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Spatial and temporal variations of rainy days and mean daily rainfall intensity in northern Nigeria

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सार – इस शोध-पत्र में 54 वर्षों के आंकड़ो का प्रयोग करते हुए उत्तरी नाइजीरिया के लिए वर्षा के दिनों के आकाशीय और अल्पकालिक विभिन्नताओं तथा दैनिक वर्षा की सघनता का विश्लेषण किया गया है। अयादृच्छिक परिवर्तनों के विस्तार और प्रकृति जैसे प्रवृत्ति और उतार-चढ़ाव की भी जांच की गई। सामान्यत: क्षेत्र के उत्तर मध्य भाग में स्थानीकृत पर्वत वैज्ञानिक प्रभाव को छोड़कर वर्षा के दिन की आवृत्ति और माध्य दैनिक वर्षा की सघनता दोनों उत्तर की ओर कम रही। अध्ययन की अवधि में वर्षा के दिनों में ह्रासमान (कम) प्रवाह के सांख्यिकीय प्रमाणों का पता चला है, किन्तु प्रवाह विश्लेषण से माध्य दैनिक वर्षा की सघनता का अभिप्राय व्यक्त नहीं होता। इससे पता चलता है कि क्षेत्र में विशेषकर सहेलियन क्षेत्र में वर्षा की वर्तमान ह्रासमान प्रवृत्ति, वर्षा के दिनों की आवृत्ति में कमी के परिणामस्वरूप उत्पन्न हुई है, वर्षा की सघनता में महत्वपूर्ण परिवर्तन से नहीं।

ABSTRACT. The spatial and temporal variations of rainy days and daily rainfall intensity for northern Nigeria for using 54 years data are analysed. The extent and nature of non-random changes, such as trend and fluctuations are investigated. In general, both the rainy day frequency and mean daily rainfall intensity decrease northwards except for localized orographic effect in the north central part of the region. There is statistical evidence of decreasing trend in the number of rainy days over the period of study, but the trend analysis showed no significance for the mean daily rainfall intensity. This suggests that the recent decreasing rainfall trend in the region, particularly in the Sahelian zone, is the result of decrease in the frequency of rainy days and not due to any significant change in the rainfall intensity.

Key words — Spatial and temporal variations, Rainfall intensity, Inter-tropical discontinuity, Rainfall parameter, Mean daily intensity.

1. Introduction

Rainfall is the single most important physical environmental factor affecting human activities, especially agriculture, in Nigeria. In the southern areas, high intensity rainfall poses serious problems of flooding, soil erosion and degradation and leaching of soil mineral nutrients. Conversely, in the drier north savanna scarcity of water and recurrent droughts result from low and unreliable rainfall amounts.

The region of study is the northern part of Nigeria (6°27′N-14°N and 2°44′E-14°42′E) covering about 729,500 sq km or about 78% of the total landmass of the country. Northern Nigeria has two distinct seasons the dry season (November-March) and the rainy season (April-October), which generally coincide respectively with the southward and northward movement of moist tropical south westerly airmass (mTs) of southern hemispheric origin and the overly drier tropical continental airmass (cTs) blowing out of the Sahara desert. This zone of transition between the two airmasses is known as the inter-tropical discontinuity (ITD). Details about the structure of the ITD, as a rain-producing system, and other systems generating rainfall over Nigeria are discussed by Adejokun (1966), Ojo (1977), Kamara (1986) and Olaniran (1987). The surface position of the ITD in northern Nigeria exhibits not only seasonal but also day-to-day variations. The movement of ITD is very irregular, varying according to the season from 2° to 5.6° of latitude per month. In general, the southward retreat of ITD is faster then its northward advance over the region of study. Areas north and immediate south of ITD would have little or no cloud development and virtually no rainfall. Conversely, when ITD is north of the study area, rainfall occurs.

