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CHARACTERISTICS OF HYDROCLIMATIC EXTREMES IN WEST AFRICA : THE LESSONS FROM THE CONSEQUENCES OF THE RECENT CLIMATIC AND HYDROCLIMATIC EVENTS

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SYNOPSIS

West Africa has been facing a series of hydroclimatic extremes since late 1960s with their serious consequences on human welfare and nation's economic development. Most parts of West Africa have been subjected to series of droughts with their consequences on crop failure, decimation of livestock and widespread starvation of the local population. In the present study, an attempt is made to examine the variational characteristics of the hydroclimatic extremes with particular emphasis on the characteristics and the effects of the relatively recent climatic and hydroclimatic events. The index used in the study is the time series of the normalised annual rainfall departure. In addition the water balance approach was employed with inflow component represented by rainfall and outflow component, by evaporation and evapotranspiration and the net runoff.

1.0 INTRODUCTION

A series of hydroclimatic events in West Africa with their serious consequences on man have demonstrated the sensitivity of human welfare and a nation's economic development. During the past three decades human societies in many parts of the world have experienced a lot of crisis triggered by climatic and hydroclimatic events and world wide attention to the impact of these climatic/hydroclimatic events on the economies of the different nations has led many people to realise that there is a growing vulnerability of the society of climatic and hydroclimatic extremes. For example, the late 1960s, most parts of West Africa have been subjected to series of hydroclimatic extremes, which have resulted in droughts, with their consequences on crop failures, decimation of livestock and widespread starvation of the local population. Indeed, these prolonged droughts have caused famine and death of the local population in the affected areas. Particularly in the southern border regions of the droughts stricken sahara desert and the sahel regions of West Africa, the drought episodes considerably reduced food production and led to series of socio-economic problems, not only in the areas affected by the droughts, but also in other parts of West Africa. These relatively recent hydroclimatic extremes in West Africa have indicated the vulnerability of man to hydroclimatic events and have created a lot of concern for these extremes and an awareness for the need to study their characteristics. They have also indicated the need to study impact assessment.

In spite of the awareness of the public in general and the various governments of West Africa in particular for the need to study the characteristics of hydroclimatic extremes and their impact assessment on the nations' economies, not much has been done to examine the characteristics of these extremes in West Africa. For example, a lot of questions remain unanswered on the trends, severity and the widespread nature of the hydroclimatic extremes. Yet, the knowledge of the characteristics of these hydroclimatic extremes is significant for understanding the causes of the extremes and for helping in the development of strategies needed to counteract the adverse consequences of the extremes.

In the present study therefore, an attempt is made to examine the variational characteristics of the hydroclimatic extremes with particular emphasis on the characteristics and the effects of the relatively recent climatic and hydroclimatic events. The period of study covers 1969-87 when the consequences of the hydroclimatic extremes have been known to be so widespread that greater concern for the need to examine the characteristics of the extremes, and the need to solve the problems arising from the consequences of the extremes have become more manifested in the governments and people of the region than ever before. Both locational and regional variations have been used for illustration particularly with respect to some river basins of West Africa.

2.0 METHODOLOGY AND DATA COLLECTION

The present paper emphasised hydroclimatic extremes as related to climatic and hydroclimatic variations, which, in West Africa, are strongly related and sometimes can virtually be equated to rainfall variations (see for example, Oguntoyinbo and Odingo, 1979; Ojo, 1985, 1986a, 1986b). The index used in the study thus emphasised rainfall variability and is the time series of the normalized annual departures of rainfall in the region. In quantitative terms, the index can be expressed in the form :

$$I_{ij} = \frac{1}{N} \sum_{j=1}^{N_j} \frac{r_{ij} - \bar{r}_i}{\sigma} \qquad \ldots(1)$$

where I_{ij} is the normalized rainfall departure, σ is the standard deviation N is the number of stations available during year j and $\bar{r}_i$, the mean annual rainfall at stations i for all seasonal years J_i, can be expressed in the form:

