Some Features of a Long Homogeneous Series of Indian Summer Monsoon Rainfall

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ABSTRACT

A long rainfall series for the contiguous Indian region for the summer monsoon season (June–September), when more than 75% of the annual rainfall occurs over large parts of the country, has been constructed by considering the rainfall data of a very large number of raingages since 1841 to present. The series from 1866–1970 has been found to be homogeneous. The statistical properties of this homogeneous time series have been investigated. The average monsoon rainfall of India is 88.75 cm with a standard deviation of 7.64 cm. Fisher's statistics g_1, g_2 and the chi-square statistic indicate that the time series is normally distributed. The years 1877, 1899, 1918, 1920, 1951 and 1965 were very bad monsoon years when the rainfall was below the 5th percentile of the distribution. The increase of 4.6% in the 30-year average from 1901–30 to 1931–60 is significant at the 5% level. The mean for the period 1931–60 is also significantly higher than the overall mean for the period 1866–1970 at the 5% level. During the period 1870–1920, the decade average was generally very steady. From 1921 onward, the decade mean increased and attained the maximum value of 93.17 cm during the decade 1941–50, and declined thereafter, the highest decline of 4.41 cm being from 1951–60 to 1961–70. The difference between the mean for the decade 1941–50 and the mean for the whole period of the series is close to the 5% significance point. Power spectrum analysis indicates the presence of a quasi-biennial oscillation in the time series. There does not appear to be a significant relationship between Indian monsoon rain and solar activity.

1. Introduction

The study of the past climate over a region will help in understanding the behavior of the atmosphere and its vagaries. Although often very difficult, it is extremely useful to construct a comparable and comprehensive continuous climatic time series. Recently, such an effort was made by Manley (1974) for temperature and Craddock (1976) for the rainfall of England. Mitchell (1975) has constructed a time series of mean surface temperature of the Northern Hemisphere since 1881 and Flohn (1975) for lake levels and river discharges of the tropical African region.

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 over that 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 temperature are small. Corresponding to temperature changes in extratropical latitudes, there may be changes in evaporation 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 useful tool in tropical latitudes for studying the long-term changes, if any, in circulation.

Lysgaard (1950) studied the precipitation changes over the whole world in a general way and found that the variation from 1910–1940 was positive in certain areas of the world, including south India and southeast Asia, and negative in certain other areas. Kraus (1958, 1960) has studied the world's rainfall pattern by the residual mass curve technique; however, as pointed out by Rao and Jagannathan (1963), there are limitations to this technique. His conclusion was that the shift of the world's rainfall pattern has been accompanied by changes of the general atmospheric circulation that prevailed during the early twentieth century warming period. Rainfall amounts increased generally in the zones of prevailing westerly winds in both hemispheres from the west coasts and far into the interior of the continents. There was a decrease of rainfall in the subtropical zone anticyclones, which were more intensely developed than before and spread toward latitudes 40–45°N.

Walker (1910) examined the southwest monsoon (June–September) rainfall series of India, taken as one unit, for the period 1841–1908 by considering the data of all available raingages of the country and observed that rainfall was below normal from 1843–1860 and 1895–1907. The Famine Commission Report has also

