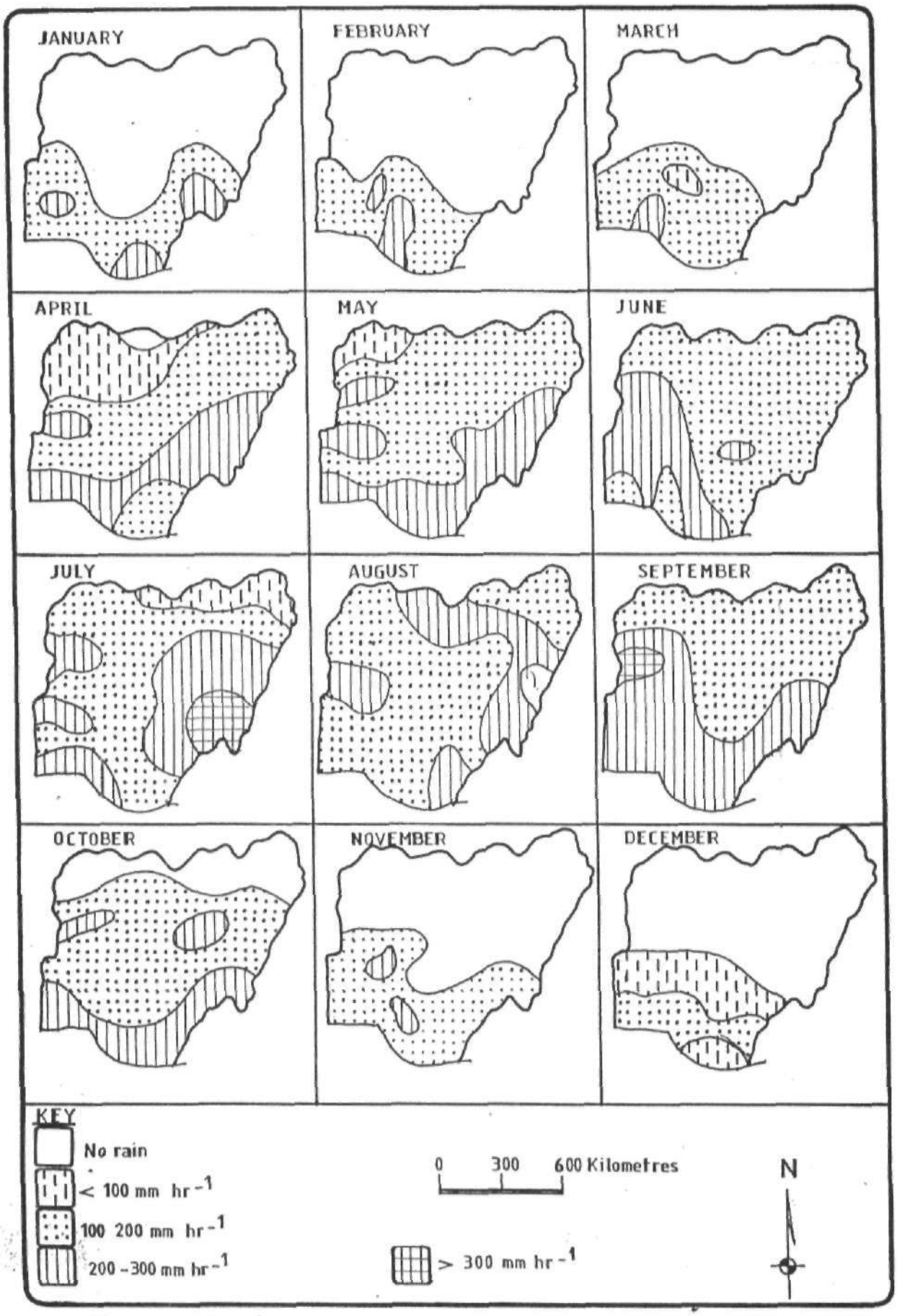


Fig. 6.9. Spatial variation of monthly maximium 10 mins. peak intensity of rainstorms in Nigeria.

SOURCE: Analysis of data

coefficients of 0.3, and 0.07 were obtained for the relationships between maximum peak intensities and longitude and latitude respectively. The relationship was not significant at .05 level. It was only the relationship with altitude that had correlation coefficient of - 0.23 and significant at .05 level.

Fig 6.9 illustrate the spatial variations of monthly maximum 10-minutes peak intensities in Nigeria. A visual examination of the maps does not reveal that maximum peak intensities has any relationship with the geographical factors of longitude, latitude and altitude. The values of maximum 10-minutes peak intensities were therefore correlated with longitude latitude and altitude. Results of the correlation analysis of the relationship between monthly maximum 10-minutes peak intensities and the geographical factors are shown in Table 6.6. Longitude has a significant inverse relationship with the maximum intensities for most months of the year. The relationships are, however, not significant in May and July.

Correlation coefficient obtained between the maximum intensities and latitude are also not significant for most months of the year except in January, May and December when the values of r = - 0.91, r = 0.32 and r = 0.33 respectively (see Table 4.7) are obtained.

Fig 6.10 shows the temporal variation of monthly maximum 10 - minute peak rainstorm intensities in Nigeria. Values of monthly maximum intensities are consistently high during the rainy season, with little intra-seasonal variations. The values do not reflect the expected low intensities that characterised

TABLE 6.4 CORRELATION COEFFICIENTS BETWEEN MONTHLY MAXIMUM 10-MINUTES PEAK INTENSITIES AND GEOGRAPHICAL-FACTORS

FACTORS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Longitude	-.28	-.51	-.45	-.30	0.09	-.31	-.03	.24	.15	-.26	-.48	-.46	-.03
Latitude	-.91	-.08	-.01	-.01	.32	-.01	.12	-.06	-.07	-.06	-.05	.33	-.23
Altitude	-.01	.09	.03	-.06	.18	.25	-.05	.17	.27	.35	.20	.32	-.23

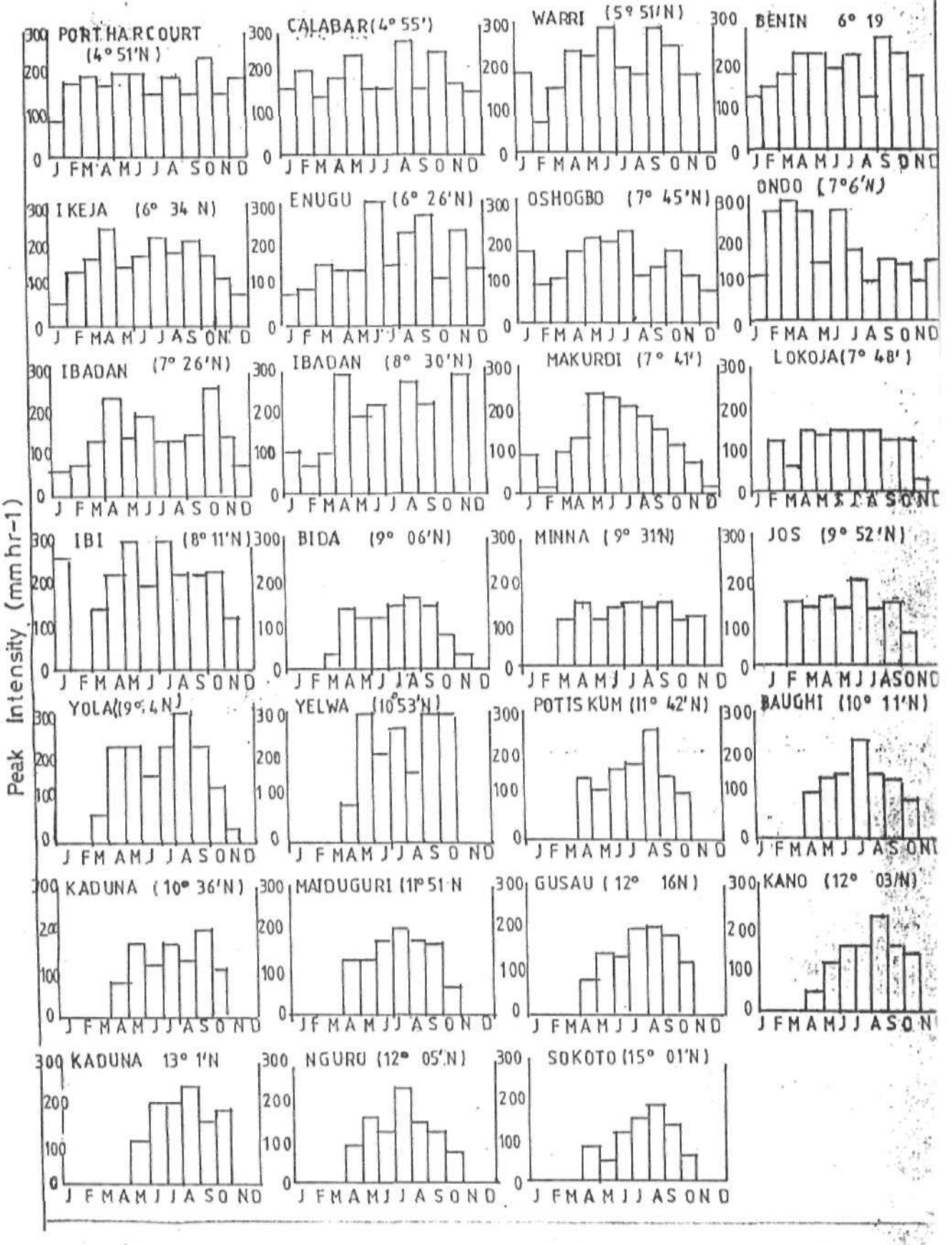


Fig 6.10 Temporal Distribution of Monthly Maximum 10-Minutes Peak intensity of Rainstorms in Nigeria.

the August break in the south-western part of the country. This incoherence is due to the inconsistent and unpredictable nature of high intensity rainfall (Kamara, 1986). The little spatial variation in intensities is due to the fact that the mechanism of rainstorm formation is rather similar all over the country.

