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An Analysis of Rainfall Trends in Kafanchan, Kaduna State, Nigeria

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Abstract: Rainfall data for 35 years (1974-2008) for Kafanchan located within latitude 9º 3′N and longitude 8º 17′ E were used in this analysis in order to detect the recent trends in the rainfall regime of the area. The calculated Relative Seasonality Index for the area revealed that rainfall regime is markedly seasonal with a long drier season. In order to identify trends, the rainfall series was divided into 10-year overlapping sub-periods 1974-1983, 1979-1988 through 1999-2008 and the Cramer's test was then used to compare the means of the sub-period with the mean of the whole record period. The results of the test revealed that the sub-period 1974-1983 and 1999-2008 for the months of June and October respectively were significantly drier. The results of the Standardized Anomaly Index revealed that rainfall yield is declining in the study area. The 5-year running mean shows that the declining yield of the annual rainfall started from 1990 to date. The results of the linear trend lines further revealed that the decline in the annual rainfall yield is predominantly as a result of the substantial decline in July, September, and October rainfall, which are the critical months for agricultural production in the area. It is recommended that agricultural planning and government policies in the area should be based on recent rainfall trends.

Key words: Kafanchan, rainfall, standardized anomaly index, sub-period, trends

INTRODUCTION

The Earth's climate is dynamic and naturally varies on seasonal, decadal, centennial, and longer timescales. Each "up and down" fluctuation can lead to conditions which are warmer or colder, wetter or drier, more stormy or quiescent (NOAA, 2007). These changes in climate may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use (Bates *et al.*, 2008). Perhaps the most well understood occurrence of climate variability is the naturally occurring phenomenon known as the El Niño-Southern Oscillation (ENSO), an interaction between the ocean and the atmosphere over the tropical Pacific Ocean that has important consequences for weather around the globe (NOAA, 2007).

Pronounced long-term trends from 1900 to 2005 have been observed in precipitation amount in some places: significantly wetter in eastern North and South America, northern Europe and northern and central Asia, but drier in the Sahel, southern Africa, the Mediterranean and southern Asia. Widespread increases in heavy precipitation events have been observed, even in places where total amounts have decreased. These changes are associated with increased water vapour in the atmosphere arising from the warming of the world's oceans, especially at lower latitudes (Trenberth *et al.*, 2007).

One of the most significant climatic variations in the African Sahel since the late 1960s has been the persistent decline in rainfall. The Sahel is characterized by strong climatic variations and an irregular rainfall that ranges between 200mm and 600 mm with coefficients of variation ranging from 15 to 30% (Fox and Rockström, 2003; Kandji *et al.*, 2006). According to IPCC, a rainfall decrease of 29-49% has been observed in the 1968-1997 period compared to the 1931-1960 baseline period within the Sahel region (McCarthy *et al.*, 2001).

The West Africa region has experienced a marked decline in rainfall from 15 to 30% depending on the area (Niasse, 2005). The trend was abruptly interrupted by a return of adequate rainfall conditions in 1994. This was considered to be the wettest year of the past 30 and was thought to perhaps indicate the end of the drought. Unfortunately, dry conditions returned after 1994 (McCarthy *et al.*, 2001).

The pattern of rainfall in northern Nigeria (Kafanchan inclusive) is highly variable in spatial and temporal dimensions with inter-annual variability of between 15

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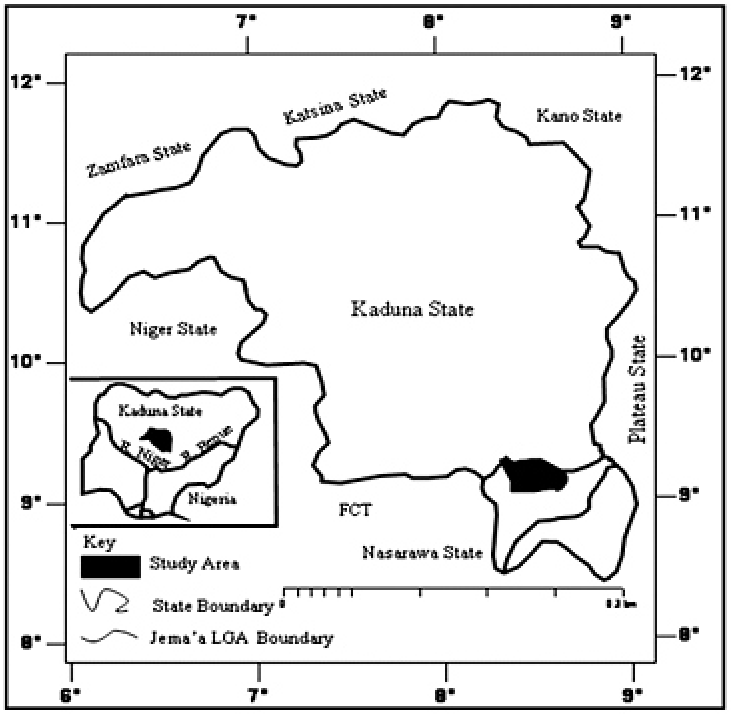


