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Some Statistical Characteristics of Drought Area Variations in the Savanna Region of Nigeria

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With 4 Figures

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Summary

The interannual variability of seasonal Bhalme-and-Mooley-type drought indices over the savanna belt of Nigeria is examined and a 57-year (1931–1987) drought area series has been derived using 34 stations. The area under drought conditions is obtained by considering areas which have drought indices of less than −1.0. The interannual variability of the drought areas is large, demonstrating large variations in the seasonal rainfall over the region. Statistical tests suggest a significant long-term increasing trend in the areal extent of drought. In particular, there is a major shift towards an increase in the mean areal extent of drought between the two periods 1931–1960 and 1961–1987.

1. Introduction

The region located within latitudes 6°27′ N–14° N and longitudes 2°44′ E–14°42′ E is the northern part of Nigeria, covering about 730,000 km^2 or about 78% of the total landmass of the country. It produces a large proportion of the grain (e.g. maize, millet, sorghum and wheat) that provide the staple diet of Nigerians. The whole of the region is covered by savanna vegetation consisting of Guinea savanna, Sudan and Sahel with the density of trees decreasing as one moves northwards (Fig. 1). This region also constitutes the main arid and semi-arid areas of Nigeria.

Rainfall variability is of greatest concern in the savanna region of Nigeria, particularly in the Sudan and Sahel areas in which natural and agricultural ecosystems are highly sensitive to small variations. The interannual variability of rainfall in the northern part of Nigeria is large: typically over 20% of the average annual values. This large variability from year to year often results in droughts which bring in their wake much suffering and calamities, with devastating effect on food production and the region's economy. For example, during the 1973–74 drought, over 300,000 animals in the north-eastern part of the country were estimated to have perished (Khalil, 1974), while agricultural yields in the country ranged between 12% and 40% of the annual averages (Oguntoyinbo and Richards, 1977). In 1987, about 5 million metric tonnes of grain, mainly millet and sorghum, valued at over four billion naira (about US$400 million) were reported, in the local media, (e.g. *New Nigerian*, 12 January, 1988) to have been lost to drought.

Because of its devastating impact, the need to study drought cannot be overemphasized. In this study, we investigate some features of the drought area variations over the savanna region of Nigeria. The main objective is to examine the interannual variability in the spatial variations of drought in order to determine the nature and extent of non-random changes such as persistence, trend and either periodic or aperiodic fluctuations in the occurrence of drought over the region of study. It

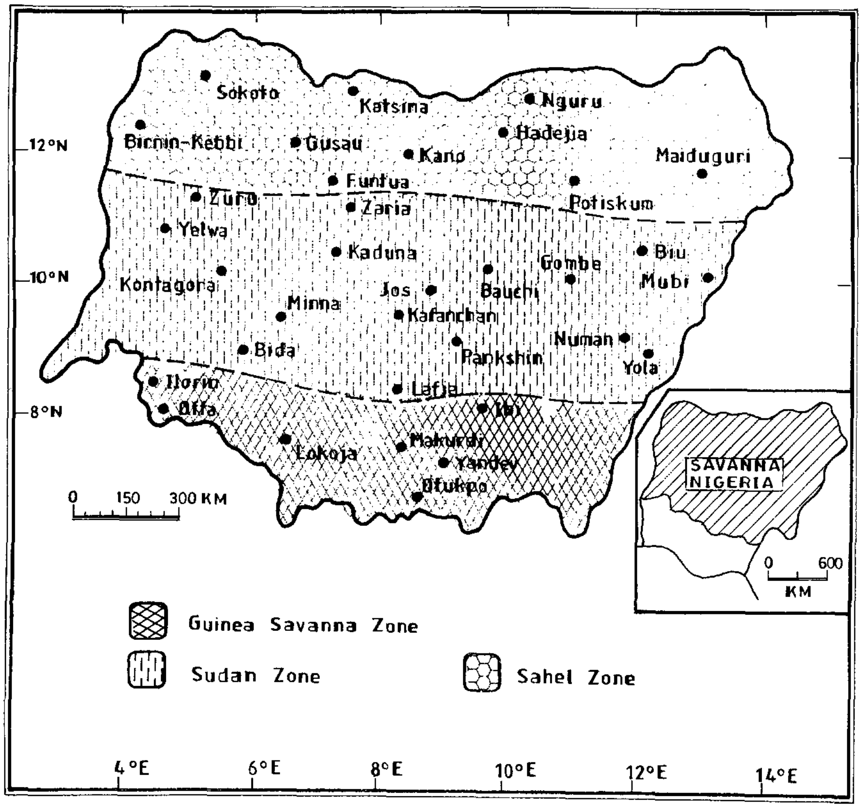

Fig. 1. Savanna areas of Nigeria and stations used

is hoped that this study will provide some useful information for planning and management of agricultural and environmental activities in the savanna areas of Nigeria.