As a direct consequence of the small-scale orographic effects often associated with increased convectivity developing over hills in convectively unstable air, one would have expected the area around Jos Plateau situated in the north-central part of Nigeria, and other highlands in the eastern part of the country to stand out prominently as area of high rainfall intensity. Surprisingly, this is not the case in this research. All the maps shows that the hilly areas such as Jos Plateau, Adamawa, and Biu highland at the eastern part of the country have equally low intensities as the other adjoining lowland areas. The result implies that although orographic lifting leads to higher units of rainfall, it may not necessarily be a causal mechanics of high intensity rainstorms. This observation fits that of Parsons and Hopps (1983) on the West Coast of USA to the effect that continuous advection of moist air that is topographically uplifted only leads to prolonged durations of low intensity rainfall with frequent meso-scale dessipation of raincell and cloud systems on orographic features. More rainfall arising from orographic feature is therefore reflected on total rainfall amount rather than an intensity.

The high intensity rainstorms that tend to occur more frequently in the northern part of Nigeria is associated with pronounced spottiness of rainfall characterising the Savanna. Studies by Ronsfield (1980) pointed to a persistent increase in the proportion of localized high intensity showers in the area of transition from the Guinea Savanna to the more arid sahel savanna. The same reasoning can also be advanced to explain the proportional increase of high intensity rainfall from the southern to the northern part of Nigeria.

From the above analysis, it is clear that intensities are not necessarily higher in places with higher annual rainfall in Nigeria. An examination of the autographic rainfall records also bear credence to this conclusion as they showed that high daily totals are not necessarily produced by high intensity rainstorms. They are largely made up of continuous light rainstorm which exceed 12mm hr^{-1} only on a few occassions. From this observation, it follows that a station has high annual rainfall, not because of the proportionately high intensity rainstorms, but because it has longer rainfall spells than the stations with lower annual rainfall. Arising from this conclusion, is the necessity to explore the spatial and temporal distribution of erosivity of rainfall in Nigeria. This is the subject of Chapter Seven.

CHAPTER SEVEN

EROSIVITY OF RAINSTORMS IN NIGERIA

7.1 INTRODUCTION

From the result of the soil investigation presented in Chapter Four, it was shown that of the erosivity indices considered, values of AI_{10} recorded the highest correlation coefficient with soil loss in the Savanah area. Lal (1979) had earlier obtained a similar result for the rainforest zone of Nigeria. It is therefore expected that AI_{10} index should be able to predict soil loss most accurately for the whole of the Nigerian environment.

This chapter, examines the spatial and temporal variations of mean erosivity using AI_{10} index which showed the highest correlation with soil loss. The relationship between the values of the erosivity and the three geographical factors were also examined. It is envisaged that the relationship established would be useful for the prediction of erosivity from rainfall amount for places without autographic raingauges in Nigeria.

7.1.1 SPATIAL VARIATIONS OF ANNUAL MEAN EROSIVITY

The spatial variations of annual mean erosivity are shown in Fig 7.1. The highest annual mean erosivity was $7.5cm^2hr^{-1}$. This value is obtained for the Niger Delta area and in the extreme northern parts of the country. Lower erosivity values of between 5 and $7.5cm^2hr^{-1}$ are obtained for the south-western areas. Similarly, low values also occurred in the North-Western, north-central. North-Eastern areas and the extreme-northern

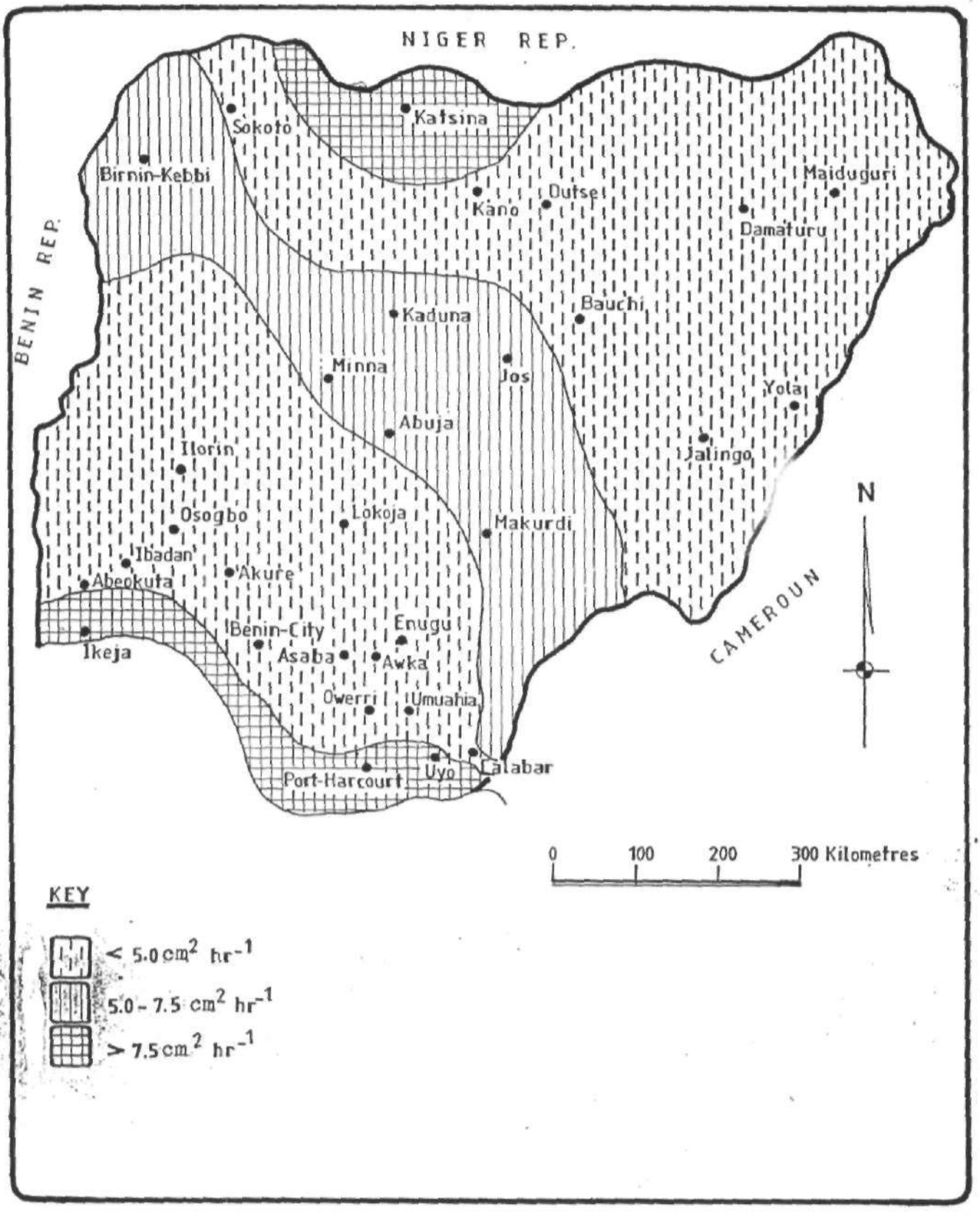


Fig. 7.1. Spatial variation of annual mean A1 10 erosivity of rainstorms in Nigeria.

SOURCE: Analysis of data

parts of the country.

The lowest values of $5cm^2\ hr^{-1}$ and below are obtained in a narrow band across the Middle-Belt area of the country in a northwest - southeast direction.

In order to investigate the spatial variation from the statistical point of view, the values of erosivity in Table 7.1 are correlated with three geographical factors of longitude, latitude and altitude with the use of multiple correlation analysis. The correlation coefficients of annual mean erosivity and latitude, longitude and altitude are - .16, .26, and -.37.

Though the result are statistically significant at .05 level, the result indicate that only 3%. 7%, and 14% of annual mean rainstorm variance are explained by latitude longitude and altitude respectively. Nevertheless, the negative correlation coefficient of -0.37 between annual mean erosivity and altitude can lead to the conclusion that areas with high altitude are associated with lower annual mean erosivity. In geneyal, the implication of the result of the regression analysis is that the highest values of annual mean erosivity can be found in the extreme northeastern part of the country. Furhtermore, as the annual mean erosivity decreased with altitude erosivity would thus, be expected to be lowest in areas with the highest relief in the country.

TABLE 7.1 MEAN MONTHLY AI10 EROSIVITY AND GEOGRAPHICAL FACTORS

FACTORS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
LONGITUDE	- .45	- .36	- .26	- .27	- .13	- .20	.25	.67	.30	- .29	-.34	- .37	.26
LATITUDE	- .62	- .72	- .65	- .64	- .52	- .37	.26	.65	.12	- .49	-.68	- .76	- .16
ALTITUDE	- .35	- .38	- .27	- .43	- .39	- .49	-.08	.22	-.02	- .51	-.37	- .22	- .37