$$\bar{r}_i = \frac{1}{N} \sum_{j=1} r_{ij} \qquad \ldots(2)$$

The rainfall data used in the study were available from different sources. Data for Nigerian stations were, for example, obtained from the Nigerian Meteorological Department in Lagos, while data for the other countries were obtained through Professor Gregory of the Department of Geography, University of Sheffield, Dr. Lamb of the Climatology Section, Illinois State Water Survey in Champaign, U.S.A. and through the efforts of Messrs Semenya, a former student of the Department of Geography, University of Lagos and Abaziem, a technologist in the Department. Data obtained through Professor Gregory and Mr. Semenya were those published

in "Resume Mensuel d'Observations Meteorologigues" by ASCENA, Dakar. The data base consists of individual monthly totals for 24 stations in the Sahel region and 36 stations outside the Sahel region. Using the various data, equation 1 was computed for the four climatic zones in the humid and sub-humid West Africa, namely, the Tropical Rainforest, Guinea Savanna, Sudan Savanna and the Sahel Savanna (Ojo, 1986a, Church, 1980 and de Blij, 1980).

In addition to equation 1, the water balance approach was employed in the present study. Basically, the water balance equation can be expressed in the form:

$$P + I + D = E + g + f_o - f_i \quad \ldots(3)$$

If Δf, the net runoff is regarded as the difference between f_o and f_i, equation (3) becomes:

$$P + I = D = E + g + \Delta f. \quad \ldots(4)$$

The inflow components of the water balance are represented by $p + I + D$ while the outflow components are represented by E, g and Δf. The relative significance of each of the inflow components in West Africa has been noted in some other studies (see for example, Ojo, 1983, 1987).

As already noted in these studies, the most significant of the three inflow components is rainfall. Although both irrigation and dew deposition can be of importance particularly in arid, semi-arid and seasonally arid areas of West Africa, they (i.e. irrigation and dew position) are of less importance than rainfall in assessing hydroclimatological consequences of climatic variations. In the present study, therefore, only rainfall, whose data is available in most parts of West Africa for all practical purposes and particularly for most agricultural practices, will be emphasized as the income component of the water balance.

The outflow components in the water balance equation (equation 3) include evaporation or evapotranspiration and the net runoff. The most significant of the outflow components is evaporation or evapotranspiration, two stages of which may be distinguished. The first stage occurs when the soil water is greater than a critical value and evaporation or evapotranspiration proceeds at approximately the maximum possible or potential rate. The second stage occurs when the soil water dries out below the critical value and it becomes increasingly difficult for additional water to be lost through evaporation and evapotranspiration. At this stage evaporation or evapotranspiration falls below the maximum possible or potential rate. As already noted in previous studies (see for example, Ojo, 1969, 1983) there is no study on the determination of the point at which evaporation or evapotranspiration begins to proceed below the potential rate in West Africa. For the present study therefore, potential evaporation or evapotranspiration has been emphasized for the purpuse of relating climatic variations to evaporation or evapotranspiration. The evaporation values were computed by using the Penman's equation as modified for West Africa (ojo, 1969). In its original form, the equation is

expressed in the form:

$$E_o = (\Delta R_n + \gamma E_a)\ (\Delta + \gamma)^{-1} \qquad \ldots(5)$$

The runoff and discharge data used in the study were those obtained from the Department of Water Resources, Lagos and from Professor L. Oyebande, a colleague in the Department of Geography, University of Lagos.