Except for a few investigations [*e.g.*, Ayoade 1975, Oyebande 1982, Olaniran 1987, Olaniran and Summer 1989 (a & b)] most studies of the rainfall regimes of Nigeria [*e.g.*, Oyebande and Oguntoyinbo 1970, Ayoade 1971 & 1973, Adefolalu and Oguntoyinbo 1985, Adefolalu 1986 (a & b), Adedoyin 1989] have used monthly and annual totals to examine large-scale fluctuations. Monthly and annual rainfall series are, however, of limited use. For aggressive rainfall, particularly for erosion studies, a knowledge about its intensity becomes very important. Also, for agricultural planning, the characteristics of rainy days is of great significance. The number of rainy days and mean daily rainfall intensity are, therefore, two rainfall parameters that are important in the studies of short period rainfall characteristics (*e.g.*, Jackson 1972).

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The spatial and temporal variations of the number of rainy days and mean daily rainfall intensity are examined in this paper for northern Nigeria. The relationships between monthly rainfall, rainy days and mean daily rainfall intensity over the region are also examined. Since the Sahelian drought that began in 1968, attention has been focussed on its recurrence in northern Nigeria [*e.g.*, Nicholson 1980, Lamb 1982, Adefolalu 1986(a)]. However, the characteristics of rainfall over the region in terms of their frequency and intensity are seldom given adequate attention. The objectives of this study are to identify the spatial and temporal variations of rainy days and mean daily intensity over northern Nigeria and to investigate the extent of linear dependency of rainfall totals on changes in rainfall frequency and intensity.

2. Analysis techniques

Thirty-four stations with varying record lengths of rainfall were used. The choice of the stations was based on the criteria of long and continuous periods of record, available daily, monthly and annual values of rainfall and reasonable geographical spread. These stations are shown in Fig. 1. Some stations had records dating back to 1907, while all the 34 stations had reliable continuous data for the period 1931-1984. A few stations that had some missing records between 1967 and 1970 were still used in the analysis.

A rainy day (RD) was defined as any day with 1 mm or more of rainfall. The mean daily intensities (MDI) were obtained by dividing monthly averages by the average number of rainy days (Jackson 1972 & 1986). Linear relationships between monthly rainfall totals, rainy days and mean daily rainfall intensity were examined. Annual RD and MDI series were then analysed by some statistical procedures enumerated in Mitchell *et al.* (1966) to determine the extent of change in them over a period of about 60 years in the region of study.

The conformity of the annual RD and MDI series to the Gaussian normal distribution was checked using the standardized coefficients of skewness (z_1) and kurtosis (z_2). The Mann-Kendall rank statistic, τ, was used to identify the existence of trends in the data.

In an attempt to determine significant changes in the temporal patterns of the annual RD and MDI, each series for stations with at least 50 years of continuous record was divided into overlapping 30-year sub-periods (1921-50, 1931-60, 1941-70 etc) and non-overlapping decadal sub-periods (1921-30, 1931-40, etc) and these were compared with the whole period. The stability in their temporal patterns was tested by Cramer's t-statistic, t_k, computed as :

$$t_k = \left[\frac{n\,(N-2)}{N-n(1+\tau_k^2)} \right]^{\frac{1}{2}} \tau_k \qquad (1)$$

where, N is entire record, n is sub-period, τ_k is a standardized measure of the difference between means given as :

$$\tau_k = (\bar{x}_k - \bar{x})/s \qquad (2)$$

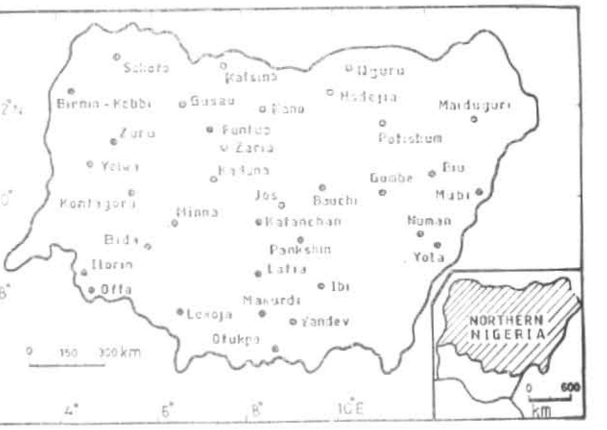


Fig. 1. Northern Nigeria and the network of selected rainfall stations

In Eqns. (1) and (2), $\bar{x}$ and s are the mean and standard deviation of the entire record respectively and $\bar{x}_k$ is the mean of the sub-period in years.

