FLUCTUATIONS IN ALL-INDIA SUMMER MONSOON RAINFALL DURING 1871–1978

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Abstract. Analysis of the All-India summer monsoon (June to September) rainfall for the period 1871 to 1978 has been made in order to understand the interannual and long-term variability of the monsoon. On a country level, India receives 85.31 cm mean monsoon rainfall which is 78% of the annual rainfall. The coefficient of variation of monsoon rainfall at the country level is 9.5%. The highest and lowest rainfall country level were observed in the years 1961 and 1877 respectively, the range being 41 cm about 48% of the long term average. There are 13/9 years of large-scale deficit/excess in the 108-yr period. There is a continuous rise in the 10-yr mean rainfall from 1899 to 1953. There are four major climatic rainfall periods in the series. Correlogram and spectrum analysis showed significant 14-yr and 2.8-yr cycles respectively in 108-yr series; however detailed examination indicated that these cycles have developed during the last 30 yr of the data period.

1. Introduction

With the rapid growth of the human population and strained resources, particularly as regards food production and water supply for people and for agriculture and industry, the study of variations in the rainfall over a region is of utmost importance. The agricultural economy of India with its large growing population is closely linked with the performance of the summer monsoon which gives 75 to 90% of the annual rainfall during the four months, June to September. The large-scale failure of rainfall in recent decades over some parts of Africa and Asia and some controversial statements on climatic change issued by various bodies and individuals (e.g. Winstanley, 1973a, b) have led to some governments expressing great concern about the grave implications of these climatic changes for global food and population policies. Therefore, monitoring of the climate is necessary for an understanding of the natural climatic change and variability in both space and time.

In the middle and higher latitudes, the year-to-year temperature changes are considerably larger than those of tropical regions. These temperature changes significantly affect the prevailing general circulation of the region. However, in tropical regions the temperature changes cannot be used as a measure of the change in the circulation features because the year-to-year changes in temperatures are small. Corresponding to temperature changes in extratropical latitudes, there may be changes in evapotranspiration in the tropics, leading to changes in circulation. Therefore, any changes in the general circulation features in the tropics are likely to be reflected primarily in rainfall changes. A long homogeneous rainfall time series having areal and temporal representativeness is a very

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useful tool in the tropical latitudes for studying the long-term changes, if any, in the circulation.

The problem of trends and periodicity in Indian climate has always attracted and continues to attract attention of public and scientists all over the globle. Considerable work has been done in India in this direction for isolated regions of the country with short period data (for further details, refer Parthasarathy and Dhar, 1978a). Very limited work has been done by taking the country as one unit. India as one unit (hereafter called as All-India), though too big an area for practical purposes, provides an overall view of the rainfall fluctuations and abnormalities which are helpful for Planners and Scientists studying circulation and changes therein. The basic force for this atmospheric motion for different parts of India is the same.

Blanford (1886) was the first meteorologist who made extensive studies of Indian rainfall. He calculated the annual rainfall of British India (the whole country as one unit) for the 19-yr period 1867 to 1885 by taking into account the raingauge data of 500 stations and found that the annual mean rainfall of British India varied from the highest value of 124 cm in 1878 to the lowest 90 cm in 1868. Walker (1910, 1914, 1922) examined Southwest monsoon (June to September) rainfall of British India (the whole country as one unit) by considering all available raingauge data (the number of raingauges varied from about 40 to 2000) for the period 1841 to 1908 and observed that the rainfall was below normal during 1843–60 and 1895–1907, the worst drought years being 1848, 1855, 1877, and 1899. After Walker's studies, little work was done during the next fifty years. The analysis of average rainfall of India (as one unit) has been done by Parthasarathy and Dhar (1976), Parthasarathy and Mooley (1978b) and Mooley and Parthasarathy (1979) with a variable number of raingauge stations.

In view of the high importance of the summer monsoon to the Indian economy and its influence on the global atmospheric circulation through the large amount of latent heat released a detailed study of century-long All-India rainfall series based on the data of a fixed and adequate number of raingauges has been made and the results are presented.

2. Details of Indian Summer Monsoon Rainfall Data

The validity of any statistical analysis depends primarily on the quality of the data used. The raingauge network over India has increased by two orders of magnitude from about 50 in 1850 to 5000 in 1970. A straightforward algebraic averaging of rainfall for all the available stations over the country would produce some interannual variability solely due to the sampling different stations during different years. To avoid this the rainfall records of about 2000 stations with data beginning prior to 1900 were examined for completeness and geographical coverage of the country. The year 1871 was the earliest that provides both adequate length of record and satisfactory geographic coverage. The network of 306 stations, one from each of the districts in the plain contiguous regions of India, and distributed fairly uniformly over the country was selected. Figure 1 shows the network selected over the region considered. The areal representativeness of a raingauge in a hilly area is small and the raingauge network in most hilly areas of the country is