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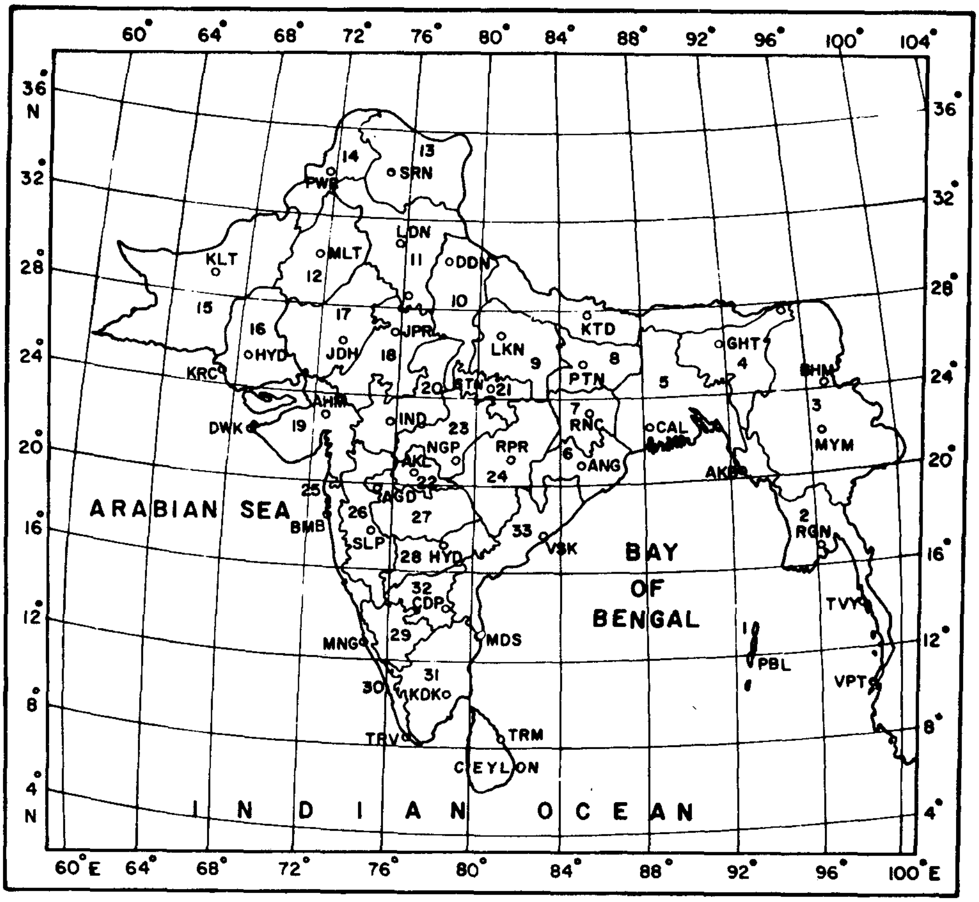

1. Bay Islands.
2. Lower Burma.
3. Upper Burma.
4. Assam.
5. Bengal.
6. Orissa.
7. Chota Nagpur.
8. Bihar.
9. United Provinces, East.
10. United Provinces, West.
11. Punjab, East and North.
12. Punjab, Southwest.
13. Kashmir.
14. North-West Frontier Province.
15. Baluchistan
16. Sind.
17. Rajputana, West.
18. Rajputana, East.
19. Gujrat
20. Central India, West.
21. Central India, East.
22. Berar.
23. Central Provinces, West.
24. Central Provinces, East.
25. Konkan
26. Bombay, Deccan.
27. Hyderabad, North.
28. Hyderabad, South.
29. Mysore.
30. Malabar.
31. Madras, Southeast.
32. Madras, Deccan.
33. Madras Coast, North.

FIG. 1. Meteorological subdivisions of British India as in 1907.

supported these facts. During this period the worst years were 1848, 1855, 1877 and 1899. Pramanik and Jagannathan (1953) and Rao and Jagannathan (1963) analyzed the southwest monsoon rainfall of India by fitting orthogonal polynomials up to the fifth degree and concluded that there was no marked change in the Indian rainfall. The time series of contiguous Indian rainfall for the period 1901–1960 has been studied by Parthasarathy and Dhar (1975, 1976) who found that the increase in the rainfall from 1901–30 to 1931–60 was significant. Mooley (1975) examined the area of the country under deficient rainfall for the period 1947–74 and showed that 1951, 1965, 1966, 1968, 1972 and 1974 were bad years when 33–55% of the country's area experienced deficient monsoon rainfall. The synoptic aspects of Indian rainfall were examined by Rao (1976) and Ramaswamy (1976). Further details of the past climatic fluctuations over the Indian region are available in the review article of Parthasarathy and Dhar (1978).

In the last 100 years, meteorologists in India have looked into various aspects of the monsoon in an effort to understand the monsoonal and global circulation features through extensive data analysis because the southwest monsoon is the only season when most parts of the country receive more than 75% of the annual rainfall and India's economy is heavily dependent on this rainfall. Recently much concern has been expressed in India regarding the decrease of monsoonal rainfall over the country; the monsoon rainfall was below normal from 1965 onward for large parts of the country. Therefore, it is felt that the study of the time series of southwest monsoon rainfall of India as a whole will be helpful in understanding the behavior of the monsoon through the past years.

An effort has been made in the present study to construct a long rainfall series for the contiguous Indian region as a whole from the earliest possible year to the present by taking into account a very large number of raingage stations spread uniformly all over the country, and to examine the statistical properties of this time series.