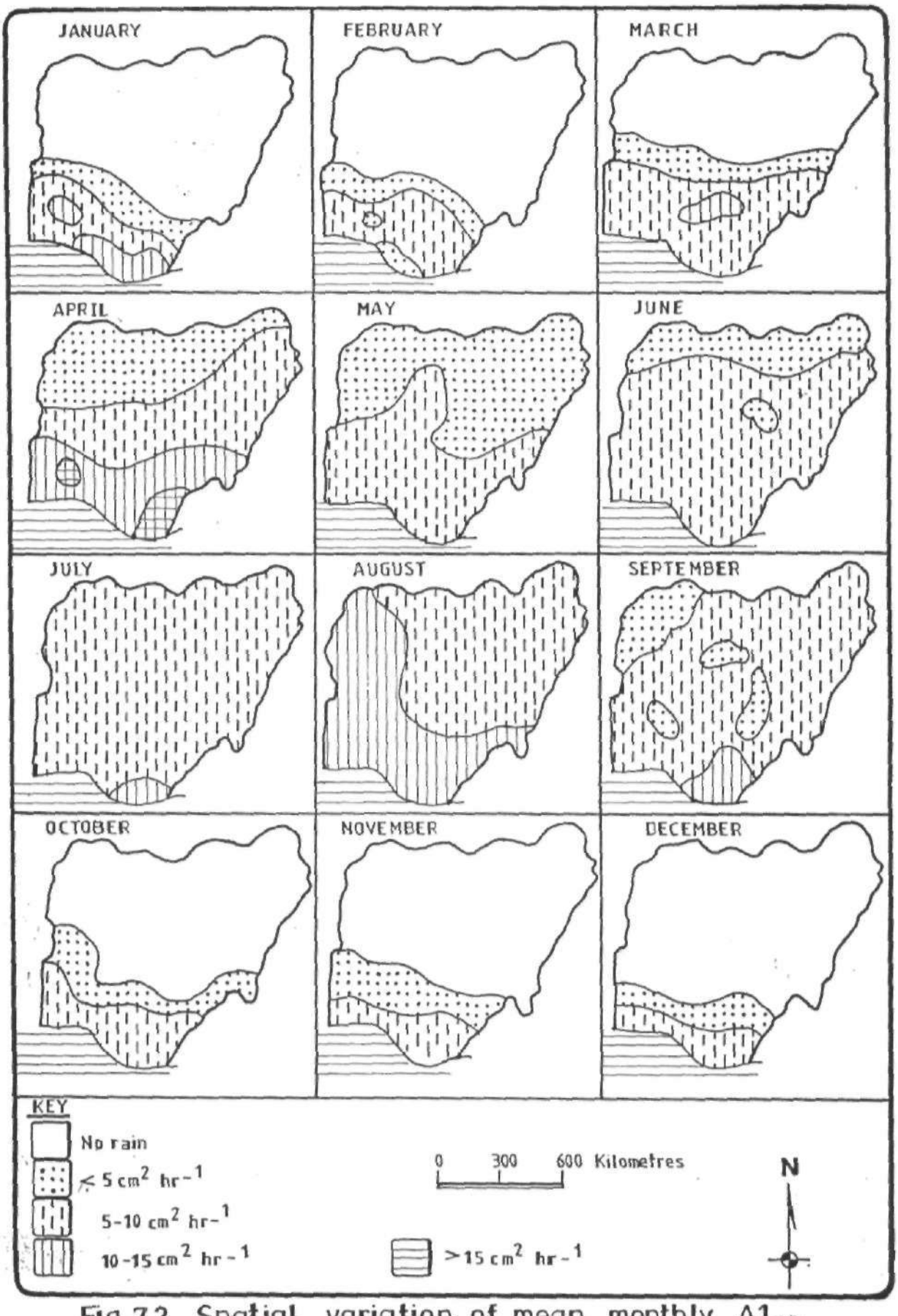


Fig. 7.2. Spatial variation of mean monthly $A1_{10}$ erosivity of rainstorms in Nigeria.

SOURCE: Analysis of data

7.1.2 SPATIAL VARIATIONS OF MONTHLY MEAN AI_{10} EROSIVITY

In January, the mean monthly erosivity of 10 - 15 cm^2 hr^{-1} were recorded in the southeastern part of the country (see Fig. 7.2). There is a general northward decrease to about 5 cm^2 hr^{-1} in the Middle Belt areas of the country. Values of less than 5 cm^2 hr^{-1} are observed for the extreme northern part. Similar trends were observed in February, March and October to December. This distribution is typical of the dry season period when only a few stations in the coastal areas consistently record occasional rainfall; especially since the ITD lies over the northern part of the Niger Delta, and no rainfall occurs north of it.

In April, most parts of the country, especially the southeastern areas, experience high monthly mean erosivities of more than $15cm^2hr^{-1}$. The values decrease progressively northward to less than $5cm^2hr^{-1}$ in the extreme northen parts. In May and June, the northeastern areas were also associated mean monthly erosivity of between 10 - 15 cm^2 hr^{-1}. Most areas in the north and extreme northern areas experienced lower erosivity of 5 cm^2 hr^{-1} and below.

In July, values of monthly mean erosivity of the magnitude of 5 - 10 cm^2 hr^{-1} were again obtained for most part of the country. The only exception was in the Niger Delta and south-eastern parts of the country which recorded erosivities of 10 - 15 cm^2 hr^{-1}. By August, the southern, the Middle Belt and the northwestern areas had erosivities of 10 - $15cm^2hr^{-1}$. However, most of the other parts of the country come under erosivities of the magnitude of 5 - $10cm^2hr^{-1}$.

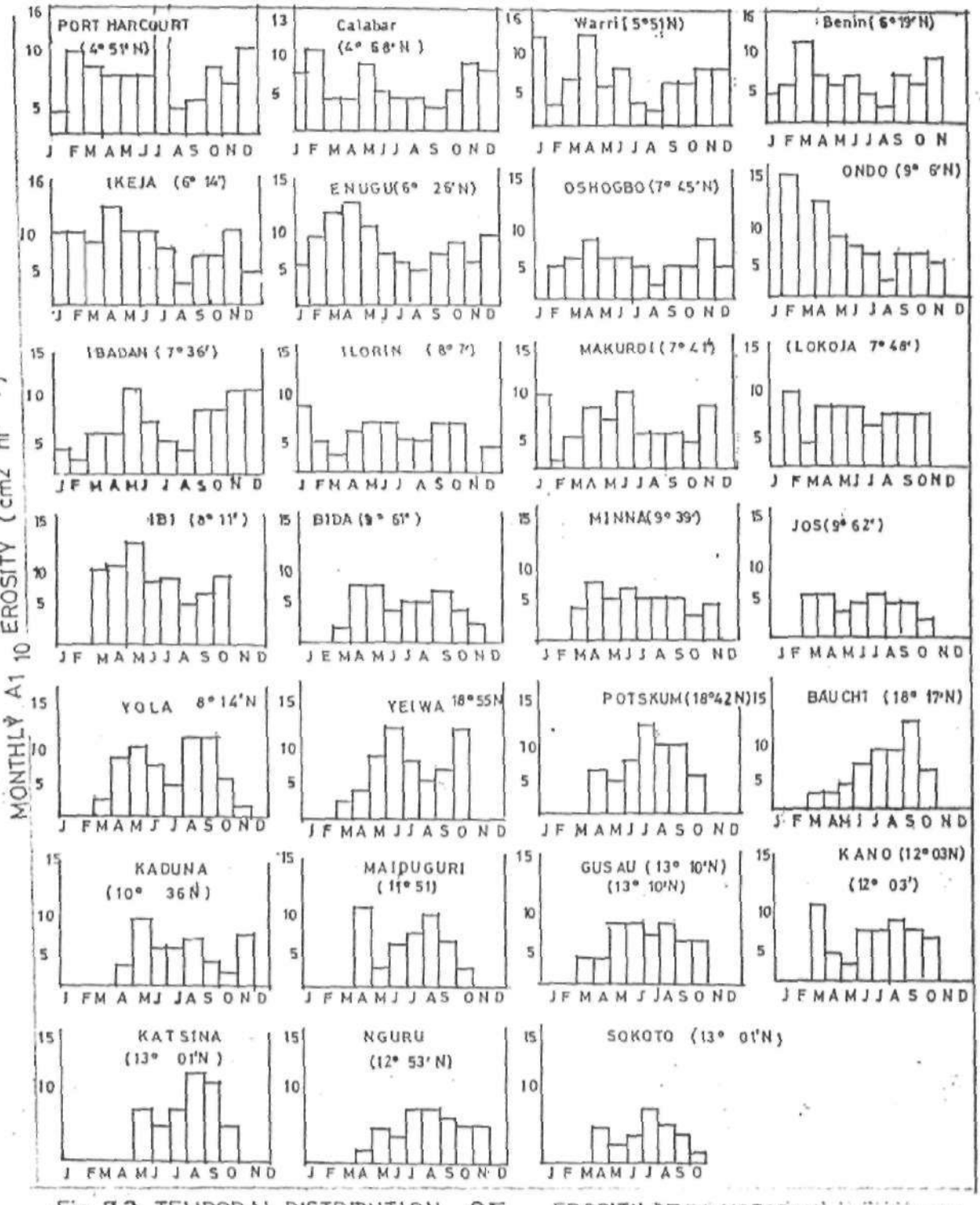


Fig. 7.3. TEMPORAL DISTRIBUTION OF EROSITY OF RAINSTORMS IN NIGERIA

Source: Analysis of data.

In September, erosivity of 5 - 10 cm^2 hr^{-1} was obtained for most parts of the country except at the Niger Delta and south-eastern parts of the country where higher erosivities of between 10 and 15cm2hr-1 occurred.

Table 7.1 shows the result of the correlation analysis of mean monthly erosivity for each month of the year with the geographical factors. During the dry season between November and March, there is an inverse relationship between values of erosivity and latitude because of the lack of rainfall in the Middle Belt, northern and extreme northen areas of the country. In April, May, June, and October, there are also an inverse relationship with latitude indicating that there are more erosivities in the southern areas which subsequently decreased northwards. During the peak of the rainy season in the north (July - September), there are generally, positive correlation between latitude and erosivity, which also suggested that the values of monthly mean rainstorm erosivity decreased from the coast northwards. This was because much of the rainfall during this period in the south, results from the persistent stratocumulus clouds arising from extreme monsoon activities that characterised the Niger Delta and the southeastern part of the country (Kamara, 1986).

On monthly basis, the temporal variation in the AI_{10} erosivity index showed distinct differences between the southern and northern parts of the country (see Fig. 7.3). In the southern zone, there are very little intra-seasonal fluctuations of erosivities. Only a few stations had some fluctuations which

showed a generaly high value or erosivity in June - July and September to November but low values during the dry season months of November to January and July - August. The northern and extreme northern parts of the country recorded low values of mean monthly AI_{10} index of rainstorms. Thus, most stations in the north exhibit August or September maximum occurrence of mean erosivity during which the values of erosivity exceeded 10 cm^2 hr^{-1} in most stations north of latitude 9^{o} N.

When the values of erosivity were correlated with longitude, latitude and altitude, inverse relationship are obtained between values of erosivity and latitude for most months of the year. This result can be explained in terms of the fact that most of the northern areas were rainless. In contrast, the Southern parts of the country received rainfall all the year round.

In July, the ITD approaches the northern region, reaching its northern-most position in August. It starts its southward recession in September. The weather associated with these positions is the characteristics showers occompanied by thunderstorms with high erosivity over northern Nigeria. The resultant high intensity and erosivity in the northern Nigeria, coupled with the low values arising from the 'August break' in the south explains the decrease of intensity and erosivity of rainstorms with latitude. This is clearly depicted by the positive correlation coefficients obtained between erosivity and latitude during this time of the year.