The student's t-test was used to examine the magnitude and significance of changes in the two variables between sub-periods 1931-1967 and 1968-1984. The earlier period represented a time of relatively wetter conditions than normal while the more recent period encompassed the persistent Sahelian drought (*see* Lamb 1982). The student's t-statistic, t_d, is given as :

$$t_d = (\bar{x}_1 - \bar{x}_2) / [\{(n_1 s_1^2 + n_2 s_2^2) / (n_1 + n_2 - 2)\}. \{(1/n_1 + 1/n_2)\}]^{\frac{1}{2}} \qquad (3)$$

where, $\bar{x}_1$, $\bar{x}_2$ are the means of different sub-periods (n_1 and n_2) of record, s_1 and s_2 their respective standard deviations.

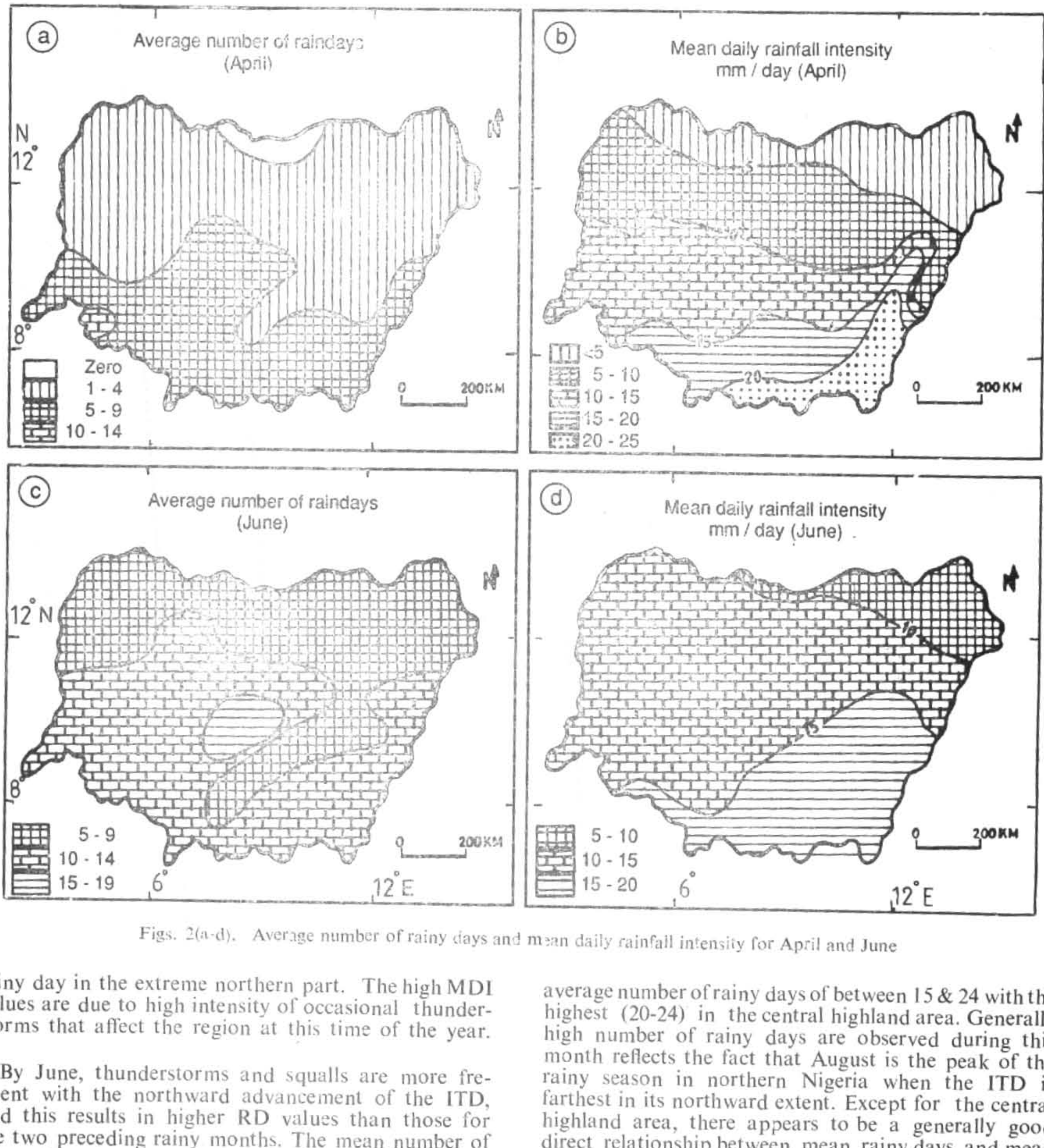
3. Results and discussion

3.1. *Spatial patterns*

In general, the months of November to March are virtually rainless in northern Nigeria, except for occasional showers in March which may affect only some areas south of 9°N in some years. The rainy months in the region are, therefore, from April to October and these contribute a minimum of about 80% of the annual rainfall totals. In some areas, particularly the extreme northern part, the rainy months contribute 100% of the annual total.

For the sake of brevity, only the results of the analysis for the months of April, June, August and October are discussed. These months represent respectively the beginning, middle, peak and end of the rainy season in the region. Annual conditions are also discussed.

Figs. 2 (a & b) show the spatial variations in patterns of rainy days and mean daily rainfall intensity for April. The maximum mean number of rainy days of between 10 & 14 found in the extreme southwestern part of the region decreases to between 1 & 4 days northwards. Mean daily rainfall intensities decrease from a maximum of between 20 & 25 mm per rainy day in the southeastern part to a minimum of less than 5 mm per