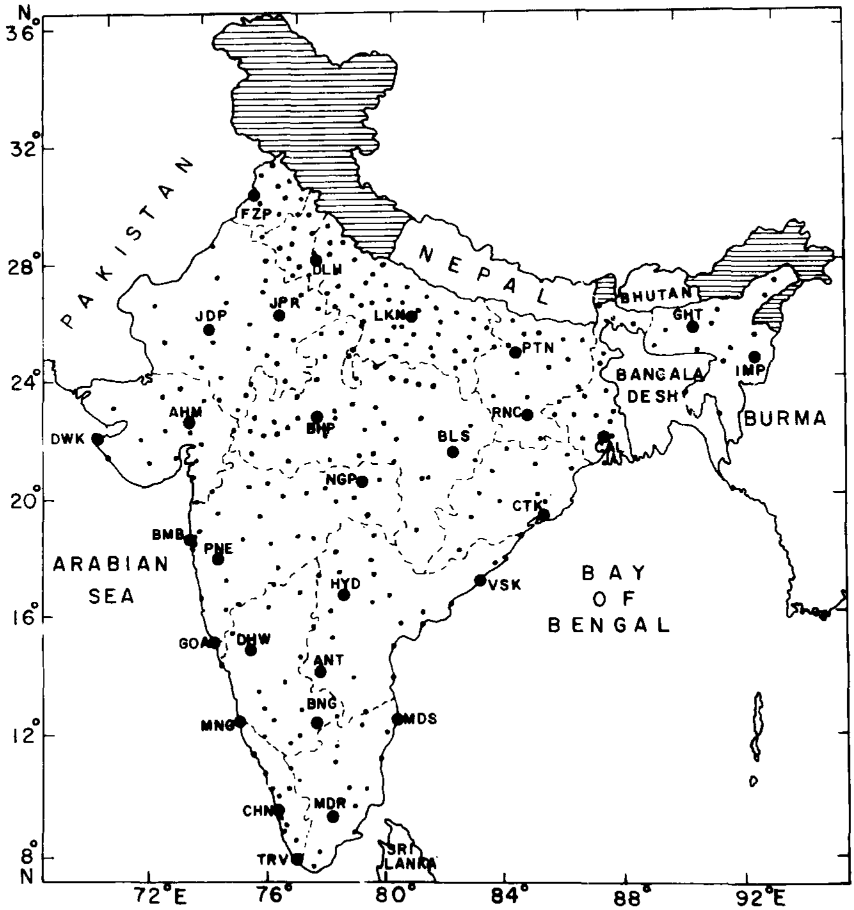

Fig. 1. Network of raingauge stations over the area considered excluding hilly area (Hatched).

inadequate. Therefore, the hilly region of the country parallel to Himalayan mountain range has not been considered. This hilly portion has been shown as hatched in Figure 1. The hilly area of the country consisting of Jammu and Kashmir, Himachal Pradesh, the hills of west Uttar Pradesh, Sikkim (part of sub-Himalayan west Bengal) and Arunachel Pradesh of north Assam has been deleted from consideration. By the exclusion of this area from India, the contiguity of the country is not affected. The area considered measures 2.88×10^6 km^2 which is about 90% of the country. Hereafter the area considered will be referred to as India or country.

June to September rainfall data of these 306 stations are obtained from the relevant India Meteorological Memoirs (for details, see Mooley *et al.*, 1981, 1983a). A careful examination of the available rainfall record for the country indicated that if the data of these stations are taken from 1871, the data gaps will be few. The missing rainfall values for these few stations were interpolated as per the ratio method suggested by Rainbird (1967) by considering nearby station or regional average of that area. The interpolated values are less than 2% of the total.

Statistical properties of 306 rainfall data series were examined. The homogeneity or stationarity of the series was tested by Swed and Eisenhart's test (runs above and below the median) and Mann-Kendall rank tests (WMO, 1966). It is seen that for each of the 306 station rainfall series the numbers of runs lie within the required limit at 5% significance level. Nature of the frequency distribution (Normality) was tested by Chi-square statistic with ten equal probability class-intervals (Cochran, 1952). Except for the series of a few individual stations scattered all over the country, all the remaining rainfall series are Gaussian. Application of Kolmogorov-Smirnov test (Cochran, 1952) to the few rainfall series which indicated non-normality at 5% level of significance on the basis of Chi-square test did not suggest any departure from normality. To examine the presence of the persistence in the time series, the auto-correlations up to three lags were checked for significance. Only four stations have shown Markov type persistence i.e. significant (at 5% level) autocorrelation with lags 1, 2, and 3. Since the number of such significant autocorrelations expected by random chance on the basis of significance at 5% level is 15, it is inferred that the rainfall series for the stations do not exhibit any persistence. It is thus seen that these 306 rainfall series are homogeneous, normally distributed and free from Markov type persistence.