The largely inverse correlation between mean erosivity suggests lower erosivity on highlands. This result can be true because, even though there is higher total rainfall on the Jos

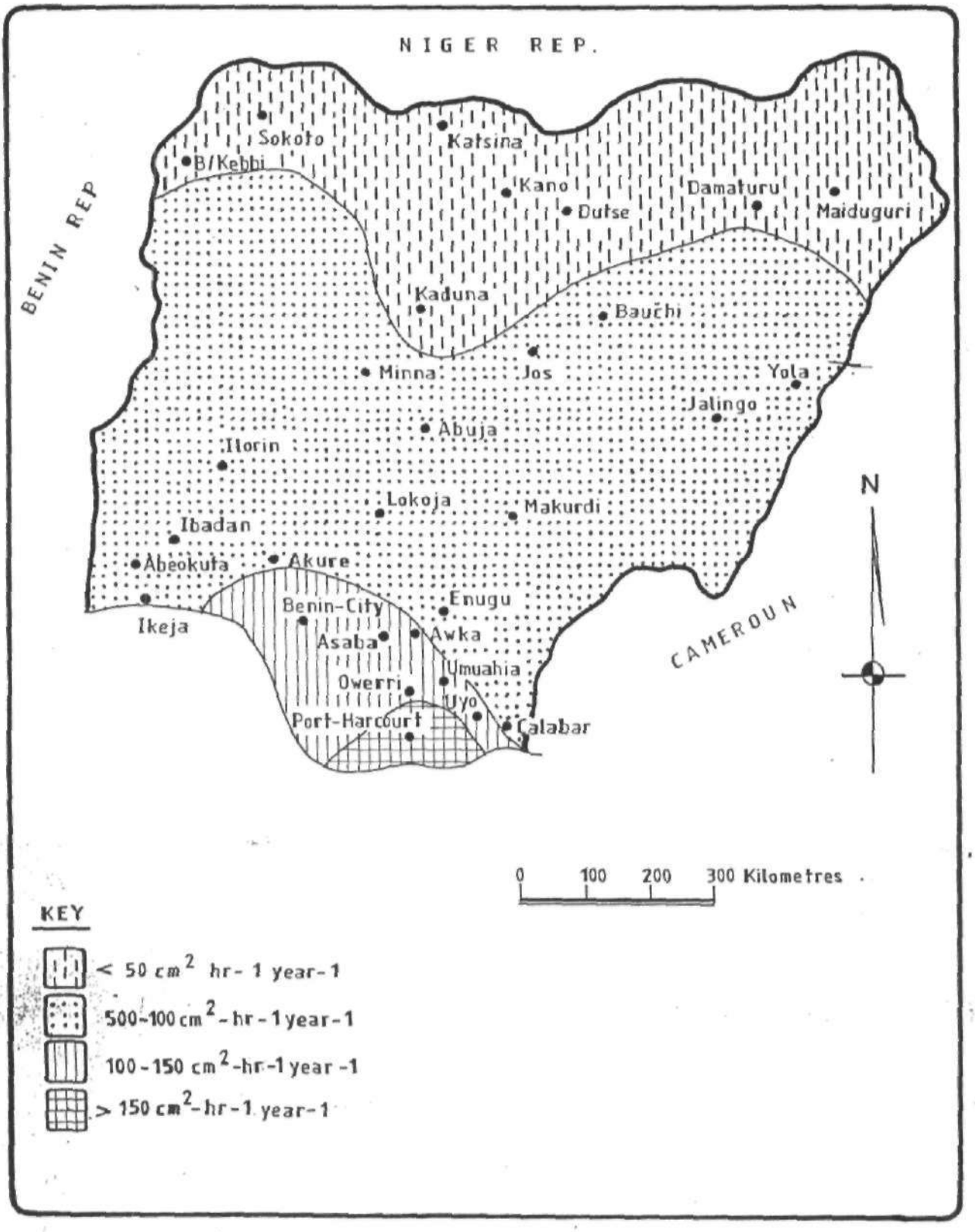


Fig. 7.4. Mean annual total A_{110} erosivity of rainstorms in Nigeria.

SOURCE: Analysis of data

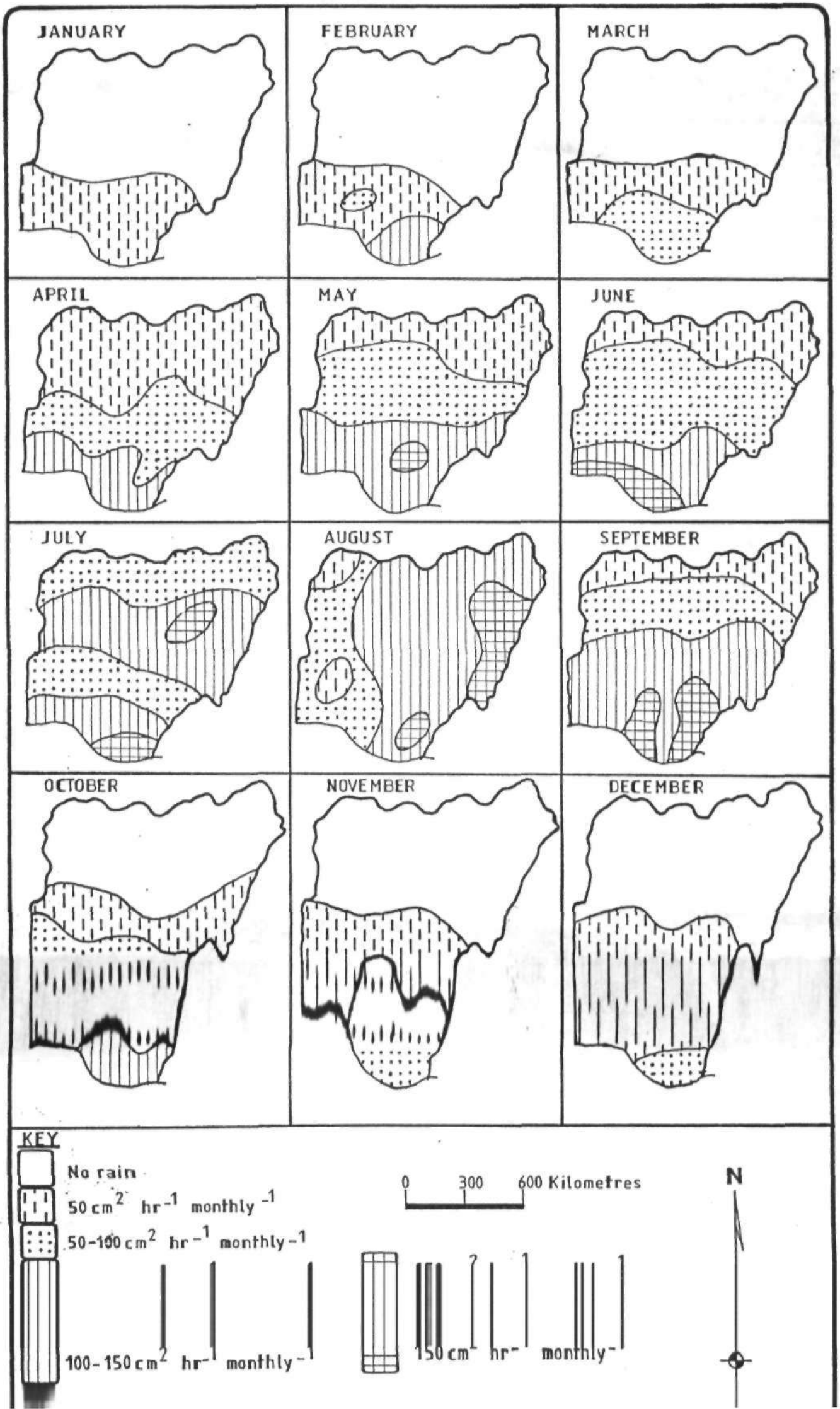

JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
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No rain
50 cm2 hr-1 monthly-1
50-100 cm2 hr-1 monthly-1
100-150 cm2 hr-1 monthly-1
150 cm2 hr-1 monthly-1
0 300 600 Kilometres
N

TABLE 7.2 CORRELATION OF MONTHLY TOTAL AI$_{10}$ EROSIVITY AND GEOGRAPHICAL FACTORS

FACTOR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
LONGITUDE	- .45	- .22	- .42	- .44	- .24	- .43	- .09	.72	- .24	- .47	- .40	- .34	- .28
LATITUDE	- .67	- .71	- .73	- .73	- .76	- .81	- .34	.25	- .63	- .85	- .74	- .74	- .81
ALTITUDE	- .58	- .56	- .26	- .26	- .35	- .46	- .06	.20	- .30	- .56	- .45	- .39	- .41

Plateau than the adjoining lands, the higher total rainfall results from prolonged rainfall of low intensity, and consequently, low erosivity.

7.2 THE ISO-ERODENT MAP OF NIGERIA

Using the AI_{10} index, the values of annual and monthly total erosivity were computed as shown in Annex 4. From the values, an iso-erodent map was drawn for Nigeria. The spatial variations of the monthly and annual iso-erodent maps were shown in Figs 7.4 and 7.5 respectively. The temporal fluctuations of the monthly erosivity are also shown in Fig 7.6.

Generally speaking, the annual erosivity decreases gradually from high values of greater than 1,000 cm^2 hr^{-1} in the Niger Delta area to less than 500 cm^2 hr^{-1} in the north-eastern areas of the country. This spatial variation implies that total storm erosiveness in the Niger Delta area is about three times that found in the extreme north-eastern area of the country.

A correlation analysis of the total erosivity with the geographical factors of longitude, latitude and altitude yeilded the correlation coefficient values of 0.08, 0.66 and 0.17 respectively. (See Table 7.2) They are all significant at .05 confidence level. This shows that latitude exerts the strongest influence on mean annual total erosivity followed by altitude, while latitude exerts the least influence. The factors therefore

explained 8%, 66 % and 17% of the variation of erosivity respectively.