2. Method of construction of the rainfall series

In India, monthly rainfall data are available in published form for some stations for more than a century. For a large number of stations the data prior to 1891 are available only in manuscript form. Blanford (1886) was the earliest meteorologist to analyze rainfall data—he used about 1500 raingage stations for a 20–30 year period for British India comprising the present India, Pakistan, Bangala Desh and Burma. Walker (1910) examined the southwest monsoon rainfall (June–September), hereafter referred to as the monsoon rainfall of British India, by taking into consideration the data of about 2000 raingage stations from 1841–1908. Walker obtained the rainfall series of British India by weighting different meteorological subdivisions according to their areas. The details of the meteorological subdivisions he considered are shown in Fig. 1. The number of raingages considered throughout the study was not the same. The number of raingages was about 1500 from 1865–1890 and about 2000 from 1891 onward. Walker did not consider the rainfall of British India prior to 1841 because the number of raingages was small. Symon's 5-inch diameter raingage, Glaisher's pattern raingage and Fleming's float gage were in use prior to 1865. However, Symon's raingage was the one mainly used. Before 1866, there was no organized meteorological service, the instruments were supplied mainly by the Medical Board or the Mathematical Instrument Department, usually with no instructions for the observer to secure uniformity of exposure or method of observation, and weather observations were made by administrative or medical officers stationed in the district. In accordance with the recommendations of the Secretary of States for British India, a large number of raingages was maintained by the Provisional Governments from 1865 onward with instructions to the observers regarding exposure and observations. After 1891, Symon's raingage was adopted as standard at all places due to the rainfall resolution. As a result, Walker (1910) felt that raingage data prior to 1865 were less reliable. We obtained the monsoon rainfall of British India as a whole (prepared as explained above) from 1841–1935 from the publications of India Meteorological Department (periodical issues of the department, namely, Seasonal Forecasts) and the published work of Walker (1910, 1914, 1922). Data after 1935 has not been considered because Burma was separated from India (actual political separation took place in 1937). Fig. 2 gives the monsoon rainfall series of pre-partition India and Burma from 1841–1935 prepared by Walker along with a low-pass moving average curve. Hereafter, this series will be referred to as rainfall for pre-partition India and Burma.

The average monsoon rainfall of contiguous India as it is at present has been computed by Parthasarathy and Dhar (1976) for each of the years from 1901–1960 from the rainfall data of about 3000 raingages by weighting the areas of the different meteorological sub-

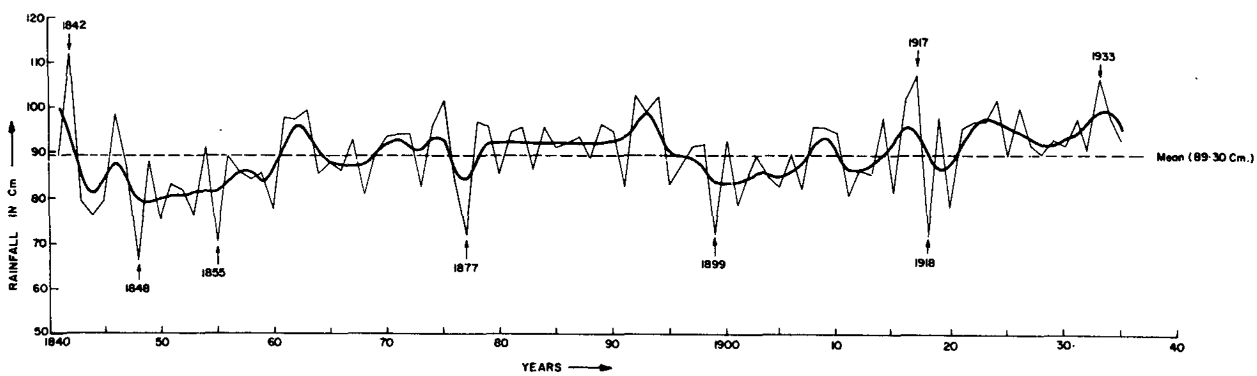

FIG. 2. Actual and filtered (low-pass) monsoon rainfall of pre-partition India and Burma from 1841–1935.