Generally in climatological studies of rainfall for long-term trends, periodicities and droughts/floods over a geographical region, it is customary (in order to reduce climatic noise- high frequency waves) to take the arithmetic average of the stations over the region under consideration and to treat this average as the average representative of that area. Such an average is likely to give a false estimate of the rainfall where the area is very large or where it contains stations getting varying rainfall amounts. Weighting by area may, to a certain extent, reduce the error, but involves some arbitrariness in the assignment of the area appropriate to each raingauge. However, in the absence of the precise knowledge of the proper weighting factor, weighting has been done by the area of the district which is quite small and also rational.

The network shown in Figure 1 has a bias towards north India consisting of the states

TABLE I: All-India Summer Monsoon (June to September) rainfall values (in mm).

	0	1	2	3	4	5	6	7	8	9
1870	–	846	910	754	971	928	776	604	974	894
1880	817	860	901	849	929	842	870	897	810	927
1890	903	789	990	953	969	825	824	890	880	628
1900	885	719	791	858	749	715	883	776	895	889
1910	935	733	804	782	899	780	950	1003	648	885
1920	717	863	867	819	862	803	901	849	766	819
1930	800	877	801	973	913	843	904	843	908	789
1940	850	729	958	866	921	907	901	942	872	902
1950	875	737	792	920	885	930	980	784	886	938
1960	839	1017	809	855	920	707	735	859	754	829
1970	939	886	653	912	747	960	855	881	908	<u>746</u>
1980	<u>881</u>	<u>845</u>	<u>737</u>	<u>964</u>						

Note: Values underlined are approximate, calculated on the basis of less number of rainfall stations.

of Punjab, Harayana, Uttar Pradesh and Bengal, in that the network is closer over these areas than over the rest of India. While the area of most of the districts is small, there are a few districts whose area is rather large. The average area represented by each raingauge over the country works out to be 100 x 100 km, but in individual cases varies from 70 x 70 km in Uttar Pradesh to 150 x 150 km in west Rajasthan. Seasonal (summer monsoon season, June to September) area-weighted rainfall series for the period 1871–1978 has been prepared for India as one unit (to be referred to as All-India rainfall series) by assigning proper area weights to each of the 306 raingauge stations. This rainfall series is given in Table I.

3. Analysis of All-India Summer Monsoon Rainfall

3.1. STATISTICAL PROPERTIES OF ALL-INDIA RAINFALL

The statistical parameters of All-India summer monsoon rainfall for the period 1871–1978 have been calculated and given in Table II. The mean All-India summer monsoon rainfall is 85.31 cm which is 78% of the annual amount. The standard deviation of the series is 8.29 cm and the coefficient of variation, 9.5%. The homogeneity of the series has been tested by Swed and Eisenhart's test of runs above and below the median. The median value is 86.66 cm and the number of runs about the median is 61. The number of runs less than 45 suggests a trend and that more than 64 suggests an oscillation, significant at 5% level (WMO, 1966). Thus it can be inferred that the All-India summer monsoon rainfall series is homogeneous.

The autocorrelation for the series is –0.118 which is too low to suggest any persistence in the series.

The frequency distribution of the time series was tested for normality by using the Chi-square test, with equal probability class intervals as suggested by Cochran (1952). The Chi-square statistic obtained is 7.00 for seven degrees of freedom, and the same is not significant at the 5% level. Hence All-India monsoon rainfall series can be taken to be Gaussian. Statistical tests requiring normality of the distribution can be applied to this time series.

TABLE II: Statistical properties of summer monsoon rainfall of India taken as one unit for the 108-yr period: 1871–1978.

Mean	= 85.31 cm
Percentage of annual	= 78.2 %
Standard deviation	= 8.29 cm
Coeff. of variation	= 9.5 %
Median	= 86.66 cm
Number of runs about the median	= 61
Chi-square (10 classes) – 7 d.f.	= 7.00
Auto-correlation coefficient (r_1)	= –0.118

3.2. Years of Large-Scale Deficient and Excess Rainfall

In order to identify the years of abnormal performance of the monsoon rainfall, we have used the criteria of droughts/floods as given in our earlier study (Mooley and Parthasarathy, 1983b). These criteria identify droughts and floods over different meteorological sub-divisions of India by using specific threshold values of rainfall expressed as standard deviates. It has already been shown that All-India rainfall series is Gaussian therefore, the standard deviate ($t_i = (R_i - \bar{R}) / \sigma$) values of $\pm$ 1.28 denote the 90th and 10th percentiles of the standard Gaussian distribution. These values can be used to find large-scale excess/deficient rainfall years respectively. Here, if t_i value of the All-India rainfall is less than -1.28 the year is taken as large-scale deficient (or drought) year and similarly, if t_i is more than + 1.28, as excess (or flood) year. The large-scale deficient and excess years and their statistical details are shown in Tables III and IV and also in Figure 2.

TABLE III: Statistics of large-scale deficient years: India taken as one unit.