2. Data Used

Monthly rainfall data from 34 well distributed stations over the savanna belt of Nigeria for a period of 57 years (1931–1987) are used in this study (Fig. 1). Only the time series of rainfall totals for the growing season months of April to October are used because they are the months during which all the stations receive at least 85% of their annual totals of precipitation. Thus the occurrence of drought during any growing season will be strongly indicative of drought conditions for the year as a whole.

3. The Drought Area

Drought as a creeping phenomenon is difficult to define and it is not easily characterized either qualitatively or quantitatively. Because of its insidious nature, many definitions of drought have been proposed and many indices are being used to come quantitatively to grip with its meteorological aspects (see e.g., Hounam et al., 1975; Oladipo, 1985; Farago et al., 1988 for details). In this study, we use the Bhalme and Mooley (1980) method to depict periods and intensity of drought. The good performance of the Bhalme and Mooley drought index (BMDI) in depicting periods and intensity of drought has been discussed by Oladipo (1985).

For the savanna region of Nigeria, the Bhalme and Mooley-type drought intensity equation is given as (Shuaibu and Oladipo, 1993).

$$I_k = 0.43 I_{k-1} + M_k/38.84 \quad (1)$$

where I_k and I_{k-1} are drought intensities for the kth and $(k-1)$th months respectively, and M_k, the moisture index for the kth month, is given as

$$M_k = 100(r - \bar{r})/s. \quad (2)$$

In Eq. (2), r is the actual monthly rainfall, $\bar{r}$ is the long-term mean monthly rainfall, and s is the corresponding standard deviation. For the initial month ($k = 1$) under consideration (in our case, April), Eq. (1) is given as

$$I_1 = M_1/38.84. \quad (3)$$

The sequences of monthly drought intensities for each growing season month and for each station were generated from Eqs. (1) and (3) and used to