Fig. 1: Map of Nigeria showing the study area

and 20% (Oladipo, 1993a; FRN, 2000). As a result of the large inter-annual variability of rainfall, it often results in climate hazards, especially floods and severe and widespread droughts with their devastating effects on food production and associated calamities and sufferings (Oladipo, 1993b; Okorie, 2003; Adejuwon, 2004).

Rainfall is one of the key climatic resources of Kafanchan. Crops and animals derived their water resources largely from rainfall. It is considered as the main determinant of the types of crops that can be grown in the area and also the period of cultivation of such crops and the farming systems that can be practiced.

Kafanchan has suffered severe droughts especially the droughts of the early 1970s and the 1980s that ravaged northern Nigeria. Conversely, flood disasters as a result of heavy rainfall were recorded in 2001, 2002, 2003, 2005 and 2006. The floods of September, 2005 alone resulted in major disasters: the washing away of farmlands, disruption of socio-economic activities, displacement of people, and damage of residences and infrastructure worth millions of naira (Abaje and Giwa, In Press).

The drought of the early 1970s and the 1980s, and the recent floods in the study area have highlighted how important it is to analyze the trends in the rainfall regime of this area.

Study Area: Kafanchan (Fig. 1), the headquarters of Jema'a Local Government Area of Kaduna State is located within latitude 9° 34′N and longitude 8° 17′ E. The vegetation of the area is the Guinea Savanna type; and the area is designated as Koppen's Aw climate with two distinct seasons, a wet season in summer and a dry season in winter. Rainfall occurs between the months of April to October with a peak in August. The mean annual rainfall is about 1800 mm and the mean monthly temperature is 25°C, while the relative humidity is about 63%. The orographic effects of the Jos-Plateau and the Kagoro Hills have positive influence on the climate of the study area influencing rainfall, temperature and relative humidity (Abaje and Giwa, 2008; Ishaya and Abaje, 2008). The main type of soil is the Ferruginous tropical soil which is related to the climate, vegetation, lithology and the topography of the area. The relief is relatively flat and undulating and it influences the drainage pattern of the area (Abaje *et al.*, 2009).

MATERIALS AND METHODS

Rainfall data for Kafanchan town from the period 1974 to 2008 (35-years) were collected from the Hydrology Section of the Kaduna State Water Board Authority (KSWBA), Kafanchan, in February, 2009.

In this study, only the time series of precipitation totals for the monthly growing season (April-October) and the annual were used. These are the months during which the study area receives over 85% of its annual rainfall totals.The standardized coefficients of Skewness (Z_1) and Kurtosis (Z_2) statistics as defined by Brazel and Balling

(1986) were used to test for the normality in rainfall series for the study area. The standardized coefficient of Skewness (Z_1) was calculated as:

$$Z_1 = \left[\left(\sum_{i=1}^{N}(xi-\bar{x})^{3}/N\right) \Big/ \left(\sum_{i=1}^{N}(x_i-\bar{x})^{2}/N\right)^{3/2}\right] \Big/ (6/N)^{1/2}$$

and the standardized coefficient of Kurtosis (Z_2) was determined as:

$$Z_2 = \left[\left(\sum_{i=1}^{N}(xi-\bar{x})^{4}/N\right) \Big/ \left(\sum_{i=1}^{N}(x_i-\bar{x})^{2}/N\right)^{2}\right] - 3 \Big/ (24/N)^{1/2}$$