S. No.	Year	Actual rainfall cm	Percentage departure from normal	Standardized value	Rank
1	1877	60.37	– 29.2	– 3.01	1
2	1899	62.81	– 26.4	– 2.71	2
3	1901	71.86	– 15.8	– 1.62	8
4	1905	71.51	– 16.2	– 1.66	6
5	1911	73.29	– 14.1	– 1.45	10
6	1918	64.81	– 24.0	– 2.47	3
7	1920	71.74	– 15.9	– 1.64	7
8	1941	72.90	– 14.6	– 1.50	9
9	1951	73.69	– 13.6	– 1.40	12
10	1965	70.68	– 17.2	– 1.76	5
11	1966	73.52	– 13.8	– 1.42	11
12	1972	65.32	– 23.4	– 2.41	4
13	1974	74.69	– 12.5	– 1.28	13
	Mean =	69.78	– 18.2	– 1.87	

TABLE IV: Statistics of large-scale excess years: India taken as one unit.

S. No.	Year	Actual rainfall cm	Percentage departure from normal	Standardized value	Rank
1	1874	97.10	13.8	1.42	7
2	1878	97.36	14.1	1.45	5
3	1892	98.96	16.0	1.65	3
4	1894	96.90	13.6	1.40	8
5	1917	100.30	17.6	1.81	2
6	1933	97.25	14.0	1.44	6
7	1956	97.95	14.8	1.52	4
8	1961	101.70	19.2	1.98	1
9	1975	96.01	12.5	1.29	9
	Mean =	98.17	15.1	1.55	

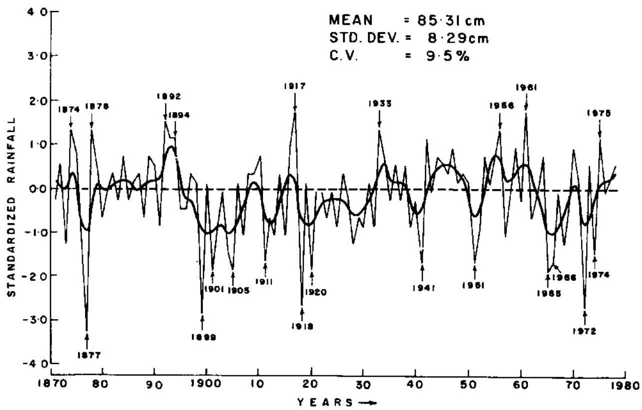

Fig. 2. Standardized actual and low-pass filtered summer monsoon (June to September) All-India rainfall 1871 to 1978.

It is seen from Table III that there are 13 large-scale deficient years and the mean percentage departure from normal (long period average) for these 13 yr is about −18%. There are four years; 1877, 1899, 1918, and 1972 when a rainfall deficiency was 20% or more from normal and the country suffered worst drought conditions. There are two consecutive years in these 13 yr, viz., 1965 and 1966. Two continuous decades i.e., 1921–30 and 1931–40 had no large-scale deficient years. This is the only 20-yr period without a single large-scale drought year as revealed by the rainfall record of India.

There are 9 large-scale excess years during the 108-yr period (Table IV). Mean excess rainfall of these 9 yr is 15%, the highest excess being 19% in 1961 and next to it being 18% in 1917.

There are three pairs of large-scale deficient years either succeeding or preceding large-scale excess years. These are 1877, 1878; 1917, 1918; and 1974, 1975.

The Mann-Kendall test applied to the time interval between two successive large-scale deficient or excess years suggested that the occurrence of the large-scale deficient or excess years is random in time continuum. Cox's test (1970) also supports randomness of the occurrence. Figure 2 shows the All-India standardized actual and low-pass filtered summer monsoon rainfall curve along with years of large-scale deficient and excess rainfall marked on the curve. The standardized All-India rainfall curve given in Figure 2 can be compared easily with standardised rainfall curve for another region.

3.3. Ten-Year Moving Average

Statistical attempts to identify climatic trends frequently employ the calculation of a moving mean; a ten-year smoothing mean can be utilized to smooth out many of the short-term fluctuations. The ten-year moving *t*-test (Cramer's test) as suggested by Lewson *et al.* (1981) has been utilized in this study.

In applying Cramer's test, the mean, $\bar{R}$, and the standard deviation, σ, are calculated for All-India series for the total number of years, N (108-yr), under investigation. The main purpose of this test is to measure the difference, in terms of a moving t-statistic, between the mean, $\bar{R}_k$, for each successive n-year period (n = 10 here) and the mean, $\bar{R}$, for the entire period. The t-statistic, t_k, is computed as

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

where τ_k is the standard measure of the difference between means given as

$$\tau_k = \frac{(\bar{R}_k - \bar{R})}{\sigma} \quad .$$

Figure 3 shows the 10-yr moving average curve and corresponding Cramer's t_k value curve along with 5% significant line. It is observed that both curves show a similar tendency. It is observed in the 10-yr moving average curve that there is a gradual rise up to 1889 and afterwards the rainfall decreases to the lowest value in the year 1899. From the year 1899 onwards there is gradual rise in the moving average curve continuously up to 1953 and decreasing afterwards, the lowest being reached in 1965 after which there is an increase. Similar features are noticed in Cramer's t-value moving curve also. The t_k value was significant at 5% level during the five 10-yr periods, 1896–1905 to 1899–1908 and 1965–1974; during these five 10-yr periods the mean rainfall of the country was lowest. It is noticed that there were three large-scale deficient years, 1899, 1901 and 1905 in the former period and four in latter period, 1965, 1966, 1972, and 1974. This indicates that the country suffered the worst drought conditions in the recent 10-yr, 1965 to 1974. It is interesting to note that the 10-yr average curve has shown gradual increase from 1899 to 1953.

