Rainfall trends in West Africa, 1901-1985

Oyediran Ojo
Department of Geography, University of Lagos
Lagos, Nigeria

ABSTRACT This paper attempts to examine the characteristics of rainfall variations between 1901-1985 in West Africa using instrumental records. It discusses the characteristics of rainfall, particularly, periodicities and variabilities, emphasizing decadal, quinquennial and annual characteristics. The paper also discusses some hydroclimatologic consequences of climatic change and climatic variations with respect to streamflow characteristics. From the various analyses, it was observed

(a) that the present century began with a relatively long period of drought persistence (1900-1926). This was followed by a wet period which lasted between 1927-1960;
(b) that the present drought conditions have been characteristically persistent since about 1961 and particularly since about 1965;
(c) that in spite of the above generalizations, no regular patterns can be observed in trends, periodicities and persistence of hydrologic consequences of rainfall variations to allow for predictability of these consequences in relation to rainfall variations; and
(d) that because of the large spatial and temporal variations in the characteristics of rainfall, and the resulting hydroclimatologic consequences, there is urgent need to improve the availability and reliability of the data.

Note: A French abstract of this paper can be found at the end of the text.

Notation

- \( P \) precipitation
- \( \bar{P}_i \) mean precipitation at station \( i \)
- \( I \) Index of variability
- \( \sigma \) standard deviation
- \( i \) station
- \( j \) month/year
- \( n_i \) number of occurrences at station \( i \)
- \( N \) number of stations
- \( N_i \) total number of occurrences at station \( i \)
- \( J \) number of months/year
- \( Y \) normalized departures of rainfall
- \( F \) probability of occurrence
Introduction

The success of any applications, impact studies and research on climatic change and climatic variability and their relationships with hydrology and water resource systems depend on the development of an adequate reliable data base. Consequently, a great deal of research effort has been devoted to examining climatic records in many parts of the world with the aim of determining climatic characteristics and their relationships with human society. For example, in Africa in general and West Africa in particular a lot of studies have been carried out on the characteristics of climatic change and climatic variability, (Grove, 1972, 1973; P. Lamb, 1980; Kerr, 1985; Ojo, 1986a, 1986b; Nicholson, 1981, 1982 and 1983). However, the results of these studies have shown divergences of opinion about the nature and characteristics of climatic variability and climatic change on the continent. Thus, many different controversial statements on the status of the characteristics and the possible future trends of climate in the region have been made by several scientists. For example, some scientists have concluded that the Sahelian droughts of West Africa have persisted since 1969 and would even persist into the next century, thus indicating climatic change to drought conditions (Lamb, 1973; Winstanley, 1973). According to Lamb (1973), the Sahelian droughts "have already a long history...it is not likely to disappear in the near future." Winstanley (1973) also noted that the downward trend in rainfall in West Africa will continue for 50 years. In contrast to these conclusions that the Sahelian droughts will persist for some time, some scientists regard the drought condition as being somewhat unusual in terms of the recent past but not necessarily deviating from the longer term probabilities. In fact, to these scientists, the recent Sahelian droughts are part of the normal climate rather than an indication of climatic change. For example, Landsberg (1975) concluded that the Sahelian drought of the 1970's has to be accepted as part of the normal climate of the region. The available data do not indicate a trend, and there is not an indication of a climatic change.

Most of the conclusions made by the scientists were based on rainfall characteristics of the early 1970's, when the consequences of the climatic events were so disastrous that greater and more widespread concern for climatic variations were demonstrated than for any other climatic event on the continent. Less has been done to examine the nature and characteristics of climatic variabilities for periods earlier than 1969 and these, in addition to the variabilities since 1969, are of significance for understanding the dynamics of hydroclimatologic components and predicting the sensitivity of water resource systems to climatic change and climatic variations.

In the present paper, therefore, an attempt is made to examine the characteristics of rainfall variations between 1901-1985 in West Africa in general and the Sahelian region in particular, using instrumental records. The paper discusses some aspects of rainfall characteristics, particularly trends, periodicities and variabilities, emphasizing decadal, quinquennial, annual and seasonal characteristics. The paper also discusses some hydroclimatologic consequences of climatic change and climatic variations, for example, with respect to streamflow characteristics within some river basins in West
Africa, persistence, severity and widespread nature of droughts and floods and aspects of spatial and temporal variations of some water balance components in the region.