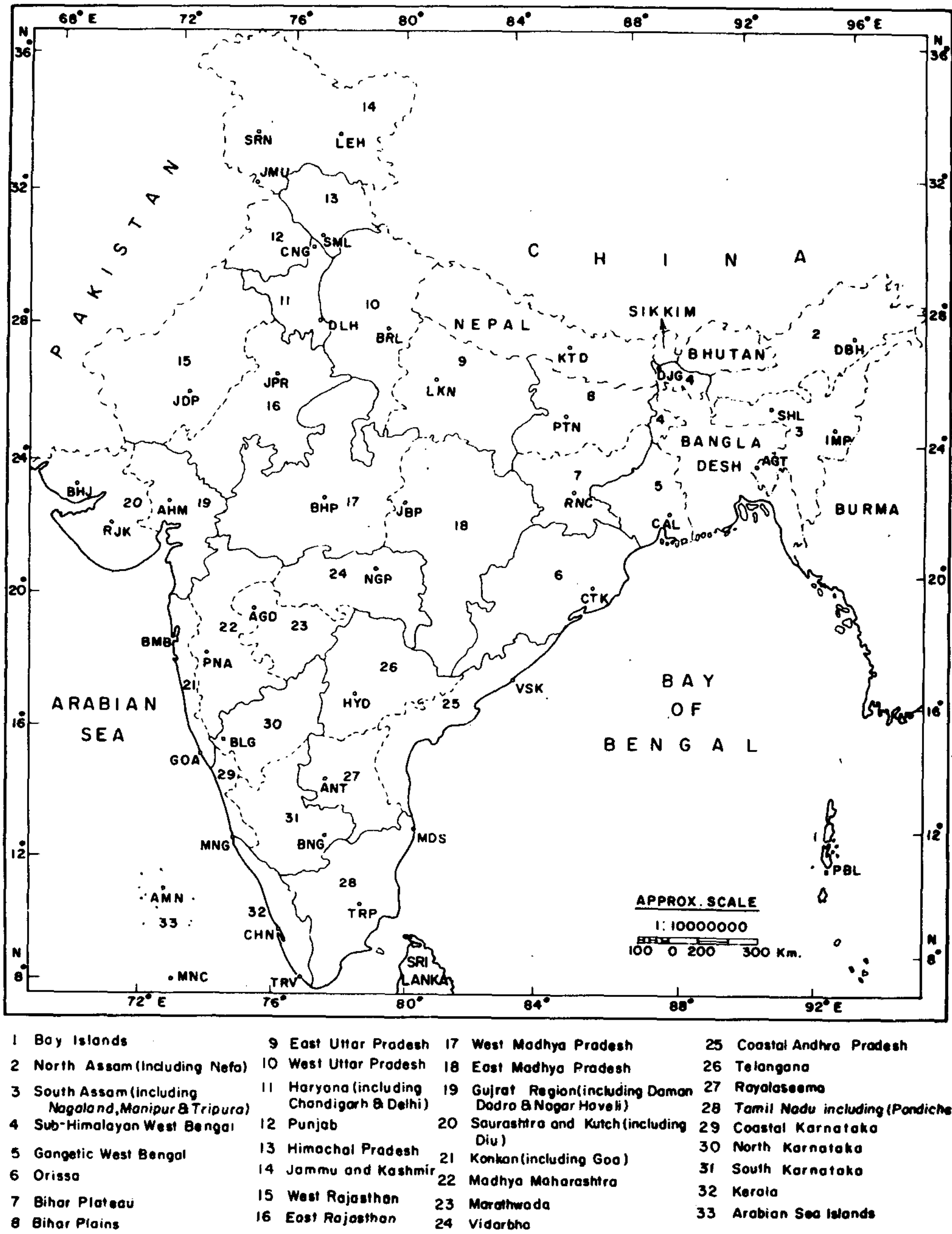

FIG. 3. Meteorological subdivisions of India as of 1 January 1971.

divisions (Fig. 3). For the present study, this series has been extended to 1970 by considering about the same number of raingages. The series has been further extended from 1971–1977 by considering about 350 observatory stations only to make the data series up to date, since the rainfall data of all the state raingages were not available in published form. The average rainfall of India after 1970 is relatively less reliable as it is based on a much smaller number of stations. The monsoon rainfall series of contiguous India from 1901 to 1977 and the low-pass-filter series are shown in Fig. 4. This series (1901–77) will be hereafter referred to as the rainfall series of India.