3.0 CLIMATIC VARIATIONS

Figure 1 shows the rainfall variability in West Africa for 1969-1987 obtained by using equation 1. The figure shows a lot of spatial and temporal variations in the rainfall characteristics, and indicates that in general, the study period is characterized by widespread drought conditions. These droughts however vary in intensity, persistence and spatial coverage. In the forest region for instance, the rainfall characteristics show that the droughts were less persistent and less sever than in the Savanna regions. The year, 1969 was characterized by slightly wet conditions in the forest region. This was followed by relatively persistent dry conditions between 1970-1974. There was a slight recovery into normal or wet conditions in 1975-76 followed by a fairly intense dry 1977 with a variability index of less than 1.5 σ. The next three years were characterized by relatively wet conditions, with the highest positive variations in 1980. Conditions were relative dry between 1981-1984 with reltively high intensities in 1983 and fairly wet conditions in 1985.

The Savanna regions of West Africa have generally experienced relatively more persistently drier conditions than the forest regions. In the Guinea Savanna for instance, conditions were fairly normal or fairly wet between 1969-72. Since 1973, however, conditions have been persistently dry with near normal conditions in 1975. Since 1976, droughts have been generally persistent with relatively high intensities particularly in 1977, 1979, and 1982-1984. The Sudan and Sahel Savannas show relatively more persistent drought conditions that either the forest or the Guinea Savanna areas of West Africa. In the Sudan Savanna region, for example, droughts have been relative more persistent and more intense with many more years having climatic indices of less than -0.5 σ. More than 60% of the period since 1969 also had indices of less than -0.5 σ. Drought conditions in the pure Sahel Savanna region have also been persistent since 1969, although there were near normal conditions in 1969 and 1975. As for the Guinea Savanna, more than 60% of the period since 1969 had drought intensities with rainfall variability characterised by climatic indices of less than -0.5 σ. Also, there were many more years with climatic indices of less than -0.5 σ, compared with either the forest areas or the Guinea or the Guinea Savanna areas.

A more detailed study of the characteristics of rainfall variations however shows that there are a lot of variations in the intensity, persistence, severity, and widespread nature of the climatic events even within a climatic region. For example, in the forest regions, the present study shows that climatic conditions, were relatively less variable

to the Western side than to the eastern side. Similarly in both the Guinea and the Sudan Savanna regions conditions were more variable to the east than to the west. In the Sahel Savanna region on the other hand, conditions were relatively more humid in the central parts than in the east or west. All these variations which occur within the same climatic region raise the problem of generalizations for a relatively large region using data obtained from a relatively small areas.

In order to further illustrate the characteristics of hydroclimatic extremes in the study areas, the groupings of flood and drought intensities in Table 1 were made (Ramasastry, 1978, Ojo, 1986, Subramaniam and Venkateswara, 1982), and the frequency of occurrence of the intensities of hydroclimatic extremes during the study period analysed.

Figure 2 shows the percentage frequency of occurrence of the intensities of hydroclimatic extremes during the study period. As can be noted from the figure, the percentage of drought years is much higher than for the flood years in all the ecological regions. The percentage occurence of each category of droughts is also higher than for each category of floods. However, the severity and persistence vary from one region to another. For example, the percentage frequency of occurrences for large and severe droughts are higher for the Sudan and Sahel Savannas, than for the Guinea Savanna and the forest areas.

Table 1:

Categorization of Intensities of Climatic Extremes (i.e. Floods and Droughts)

DROUGHTS		FLOODS	
Departure Range	Drought Intensity	Departure Range	Drought Intensity
0 to $-\frac{1}{2}\sigma$	Moderate	0 to $+\frac{1}{2}\sigma$	Moderate
$-\frac{1}{2}\sigma$ to $-\sigma$	Large	$+\frac{1}{2}\sigma$ to $+\sigma$	Large
$-\sigma$ to -2σ	Severe	$+\sigma$ to $+2\sigma$	Severe
Less than -2σ	Disastrous	More than $+2\sigma$	Disastrous

Figure 2 also shows that the percentage frequency of occurrences of floods are highest for the forest region than for the other three regions. Indeed, the percentage frequency of occurrence of floods in both the Sudan and the Sahel Savanna regions are relatively neglible.