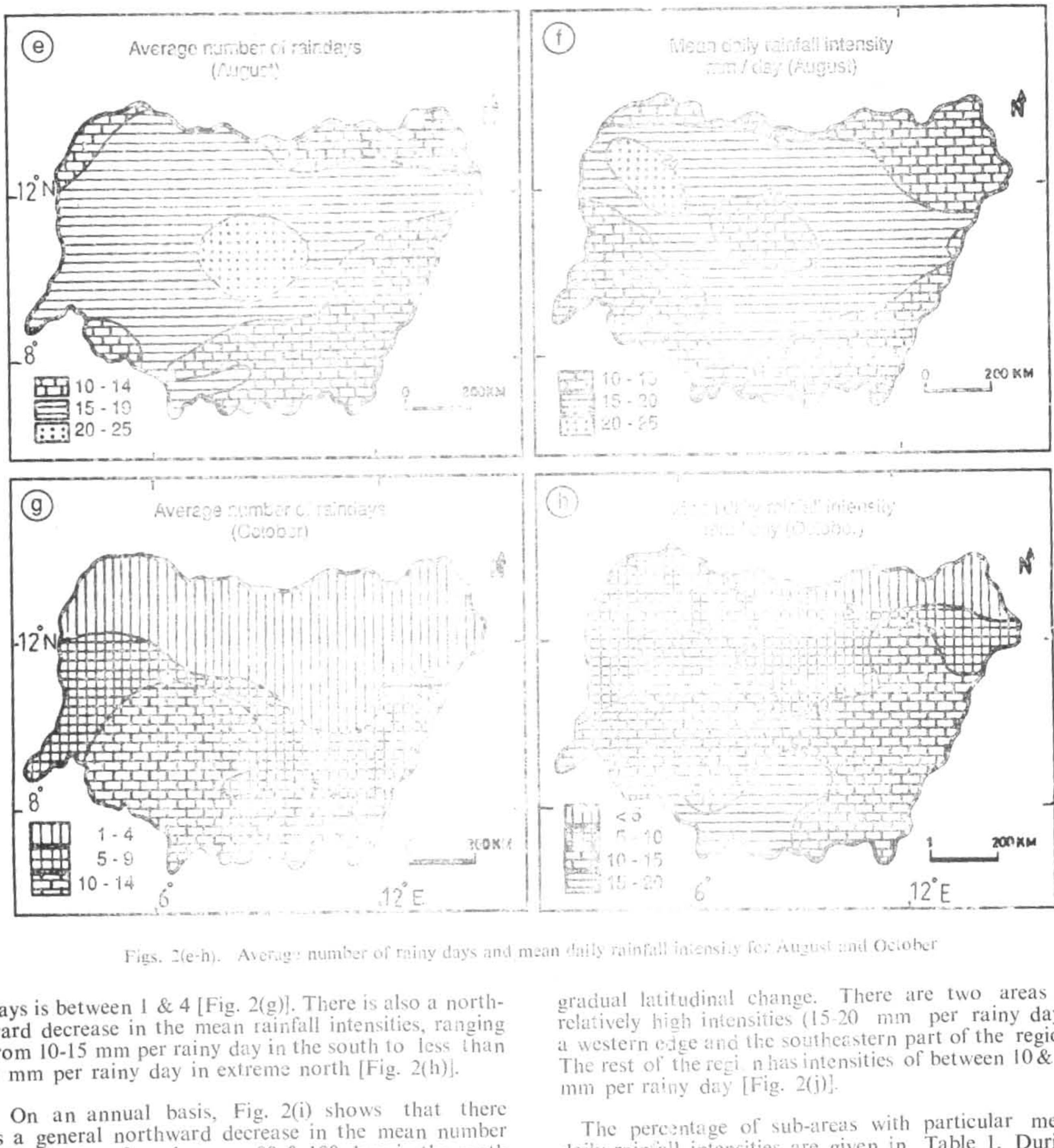
Figs. 2(a-d). Average number of rainy days and mean daily rainfall intensity for April and June

rainy day in the extreme northern part. The high MDI values are due to high intensity of occasional thunderstorms that affect the region at this time of the year.

By June, thunderstorms and squalls are more frequent with the northward advancement of the ITD, and this results in higher RD values than those for the two preceding rainy months. The mean number of rainy days decreases from between 10 & 14 in the south to a minimum of between 5 & 9 in the north, while the highest values of between 15 & 19 obtain in the central highland of the region [Fig. 2(c)]. There is also a northward decrease in the mean daily rainfall intensity from a maximum of between 15 & 20 mm per rainy day south of latitude 10°N to less than 10 mm in the extreme northeastern part [Fig. 2(d)].

The August maps [Figs. 2 (e & f)] show that only the extreme northeastern, extreme northwestern and the southeastern areas of the region have mean rainy days of between 10 & 14. The rest of the region has average number of rainy days of between 15 & 24 with the highest (20-24) in the central highland area. Generally high number of rainy days are observed during this month reflects the fact that August is the peak of the rainy season in northern Nigeria when the ITD is farthest in its northward extent. Except for the central highland area, there appears to be a generally good direct relationship between mean rainy days and mean daily rainfall intensity. The extreme northern and southern parts have intensities between 10 & 15 mm per rainy day. A very high mean daily intensities of between 20 and 25 mm per rainy day are observed for a small area in the northwest, while the rest of the region has intensities of between 15 and 20 mm per rainy day.