Two long-time series (i.e., one from 1841–1935 for pre-partition India and Burma and another from 1901–1977 for India) are available for the monsoon season (June–September). The area of India considered for these two series is different (see Figs. 1 and 3). From these two series we have prepared one continuous series from 1841–1977 by combining them suitably. There is an overlapping period of 35 years from 1901–1935 for these two time series. It is first necessary to ascertain

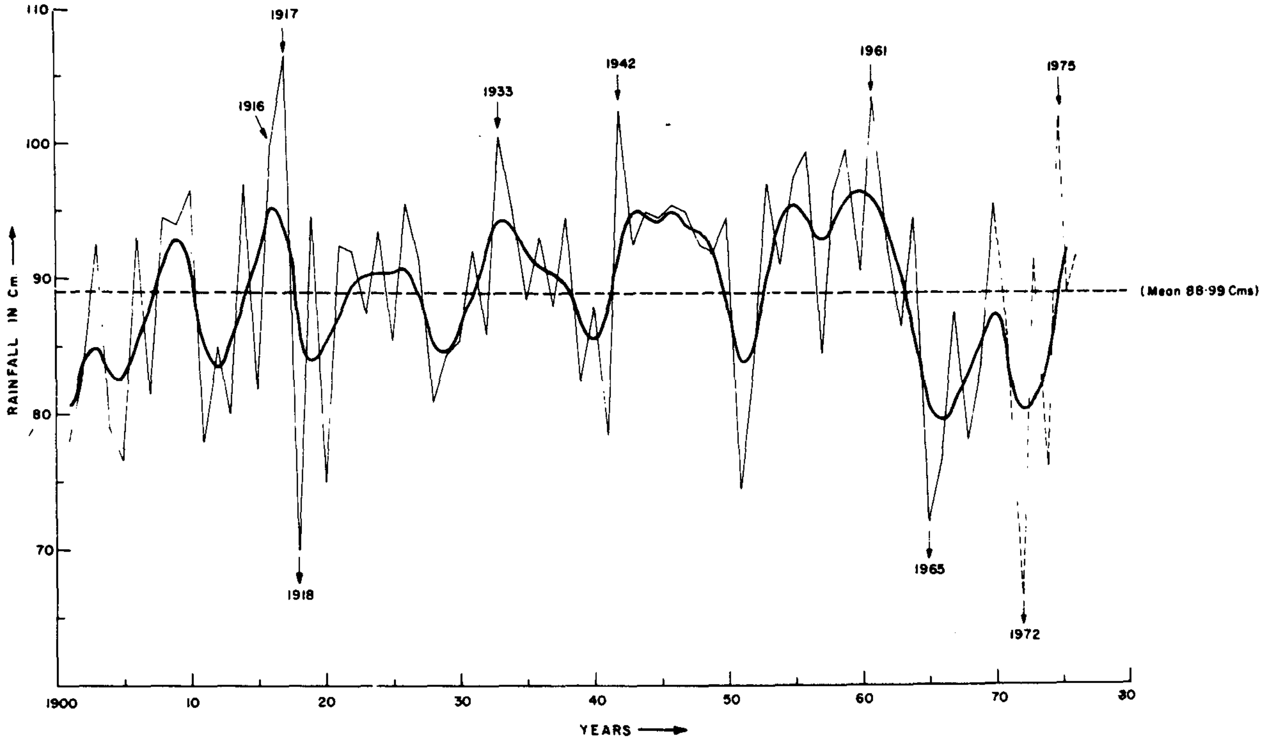

Fig. 4. Actual and filtered monsoon (June–September) rainfall of India from 1901–1977. (The values for 1971–1977 are approximate).

whether or not these two series come from the same population. In this connection, the F-test (Natrella, 1963) was applied (for the 35 years) to test whether the two series come from a population with the same variance. The F-ratio is 1.032, while the value (for 32 degrees of freedom) significant at the 5% level is 1.975. Thus it is seen that the two series come from populations with the same variance. Next the significance of the difference of the two means was tested by Student's t-test and the Mann-Whitney's rank test [non-parametric test (Siegel, 1956)]. For the period 1901–35, the mean and standard deviation for pre-partition India and Burma series are 90.89 and 8.08 cm, whereas for the other series the values are 88.21 and 8.21 cm, respectively. The calculated Student's t-value is -1.357 and Mann-Whitney's rank statistic is -1.391, indicating that the two series come from populations with the same mean. It can be concluded that these two samples for the 35-year period from 1901–1935 come from the same population. The scatter diagram in Fig. 5 shows the relationship between these two time series. The correlation coefficient is $+0.92$ and the equation of regression is $Y=3.63+9.93\ X$, where Y is the rainfall of India and X the rainfall of pre-partition India and Burma. From this regression equation we calculated the time series backward, i.e., prior to 1901, and constructed the time series for India from 1841–1977. The fact that the two series for the common period come from the same population gives validity for converting the series for pre-partition India and Burma for the period 1841–1900 into the series for India for the period 1841–1900 by the use of the regression equation.