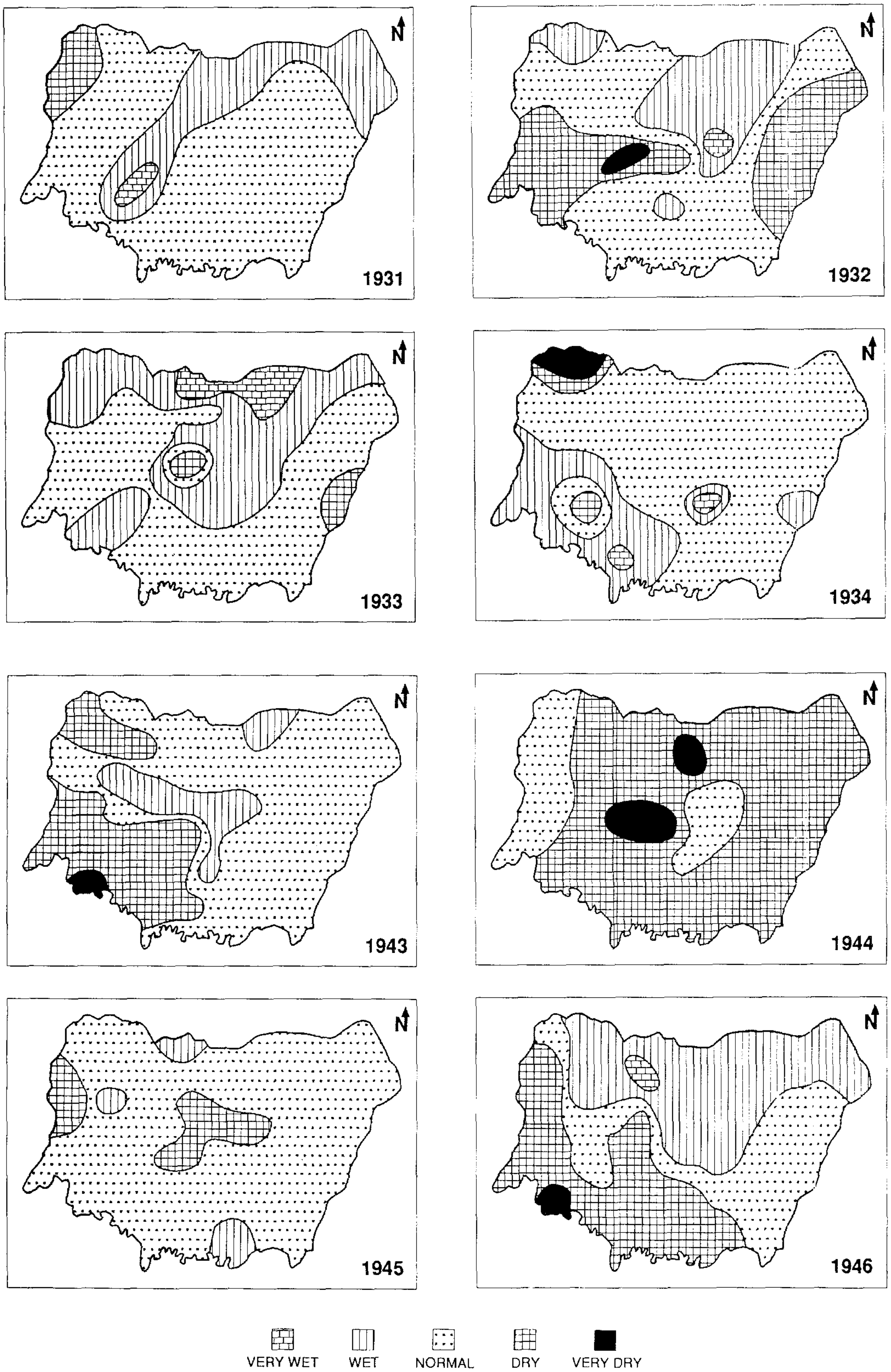

Fig. 2. Spatial changes in drought occurrence