A lot of variations however occur from one station to another. For example, a comparison of the situation in Kaduna (Sudan), Maiduguri (Sahel), Yola (Guinea) and Calabar (Forests) shows that the greatest drought striken locations are Kaduna and Maiduguri. In Kaduna and Maiduguri both of which had more than 80% of the study period as drought years, the occurrence of both severe and disastrous droughts was also greater than in Calabar and Yola. The fact that there were greater percentages of drought years in all the stations indicates the severity and widespread nature of the recent droughts in West Africa.

4.0 OTHER HYDROCLIMATIC EXTREMES

The problem of generalizing for a relatively large area using data from a relatively small area can further be illustrated by the fact that the characteristics of hydroclimatic extremes can be different in stations located close to one another in the same climatic region. For example, although Sokoto and Maiduguri are both located to the east of the Sahel region of West Africa, the 1969-87 droughts were generally more persistent and more severe in Sokoto than in Maiduguri. The periods of recoveries in Sokoto were for instance 1976-78 while in Maiduguri, the periods were 1970, 1975-77 and 1979. The situation in both Kano and Khaduna during the study also illustrates the fact that a lot of variations can occur between locations in the same climatic zone. Although both these locations are in the Sudan Savanna, Kaduna had more wet years than Kano, while some years which were wet in Kaduna, were characterised by droughts in Kano.

Other hydroclimatic extremes can be illustrated by examining the consequences of the characteristics of the extremes. Probably the most obvious consequences were on the river regimes. For example, the patterns of the hydroclimatic extremes were reflected in the discharges and runoffs of the rivers of West Africa. Over the river Niger, for instance, as typified by the conditions at Koulikoro and Niamey during the period of 1969-77 for which data was available to the writer, only 1969 was characterized by positive variabilities of the manual discharge of this river. Between 1970-77 negative variabilities and consequently drought conditions prevailed. However, the severity of these droughts varied from one year to another with 1973 and 1977 characterized by variabilities between approximately - 40% and-45%. The period 1974-76 showed some near normal conditions as both locations had variabilities between -5% and-10%.

Results similar to those at both Koulikoro and Niamey on the river Niger were also obtained for some other rivers of West Africa. For example, at Guessabo on river Sassandra, Save Bridge on River Queme and at Bakel on river Senegal, conditions, were generally dry, particularly between 1970-71. However, the severity of the hydroclimatic extremes vary from year to year and with the locations. At Sava Bridge, for instance, the severity of the extremes were greatest in 1973, 1977 and 1978 with about -84%, -73% and -72% relative variabilities respectively. At Guessaba on river Sassandra, on the other hand, drought severity was greatest in 1974 with relative variability of -48%. Other years with fairly severe drought conditions were 1971-1973 and 1975-77 with variabilities between -19% and -13%.

Much greater variations in occurrence, severity and widespread nature of hydroclimatic extremes were reflected in the variations of the discharges of the river located to the east of the drought stricken Sahel region. For example, at Maradi and Dolbel, both on river Goulbi, most of the years between 1969-77, for which data was available, were characterized by drought conditions. Moreover, the year to year variabilities in the percentage deficiency of mean annual discharge of Maradi and Dobel emphasize the point that drought characteristics can be different for locations close to one another even in the same climatic region. For

emample, drought conditions were more persistent at Dolbel occurring approximately between 1970-74 and 1976 with slight recovery in 1975. At Maradi, on the other hand, droughts occurred in 1969, 1972-73 and 1976-77. Also, the severity of droughts were greater at Maradi than at Dolvel. It is also important to note that at Maradi, 1970 and 1974-75 were generally characterized by very wet conditions with percentage variabilities usually greater than greater than +40%. In contrast to the situation in Maradi, these years showed either negative variabilities or near normal conditions with positive variabilities less than 10% in Dolbel.