There is a rapid decrease in the mean number of rainy days in October. The southern part of the region has about 10-14 days of rain on the average. North of 12°N, however, the average number of rainy

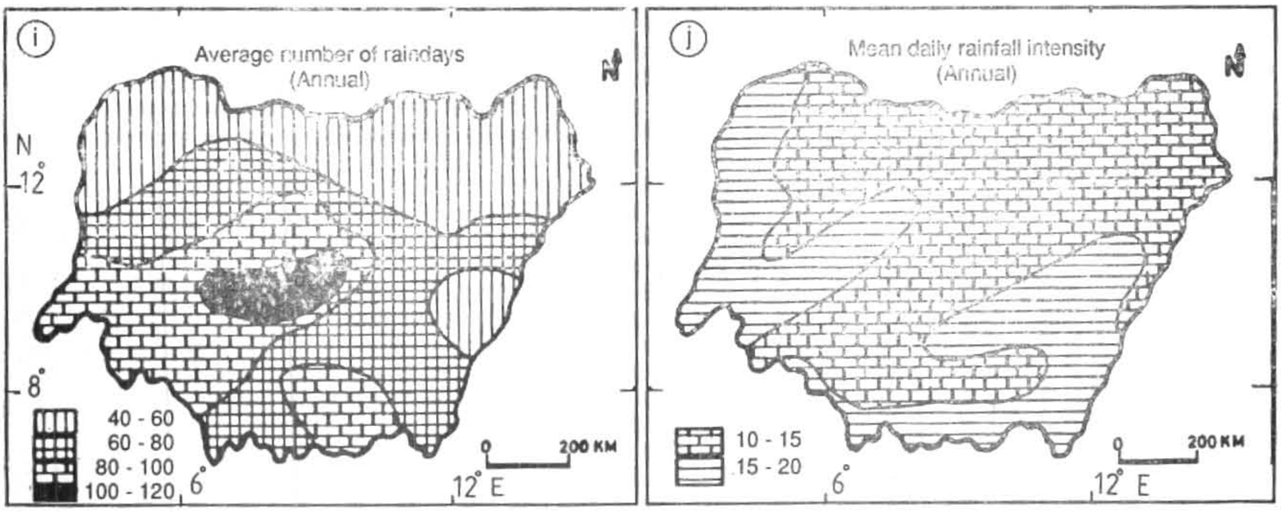


Figs. 2(e-h). Average number of rainy days and mean daily rainfall intensity for August and October

days is between 1 & 4 [Fig. 2(g)]. There is also a northward decrease in the mean rainfall intensities, ranging from 10-15 mm per rainy day in the south to less than 5 mm per rainy day in extreme north [Fig. 2(h)].

On an annual basis, Fig. 2(i) shows that there is a general northward decrease in the mean number of rainy days from between 80 & 100 days in the south to between 40 & 60 days in the extreme north. This general latitudinal decrease is interrupted by the central highlands where rainy days of between 100 & 120 are observed. In general, the orientation of the area with maximum number of rainy days (80-120) corresponds well with the general direction of the rain-bearing southwesterly wind from the southern part of the country. The latitudinal decrease in the mean number of rainy days is also interrupted by the rain shadow effects of the highlands (Mambila Plateau) in the central eastern part of the region. The spatial variation of the mean daily rainfall intensity does not reflect a gradual latitudinal change. There are two areas of relatively high intensities (15-20 mm per rainy day); a western edge and the southeastern part of the region. The rest of the region has intensities of between 10 & 15 mm per rainy day [Fig. 2(j)].

The percentage of sub-areas with particular mean daily rainfall intensities are given in Table 1. During the relatively dry month of March, about 53% of the region has low intensities of less than 5 mm per rainy day, while 24% and 14% have intensities of 5-10 and 10-15 mm per rainy day respectively. Only about 9% of the region has high intensities of between 15 & 20 mm per rainy day. With increase in the number of rainy days in April, there is also an increase in the percentage coverage of high rainfall intensities. About 52% of the region has intensities of greater than 10 mm per rainy day while about 31% has intensities of between 5 & 10 mm per rainy day and the rest area with low intensities of less than 5 mm per rainy day.