On monthly basis, there is significant erosiveness only in the Niger Delta during the dry months of October to March. Between April and June, total erosiveness decreases from high values of about 150 cm^2 hr^{-1} in the Niger Delta area to low values of about 50 cm^2 hr^{-1} or less in the northern areas.

In July and August, much of the northern areas and south-eastern Nigeria have high erosivity of 150 cm^2 hr^{-1}. The high erosivities obtained in the south-eastern areas could be due to the high indicence of rainfall occurring all year round. The high erosivities occurring in the northern areas during these months is related to high rainfall since these are the rainest months of the year on the region. On the other hand, relatively lower values of erosivity are obtained for the southwestern areas of the country can be attributed to the well known August-break.

In September, most of the southern areas have high erosivity values of 150 cm^2 hr^{-1} and above. Erosivities then decreased gradually northward to values less than 50 cm^2 hr^{-1} in the extreme northern areas.

When the values of total AI_{10} index of erosivity were correlated with longitude, low negative orrelation coefficients were obtained for all the months of the year, except for August (see Table 7.4). Between January and July, and between September and December, the inverse correlation coefficient observed ranged between 0.09 to 0.47. However, in August, a strong positive correlation coefficient of 0.72, which was significant at .05

confidence level, was obtained, indicating higher erosivity in the east than in the western parts of the country.

The correlation coefficient between total erosivity and latitude in June and July are - 0.34 to and 0.81 respectively, while it is 0.25 for August. All the values for the three months are significant at 0.05 level. The positive relationship obtained in August suggest that erosion will be higher in the northern part of the country than in the southern area during the month. This again is as a result of the August break in the south.

There are an inverse relationship of total erosivity with altitude throughout the year, except in July and August (see Table 7.4). The inverse relationship that exist for most part of the year is an indication that areas located on low altitudes experience higher erosivities than those on the higher altitudes. This further validates the earlier observation that most of the southern areas with low topography have more erosive rainstorms almost all year round, except in the month of August during which erographic effect becomes most evident.

The temporal variations of erosivity is illustrated in Fig. 7.6. All stations situated in the Niger Delta, the south-western and the south-eastern areas of the country, recorded erosivities of the magnitude of between 17.0 $cm^2\ hr^{-1}$ and 150 $cm^2\ hr^{-1}$ during the long wet season that extends from March to November in these areas. Even though erosivity is noted for all months of the year, erosivity values are very low during the dry season between December and February. The highest values of erosivity occur during June-July and September in these southern areas. The peak period of erosivity coincide well with the periods of major rainfall peaks in the sourthern areas. The minimum values during

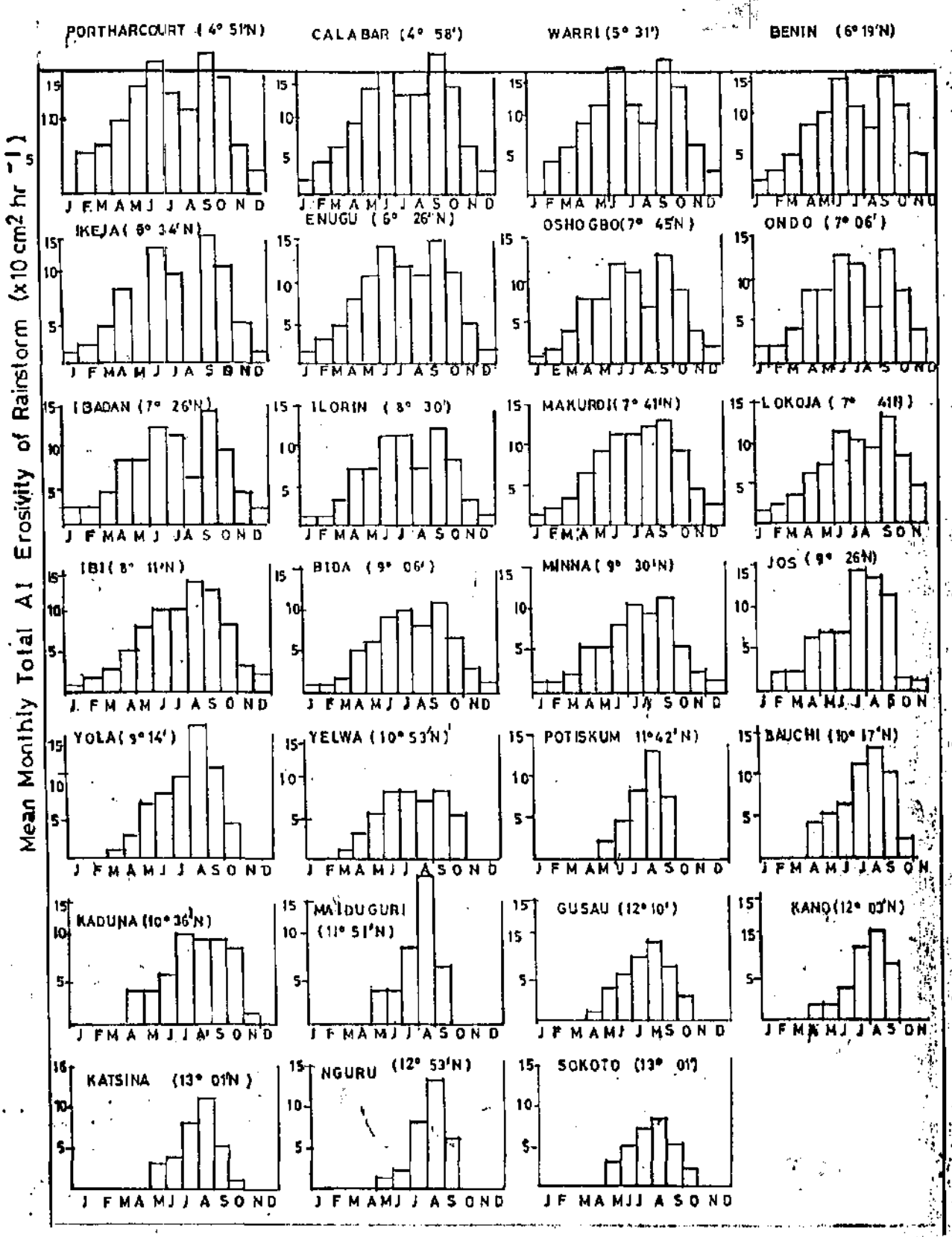


Fig. 7.6. Temporal Distibution of Monthly Total. Erosivity of Rainstorms In Nigeria

Source: Analysis of data

the rainy season occur in August in the southwestern areas of the country.

Most stations in the northern zone and those situated in the Middle-Belt of the country have long, dry seasons, coupled with a generally lower values of erosivities than the southern areas. However, maximum erosivities of 100 cm^2 hr^{-1} and above were recorded for most Middle-Belt and northern areas in August. Most stations in the areas had considerable intra-seasonal fluctuations. In Maiduguri, for instance, values ranged from 10 cm^2 hr^{-1} at the beginning of the rainy season in May to a maximum of 190 cm^2 hr^{-1} in August. The temporal variation of total erosivities coincides with peak periods of August maximum rainfall. Also, the low periods of erosivity in the southern areas coincide with the period of southern dry season which is between November and March; and the period of low rainfall in the southwestern areas in August.

Elevation appears to have induced high erosivities on the Jos Plateau and its environs located in the northcentral areas of the country. The elevation induced erosivity becomes very evident during the months of July, August And September when higher erosivities are obtained for the Jos Plateau than in areas of the same latitude as Jos. In Jos for instance, erosivities for July, August and September months are 140, 130 and 120 cm^2 hr^{-1}, respectively, while erosivities for Minna located on approximately the same latitude as Jos has erosivities of 100, 90 and 110 cm^2 hr^{-1}, for those three months respectively.

In general therefore, the annual erosivities in Nigeria range from 140cm^2hr^{-1} for Sokoto to 1759cm^2hr^{-1} in PortHarcourt

(see Table 7.3). The distribution of annual erosivities in Nigeria show a distinctive areal pattern. The highest erosivity band is in the Niger Delta and the souph-east areas of the country. There is a general southnorth gradient with annual erosivities decresing from the coast northward. According to the iso-erodent maps in Fig. 7.4 and 7.5, the distribution of erosivities seemed to the influenced by the zones of the ITD and the consequent effects of the zones on the surface as they move north and south over the country throughout the year. As a result, there is a tendency for a broad area of the country to experience fairly similar values of mean rainstorm erosivities at any single time. Over a season, however, the amount of erosivities for one zone becomes quite distinct from the others. In addition, local topographic difference become apparent as in the case of Jose Plateau and its environs.

On the basis of general distribution of rainstorm erosivisities in Nigeria, 3 broad zones are easily recognizable: The high, moderate and low erosivities zones.

7.2.1. THE HIGH EROSIVITY ZONE

The high erosivity zone can be delimited by the threshold value of $100cm^2\ hr^{-1}$ and above. The zone covers the Niger Delta and the southeastern parts of Nigeria where erosion has reached hazardous dimensions. Erosivity therefore explains the high degree of erosion ebing experienced in the eastern part of the country.

7.2.2 MODERATE EROSIVITY ZONE

The moderate erosivity zone includes the southwestern, the Middle-belt and the northern areas of Nigeria which are $100cm^2hr^{-1}$. Erosivity occur between 7 to 9 months of the year in this zone, usually between March/April and October. The Jos Plateau (1,285m above sea level) and its environs, however, receive higher annual erosivity than what the rainfall belt in the latitude would suggest.

7.2.3 THE LOW EROSIVITY ZONE

The extreme northern areas of the country are characterised by low annual erosivities which are generally lower than $50cm^2hr^{-1}$ erosivity occurring for only about 5 - 7 months of the year, usually between April/May to September/October.

CHAPTER EIGHT

DISCUSSIONS, SUMMARY AND CONCLUSIONS

8.1 GENERAL

Soil erosion is a serious problem in the tropics and in Nigeria in particular. Many densely populated areas are being devastated at an alarming rate. The estimated cost of soil erosion control is staggering and cannot possibly pass the Nation's litumus test of affordability. This calls for the need to thoroughly understand the factors of soil erosion with a view to finding the most cost-effective method of controlling the menace of soil erosion in the shortest possible time.

