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DROUGHT IN NORTHERN NIGERIA: AN INDICATION OF ABRUPT CLIMATIC CHANGE?

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SUMMARY

The Mann-Kendall-Sneyers trend test is used to examine the extent of climatic jumps in the rainfall series of six synoptic stations in northern Nigeria. A sequential version of the test which uses the intersection of two curves produced by the progressive forward and backward applications of the test is used to determine the approximate beginning points of trends in the series. The results indicate that the rainfall series exhibit a general downward trend with significant abrupt changes in the late 1960s and early 1970s. This downward trend is interpreted as an indication of an abrupt change in the mean climatic conditions over the region, and suggests bistable modes of oscillation in the climate. The discontinuous changes of rainfall in the region after the 1970s requires that agricultural and hydrological planning must take cognizance of the recent climatic normals.

INTRODUCTION

The problem of climatic change has been the focus of scientific research in the last quarter of a century. In the semi-arid tropics, precipitation is a good indicator of climatic change because of its high interannual variability and frequent occurrence of droughts. The catastrophic Sahelian drought of 1969-73 attracted widespread interest and the long-term trends in the precipitation series of the region have been studied by many researchers (see e.g. Dennett et el., 1985; Hutchinson, 1985; Lamb, 1985; Todorov, 1985; Adefolalu, 1986; Nicholson, 1989). In recent years, there is a considerable speculation about the continuance of this drought in the Sahel and other parts of Africa, especially southern Africa.

The strong persistence of the Sahelian drought is also reflected in the rainfall trends for northern Nigeria (Adefolalu, 1986). This paper presents preliminary results of an attempt made to answer the question — is continued drought in northern Nigeria an indication of an abrupt climatic change? The purpose is to use a statistical method to establish the recent climatic trend in the region with the aim of making a modest contribution to research on climatic change in the Sahel. This is because the climate of the extreme northern part of Nigeria is, to a large extent, an epitome of the Sahelian climate.

According to Mitchell et al. (1966) and Goossens and Berger (1987), a climatic discontinuity is an abrupt and permanent change during the period of record from one average value to another. This is what we call an abrupt climatic change. Some techniques have been proposed to detect climatic variability and change. The common ones include (a) residual mass curves, (b) non-overlapping consecutive epoch analysis, (c) two-phase regression, (d) Cramer's test, (e) Mann-Kendall rank statistic, (f) Spearman rank correlation, (g) cumulative sum test, (h) CUSUM technique and (i) likelihood ratio test. Detail discussions about these techniques can be found variously in Kraus (1954), Mitchell et al. (1966), Buishand (1982), Karl and Riebsame (1984), Sneyers (1990) and Srikanthan and Stewart (1991). In this study we use the distribution-

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free Mann-Kendall-Sneyers trend test (Sneyers, 1990). The stations used in the analysis are shown in Fig. 1.

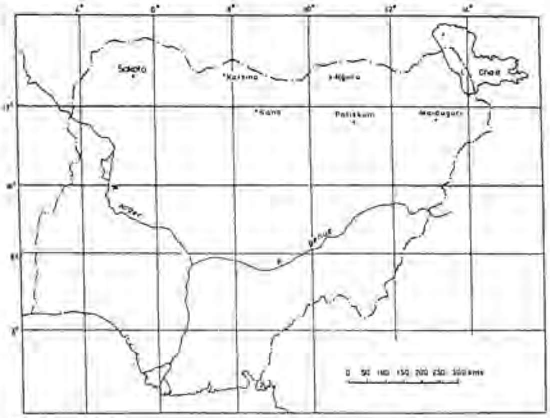

Fig. 1: Map of Nigeria showing selected precipitation stations.

RECENT RAINFALL TRENDS

Rainfall in northern Nigeria is highly variable in spatial and temporal dimensions with a high interannual variability of between 15 and 20% (see Oladipo and Salahu, 1992). Fig. 2 shows the recent course of annual rainfall, expressed as normalized departures from their long-term means, for selected synoptic stations in northern Nigeria. In general, the figure reveals that in the decades preceding the 1950s, brief drought periods alternated with wet conditions. There is some evidence of droughts in the 1910s, 1930s and 1940s. The 1950s were generally free of drought, and the region received copious rainfall. From about 1968, however, the rainfall benevolence ended and droughts of various intensities affected the region from year to year. The downward trend in the rainfall which culminates in drought in the early 1970s is particularly remarkable. It is obvious from Fig. 2 that the disastrous drought of the period 1969-73 has not ended. Drought has continued unabated in the Sahel zone of Nigeria since the late 1960s with only some evidence of relief in some years. An interesting feature of Fig. 2 is that the droughts of the 1980s are more severe than the severest years of the much publicized Sahelian drought. This strong persistence of drought in the last two decades points towards an indication that the long-term precipitation series in the Nigerian Sahel can no longer be interpreted as a random succession of dry years in a stationary rainfall process. In this an indication of an abrupt climatic change? To answer this question, the long-term (1915-90) annual precipitation series of six synoptic stations in northern Nigeria are studied. Details of the statistical analyses are given in the next section.