Figs. 2 (i & j). Average number of rainy days and mean rainfall intensity for annual conditions

TABLE 1

Percentage of total area having particular mean daily rainfall intensities

Month	Intensity (mm per rainy day)				
	5	5-10	10-15	15-20	20-25
March	53	24	14	9	0
April	17	31	29	15	8
May	0	22	59	19	0
June	0	11	63	26	0
July	0	0	52	48	0
August	0	0	48	48	4
September	0	0	69	31	0
October	11	29	52	8	0

With progressive increase in the mean number of rainy days between May and September, no part of the region has mean daily intensities of less than 5 mm per rainy day. About 78%, 89%, 100%, 96% and 100% of the region have mean daily rainfall intensities of between 10 & 20 mm per rainy day during the months of May, June, July, August and September respectively. In August, about 4% has very high intensities of between 20 & 25 mm per rainy day. By October, only about 60% of the region has intensities between 10 & 20 mm per rainy day, with 29% of the region having intensities between 5 & 10 mm per rainy day and the rest with less than 5 mm per rainy day.

In terms of rainfall erosivity, therefore, the rainfall characteristics during the months of July and August, when about half of the region is liable to having mean daily rainfall intensities of over 15 mm per rainy day, are the most crucial. The high intensities, coupled with large number of rainy days, would cause more soil erosion during these months than at any other time of the year.

3.2. *Temporal variations*

Only 26 stations with long continuous records were subjected to battery of time series analytical procedures already discussed. All the RD series are normally distributed over the study period, and only about 12 % (3) of the MDI series show evidence of significantly non-normality at 95% confidence level. Because the evidence of non-normality is slight, they are not transformed.

Fourteen stations, located north of 10°N, show significant statistical evidence of non-randomness in their rainy day series as tested by the Mann-Kendall rank statistic using the usual criterion of 95 per cent confidence level. All the trends are negative, indicating a general tendency to decrease number of rainy days over the northern portion of the study region, especially the Sahelian zone during the period of study (1921-

1984). Non-randomness of the MDI series at the 95% significance level is found at only five stations; 2 show positive trend, and 3 negative. No coherent geographical pattern of trend is found.

In general, the results of Cramer's test are often difficult to interpret for overlapping periods. However, cautiously accepting the results of computed t_k values for the overlapping periods, more than 60% of the stations show statistically significant values at the 95% significance level in the RD series in the 1931-1960, 1941-1970, 1951-1980 and 1961-1984 sub-periods. In general, the mean number of rainy days in the sub-period 1961-1984 is smaller than those of the preceding overlapping 30 years sub-periods. For the two non-overlapping sub-periods (1931-1960, 1961-1984), nearly all the RD series show statistically significant t_k values. There is a very strong indication that the sub-period 1931-1960 has larger than normal days of rain while the reverse is the case for the succeeding 24-year sub-period. On decadal basis, the results of Cramer's test indicate that the decade 1951-1960 is marked by larger number of rainy days than normal, while the decades 1971-1980 and 1981-1984, especially the latter period, have fewer number of rainy days than any other decades in the period of study. There is no indication of any significant change in MDI series over the period of study in both the 30-year (overlapping and non-overlapping) and the decadal sub-periods. Only about 18% of the series show any significant evidence of greater than normal mean daily rainfall intensities at 95% significance level in the sub-period 1961-1984 relative to the preceding 30-year sub-period (1931-1960), and there is no evidence of any regional clustering of the significant cases.

All the stations north of 10°N, representing about 60% (16) of the total RD series in the region of study, show significant t_d at 95% significance level. The results of the t_d-test indicate that the sub-period 1968-1984 has fewer number of rainy days than the sub-period 1931-1967. Only two t_d-test results of MDI series are significant at 95% significance level, indicating no general significant difference in the mean daily rainfall intensities between the wetter sub-period 1931-1967 and the recent drier sub-period 1968-1984.