Data and methodology

The rainfall data used in this study consisted of 60 stations in West Africa, twenty-four of which were in the Sahel region while 36 stations were outside the Sahel savanna. Data from the Nigerian stations were 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 Climatology Section, Illinois State Water Survey; and through Mr. Semenya of the Department of Geography, University of Lagos. Data obtained through Professor Gregory and Mr. Semenya were those published in "Resume Mensuel D'Observations Meteorologiques" by ASECNA, Dakar. Because of the problems associated with data collection in the region, the number of years for which data were available varies from station to station. For example only 5 of the 24 stations in the Sahel region have the complete 85 year (1901-85) record of rainfall while another seven stations have records for about 80 years. All the stations used in the present study, however, have rainfall records for periods of at least sixty years.

The mean annual rainfall for n years, at each station (i) was computed by using the equation which can be expressed in the form:

\[ P_i = \frac{1}{n} \sum_{j=1}^{n} P_{ij} \]  

(1)

where \( j \) refers to the year.

Although there are many approaches to defining droughts, the present paper emphasizes droughts as related to rainfall variations because climatic variations in West Africa can virtually be equated to rainfall variations (see for example, Oguntoyinbo and Odingo, 1979; Ojo, 1986a, 1986b). The index used in the study thus emphasizes rainfall variability and is the time series of the normalized annual departures of rainfall in the region. Using the various data, the climatic index (equation 2) was computed for the five climatic zones in West Africa, namely, the Tropical Rainforest, Guinea Savanna, Sudan Savanna, Sahel Savanna and the Southern Sahara (Ojo, 1986a; Church 1980). Quantitatively, the climatic index used can be expressed in the form:

\[ I_{ij} = \frac{1}{N} \sum_{j=1}^{N} \frac{P_{ij} - P_i}{\sigma_i} \]  

(2)

if calculated for one year \( j \), at station \( i \); or

\[ I_{ij} = \frac{1}{N} \left[ \frac{P_{ij} - P_i}{\sigma_i} \right] \]  

(3)
Rainfall variabilities

Figure 1 shows the rainfall variability indices in West Africa for 1901-85 averaged for all the 60 stations used in this study using the results obtained from equations 2 and 3. In general, three major periods can be observed since 1901. The century began with a relatively long period of drought which lasted until about 1926 with breaks of relatively normal or wet periods which lasted one or two years each. Over the period 1901-1926 only three years may actually be regarded as wet, with climatic indices greater than $+\sigma/2$. In contrast there were about 10 years with climatic indices equal to or less than $-\sigma/2$. On the whole about 52% of the period may be regarded as normal with climatic indices between $\pm\sigma/2$.

CLIMATIC INDICES FOR WEST AFRICA: 1900-1985 (Average for 60 Stations)

(a) Quinquinal
(b) Yearly

The second period is a relatively wet period which lasted from 1928 to 1960. For most of this second period, two or three relatively wet years were generally followed by another two or three years characterized by near normal, but slightly drier conditions. About 11 years of the 33-year period have climatic indices which are greater than $+\sigma/2$ while only three years have indices which are $-\sigma/2$ or less. The remaining nineteen years have standard deviations which are between $\pm\sigma/2$. During the six years from 1961 to 1966 conditions
were near normal with indices between $+\sigma/2$. From 1967 droughts have been relatively persistent and the indices for most of the years are equal to or less than $-\sigma/2$.

Temporal variation also occurred on the decadal and quinquennial scales. For example the decades 1900-09, and 1930-39 were near normal. Similarly, the 1960-69 decade was near normal with slight negative index. In contrasts, 1950-59 was a relatively wet decade while 1940-49 and 1970-79 were relatively dry decades. The worst conditions occurred during the 1970-79 decade, with an index of $-0.62$.