METHODOLOGY

This study is based on the long-term annual rainfall series for the period 1915-1990 at six synoptic stations which have rainfall records for upwards of 45 years. These stations are located on the southern fringes of the Sahel and generally north of the 1000mm isohyetal band. Some gaps in the case of Katsina are not expected to significantly affect the analysis carried out in this study.

The Sneyers version of the Mann-Kendall non-parametric test is applied to the data sets. This distribution-free trend test is based on the fact that, under the hypothesis of a stable climate, the succession of climatological values must be independent and the probability distribution must remain always the same. In other words, a stable climatic series is a simple random series, and the application of the Mann-Kendall-Sneyers trend test allows the detection of the non-random character of the time series. Following the works of Goosens and Berger (1986) and Sneyers (1990), a summary of the statistic is given below.

Let $x_1, \ldots, x_n$ $(1 \leq i \leq n)$ be a time series in which we want to detect a trend or change. For each element x_i, the numbers n_i of elements x_j preceding it $(i > j)$, such that $x_i > x_j$, are computed and summed as

$$t_k = \sum_{i=1}^{i=k} n_i \qquad (1)$$

Under the null hypothesis of no trend, t_k is shown to be normally distributed with an expected value (mean) and variance given respectively as

$$E(t_k) = k(k-1)/4 \qquad (2)$$

and

$$\mathrm{var}(t_k) = k(k-1)(2k+5)/72 \qquad (3)$$

To test the statistical significance of t_k, a two-tailed test is used. The null hypothesis