In general, the results indicate statistically significant change in the number of rainy days over the northern part of Nigeria, especially north of 10°N, for successive periods, at least, since 1931. The decade 1951-1960 has more number of rainy days than normal, while the recent decades 1971-1980 and 1981-1984 are periods with fewer than normal number of rainy days. Conversely, there is no statistically significant change in the mean daily rainfall intensities over northern Nigeria. This non-significant trend in rainfall intensities during the period of study is in good agreement with the work of Olaniran and Summer [1989 (b)]. Thus the decreasing trend observed for the annual rainfall series in the region north of 10°N in recent years [*e.g.*, Adefolalu 1986 (a & b)] is a function of decrease in the number of rainy days rather than any appreciable changes in the rainfall intensities.

3.3. *Relationships between average monthly rainfall, average number of rainy days and mean daily rainfall intensity*

All the monthly relationships between rainfall totals and rainy days are statistically significant at 95% confidence level. The least correlation coefficient (r) value is 0.81 for August. The very high r values in April ($r=0.90$) and October ($r=0.93$), marking the beginning and end of the rainy season respectively, are masked by the occurrence of considerable number of very low values (close to zero), the inclusion of which tends to suggest that higher average monthly rainfall totals are associated with greater number of rainy days. In reality, the beginning and end of the rainy season in northern Nigeria are marked by the sporadic occurrence of few and shortlived, but intense, organized bands of thunderstorm squalls. There is no significant difference in the strength of the relationships between average monthly rainfall and mean number of rainy days during the very rainy months of May ($r=0.84$), June ($r=0.85$), July ($r=0.87$), August ($r=0.81$) and September ($r=0.86$), except for a relatively weaker relationship in August during the peak of the rainy season. High relationship, in general, between the average monthly rainfall and the mean number of rainy days also holds on the seasonal basis.

The relationships between the average monthly rainfall and the mean daily rainfall intensity, as indicated by their r values, are non-significant during the very rainy months of June ($r=0.48$), July ($r=0.04$), August ($r=0.35$) and September ($r=0.58$) using the 95% confidence level. Higher r values at the beginning (April, $r=0.79$) and end (October, $r=0.82$) of the rainy season correlates with the occurrence of few, but intense, rainstorms generated by the squalls. The characteristics and dynamics of these squalls have been examined by Fernandez (1982, 1989), Botton (1984), Omotosho (1985) and Duhia & So (1987) among others. Seasonwise, there is no significant relationship between the average monthly rainfall and the mean daily rainfall intensity. Thus the results indicate that the seasonal rainfall over northern Nigeria is significantly controlled only by the frequency of rainy days and not by changes in the mean rain per rainy day.

4. Conclusions

Except for localized orographic effects, there is generally a northward decrease in the spatial variations of rainy day frequency and mean daily rainfall intensity in northern Nigeria.

There is statistical evidence of decreasing trend of rainy days over the region, and Cramer's test showed significant secular changes in the number of rainy days for successive periods, at least, since 1931. On the other hand, the trend analysis of the MDI series showed little of significance, and there is no statistically significant evidence to indicate that the series have undergone secular changes in the time period analysed. The very strong relationships between monthly rainfall totals and rainy days show that the variations in the frequency of rainy days exert a major control on seasonal rainfall totals. However, there are no significant statistical relationship between monthly rainfall and mean daily rainfall intensity.

It can be concluded from this study that the recent decreasing trend in seasonal rainfall over a large portion of northern Nigeria is due to decreasing frequency in the number of rainy days rather than any appreciable changes in the rainfall intensities. This might suggest the frequency of the ITD-related rainfall-producing systems is on the decrease rather than the intensity of the rainfall activity. Further the significant decreasing trend in the number of rainy days is an indication of reduction in the length of growing season over the region in recent years. The implication of this conclusion is that our future agricultural planning must take cognizance of the recent decreasing trend and secular changes in the rainy day frequency over the region. Short duration, but high yielding, crop varieties need to be developed for successful agriculture in the region.

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