The fact that hydroclimatic consequences of the recent 1969-84 climatic events vary so much in time and space thus reducing the validity of generalization for a relatively large area, using information from a relatively small area, is also illustrated by comparing the patterns of variabilities of potential evaporation in Sokoto and Maiduguri. As already noted, the evaporation values were computed by using Penman's equation as modified for West Africa. For both locations, the relative variabilities were less than 10%. This is not surprising in view of the generally high constant temperature and incoming solar radiation throughout the year in West Africa. However, whereas the years 1969, 1973, 1975-76, and 1979-80 had positive variabilities of more than 2% in Maiduguri, only 1969 and 1972-73 had similar characteristics in Sokoto. In general, Sokoto had more years with near normal conditions than Maiduguri. In both locations the highest negative variabilities occurred in 1973 with -8% in Maiduguri and -5½% in Sokoto.

5.0 THE LESSONS FROM THE CHARACTERISTICS OF THE HYDROCLIMATIC EXTREMES

Variations in the characteristics of hydroclimatic extremes are particularly important because of their effects on the human society, through their consequences on the various sectors of the economies. For example, these variations can have a lot of effects on water resources and those sectors of the economy which depend upon them. Thus, the urgent need to accurately assess the impact of the hydroclimate extremes on water resources development and planning can not be overemphasized. In West Africa for instance, this need has become most apparent within the last two decades than at any other time in recent climatic history, following the catastrophic droughts which struck the Sahel region in the early 1970s, and which demonstrated the sensitivity of human welfare and a nation's economic development to climatic events. The sahelian droughts, especially those of the 1969-73, focussed the attention of the public in general and the meteorological and hydroclogical communities in particular, on the need to research into climatic events and their impact on water resource development. The droughts more than ever before increase the awareness of scientists and the generality of the public on the need to research into the characteristics and consequences of the hydroclimatic events particularly with respect to the predicability, amelioration and control of these events.

One other important lesson related to the variational characteristics of the recent hydroclimatic events has been emphasized in the present study, namely, that related to the problem of generalizations for a relatively large relation using data obtained from a relatively small area. For example, much as the characteristics of the hydroclimatic extremes, particularly droughts have been noted for their intensity, and

and generally widespread nature, more detailed analysis indicate that these characteristics and the resulting hydrological consequences vary so much in time and space that, generalizations which are usually stated for the hydroclimatic extremes may not be applicable for planning and development of water resources in different areas in the region. The variational characteristics thus, considerably limit the representativeness of such generalizations, and the use of most of the hydroclimatic data which are currently available for impact studies in West Africa.

6.0 CONCLUSION

At present, a major problem facing the application of hydroclimatic studies in West Africal is the lack of information on the hydroclimatic characteristics. This problem has particularly inhibited planning and development in many countries in the region, especially in areas most affected by the much publicized droughts of the past two decades. To date, no country in West Africa has accurate and continuous information on the temporal and spatial characteristics of any of the hydroclimatic components. Studies available for many areas employ the data available in only few and scattered locations. The results of such studies are no doubt useful only for giving basic and general ideas of the variational characteristics of the hydroclimatic parameters. For more useful application and impact studies, the validity of such generalizations is considerably limited mainly because locations close to one another in the region sometimes experience contrasting types of climatic and hydroclimatic characteristics.

The urgent need to improve on the acquisition of data and information on hydroclimatic characteristics in West Africa is further illustrated by the fact that most of the available information in the region are those empirically determined. Such empirically determinec relations may be valid within reasonable errors only for the locations for which they have been derived. The validity of such relations must be ascertained for other locations before making any conclusions which car scientifically be acceptable for planning and development.