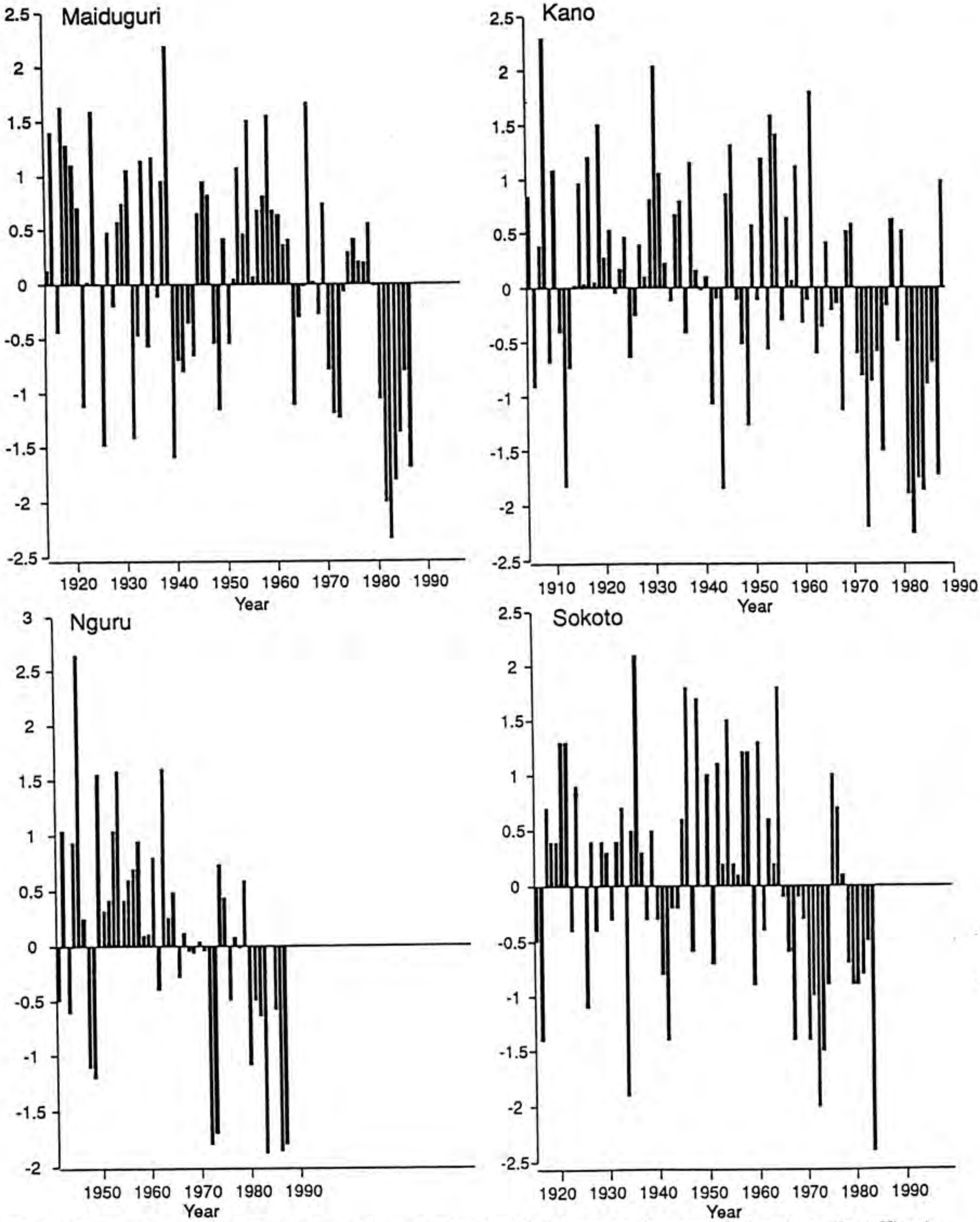

Fig. 2: Time series of the yearly average of the normalised rainfall departure for some stations in northern Nigeria.

being rejected for high values of $|u(t_k)|$ has a normalized statistic:

$$u(t_k) = (t_k - E(t_k))/\text{var}(t_k)^{1/2} \qquad (4)$$

The probability associated with $u(t_k)$ is then calculated as

$$a_1 = P(|u| > |u(t_k)|) \qquad (5)$$

If a_0 is the significance level of the test (e.g. $a_0 = 0.05$), the null hypothesis is accepted or rejected according to whether $a_1 >$ or $< a_0$. When the values of $u(t_k)$ are significant, the existence of an increasing trend ($u(t_k) > 0$) or a decreasing trend ($u(t_k) < 0$) in the same series will be indicated. For $a = 0.05$, the critical value of $u(t_k)$ to be exceeded is 1.96.

According to Sneyers (1990), the sequential version of this test enables detection of the approximate starting point of a trend to within a prescribed confidence limit. This method uses a graphical representation of the ensemble of all $u(t_k)$ along the time axis. An approximate time of occurence of the trend is determined as the intersection of the direct and retrograde curves of $u(t_k)$, if it occurs within the confidence interval.

Fig. 3: Abrupt climatic change of the annual rainfall time series of Kano as derived from the sequential version of the Mann-Kendall-Sneyers test. $u(t_1)$ and $u(t_2)$ are direct and backward curves respectively.

RESULTS

Fig. 3 shows graphically the direct ($u(t_1)$) and backward ($u(t_2)$) application of the Mann-Kendall-Sneyers test for Kano. The horizontal dotted lines indicate the 5% confidence interval. The test statistics of annual precipitation for all the six stations have downward trends. The beginning of the trend varies from one station to another. In general, however, the variations are such that the decreasing trends in the rainfall series started in most of the stations in the late sixties and early seventies, reached the 5% significance level in the seventies and eighties, and continued until the last year of study (1990). Table 1 shows the

TABLE 1: APPROXIMATE DATES OF THE BEGINNING OF DECREASING TREND AND SIGNIFICANT CHANGE IN THE MEANS OF THE RAINFALL SERIES OVER NORTHERN NIGERIA.

Station	Beginning of the downward trend	Date of statistically significant change in the mean
Kano	1970	1976
Katsina	1964	1971
Maiduguri	1978	1985
Nguru	1972	1976
Potiskum	1967	1975
Sokoto	1970	1982

local differences in the onset [illegible] the downward trends and dates of significa... changes in the means of the rainfall series. A notable feature of Table 1 is that the downward trends started and reached significant levels earlier in the stations located in the central portion of the study region than those located in the extreme eastern and western sub-areas. This may be attributed to the local characteristics of the westward-propagating squall lines which are the main rain-producing systems over the region, and the WNW-ESE tilt of the Inter Tropical Discontinuity (ITD) which influences their generation and intensity.