for some selected years

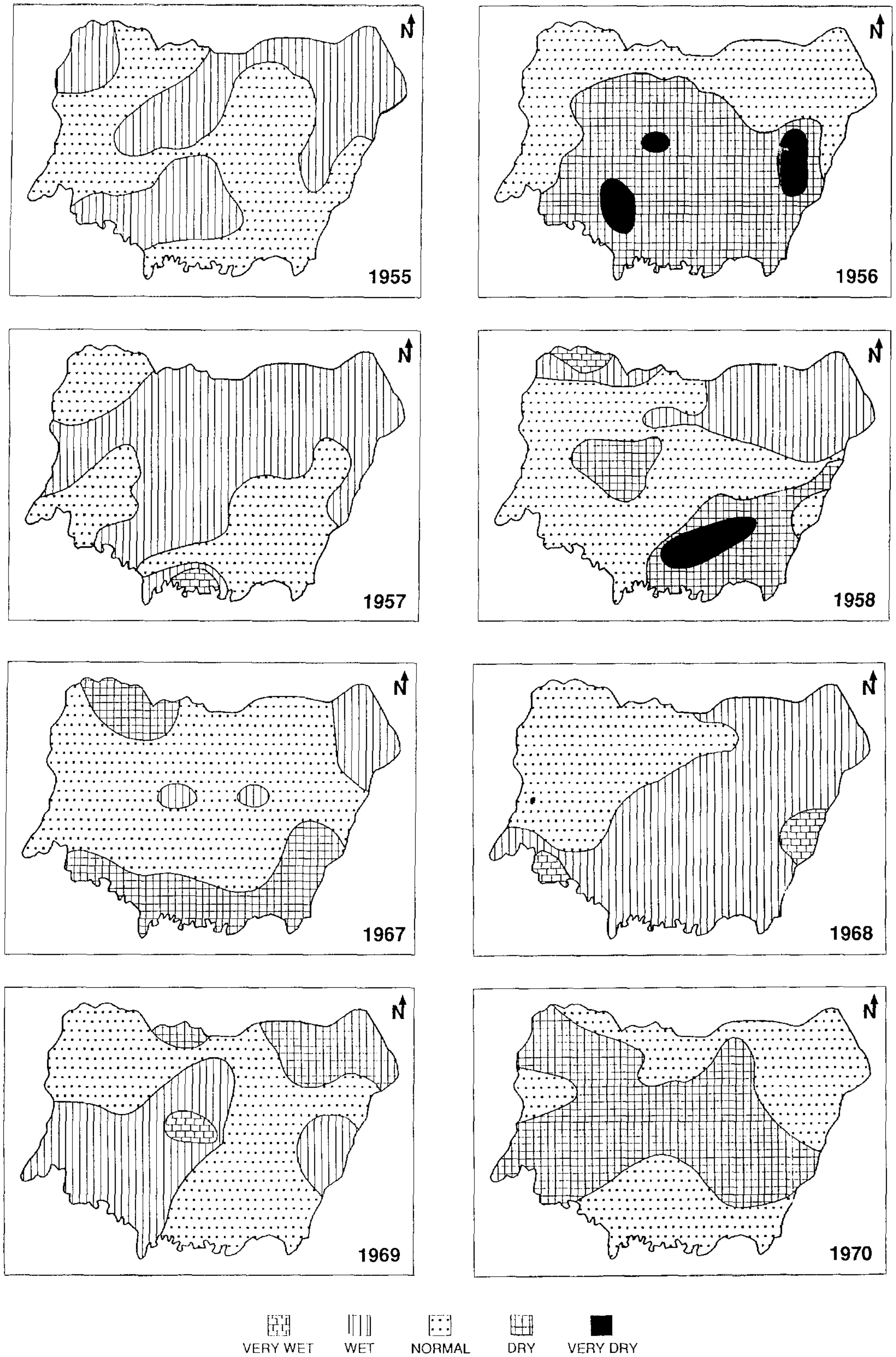

Fig. 2. (*Continued*)