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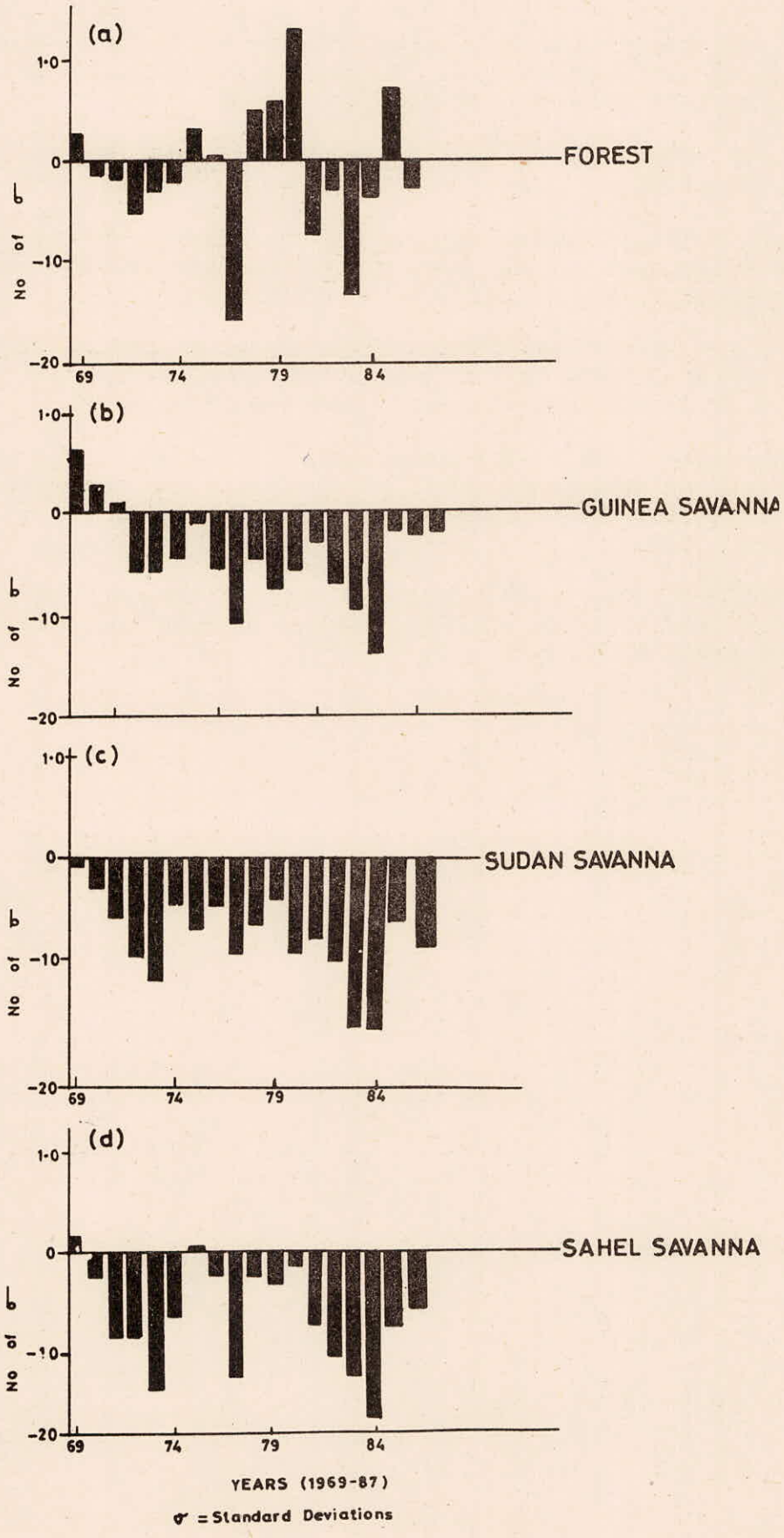