Where $\bar{x}$ is the long term mean of x_i values, and N is the number of years in the sample. These statistics were used to test the null hypothesis that the individual temporal samples came from a population with a normal (Gaussian) distribution. If the absolute value of Z_1 or Z_2 is greater than 1.96, a significant deviation from the normal curve is indicated at the 95% confidence level. If the data are not found to be normally distributed, various transformation models could be used to normalize the series such as Log transformation and Lambda transformations of Box and Cox (1964) and Square and Cube Root transformations (Stidd, 1970) amongst others. Walsh and Lawler (1981) statistic was also used to calculate the Relative Seasonality Index (SI) of the rainfall series in order to show the class into which the climate of the study area can be classified. The formula is given as:

$$SI = \frac{1}{R}\sum_{n=1}^{n=12}\left|\bar{x}_n - \frac{\bar{R}}{12}\right|$$

Where $\bar{x}_n$ is the mean rainfall for month n and $\bar{R}$ is the mean annual rainfall. This index can vary from zero (if all the months have equal rainfall) to 1.83 (if all the rainfall occurs in a single month). Table 1 shows the seasonality index classes as proposed by Walsh and Lawler (1981).

In order to identify trends, the rainfall series was divided into 10-year overlapping sub-periods 1974-1983, 1979-1988 through 1999-2008. The Cramer's test is then used to compare the means of the sub-period with the mean of the whole record period. In applying Cramer's test, the mean ($\bar{x}$), and the standard deviation (*S),* are calculated for the area for the total number of years, *N,* under investigation. The purpose of this statistic is to measure the difference in terms of a moving *t*-statistic, between the mean ($\bar{x}k$), for each successive n-year period and the mean ($\bar{x}$) for the entire period. The *t*-statistic is computed as:

Table 1: Seasonality index classes

Rainfall regime	*SI* class limits
Very equable	≤ 0.19
Equable but with a definite wetter season	0.20-0.39
Rather seasonal with a short drier season	0.40-0.59
Seasonal	0.60-0.79
Markedly seasonal with a long drier season	0.80-0.99
Most rain in 3 months or less	1.00-1.19
Extreme, almost all rain in 1-2 months	≥1.20

$$t_k = \left(\frac{n(N-2)}{N - n(1+\tau_k^2)}\right)^{1/2} \tau_k$$

where τ_k is a standardized measure of the difference between means given as:

$$\tau_k = \frac{\bar{x}k - \bar{x}}{S}$$

where $\bar{x}k$ is the mean of the sub-period of n-years. $\bar{x}$ and S are the mean and standard deviation of the entire series respectively and t_k is the value of the student *t*-distribution with *N-2* degrees of freedom. It is then tested against the "students" *t*-distribution table, at 0.95 confidence level appropriate to a two-tailed form of test, it is accepted that the difference between the overall mean and the mean certain parts of the record are significant.

To examine the nature of the trends, the Standardized Anomaly Index (SAI) is then used. It provides an area-average index of relative rainfall yield based on the standardization of rainfall totals. It was calculated as:

$$z = \frac{x - \bar{x}}{S}$$

where $\bar{x}$ and S are the mean and standard deviation of the entire series respectively. This statistic will enable us to determine the dry (-ve values) and wet (+ve values) years in the record. It was smoothened with a 5-year running mean.

To further examine the nature of the trends in the rainfall series, linear trend lines were also plotted for both the annual and for the months of April to October using Microsoft Excel statistical tool, and estimation of changes in the rainfall series was determined. Comparisons were then made with the long-term mean totals.

RESULTS AND DISCUSSION

The mean ($\bar{x}$), standard deviation (*SD*), coefficients of variation (*CV*), standardized coefficients of skewness (Z_1) and Kurtosis (Z_2) of rainfall for Kafanchan are presented in Table 2 for the months of April to October and the annual.

Table 2: General statistics of monthly and annual rainfall for Kafanchan.