Rainfall erosivity is a major factor of soil erosion. It is however, difficult to measure directly. Therefore, values of erosivity can be more easily estimated from rainfall intensity, proving various erosivity indices. Many of these erosivity indices are currently in use. Some of them have been tested and found suitable in some environments that are not very similar to that of Nigeria. It was from these standpoint that present work investigated the performance of erosivity indices in Nigeria, in order to estimate the highly variable soil loss that characterizes various Nigerian environments.

8.2 OVERVIEW OF THE INVESTIGATION

The objectives of the study are to:

a. Provide data base for the nature of rainfall intensity and erosivity in Nigeria.

b. Determine the intensities of rainstorms at the

Meterological Stations in Nigeria

c. Determine the erosivity of the rainstorms using their intensities and kinetic energies.

d. Investigate the spatial and temporal variations of the rainstorm characteristic over Nigeria.

e. Determine the erosivity index that best predicts soil erosion laws in Nigeria, using the savanna area as the study case.

f. Examine the behaviour of the predictor index over space and time for the 10-year period of study.

g. Produce an iso-erodent map of Nigeria on the basis of the predictor index of erosivity.

The data for the study came from two main sources. The first source was the twenty-seven synoptic stations that were selected for analysis on the criterion basis that they have autographic records of 10 years or more. Even though the stations were not evenly distributed through out the country, they were thought to be fairly representative of the different rainfall zones in Nigeria. The second data source was the field investigation that was carried out in Samaru, Kaduna State. It provided the basis for testing the applicability of six selected erosivity indices in the estimation of soil-loss.

The data assembly for this study was carried out in three phases. Phase one involved the determination of rainfall characteristic from autographic charts that were stored at the Nigerian Meteorological Service, Oshodi, Lagos. The rainfall characteristics determined were amount, duration and intensity of rainfall, for each rainstorm that occurred during the 10-year period. The results were also recorded and the intensities and erosivities were calculated.

Phase two of data assembly was that of the field investigation carried out in Samaru-Zaria. This involved actual measurement of soil losses using splash (wash) traps constructed for the purpose of the investigation.

Phase three of data collection focussed on the determination of rainfall intensities and erosivities for selected time intervals. These were used in the study as the correlated of soil loss from water erosiion.

8.3 ANALYTICAL PROCEDURES

Two categories of data were obtained for the thesis. The first was the data obtained from soil loss investigation that was carried out in Samaru between June and October 1984. The second category was the data on amounts and durations of the 27 synoptic stations in Nigeria. The computer was programmed to calculate the intensities and erosivities of the rainstorms from the second category of data.

The relationships existing between total sediments detached and 10 rainstorms characteristic were examined using regression and correlation analyses.

In order to show the empirical behaviour of intensities and erosivities of the rainstorms over Nigeria during the 10-year period, the percentage frequency distributions were calculated.

To facilitate the estimation of the values of the rainstorm variables for most areas of Nigeria without rainfall records, the annual and monthly values of intensities and erosivities were correlated with the three selected geographic factors of longitude, latitude and height factors.

8.4 RESULTS OF THE STUDY

The result of the soil loss investigation revealed that the value of R^2 associated with AI_{10} erosivity was 0.8 which implies that 80% of the variation of erosivity was explained by the AI_{10} regression models. The remaining 20% variation of erosivity could be due to other factors of soil erosion. Consequently, it was deduced that of all the 6 erosivity indices and the other 4 rainstorm characteristics, AI_{10} index has the strongest relationship with sediments detached. In addition, it was observed that rainfall-amount related indices such as AI_{10} and AI_{15} were better predictors of erosion hazard than the energy parameters of EI_{10} EI_{15} and EI_{30} which Wischmeier and Smith (1959) suggested. The difference could be due to the different types of rainstorm occuring in the two environments where the observations were made.

The frequency distribution of average intensities of rainstorms showed that the proportion of rainstorms with intensities lower than 5mm hr^{-1} was high in the south and decreased with latitude. Conversely, the proportion of rainstorms higher than 5mm hr^{-1} increased with latitude northward.

Spatial variations of both annual and monthly mean intensities showed identically low mean intensities. The temporal variations of monthly mean intensities in most southern stations showed high values at the beginning and at the end of the rainy season with low values between July and September. The northern stations on the other hand, gave single maximum usually between June and September.

The frequency distributions of peak intensities showed that more than 30 percent of peak intensities of the storms fell below 12.5 mm hr^{-1}. The percentage of the non-erosive peak intensity decreased from the coastal areas northward. The percentage of the erosive peak intensity, on the other hand increased from 22 to 25 percent in the south to about 40 percent in the north.

Both the amount of rainstorms and their monthly peak intensities showed some high degree of spatial variation in terms of longitude, latitude and altitude. They gave an inverse correlation with latitude, longitude and a non-significant correlation with altitude. This result implies that on annual basis, there were higher rainfall intensities in the northern

than in the southern parts of the country and there were higher rainfall intensities in the eastern than in the western parts of the country. These trends are consistent with the earlier observation of percentage frequency of peak intensities of rainstorms by Torrance (1978) who noted that the highest peak intensities of rainstorms are more frequently recorded in the drier areas than in the wettest regions. During the rainy seasons, the results indicated higher peak intensities in the eastern than in the western parts of the country. The higher intensities in the eastern parts was ascribed to the fact that the stations in the Niger Delta and the eastern Nigeria do not usually experience August break because of the climatic conditions that constantly favour the propagation of rainstorms in the area (Iloeji, 1976); and also due to the frequent monsoon rainfall of the Niger Delta (Kamara, 1986).

The temporal variations of intensities showed higher values at the beginning and at the end of the rainy season; and much lower values in July and August. In the northern areas, intensities are higher for the months of July, August and September than other months of the year. These temporal variations can be attributed to the migratory movements of the ITD Consequently, the two periods when rainfall intensities are highest are at the beginning and at the end of the rainy season when the ITD and its meso-scale propagating systems move over Nigeria. In the northern parts of the country on the other hand, the movements of the ITD coupled with the small-scale thunderstorm propagation systems explained the consistently high

intensities between May and September.

Annual mean erosivity gave positive correlations with both longitude and latitude. It however, showed negative correlations with altitude. Mean monthly erosivity, generally speaking, had strong inverse relationships with longitude, latitude and altitude for the period between July and September when the relationship was the reverse.

The annual total erosivity also recorded negative correlations with latitude, longitude and altitude except between July and September during which positive correlations were obtained.

The temporal variations of both mean and total erosivity showed similar trends. Their temporal variations showed that erosivity occurred in all months of the year in the southern parts of Nigeria. The stations in the south showed multi-modal distribution of rainstorm erosivity with peaks occurring either in April/May or September/October. There were usually low periods of erosivity in July, August and September. Temporal variations of erosivity in the middle-belt area showed that there were two or more peaks, though, there were fewer peaks here than the southern areas of the country. Temporal variations of erosivities in the northern areas gave unimodal distribution about August and a general lower monthly values than those of the southern and middle-belt areas.

The spatial variations of erosivities in Nigeria showed high

values in the south-eastern parts of Nigeria. The spatial variation of erosivities therefore partly explained the high incidence of erosion in the eastern part of Nigeria. The variations of erosivity had, however, not explained the high incidence of erosion in most part of the eastern states, in areas of high relief and some northern parts of the country.

The spatial variations of erosivities did not necessarily reflect the spatial variations of intensities; rather erosivities are high in areas with long rainspells and low in areas with short rainspells. The spatial variations of erosivities can therefore be linked to one or more of the following rainstorm propagating systems; coastal effects; monsoon effects; local thunderstoms and disturbance lines (Oguntoyinbo et. al., 1978). It can, however, be recalled that the weather structure associated with the two sides of the ITD fell into four main zones of A,B,C, and D. Zone C and to a lower extent, zone B, are characterised by conditional instability and high humidity. Hence, any low level convergence is sufficient to result into rainfall. Eventhough, conditional instability is nearly always present in the tropics the areas pervaded by zones A and D of the ITD are often characterised by high stability. Consequently, none of the rainstorm propagating systems can give rise to any meaningful rainfall in the zones. The extent of any low-level convergence and instability by any single or more of the rainstorm propagating systems therefore depends on the weather imposed by the ITD oscillations over the areas in question.

In view of the significant relationship that existed between erosivity and the geographical factors of longitude, latitude and altitude; it is possible to estimate erosivity using a model of regression line of erosivity on the three geographical factors. The linear relationship that existed between erosivity and the geographical factors has the property shown by equation 5.1. The annual AI_{10} is given by equation 5.2 and the equations that gave the estimates of erosivities of the twelve months of the year are given in Table 5.6. This study therefore makes it possible for values of erosivity to be estimated, with at least 70 percent accurracy, for any part of Nigeria whose longitude, latitude and altitude are known.

8.5 CRITIQUE OF THE RESEARCH

A comparison of the relative performance of erosivity indices in measuring soil loss in Samaru using partial and multiple correlation revealed that Lal's AI_{10} erosivity index recorded the highest correlation. Lal's AI_{10} erosivity index had already been accepted as the best index in the southern Nigeria (Agu, 1983). It can therefore be stated that Lal's AI_{10} erosivity index is the most applicable to the Nigerian environment.

The other achievements of the research are as follows:

a. The research has provided the data base for investigating the intensities and erosivities of rainstorms in Nigeria.

b. It has provided the needed information on the behaviour of the spatial and temporary rainstorms characteristics in a

humid tropical environment.

c. It has established the relationships between the intensities and erosivities of rainstorms.

d. It has delimited the erosivity index that best predicts soil loss in the Nigerian environment.

e. The study made it possible to provide a preliminary iso-erodent map of the country.

The research however, has the following limitations:

a. The data covers only 10 years of rainfall record at 27 synoptic stations.

b. Intensities and erosivities or rainstorms were only determined by indirect method. This might have resulted into loss of some information.

c. Conclusions were drawn on the basis of the linear regression model. The assumptions to this conclusion were highlighted in Chapter Three.

d. An iso-erodent map was based on the data obtained from the soil loss investigation in Samaru in the savanah region of the country.