Fig. 1: RAINFALL VARIATIONS IN WEST AFRICA

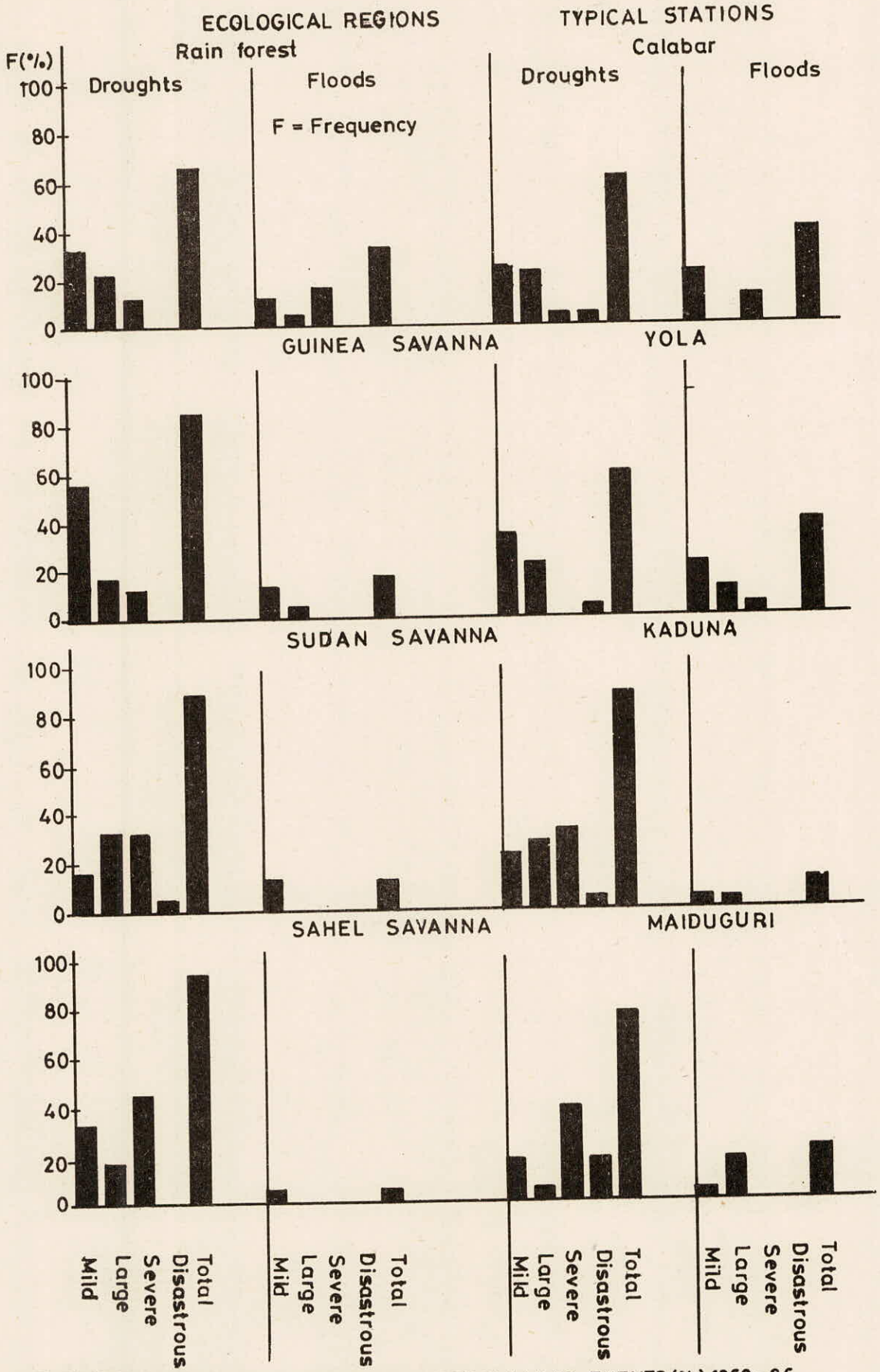

Fig.2: DISTRIBUTION OF EXTREME HYDROCLIMATIC EVENTS (%) 1969-86.