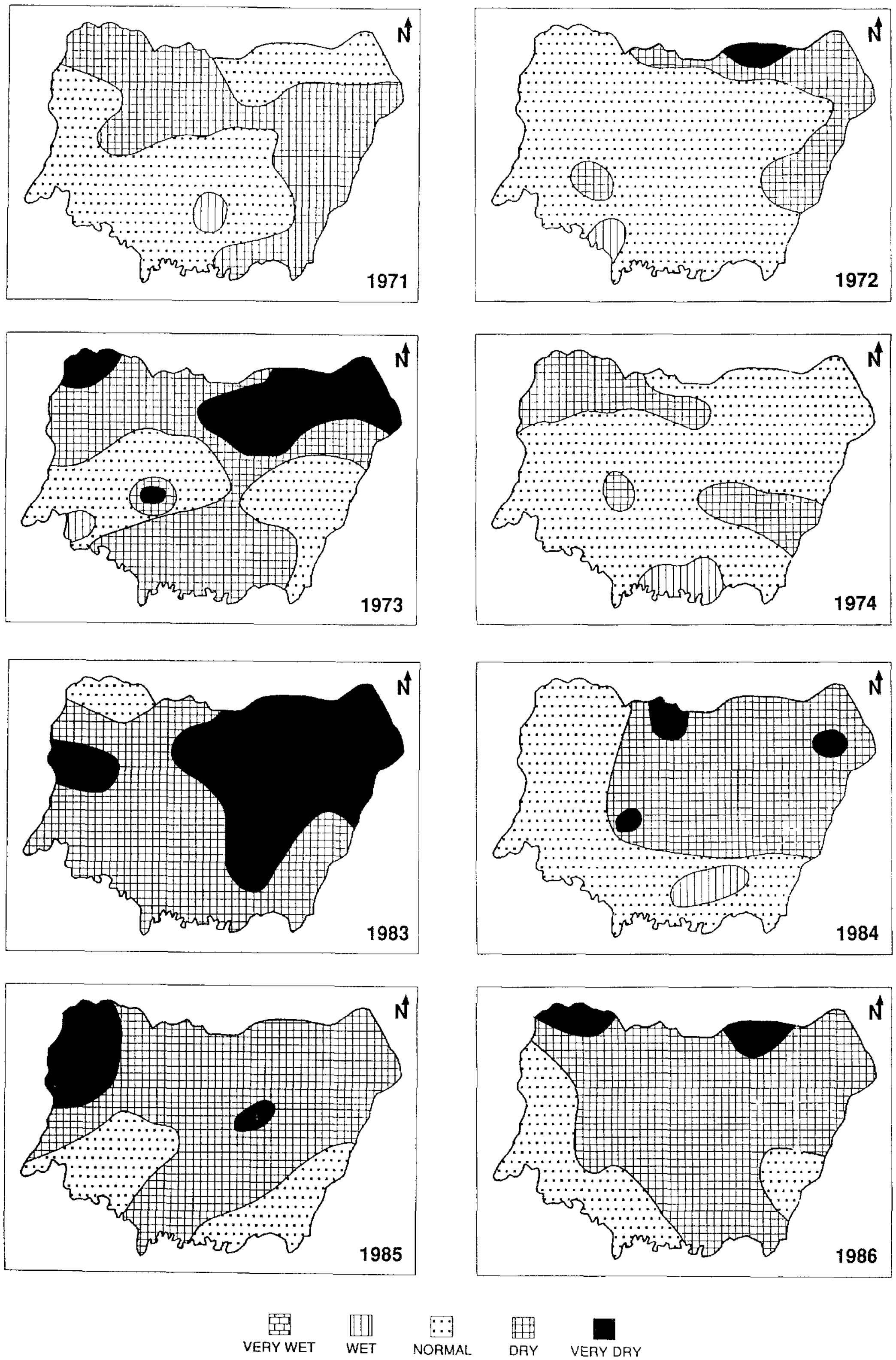

Fig. 2. (*Continued*)

obtain mean growing season drought index series for all the stations. The seasonal indices were then used to classify a year into any of the following wetness/dryness categories:

(i)	Severe drought	$\text{BMDI} < -3.0$
(ii)	Moderate drought	$-1.0 > \text{BMDI} \geqslant -3.0$
(iii)	Normal	$-1.0 < \text{BMDI} \leqslant 1.0$
(iv)	Moderately wet	$1.0 < \text{BMDI} \leqslant 3.0$
(v)	Extremely wet	$\text{BMDI} > 3.0$

Maps of different moisture conditions for each year from 1931 to 1987 were generated and examined for recurrent spatial patterns. The maps were then analysed further to determine changes in their areal coverage as percentages of the regional area.

Figure 2 shows the interannual variations in the spatial patterns and characteristics of dryness/wetness conditions over the region for some remarkable years. Similar noisy patterns of moisture conditions are obtained for the other years that are not shown in Fig. 2. For the purpose of our discussion, the terms "dry" and "very dry" in Fig. 2 are used synonymously with "moderate drought" and "severe drought", respectively. Figure 2 shows that, except for some years, the areas under moderate to severe drought are not contiguous, with often isolated areas under drought conditions. The areal coverage of moderate to severe drought changes markedly from year to year, but it is large enough to cover at least 10% of the study area in about 70% of the years.

The droughts of the 1930s were spotty, of localized intensity and affected different parts of the region at different times. The major drought year was 1932 when more than 30% of the region was affected by moderate to severe drought. On the other hand, the 1940s witnessed some years of large scale droughts, particularly 1942, 1944 and 1949 when more than 45% of the region was affected by moderate to severe drought. While the early 1950s, with the exception of 1952, were generally wet, relatively extensive droughts again affected the region in 1956, 1958 and 1959. Drought again affected different parts of the region in the 1960s. Extensive drought, covering more than 50% of the region, occurred in 1961, while moderate drought affected the northeastern and southwestern parts in 1964. About 30% and 27% of the region was affected by moderate drought in 1965 and 1967, respectively.

The droughts of the 1970s and 1980s were more extensive, more severe and more persistent than those of the preceding decades. Moderate to severe drought covered more than 40% of the savanna belt of Nigeria in 1970, 1971, 1973 and 1977. Severe drought covered about 40% of the region in 1983 and 1987, while more than half of the region was affected by moderate to severe drought in each of the years between 1982 and 1987. The intensities of the 1983 and 1987 droughts, as depicted by the BMDI values, were more severe than that of 1973 which is usually regarded as the worst year of the 1968–1973 catastrophic Sahelian drought.

For a deeper understanding of the interannual variations of the drought regime over the savanna belt of Nigeria, the yearly percentage area of the region that experienced moderate to severe drought for the period 1931–1987 was obtained by using the precipitation totals of the subareas that were affected by the drought categories. The drought area series were then subjected to a number of time series analytical procedures using statistical methods discussed in Mitchell et al. (1966).