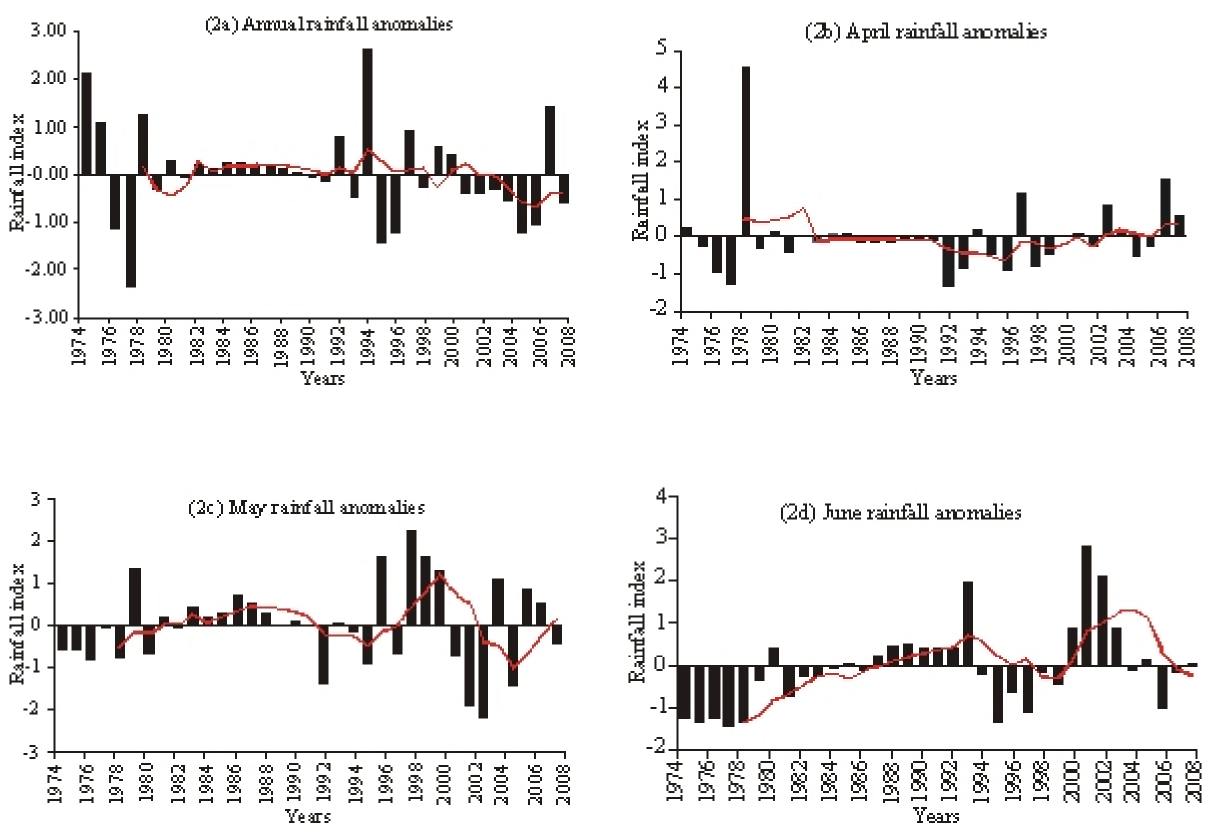
Statistics	April	May	June	July	August	September	October	Annual
$\bar{x}$	107.57	198.33	232.05	346.29	381.20	336.54	164.40	1797.78
SD	72.90	52.56	51.50	85.66	88.74	78.60	72.32	209.68
CV	67.77	26.50	22.19	24.74	23.28	23.36	44.00	11.66
Z_1	2.98*	0.03	0.83	0.86	0.76	0.02	0.63	0.03
Z_2	12.94*	0.03	1.09	2.15*	1.22	0.67	1.88	1.00

*: Statistically significant at 95% confidence level

Table 3: Results of sub-period analysis (Cramer's Test)

	Sub-period					
Months/Annual	1974-1983	1979-1988	1984-1993	1989-1998	1994-2003	1999-2008
April	0.61	- 0.36	- 0.95	- 1.08	- 0.22	0.61
May	- 0.57	1.14	0.29	0.33	0.07	- 0.47
June	- 2.25*	- 0.25	1.41	0.85	1.60	1.62
July	0.88	0.64	- 0.33	0.57	- 0.47	- 1.38
August	- 0.04	- 0.78	0.54	- 0.40	- 0.75	0.57
September	- 0.18	- 0.12	0.54	0.47	0.28	- 0.61
October	1.52	1.04	- 0.22	0.50	0.03	- 2.00*
Annual	0.40	0.43	0.36	0.25	0.18	- 0.95