8.6 SUGGESTIONS FOR FUTURE RESEARCH

The approach to this study is primarily a empirical approach to the study of intensity and erosivity of rainstorms in Nigeria. using data for a period of about ten years.

Thus if this study is to be replicated in future, there will be a need to use longer rainfall records and more rainfall stations. There is also a need to measure soil loss in the various ecological zones of the country for correlations with rainfall intensities and erosivities.

Our knowledge of storm dynamics is still rather scanty because of the general scarcity of relevant meteorological data. This implies the need for the Nigerian Meterological Services to carry out more accurate and meaningful recording of various rainfall characteristics for use in future studies. This also suggests the need to research into the nature of the atmospheric processes in order to make available extensive and reliable data-base. This will no doubt help us to understand the nature of erosion and the danger it poses to human survival in Nigeria in particular and the tropics in general.

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ANNEX 1 MEAN MONTHLY INTENSITIES OF RAINSTORMS IN NIGERIA (mm hr^{-1})

STAION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
PORT-HARCOURT	4.1	10.7	9.7	8.4	7.5	6.0	5.2	3.5	4.6	5.6	10.7	8.9	5.7
CALABAR	10.4	11.4	5.3	5.5	6.8	6.3	4.8	4.9	4.5	5.5	11.0	8.3	5.9
WARRI	12.6	12.7	8.9	9.4	7.9	7.4	4.9	5.5	5.9	6.8	13.1	9.5	7.2
BENIN	10.5	9.7	10.5	10.6	8.2	8.7	5.2	4.3	5.6	7.9	11.7	8.2	6.7
IKEJA	8.8	10.3	10.8	10.5	8.7	8.0	5.0	4.9	4.6	7.4	14.0	6.8	7.3
ENUGU	7.3	8.3	10.7	8.7	8.8	7.0	7.0	5.3	6.4	6.1	7.1	9.0	7.1
OSHOGBO	9.8	8.3	7.6	8.6	6.5	7.7	5.0	4.1	7.6	9.5	14.5	12.9	7.2
ONDO	7.1	12.1	10.8	9.6	9.3	7.8	5.3	4.4	6.6	9.2	10.4	10.8	7.2
IBADAN	8.7	7.5	6.8	9.9	7.9	8.0	4.1	6.8	6.6	15.5	11.7	14.9	8.2
ILORIN	6.8	7.9	7.5	7.1	8.0	6.8	5.2	4.4	6.9	7.7	12.4	11.0	6.8
MAKURDI	7.0	2.5	5.6	9.3	7.0	7.3	4.6	5.0	5.4	5.3	6.5	10.0	5.9
LOKOJA	0.3	16.7	9.0	7.2	10.4	7.3	6.9	6.0	6.7	8.9	10.6	4.0	7.4
IBI	1.0	---	6.6	7.5	6.4	6.9	6.3	4.9	5.2	7.0	7.2	----	6.0
BIDA	2.7	----	4.2	9.6	9.3	8.6	6.4	6.1	8.0	9.5	5.3	----	7.7
MINNA	3.0	----	7.9	7.5	6.8	7.8	7.5	6.7	6.6	7.7	4.4	----	6.9
JOS	4.6	4.2	10.0	8.5	8.9	7.9	7.3	6.1	8.0	5.8	6.0	22.0	7.5
YOLA	---	----	5.0	7.4	7.7	10.0	4.7	8.6	11.4	9.2	15.0	----	8.6
YELWA	1.0	----	4.0	7.4	10.5	9.7	6.9	6.6	7.5	11.0	3.0	----	7.9
POTISKUN	0.0	----	8.0	9.1	7.0	8.0	8.9	7.6	8.9	5.5	4.0	----	8.0
BAUCHI	4.0	----	12.0	7.7	10.5	9.5	9.9	8.1	8.2	7.5	3.0	----	8.9
KADUNA	----	3.0	3.2	7.1	8.1	6.8	6.8	8.3	8.4	7.0	15.0	----	7.7
MAIDUGURI	----	----	----	8.9	6.0	11.3	16.3	11.1	11.1	5.7	----	----	10.2
GUSAU	1.0	6.0	6.2	4.9	8.6	10.5	8.2	9.0	9.3	8.9	6.0	----	8.9
KANO	4.0	2.0	18.0	5.0	8.6	10.3	9.2	8.1	10.7	7.5	----	----	9.2
KATSINA	----	----	----	3.0	12.0	10.6	9.2	10.6	11.9	8.3	----	----	10.5
NGURU	----	----	----	6.0	13.4	8.5	7.3	7.3	10.1	6.7	19.0	----	8.3
SOKOTO	----	----	15.0	17.1	6.6	9.0	9.4	8.4	10.5	7.3	14.0	----	9.2

ANNEX 2 MEAN MONTHLY 10-MINUTES PEAK INTENSITIES OF RAINSTORMS IN NIGERIA

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEAN PEAK INTENSITY
PORT-HARCOURT	14.5	41.2	34.3	26.3	28.3	27.5	16.5	15.6	19.5	26.6	27.2	31.2	22.7
CALABAR	29.6	31.2	17.7	19.4	23.2	17.9	15.2	17.0	14.2	15.2	29.7	30.3	21.3
WARRI	34.8	21.2	28.3	30.9	24.1	22.1	14.7	12.4	17.7	23.2	27.9	20.5	20.7
BENIN	22.4	22.2	34.2	32.0	25.1	24.5	15.6	12.9	20.2	26.4	47.0	31.1	22.1
IKEJA	40.1	33.5	34.2	39.0	31.3	28.4	24.5	15.1	18.9	27.7	41.2	21.9	27.7
ENUGU	20.8	32.4	34.4	42.2	32.9	24.5	21.5	18.4	25.7	29.9	26.4	27.4	26.8
OSHOGBO	41.5	28.3	22.4	30.3	21.9	25.0	19.5	11.7	28.7	24.9	23.1	26.6	22.3
ONDO	28.2	45.2	32.8	39.8	32.5	27.0	18.1	13.2	21.8	30.9	29.6	48.9	24.5
IBADAN	24.6	22.9	28.3	43.2	39.1	31.1	18.4	19.6	33.6	42.1	49.6	27.0	31.2
ILORIN	39.2	22.2	18.4	24.3	28.4	25.5	18.5	17.7	26.0	30.5	54.9	26.7	24.7
MAKURDI	32.0	5.5	29.2	28.3	27.7	31.5	23.5	19.9	19.3	20.5	29.1	19.0	23.5
LOKOJA	1.3	38.5	20.9	29.1	30.3	28.0	20.5	18.5	24.9	27.2	15.0	18.3	24.3
IBI	3.5	——	28.7	32.0	31.0	32.7	24.2	22.5	24.9	32.0	27.0	——	27.5
BIDA	9.3	——	12.2	26.5	29.4	23.0	22.0	18.7	22.6	23.7	15.5	——	22.6
MINNA	0.0	——	25.9	30.4	26.8	30.3	22.8	21.6	25.5	25.5	25.6	——	25.3
JOS	8.1	9.2	31.4	23.8	22.4	21.3	20.9	19.3	22.7	14.8	15.0	57.0	21.0
YOLA	——	——	24.8	27.1	25.8	27.1	18.5	29.2	33.5	25.8	15.0	——	27.2
YELWA	1.0	——	11.7	17.4	28.0	33.9	22.0	19.6	22.2	32.7	5.3	——	24.0
POTISKUM	1.0	——	8.0	29.3	22.3	26.7	39.0	27.5	30.2	25.7	8.0	——	29.6
BAUCHI	4.0	——	12.0	18.3	22.7	28.1	31.3	25.9	23.9	23.2	4.5	——	26.1
KADUNA	——	30.0	6.2	32.6	26.9	29.2	23.2	27.2	25.0	19.0	26.5	——	25.5
MAIDUGURI	——	——	——	24.6	23.3	32.1	37.9	37.6	35.0	22.0	——	——	34.6
GUSAU	1.0	14.0	15.0	12.4	30.9	28.9	26.0	28.0	27.8	23.6	11.0	——	27.6
KANO	4.0	8.0	47.0	15.9	19.5	34.4	28.9	31.3	31.3	33.3	——	——	32.0
KATSINA	——	——	——	6.3	38.8	29.7	32.2	37.2	33.4	31.4	——	——	36.5
NGURU	——	——	——	13.0	23.0	21.3	27.6	26.6	30.4	25.3	30.0	——	26.9
SOKOTO	——	——	15.0	27.5	15.8	21.1	25.7	20.5	21.6	13.3	22.3	——	21.6

ANNEX 3 MONTHLY MAXIMUM PEAK INTENSITIES OF RAINSTORMS IN NIGERIA (mm hr^{-1})