4. Analysis of the Drought Area Series

4.1 *Frequency Distribution of the Series*

The drought area series for the period 1931–1987 is shown as bars in Fig. 3. Swed and Eisenhart's (1943) non-parametric runs (U) test was used to test the homogeneity of the series with the distribution of U obtained from the tables by Owen (1962). The homogeneity of the series was confirmed by the U test. Next, the frequency distribution of the drought area series was tested for normality by applying Fisher's coefficients of skewness (g_1) and kurtosis (g_2) compared with their standard errors (SE). If either $g_1/\text{SE}(g_1)$ and $g_2/\text{SE}(g_2)$ or both are greater than $|1.96|$, the series is considered as significantly different (at the 5% level) from a normal distribution.

A set of statistical parameters of the drought area series are given in Table 1. The mean value suggests that, on the average, about 28% of the savanna region of Nigeria experiences drought conditions every year, while the interannual variability, as expressed by a coefficient of variation of 96.6%, is very high. The results of the g-statistic test show that the series is significantly different from normal: It is positively skewed. However, a

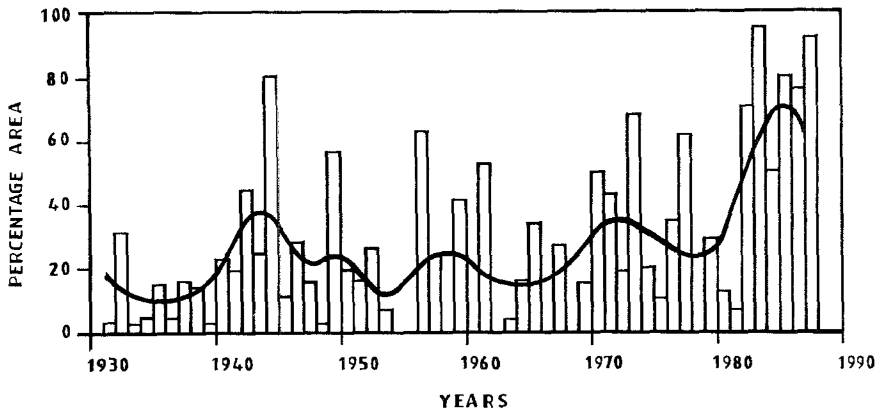

Fig. 3. Drought area variations for the period 1931–1987 in the savanna areas of Nigeria. The heavy line shows the smoothed series obtained by a low-pass filter

square-root transformation of the series is normally distributed with $g_1/\mathrm{SE}(g_1) = -0.05$ and $g_2/\mathrm{SE}(g_2) = -1.35$ well below the critical test statistical values at the 5% level.

4.2 *Persistence, Trends and Fluctuations*

Non-random variables, such as persistence, trends and fluctuations, in the series were investigated by making use of lag-one serial correlation (r_1), von Neumann ratio (V), Mann-Kendall rank statistic (τ), Mann-Whitney's test and Cramer's test (Mitchell et al., 1966). The significance of r_1 was tested using the one-tail 95% significance point of the Gaussian distribution. According to Gilman et al. (1963), the persistence of the first order Markov process has the property $r_n = (r_1)^n$. If the relationships $r_2 = r_1^2$ and $r_3 = r_1^3$ are satisfied, then the Markov persistence can be assumed. Thus the serial correlations of lag-two (r_2) and lag-three (r_3) were computed and compared with r_1^2 and r_1^3, respectively. The value of r_1 (Table 1) is positive and significantly greater than the test value with values $r_2 = 0.276$ and $r_3 = 0.280$ greater than r_1^2 and r_1^3, respectively. This suggests a Markov linear persistence. The increase in the serial correlation coefficients with increasing time lag suggests a strong persistence in the annual drought area series. This may be an indication of the potential for self-reinforcing drought in the savanna areas of Nigeria as suggested by Eltahir (1989) over central Sudan. But, it is not claimed to be a validation of the controversial biogeophysical feedback mechanism of Charney (1975), especially because of the short-term (57 years) data used.

Table 1. *Statistical Properties of the Drought Area Series (1931–1987)*

Mean	27.52%
Median	19.00%
Upper quartile	43.00%
Lower quartile	5.00%
Extreme values	0,97%
Standard deviation	26.58%
Coefficient of variation	96.58%
No. of runs about the median	30
$g_1/\mathrm{SE}(g_1)$	3.04*
$g_2/\mathrm{SE}(g_2)$	−0.12
r_1	0.21*
V	1.54*
τ	0.21*
t-statistic	−2.35*
Mann-Whitney statistic	1.92⁺

* significant at 95%; ⁺ significant at 90%

Using the transformed data, we used the von Neumann ratio (ratio of the mean square successive difference to the variance), V, as another test of randomness against unspecified alternatives. The value of V (Table 1) when compared with its test statistic (V_t) indicates that a source of non-random variance exists in the data. The Mann-Kendall rank statistic, τ, of randomness against trend was also used to investigate any secular trend in the original series. A significant increasing trend is identified by the τ value.