Similarly the sliding Cramer's test statistic was calculated for 20- and 30-yr sliding window widths. For significance of Cramer's t-value at 5% level, the required t-value is $\pm$ 1.96 or more. There are three lowest average of 20-yr periods, 1895–1914, 1896–1915 and 1899–1918 and one highest average period 1942–1961, significant at 5% level. For 30-yr average periods, there are seven periods with lowest average i.e. 1895–1924 to 1901–1930 and two highest average period, 1932–1961, and 1933–1962 respectively, significant at 5% level.

The main purpose of applying moving Cramer's test to 10-, 20-, and 30-yr sliding window widths to All-India rainfall series is to find out significant periods with abnormal averages, if any. The anomalous features of the General Circulation of the atmosphere can be examined against the background of these periods of anomalous rainfall.

However, simple moving averages introduce apparent cycles even in the series that are wholly random and this effect is called 'Slutzky-Yule Effect'. In order to overcome this problem the All-India series has been subjected to low-pass filter analysis.

3.4. Low-pass Filter

To understand the nature of the fluctuation or trend if any, the All-India series has beer

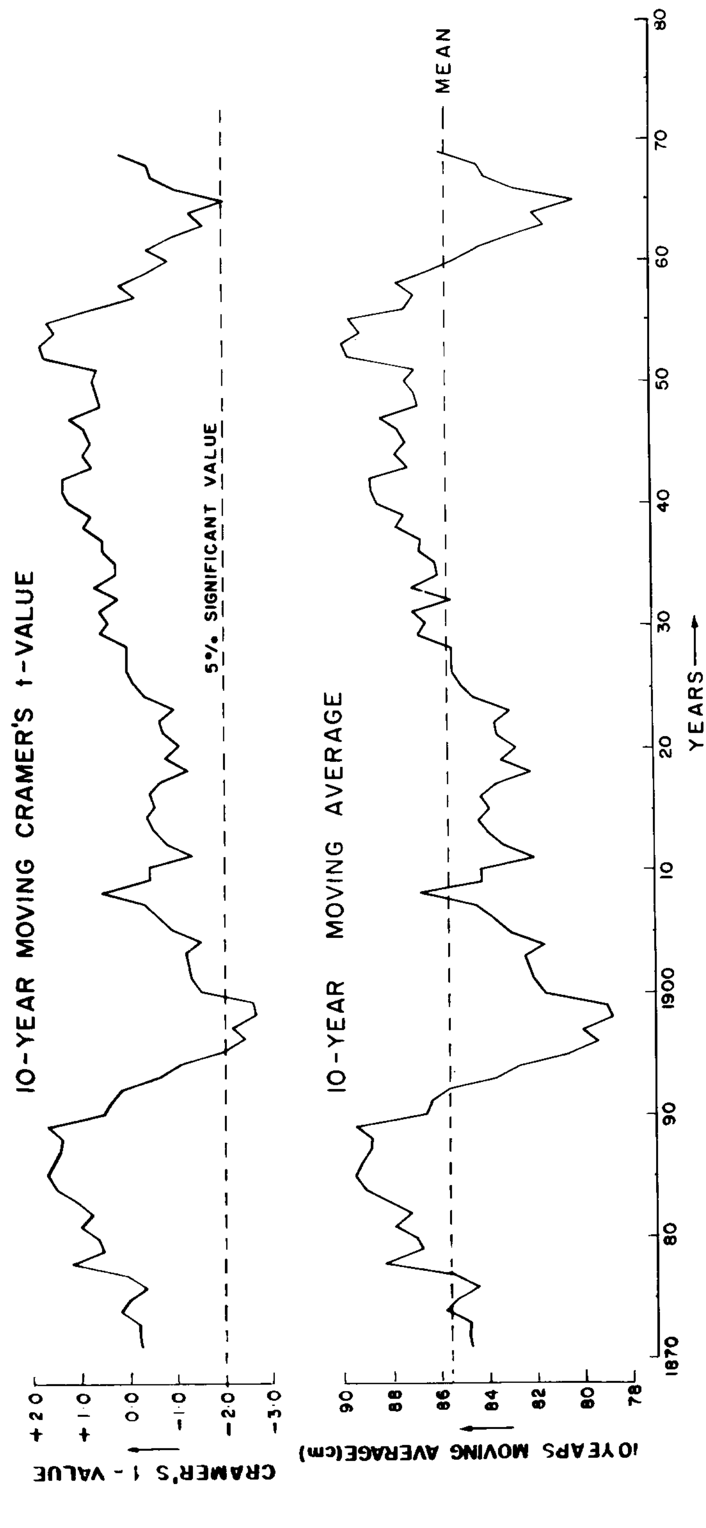

Fig. 3. Ten-year simple moving average and Cramer's t-statistic value for All-India summer monsoon rainfall for the period 1871–1978.