The climatic jump indicated in the rainfall series of the six stations suggests that the northern part of Nigeria is currently experiencing drier than normal moisture conditions. With a view to specifying the degree of nonstationariness in the rainfall climate of the region, the series were divided into two reference periods; wetter (period preceding the date of the beginning of downward trend) and drier (period after the onset of the decline) periods. Some measures of central tendency for the precipitation series were computed. The reference periods were compared with each other and significant difference between their means was tested for using the Student's statistic, t_d, with $n_1 + n_2 - 2$ degrees of freedom where n_1 and n_2 are the sample sizes for the wetter and drier periods respectively. Some descriptive statistical properties of the rainfall series for the two reference periods are given in Table 2. The table stresses the large differences in the data between the two periods. All the stations show statistically significant t_d values at the 95% significance level. This suggests significant differences in the means of the sub-period rainfall series, and also indicates that the reduced rainfalls of the recent years are not due to chance.

DISCUSSION AND CONCLUSION

Graphical plots of the Mann-Kendall-Sneyers trend test provide evidence of climatic jump or abrupt transition in the means of the annual rainfall series in northern Nigeria. In particular, rainfall has consistently decreased over the region since the 1970s. The results of statistical analyses indicate that the long-term rainfall series show highly significant departure from stationarity. Thus the reference period of study (1915-1990) can be split into two parts, corresponding respectively to the periods preceding 1970 and 1970-1990. The latter period corresponds to the drought which has been persistent over the region since the beginning of the catastrophic Sahelian drought in 1968. The patterns are consistent with the observation made by Demaree (1990) and Demaree and Nicolis (1990) for the Mauritanian rainfall, and are in good agreement with the results of Snijders' (1986) analysis for Burkina Faso. A similar conclusion of change in the means or normals of rainfall in some parts of the Sahel around the seventies has also been reported by Todorov (1985).

Our analysis indicates a rather bistable behaviour of the rainfall regime in northern Nigeria in which there is a transition from a wetter to a drier period. This may be indicative of the existence of multi-stable climate regimes over the Sahel which in turn would suggest some external forcing of the climate system. However, because climatic forcing is linked to many complex non-linear atmospheric mechanisms that are still poorly understood, there is no attempt in this paper to explain the triggering action responsible for

TABLE 2: DESCRIPTIVE STATISTICS FOR ANNUAL RAINFALL SERIES IN NORTHERN NIGERIA (SEE TEXT).

Station	Reference period	Maximum (mm)	Minimum (mm)	Mean (mm)	Standard deviation (mm)	Reference period as % of long term mean	t_d
Kano	1906-1970	1181.9	484.1	859.8	158.4	105	4.59
	1971-1990	1047.0	416.1	671.2	160.0	82	
Katsina	1924-1964	993.0	465.3	744.9	125.4	110	5.55
	1965-1990	738.8	390.0	563.9	115.8	83	
Maiduguri	1915-1977	963.4	398.5	650.2	139.3	105	4.13
	1978-1990	711.1	263.5	472.4	141.8	76	
Nguru	1942-1971	868.2	390.3	546.9	115.6	112	4.46
	1972-1990	587.8	236.7	390.5	119.6	80	
Potiskum	1936-1966	1053.1	382.5	814.2	175.5	112	4.21
	1967-1990	968.1	362.0	622.1	150.0	86	
Sokoto	1916-1970	1025.1	413.5	731.9	137.7	106	4.49
	1971-1990	850.4	338.1	572.7	123.5	83	

the observed bistable modes of rainfall regime in the study region. A bimodal stochastic model proposed by Demaree and Nicolis (1990), in which the climate system switches back and forth between them as a result of the internal fluctuations or external random perturbations, appears to capture the transition time statistics of the rainfall series in the region, at least in the statistical sense. The model, nonetheless, still fails to provide the physical mechanisms by which such switches are possible. Suffice to mention in this paper that because irregularity is a fundamental property of the atmosphere, its state may be multi-modal even without the aid of any varying external influences due to its chaotic and intransitive behaviour (Lorenz, 1984; 1990).

On a more practical note, this study clearly demonstrates that a definite change is taking place in the rainfall regime of northern Nigeria. Unfortunately, the change is for a drier condition with decrease in rainfall by up to 20% in some areas. This observation means that the use of long-term means or normals for hydrological and agricultural planning in the region is inappropriate. Todorov has discussed the danger of using 30-year means as normals without incorporating recent rainfall values. It is recommended that climate-related drought mitigation measures in the region must take cognizance of the rainfall values in the last two decades.

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