*: Significant at 95% confidence level



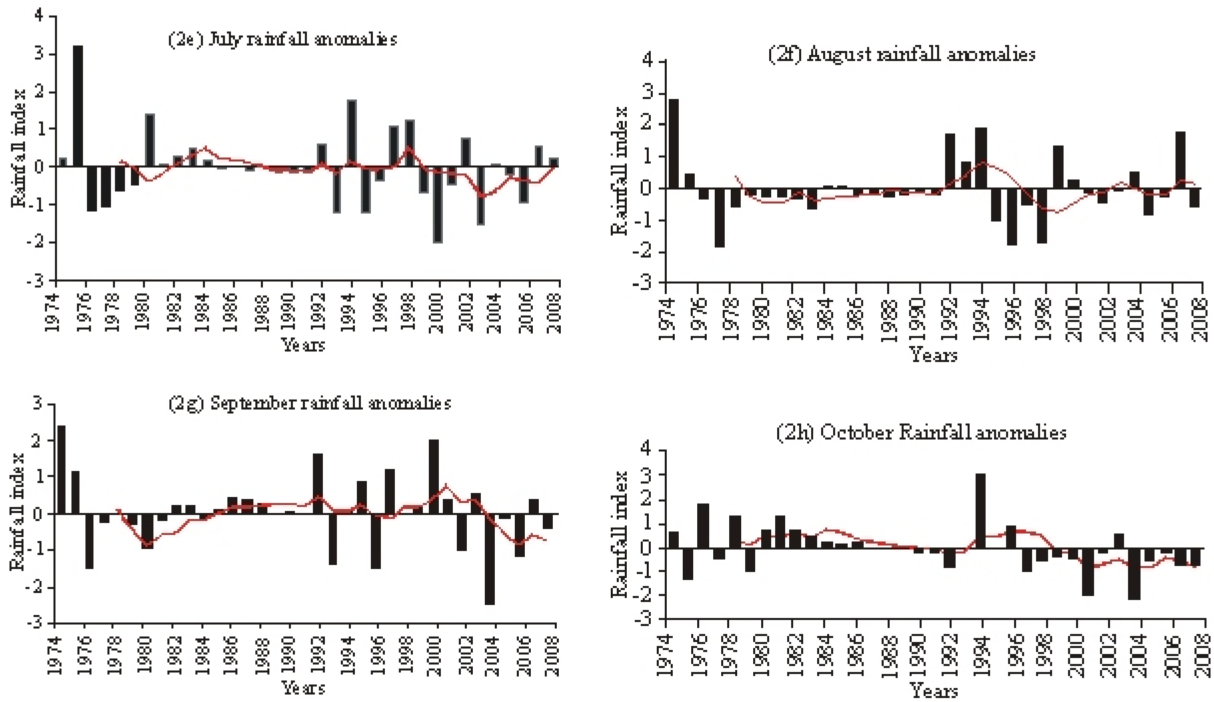


Fig. 2: Rainfall anomalies for (a) Annual total, (b) April, (c) May, (d) June, (e) July, (f) August, (g) September and (h) October

The results of the standardized coefficients of Skewness (Z_1) and Kurtosis (Z_2) show that all the months and the annual were accepted as indicative of normality at the 95% significant level with the exception of Z_1 and Z_2 for the month of April and Z_2 for the month of July that show a significant deviation from normal. Based on these results, no transformation was done to the data.

The calculated Walsh and Lawler (1981) Relative Seasonality Index of the rainfall series for the study area was 0.85. This result revealed that rainfall regime in the area is markedly seasonal with a long drier season.

Table 2 shows the results of sub-period analysis (Cramer's test) for the monthly and annual rainfall. The t_k values for the annual rainfall shows that the period 1999-2008 was drier, but not of significant importance, while all other periods were wetter but also not of statistically significant importance. A closer examination of Table 3 revealed that there is a recent decrease in the annual rainfall series especially in the sub-period 1999-2008 as indicated by the negative value of t_k(-0.95). The monthly t_k test showed that there were no significant changes from long-term conditions in all the sub-periods in the months of April, May, July, August, and September. Only the sub-period 1974-1983 and 1999-2008 for the months of June and October respectively show significant deviation from the long-term conditions; they were significantly drier.