subjected to a Binomial low-pass filter (WMO, 1966). Here we used five term Binomial filter (for details refer to Tyson *et al.*, 1975) in smoothing the series. The smoothed rainfall S_i is given by

$$S_i = 0.06\,R_{i-2} + 0.25\,R_{i-1} + 0.38\,R_i + 0.25\,R_{i+1} + 0.06\,R_{i+2}\,.$$

The frequency response of the series S_i is approximately $R(f) = \cos^p \Pi f \Delta t$, where p is the order of the binomial expansion. The function gives ratio smoothed to unsmoothed amplitudes of 0.952, 0.925, and 0.813 for periods 20, 16, and 10 yr respectively.

The All-India rainfall series was subjected to the above low-pass filter. The filtered rainfall curve and the standardized actual rainfall curve are shown in Figure 2. It is observed from the figure that the low-pass filter curve is almost below the normal rainfall line during the (i) 38-yr period 1895 to 1932 and (ii) 10-yr period 1965 to 1974. Many droughts occurred during these periods, the worst period being 1899 to 1920. The low-pass filter curve is above normal during the (i) 23-yr period 1872 to 1894 and (ii) 32-yr period 1933 to 1964, when few droughts and many floods are noticed.

3.5. Residual Mass Curve Analysis

Figures 2 and 3 show that the All-India rainfall series has some systematic variations and that the series can be sub-divided into distinct periods (or epochs). In order to follow these periods in the rainfall series, the All-India series has been studied using the residual mass-curve technique suggested by Kraus (1955). Figure 4 gives the residual mass-curve of All-India summer monsoon for the period 1871–1978. The four different climatic periods during the 108-yr of All-India rainfall are clearly seen in this figure. These are, (i) increasing tendency during 1878 to 1898 (21 yr), (ii) decreasing tendency during 1899 to 1932 (34 yr), (iii) increasing tendency during 1933 to 1964 (32 yr) and (iv) decreasing tendency after 1965.

Joseph (1976) identified three different rainfall periods in Indian monsoon rainfall during 1891 to 1974. There are two bad rainfall periods (deficient rainfall years), 1891–1920 and 1965–1974 and one good rainfall period 1931–60. He further showed that the regional circulation features like storms/depressions, position of monsoon trough and upper wind features were distinctly different for good and bad rainfall periods. Chaplygina (1974) who has examined the zonal and meridional circulation over the whole northern hemisphere during 1895 to 1969, has brought out that there were three periods during which the values for these characteristics were constantly in excess of their long-period averages.

4. Periodicities

We have subjected the All-India rainfall series to correlogram and spectrum analysis in order to see, if any, cycles are present in the series.