We also used the Student's t-test to determine whether the means of the transformed data for the sub-periods 1931–1960 and 1961–1987 have shown significant changes through time. The Student's t-test indicates a sharp increase in the areal extent of drought in the period 1961–1987. The non-parametric equivalent of the Student's t-test, the Mann-Whitney test, was applied to the original data and also shows a significant increase in the areal extent of drought in the period 1961–1987 relative to the preceding 30-year period 1931–1960.

To understand the nature of the trend, the series

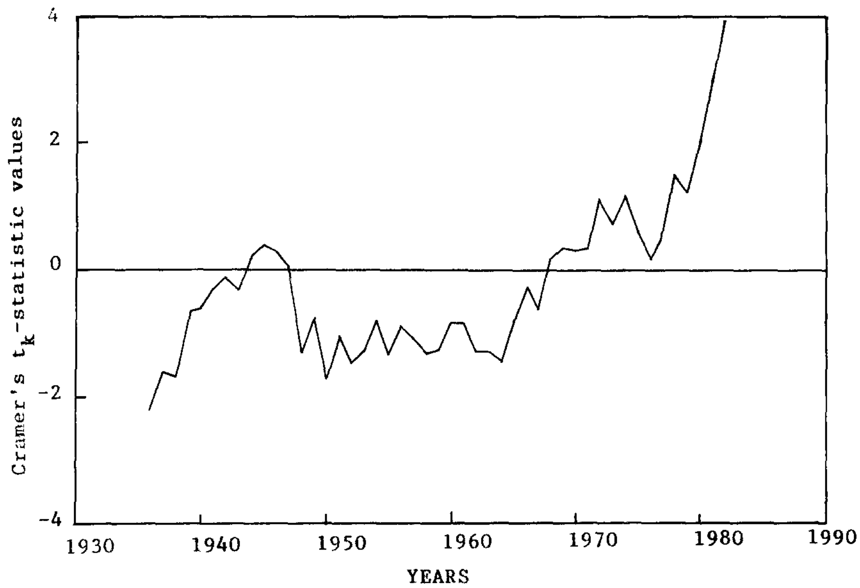

Fig. 4. Cramer's t_k statistic test values for moving 11 year subperiods

was subjected to low-pass filter in order to suppress the high frequency oscillation. The weights used were nine ordinates of the Gaussian probability curve which conform to binomial coefficients: 0.24 for the central year (i), 0.20 for the years ($i \pm 1$), 0.12 for the years ($i \pm 2$), 0.05 for the years ($i \pm 3$), and 0.01 for the years ($i \pm 4$). The filter has a response function equal to unity at infinite wavelengths but decreases asymptotically to zero with decreasing wavelengths. Its response is given as

$$R(f) = \exp(-2\pi^2 \sigma_g f^2)$$

where $R(f)$ is the frequency response, f is the frequency, σ_g is the approximate standard deviation which in our case have $6\sigma_g = 10$ years or $\sigma_g = 1.67$ years (Mitchell et al., 1966). The thick continuous curve in Fig. 3 shows the smoothed values of the drought area series obtained by applying the 9-point Gaussian low-pass filter with truncated end points. It can be seen that the series is dominated by aperiodic episodic fluctuations characterized by some clustered years with large/small areal coverage of drought. Large scale droughts ($>30\%$ coverage) occurred in the 1940s and early 1970s with a significant increasing trend in the 1980s.

To further examine the statistical significance of the deviation of the persistently large/small values of the drought area from its long-term mean, the drought area series was subjected to the running-mean version of Cramer's t_k test. For each successive n-year period, the t-statistic, t_k, was computed and tested for significance with $N - 2$ degrees of freedom, where N is the length of the series. The purpose of the test is to measure the difference between each successive n-year period and the mean for the entire period. Because overlapping subperiods were used in the analysis, the interpretation of the results requires some care (Mitchell et al., 1966).