Fig. 2 shows the graphical presentation of the standardized anomaly index for both the annual and monthly rainfall smoothened out with the 5-year running mean. It is clear from these results that rainfall yield is declining in the study area. Fig. 2a shows that the highest rainfall was recorded in 1994, whereas 1977 was a year of extremely low rainfall. This was the period of the intense drought that ravages the Sudano-Sahelian zone of Nigeria. The 5-year running mean shows that the recent declining yield of annual rainfall started from 1990 to date. The decline does not show a distinct trend because there are fluctuations.

Monthly rainfall yields reach their maximum between July and September. Fig. 2 (b-h) shows the monthly *SAIs* that were therefore derived in order to examine the within season consistency of the annual trends identified above and also smoothened out with the 5-year running mean. It is clear from these results that the substantial decline in the annual rainfall yield is predominantly as a result of the decline in July to October rainfall. These are the critical months for annual agricultural cycle. This result seems to be in good agreement with the study of Eldredge *et al.* (1988) for Western Sudan in which they found out that relative dry conditions have persisted in the region since 1966 due mainly to a decline in rainfall during July, August and September. These are months in which rainfall yields reach their maximum.

The results of the linear trend lines for the period of study (1974-2008) clearly demonstrate a general tendency for a decrease in rainfall in the area (Fig. 3).