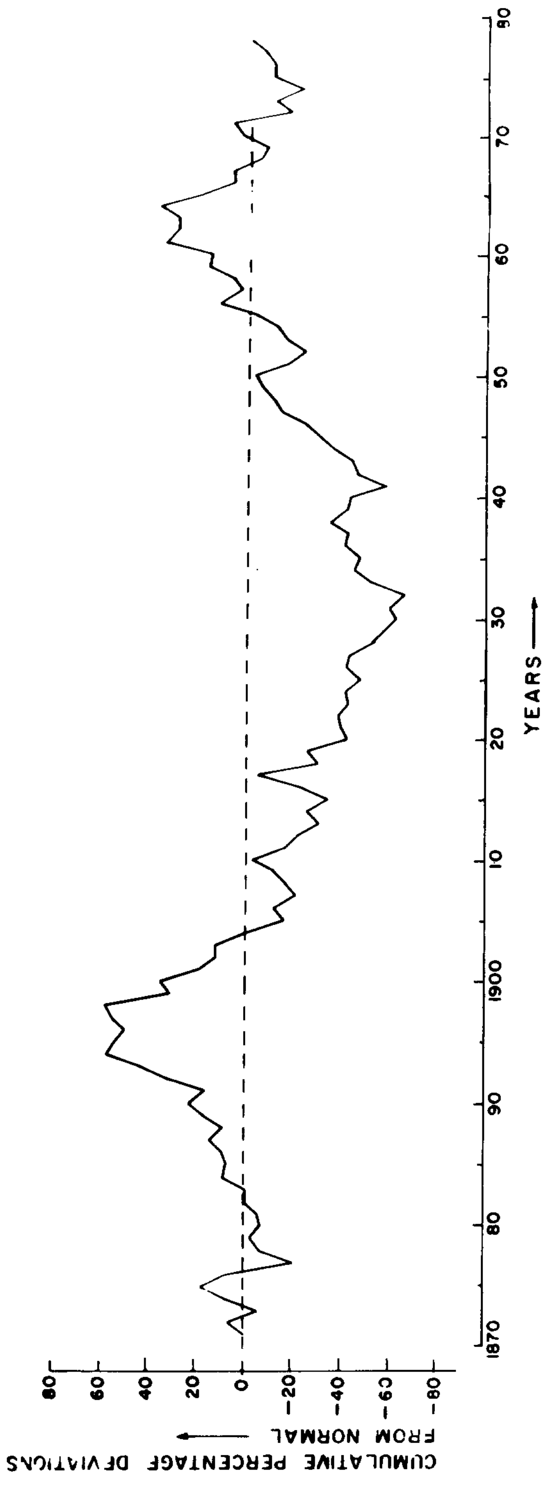

Fig. 4. Residual mass curve of All-India summer monsoon rainfall: 1871–1978.

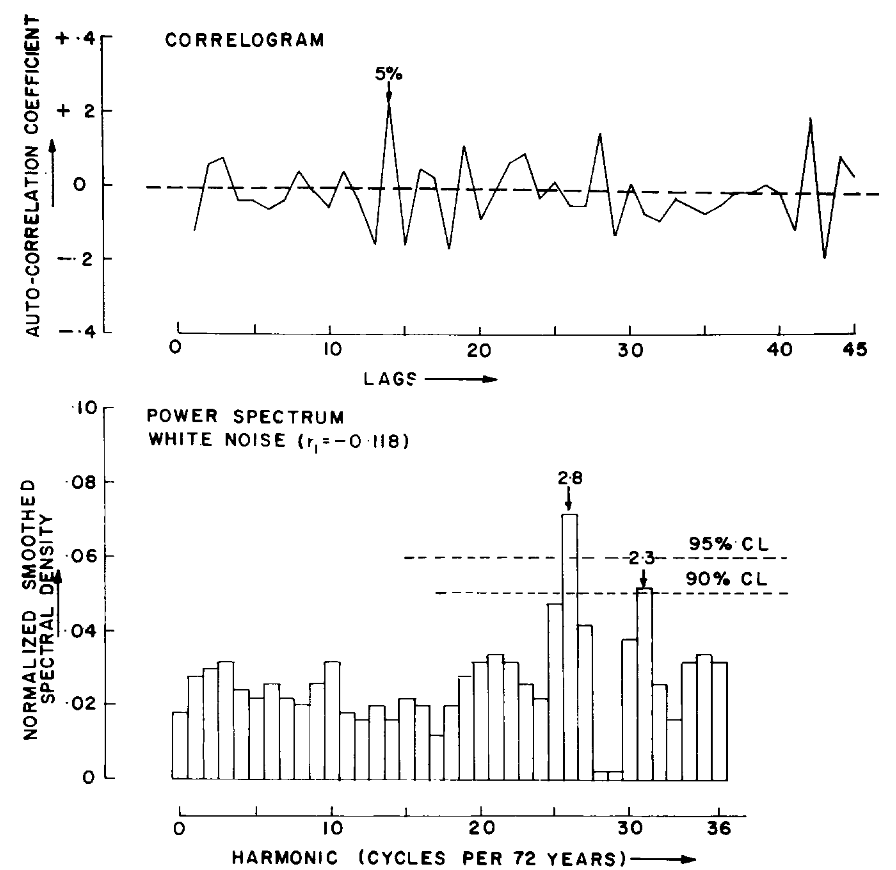

Fig. 5. Correlogram and spectrum analysis of summer monsoon rainfall of All-India series: 1871–1978.

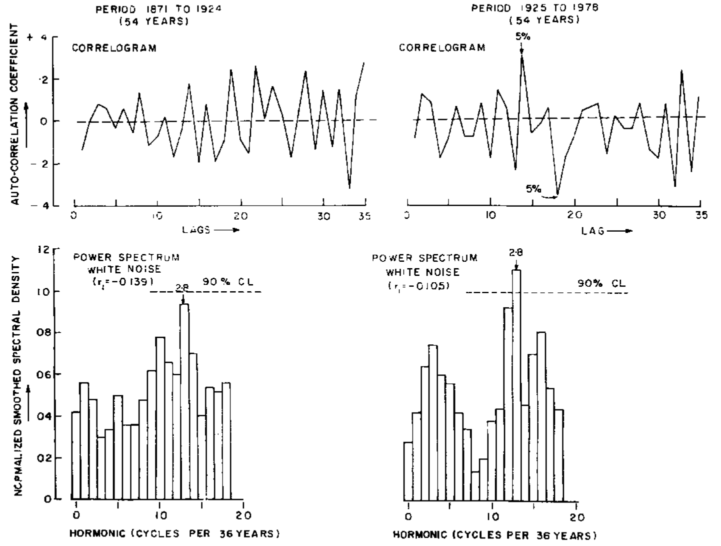

Fig. 6. Correlogram and spectrum analysis of summer monsoon rainfall of All-India series for the periods: 1871–1924 and 1925–1978.