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	OVERALL MAXIMUM
PORT-HARCOURT	87.0	174.0	194.0	174.0	199.0	198.0	152.0	194.0	152.0	257.0	152.0	190.0	257.0
CALABAR	152.0	198.0	130.0	183.0	229.0	158.0	152.0	274.0	152.0	244.0	168.0	152.0	274.0
WARRI	183.0	69.0	152.0	244.0	229.0	309.0	198.0	176.0	297.0	252.0	185.0	16.0	309.0
IKEJA	130.0	145.0	175.0	229.0	229.0	191.0	229.0	122.0	267.0	229.0	175.0	107.0	267.0
ENUGU	69.0	145.0	168.0	244.0	152.0	183.0	221.0	192.0	206.0	183.0	122.0	76.0	244.0
BENIN	80.0	91.0	152.0	137.0	137.0	305.0	152.0	229.0	267.0	114.0	229.0	143.0	305.0
OSHOGBO	175.0	99.0	114.0	182.0	213.0	198.0	137.0	137.0	152.0	257.0	180.0	84.0	234.0
ONDO	107.0	270.0	288.0	270.0	144.0	274.0	183.0	99.0	148.0	137.0	98.0	152.0	188.0
IBADAN	69.0	80.0	145.0	242.0	152.0	198.0	137.0	137.0	152.0	257.0	180.0	84.0	240.0
ILORIN	114.0	84.0	114.0	290.0	190.0	206.0	137.0	274.0	221.0	137.0	290.0	61.0	290.0
MAKURDI	99.0	9.0	107.0	137.0	236.0	229.0	206.0	192.0	168.0	107.0	76.0	23.0	236.0
LOKOJA	2.0	130.0	69.0	145.0	141.0	145.0	145.0	145.0	137.0	137.0	30.0	38.0	145.0
IBI	267.0	0.0	152.0	229.0	305.0	190.0	305.0	229.0	221.0	229.0	114.0	0.0	305.0
BIDA	15.0	69.0	38.0	145.0	130.0	119.0	142.0	160.0	152.0	91.0	38.0	0.0	160.0
MINNA	30.0	84.0	122.0	152.0	114.0	145.0	152.0	145.0	152.0	107.0	107.0	61.0	152.0
JOS	23.0	8.0	154.0	145.0	152.0	137.0	198.0	130.0	153.0	79.0	15.0	57.0	198.0
YOLA	0.0	0.0	76.0	229.0	229.0	160.0	229.0	305.0	229.0	130.0	29.0	0.0	305.0
YELWA	1.0	0.0	46.0	84.0	305.0	213.0	274.0	160.0	305.0	305.0	8.0	190.0	305.0
POTISKUM	1.0	0.0	8.0	152.0	114.0	168.0	183.0	259.0	152.0	107.0	8.0	0.0	259.0
BAUCHI	4.0	0.0	13.0	114.0	145.0	152.0	236.0	152.0	137.0	91.0	5.0	0.0	236.0
KADUNA	0.0	30.0	8.0	91.0	168.0	122.0	168.0	130.0	198.0	107.0	30.0	0.0	198.0
MAIDUGURI	0.0	0.0	0.0	130.0	130.0	175.0	198.0	168.0	160.0	61.0	0.0	0.0	198.0
GUSAU	1.0	14.0	46.0	84.0	145.0	130.0	190.0	198.0	175.0	118.0	11.0	0.0	198.0
KANO	4.0	8.0	47.0	46.0	107.0	152.0	152.0	229.0	152.0	130.0	0.0	0.0	229.0
KATSINA	0.0	0.0	0.0	11.0	107.0	203.0	203.0	242.0	157.0	184.0	0.0	0.0	242.0
NGURU	0.0	0.0	0.0	95.0	160.0	114.0	229.0	152.0	114.0	76.0	30.0	0.0	229.0
SOKOTO	0.0	0.0	15.0	89.0	53.0	114.0	152.0	192.0	137.0	61.0	61.0	0.0	192.0

ANNEX 4 MEAN MONTHLY AI_{10} EROSIVITY OF RAINSTORMS IN NIGERIA ($cm^2\ hr^{-1}$)

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEAN AI_{10} EROSIVITY
PORT-HARCOURT	2.9	10.4	8.4	7.3	6.8	6.5	14.7	3.4	4.1	8.1	6.3	10.1	8.5
CALABAR	7.1	10.4	3.6	4.1	8.2	4.7	3.9	4.0	3.3	5.3	8.3	7.3	5.0
WARRI	10.5	2.6	5.7	11.4	4.7	7.2	2.7	2.3	5.1	5.1	7.2	6.9	5.3
BENIN	4.3	5.3	9.6	6.3	5.3	6.1	4.4	2.3	6.3	5.4	8.2	5.6	5.2
IKEJA	9.1	9.2	8.3	12.3	8.5	8.8	6.6	3.4	5.7	6.2	8.9	4.3	7.5
ENUGU	4.9	8.3	10.7	12.2	9.1	5.7	5.2	4.3	6.4	6.8	5.2	7.7	6.8
OSHOGBO	16.5	4.2	4.7	6.6	5.2	5.1	4.2	1.8	4.2	4.0	6.7	4.1	4.4
ONDO	4.5	14.4	7.5	11.1	6.7	5.8	4.7	2.1	4.6	5.4	4.3	12.2	5.3
IBADAN	2.5	2.0	5.3	16.2	9.6	5.6	3.9	2.5	7.8	8.1	9.7	10.3	6.8
ILORIN	7.6	3.7	2.2	4.9	6.0	5.6	3.5	4.3	5.8	6.0	16.2	3.4	5.2
MAKURDI	8.8	0.6	3.7	7.0	5.6	9.1	4.2	3.5	4.2	3.2	7.2	2.8	4.9
LOKOJA	0.1	8.6	3.4	6.5	7.3	7.0	4.5	5.5	5.9	5.8	1.4	1.9	5.8
IBI	0.1	—	8.6	9.0	11.6	8.2	7.9	5.4	6.4	8.0	12.8	—	7.7
BIDA	0.5	0.3	1.6	6.8	6.7	4.3	5.3	5.1	5.8	3.9	1.7	—	5.2
MINNA	1.7	0.4	3.9	6.5	4.5	6.3	5.3	5.2	4.7	3.0	3.7	0.0	4.9
JOS	0.4	0.5	4.6	5.2	3.4	3.7	4.5	3.8	4.0	1.6	1.3	5.0	3.9
YOLA	—	—	1.5	6.7	7.6	6.4	3.6	9.5	9.1	4.4	0.9	—	7.2
YELWA	0.0	—	1.7	3.0	6.8	9.6	6.4	3.9	4.5	9.8	0.1	—	5.8
POTISKUM	0.1	—	0.2	5.1	3.8	6.0	10.4	6.7	6.2	3.6	0.1	—	6.7
BAUCHI	0.03	—	1.8	1.9	3.4	5.3	7.4	5.6	9.8	3.9	0.1	—	6.2
KADUNA	—	1.9	0.2	2.4	8.2	4.5	4.6	6.0	3.2	2.0	5.8	—	4.7
MAIDUGURI	—	—	—	8.5	2.0	5.1	6.3	8.1	5.2	1.6	—	—	6.1
GUSAU	—	0.5	3.4	2.5	6.8	6.7	6.4	6.7	5.3	4.6	0.3	—	6.1
KANO	—	0.2	9.2	2.5	2.0	6.2	6.4	7.3	6.4	4.9	—	—	6.1
KATSINA	—	—	—	0.3	6.0	4.3	6.2	9.8	9.3	3.9	—	—	7.5
NGURU	—	—	—	1.1	3.9	3.0	6.3	6.0	4.5	4.0	3.5	—	5.2
SOKOTO	—	—	0.2	3.9	1.9	2.9	5.6	3.7	2.8	1.3	1.5	—	3.6

ANNEX 5 MONTHLY TOTAL AI_{10} EROSIVITY OF RAINSTORMS IN NIGERIA ($cm^2\ hr^{-1}$)

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL MEAN
PORTHARCOURT	10.2	62.3	83.3	100.6	109.7	164.2	181.1	125.9	142.9	195.4	82.8	56.0	175.87
CALABAR	16.7	85.2	37.0	13.7	11.5	11.6	10.2	159.5	09.7	12.4	11.9	9.9	84.34
WARRI	28.5	15.2	69.6	13.6	09.3	11.5	08.3	65.7	11.6	09.5	11.4	10.0	138.5
BENIN	12.8	19.4	89.1	78.1	95.1	138.1	147.0	81.8	299.2	117.5	65.7	13.9	101.21
IKEJA	19.4	46.8	39.9	15.7	14.9	13.5	11.3	56.0	09.1	09.5	11.5	8.3	73.61
ENUGU	9.0	46.8	61.8	123.5	167.9	97.1	106.3	97.4	168.4	114.8	09.3	15.3	69.07
OSHOGBO	33.0	57.6	42.1	78.5	72.7	96.1	89.8	35.3	96.7	80.6	30.8	12.4	86.85
ONDO	9.0	04.9	72.5	12.2	10.2	08.9	08.4	60.5	09.7	08.4	08.1	12.0	71.66
IBADAN	4.6	11.8	34.2	15.9	10.9	08.6	07.7	39.9	10.7	10.8	09.7	15.5	70.26
ILORIN	17.0	01.0	16.0	09.6	10.0	10.0	08.1	66.3	10.6	10.8	13.5	7.0	58.55
MAKURDI	12.0	12.3	10.8	11.8	11.1	15.6	08.6	70.1	10.3	08.5	13.4	14.0	48.69
LOKOJA	1.0	12.3	3.0	11.9	13.6	12.7	10.5	99.0	11.7	11.3	07.8	8.7	52.62
IBI	1.0	----	7.3	13.7	13.7	12.8	09.3	98.4	10.2	11.7	17.9	---	71.70
BIDA	.7	.6	10.3	11.7	12.2	10.3	11.4	111.2	11.7	09.9	05.7	---	56.45
MINNA	2.0	.5	3.5	10.3	08.9	11.4	11.7	109.4	09.0	07.2	06.9	---	55.01
JOS	2.0	1.5	.3	09.4	07.5	08.8	12.3	122.0	09.0	04.9	08.5	9.0	60.95
YOLA	----	----	.2	10.1	10.6	13.8	07.3	193.1	13.7	08.9	03.5	----	61.38
YELWA	.40	----	2.0	07.5	10.5	13.7	10.6	85.3	10.0	10.5	01.3	----	52.90
POTISKUM	.30	----	.3	07.4	07.5	09.6	14.3	159.5	09.9	07.5	01.0	----	51.74
BAUCHI	.20	----	----	06.0	07.6	10.9	12.4	133.7	11.8	07.8	01.5	----	55.95
KADUNA	----	2.0	.3	17.4	71.1	71.1	75.3	137.9	75.8	10.5	12.0	----	41.08
MAIDUGURI	----	----	----	11.4	5.4	10.2	10.7	128.9	8.6	4.2	----	----	27.36
GUSAU	----	.1	15.0	7.0	8.3	10.8	10.9	146.6	9.9	8.4	3.0	----	49.54
KANO	----	.2	12.0	8.6	6.7	11.6	11.5	101.9	11.2	9.0	---	----	26.78
KATSINA	----	----	----	3.0	7.8	7.4	10.7	138.9	14.6	7.2	---	----	34.42
NGURU	----	----	----	5.7	7.1	6.7	9.0	96.1	18.4	6.5	11.0	----	23.18
SOKOTO	----	----	0.2	6.6	6.7	18.4	47.5	43.9	21.4	4.0	5.0	----	14.19