Values of the t_k-statistic for 11-year running means are shown in Fig. 4. Cautiously accepting Cramer's test results for the overlapping subperiods, three epochs can be identified in the drought area series: prior to 1948, between 1948 and 1964 and after 1964. In general, the means show rising a trend in the 1930s through 1940s, relatively stable conditions in the 1950s and a sharp rising trend towards enlarged areal coverage by drought since the 1960s. A statistically significant ($t_k > 2$) increase in the areal coverage of drought, as depicted in Fig. 4, occurred in the 1980s.

5. Conclusions

Examining the areal variations of drought for a 57-year period (1931–1987) in the savanna areas of Nigeria, we note that large interannual variability occurs in the spatial occurrence of drought over the region. Discrete areas do catch the brunt of droughts on a year-by-year basis. This study suggests that drought over the savanna region of Nigeria is becoming more severe and spatially more extensive in recent years with a strong persistence in the successive values of seasonal drought occurrence. Statistical tests provide evidence of a major shift in the mean areal extent of drought in the region between the two periods 1931–1960 and 1961–1987. The latter period (1961–1987) is characterised by more severe and extensive droughts than those of the preceding 30-year (1931–1960).

Using the drought area series as an indicator of climate variability, this study demonstrates that a change towards higher frequency of occurrence of more spatially extensive droughts is taking place in the climate regime of the savanna areas of Nigeria over the 57-year period for which we have good climatological records. Whether or not this tendency towards high frequency of drought in the region can be linked to global-mean warming (e.g. Hulme and Kelly, 1992) or the Charney's mechanism is difficult to say because of the limited period of analysis. However, it is suggested that a prolonged drought, such as that presently being witnessed in the region, is capable of causing extensive damage to the precarious equilibrium of plant communities adapted to the variable climate. This damage may possibly feed Charney's mechanism. In any case, while a mechanistic link between drought and the albedo feedback mechanism of Charney remains controversial, this study calls for a continued interest in the monitoring of the climatic and surface characteristics of the savanna region of Nigeria in order to have a good indication of the relative contributions of changes in land characteristics to regional climate change.

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References

Bhalme, H. N., Mooley, D. A., 1980: Large-scale droughts/floods and monsoon circulation. *Mon. Wea. Rev.*, **108**, 1197–1211.

Charney, J. G., 1975: Dynamics of deserts and drought in the Sahel. *Quart. J. Roy. Meteor. Soc.*, **101**, 193–202.

Elthair, E. A. B., 1989: A feedback mechanism in annual rainfall, central Sudan. *J. Hydrol.*, **110**, 323–334.

Farago, T., Kozma, E., Nemes, Cs., 1988: Quantifying droughts. In: Antal, E., Glantz, M. H. (eds.) *Identifying and Coping with Extreme Meteorological Events.* Budapest: Hungarian Meteorological Service, pp. 62–110.

Gilman, D. L. et al., 1963: On power spectrum of "red noise". *J. Atmos. Sci.*, **20**, 182–184.

Hounam, C. E. et al., 1975: *Drought and Agriculture.* Geneva: WMO Tech. Note 138, 127 pp.

Hulme, M., Kelly, P. M., 1992: *Climate Change, Desertification and Dessication with Particular Emphasis in the African Sahel.* A briefing paper prepared for the Overseas Development Administration. Climate Research Unit, Norwich, 23 pp. (unpublished).

Khalil, T. M., 1974: *Nort-Eastern State Report on Long-Term Strategies to Combat Drought.* Maiduguri, Nigeria: Ministry of Natural Resources, 53 pp.

Mitchell, J. M. et al., 1966: *Climate Change.* Geneva: WMO Tech. Note 79, 79 pp.

Oguntoyinbo, J. S., Richards, P., 1977: The extent and intensity of the 1969–1973 drought in Nigeria: A provisional analysis. In: Dalby, D., et al. (eds.) *Drought in Africa 2. African Environment Special Report 6.* London: U.K., pp. 114–126.

Oladipo, E. O., 1985: A comparative performance analysis of three meteorological drought indices. *J. Climatol.*, **5**, 655–664.

Owen, D. B., 1962: *Handbook of Statistical Tables.* New York: Addison-Wesley, 580 pp.

Shuaibu, U., Oladipo, E. O., 1993: A Bhalme-Mooley-type meteorological drought intensity index for northern Nigeria. *Zaria Geographer*, (in press).

Swed, F. S. Eisenhart, C., 1943: Tables for testing randomness of grouping in a sequence of alternation. *Ann. Math. Stat.*, **14**, 66–87.

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