4.1. Correlogram Analysis

Calculations of auto-correlation of a time series will help in finding out the cycles, if any, in the series. The auto-correlation coefficients of All-India rainfall series have been worked out up to 45 lags and the correlogram is shown in Figure 5. The correlogram shows that the series is somewhat oscillatary in nature. The correlation coefficient (*CC*) for lags 31 to 40 are continuously negative but not significant. A high *CC* is noticed for lags 14, 42, and 43 but *CC* is positive and significant at 5% level for lag 14 only. To test further the persistent existence of 14-yr cycle in the series we have divided the data into two equal parts of 54 yr and examined the correlogram. The correlograms are shown in Figure 6. The 14-yr cycle is only seen in the second half of the series i.e., 1925–1978 and not in the first half of the series.

4.2. Spectrum Analysis

The time series of All-India rainfall has been subjected to power spectrum analysis by following the method of Blackman and Tukey (1958) as given in WMO Technical Note 79 (1966). The spectrum results are shown in Figure 5. There is a cycle of 2.8 yr significant at the 5% level and another at 2.3 yr significant at the 10% level. In order to see whether these cycles exist throughout the entire series, we have divided the data into two equal parts and subjected each of these to spectrum analysis. The results are shown in Figure 6. The 2.8 yr cycle is seen to be statistically significant at the 10% level in the 2nd half of the series i.e., 1925–1978 only. In view of this we have examined the data in detail to find out actually when the 2.8 yr cycle, generally called as Quasi-Biennial-Oscillation (QBO) has developed in the series. Table V gives the details of spectrum, the spectrum being calculated for different lengths of the data series starting from the year 1871 onwards. The auto-correlations (*CC*s) up to the first three lags for the different

TABLE V: Spectrum analysis and correlogram results of All-India summer monsoon rainfall.

S. No.	Period of data	No. of years	Max. lags given	Auto-correlation value			Significant cycle in years
				Lag-1	Lag-2	Lag-3	
1	1871–1900	30	10	–0.125	–0.276	+0.078	4.00
2	1871–1910	40	15	–0.047	–0.032	+0.175	–
3	1871–1920	50	20	–0.136	–0.005	+0.089	–
4	1871–1930	60	20	–0.135	–0.007	+0.082	–
5	1871–1940	70	25	–0.135	+0.013	+0.073	–
6	1871–1950	80	25	–0.111	+0.068	+0.061	–
7	1871–1960	90	30	–0.091	+0.036	+0.069	2.72
8	1871–1970	100	30	–0.084	+0.040	+0.117	2.85, 2.72[a]
9	1871–1978	108	35	–0.118	+0.055	+0.084	2.80[a], 2.69, 2.33
10	1871–1978	108	36	–0.118	+0.055	+0.084	2.76[a], 2.32

[a]) Significant at 5% level.

data lengths used did not show any persistence. Lag one *CC* is negative and lag three *CC* is positive throughout the period but lag two *CC* is negative up to the year 1930 and became positive afterwards. However, none of the *CC*s are significant at 5% level. The lag one *CC* is small and negative, almost the same in all the cases. This shows the stationarity of the All-India rainfall series. Only the cycles which are significant at 90% level or more are given in the Table V. There is no cycle between 2 and 3 yr period up to the first 80-year length of the series i.e., 1871–1950, thereafter it is seen to be significant at 5% level in the series for the period 1951–78. This shows that the presence of *QBO* in All-India rainfall series is of recent origin.

5. Conclusions

The detailed statistical analysis of the All-India summer monsoon rainfall during the period 1871–1978 enables us to draw the following conclusions:

(i) The average summer monsoon rainfall of the country is 85.31 cm with a coefficient of variation of 9.5%. The rainfall series is homogeneous, Gaussian-distributed and does not indicate any persistence.

(ii) The highest rainfall recorded is 101.70 cm (i.e., 119% of the normal) in 1961 and the lowest 60.37 cm (71% of the normal) in 1877.

(iii) There are 13 and 9 large-scale deficient and excess rainfall years respectively in the 108-yr period.

(iv) There has been a continuous increase in the 10-yr mean rainfall from 1899 to 1953.

(v) Cramer's *t*-value is significant at 5% level during 10-yr periods 1896–1905 to 1899–1908 and 1965–1974. These periods have the lowest 10-yr average rainfall.

(vi) The low-pass filter rainfall curve is almost below the average rainfall line for the years 1895–1932 and 1965–1974 and above it for 1872–1894 and 1933–1964 during the period of study.

(vii) The country's rainfall has passed through four major rainfall periods among which there are two consecutive periods exceeding 30-yr of decreasing and increasing tendency. These periods are, 1899–1932 and 1933–1964 respectively.

(viii) Two cycles, 14-yr and 2.80 yr which are noticed in 108-yr period are not consistently observed throughout the data record.

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