On the quinquennial (five-year) scale, seven of the seventeen quinquennial periods have positive indices. Of the periods with negative indices, the worst were 1910-14, 1970-74 and 1980-84 with climatic indices less than $-\sigma/2$. No regular periodicities may be discerned visually for either the decadal or the quinquennial periods.

Rainfall variations were also examined on a regional basis, using the five climatic regions already noted. The analysis shows that a lot of variation also occurs between the different climatic zones and even within the same climatic zone. For example, drought conditions were more persistent and more widespread in the Sudan Savanna, the Sahel Savanna and the Southern Sahara than in either the tropical rainforest region or the Guinea Savanna.

**Hydroclimatic consequences**

Rainfall variations in West Africa have many hydroclimatic consequences, probably the most obvious of which are the occurrences of droughts and floods discussed above, and in addition, variations in the discharges of the region's rivers. Unfortunately in West Africa runoff data exist for only a very sparse network, for very short periods, and in many cases the data are not continuous. Thus, it is very difficult to analyze and discuss adequately these aspects of the hydroclimatologic consequences of rainfall variations.

From the few data available, it is evident that a lot of variation in both space and time occurred in these hydroclimatologic consequences. For example, between 1969-77, runoff data for the river Niger at both Koulikoro and Niamey, show that only 1969 experienced a positive variability index in the annual runoff. Negative variabilities prevailed between 1970-77.

More detailed analyses of the variations of the occurrence, severity and widespread nature of the hydroclimatic characteristics show that it is difficult to generalize for relatively large areas using information from a relatively small area. For example, in contrast to conditions at Save Bridge on River Queme and at Bakel on River Senegal where the driest years of the 1971-80 decade were 1973, 1977 and 1978, the driest year at Quessaba on River Sassandra was 1974. Variations sometimes occur in the characteristics of the discharges along the same river. For example, although most of the years between 1969 and 1977 were characterized by drought conditions at Maradi and Dobel on river Goulbi, the year-to-year variabilities in the percentage of deficiency of annual discharges at both locations show that droughts were more persistent at Dobel, occurring approximately between 1970-74 and 1976 with slight recovery in 1975. At Maradi on the other hand, droughts occurred in 1972-73 and 1976-
77. Also the severity of droughts were greater at Maradi than at Dobel. It may also be noted that conditions at Maradi show that the years 1974-75 were characterized by very wet conditions in contrast to Dobel where the years showed either negative variabilities or positive conditions near normal.

Conclusions

West Africa, like many other parts of the continent, has experienced pronounced climatic variations, with their accompanying climatic events and the hydroclimatologic consequences of these events. The patterns of the rainfall variabilities since 1901 in the region shows that the 20th century began with a relatively long period of dry climatic conditions which were fairly persistent until about 1926 with occasional breaks of normal or wet conditions. This was followed by a relatively wet period which lasted until about 1960. From about 1961 droughts have been relatively persistent in West Africa and particularly since 1969, droughts have been so persistent that the climatic indices for most of the years have been equal to or less than $-0.5$.

More detailed analysis however shows a lot of spatial and temporal variations in the characteristics of rainfall since 1901, so that it becomes difficult to generalize for relatively large areas, using information from a relatively small area. The study also reveals that the validity of the empirically determined data and information on hydrology and hydroclimatology is considerably limited particularly for the purpose of the application of these data for research and development. Any empirical data and information obtained for any area may be valid within reasonable bounds only in such an area for which the data and information were derived. Any generalizations for larger regions need careful error analysis.

The above conclusion raises the important issue of obtaining adequate and reliable data. At present, no country in West Africa has accurate and continuous information on the spatial and temporal characteristics of rainfall or any other hydroclimatic components. Indeed, Africa in general and West Africa in particular, are in serious need of a vast variety of information on water resources, to improve the capacity to plan for the future of the various countries.

There are, however, data sets of varying degrees of completeness on rainfall, archived by many national agencies and individual research centres in the region. A number of institutions are also engaged in research projects which are only indirectly related to hydrology and water resources, but whose results and data sets can be useful in advancing the cause of hydrology. The co-ordination of the efforts of these various groups will considerably improve the validity of studies in hydrology and water resources, and rainfall in particular.

References

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