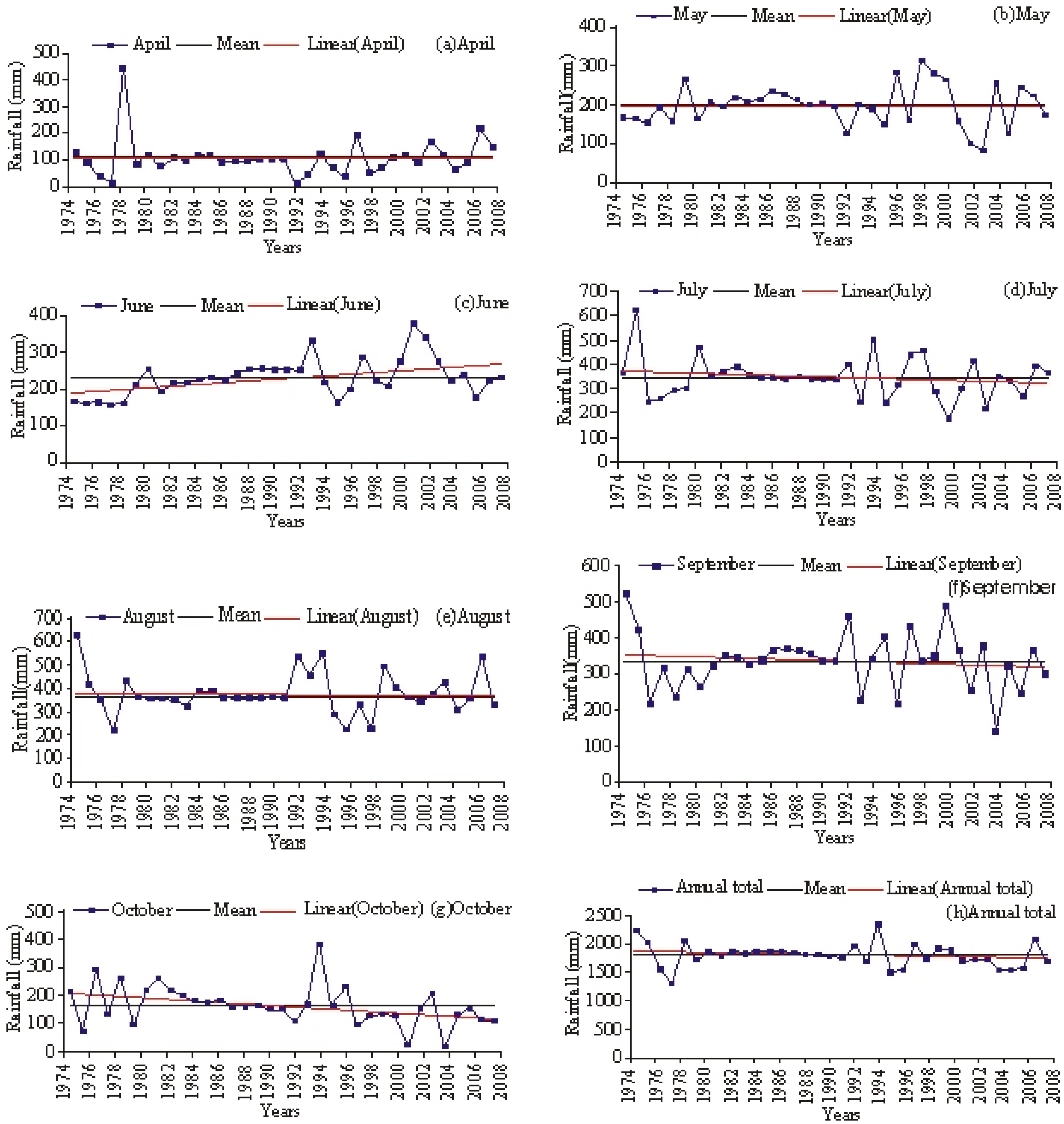


Fig. 3: Rainfall trends for (a) April, (b) May, (c) June, (d) July, (e) August, (f) September, (g) October, and (h) Annual total

From the linear trend lines of the monthly rainfall, there is a clear indication of a decrease in rainfall amounts over time. Estimation of changes in the monthly rainfall expressed in mm for the period of study shows little or no change in the month of April. For the month of May, there is a decrease of approximately 5.0 mm at the rate of 0.14 mm year^{-1}. Compared with the long-term mean, it means that May rainfall was decreasing at a rate of 0.07% per year. The month of June shows a significant increase in rainfall of approximately 80.0 mm at the rate of 2.29 mm year^{-1}. When compared with the long-term mean, it means that June rainfall was increasing at a rate of 0.99% per year. There is a decrease of approximately 50.0 mm at the rate of 1.43 mm year^{-1} for the month of July, a decrease of approximately 10.0 mm at the rate of 0.29 mm year^{-1} for the month of August, a decrease of approximately 30.0 mm at the rate of 0.86 mm $year^{-1}$ for the month of September, and a significant decrease of approximately 90.0 mm at the rate of 2.57 mm $year^{-1}$ for the month of October. When compared with the long-term mean totals, it is also clear that the monthly rainfall was decreasing at a rate of 0.41% per year in July, 0.08% per year in August, 0.26% per year in September, and 1.56% per year in October.

Estimation of changes of the annual rainfall for the period of study indicates a decrease of approximately 120.0 mm at the rate of 3.43 mm $year^{-1}$. Compared with the long-term average total, it means that the annual rainfall was decreasing at a rate of 0.19% per year. It is also clear from the results of the linear trend lines that the decline in the annual rainfall yield is predominantly as a result of the substantial decline in July, September, and October rainfall.

CONCLUSIONS

Rainfall is a renewable resource, highly variable in space and time and subject to depletion or enhancement due to both natural and anthropogenic causes. A variety of approaches to measuring the attributes of this resource have been presented, all of which have shown its basically unstable nature.

It is clear from the results of the analysis that the trend in the rainfall series is decreasing on annual basis. The sub-period analysis (Cramer's test) revealed a recent decrease in the annual rainfall series in the sub-period 1999-2008. The recent decline in the annual rainfall yield is predominantly as a result of the substantial decline in July to October rainfall. This trend may be related to the convergence of the trade wind and the monsoonal airflow, in the region of the Inter-Tropical Discontinuity (ITD) which is unable to produce sufficient vertical motion (and depth of clouds) to induce rainfall, and that the variation in the intensity of rainfall implies some form of dynamic activity other than that of surface convection.

Decline in rainfall in the months of July to October might have serious agricultural implications because most agricultural activities in this area rely on rainfall of this period. The declining in the annual rainfall yield may lead to the lowering of the water table. This has an implication in digging of wells, construction of bore holes, and other water resource development projects that depend on water from rivers and ground water sources.

It is recommended that farmers should overcome the problem of declining rainfall by planting drought resistance crops or early maturity species. Diversifying the economic base of the populace with emphasis on reducing over dependence on rain fed agriculture is another way of coping with this problem. It is also recommended that government policies in this area should be based on recent rainfall trends.

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