3. Analysis of rainfall series

Even though a time series of Indian monsoon rainfall has been constructed for the period 1841–1977 we shall study the properties of the series for the period 1866–

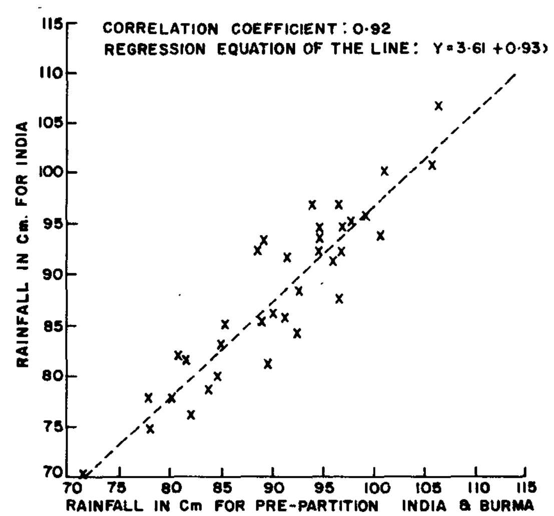

Fig. 5. Scatter diagram of monsoon rainfall for the period 1901–35.

TABLE 1. Statistical parameters of monsoon rainfall of India.

	Homogeneous rainfall series of India (1866 to 1970)—105 years
Mean (cm)	88.75
Lowest value (cm)	70.09
Corresponding year	1877
Highest value (cm)	106.61
Corresponding year	1917
Standard deviation (cm)	7.64
Cofficient of variation	8.6%
Skeewness (g_1)	−0.410
Kurtosis (g_2)	−0.235
$g_1/\sigma g_1$*	−1.768
g_2/σ_{g_2}*	−0.401
Chi-square value (degrees of freedom = 7)	9.95

* σ_{g_1} and σ_{g_2} are the standard errors of g_1 and g_2.

1970 for the following reasons:

1) Rainfall for the period 1841–65 is less reliable due to the use of different types of raingages, non-standard and nonuniform exposure, and absence of standard and uniform instructions for observation. In fact, Fig. 2 reveals that the mean Indian monsoon rainfall for the period 1841–60 is substantially less than that for the post-1860 period. It has also been found that although there was a significant increase in the mean from the first half to the second half of the period 1841–1977, there is no significant increase in the mean from the first half to the second half when we consider the period 1866–1970.

2) Monsoon rainfall for India for the period 1971–77 is based on a very much smaller number of raingage stations (∼350) and the average obtained on the basis of this sparse network of stations may not be representative of the large Indian area.

a. Homogeneity of the series

We have tested the series (1866–1970) for homogeneity using the Swed and Eisenhart's (1943) runs test. Runs above and below the median were counted. Too many runs would indicate oscillation, whereas too few runs would indicate trend. If neither oscillation nor trend is present, the series can be taken as homogeneous. The median value is 90.44 cm and the number of runs about this median value is 49. For the series to be non-homogeneous at the 5% level, the number of runs must lie outside the range 44–61 [from statistical tables of Owen (1962)]. In the present case with 49 runs it can be inferred that the constructed series 1866–1970 is homogeneous. This time series for the period 1866–1970 will hereafter be referred to as the long homogeneous series.

b. Randomness of the series

Randomness of the series was confirmed by using the Swed and Eisenhart's (1943) test as applied in Section 3a.

The Mann-Kendall rank statistic test was also applied to test the randomness of the series. [for details of the method see WMO Technical Note No. 79 (1966)]. The Mann-Kendall rank statistic τ calculated for the long homogeneous series is 0.126, whereas to be significant at the 5% level τ should be 0.130 or more. This would indicate that the series can be taken as random and that there is no cause for fear of a disastrous decreasing trend in monsoon rainfall setting in over India. The few random occasions of large deviations of monsoon rainfall from the normal have to be faced by the country.

c. Frequency distribution of the series

The frequency distribution of the time series was tested for normality by 1) testing the significance of Fisher's statistics g_1 and g_2 and 2) by using the chi-square test, with equal probability class intervals as suggested by Cochran (1952). Fisher's statistics are significant at 5% level if they are equal to or more than 1.96 times the standard error. The chi-square statistic was evaluated by using 10 class intervals. The degrees of freedom in this case is seven. Table 1 gives the mean of the long homogeneous series, extremes and the corresponding year, standard deviation, coefficient of variation g_1, g_2, the ratios $g_1/\sigma g_1$, $g_2/\sigma g_2$ and the value of the chi-square statistic. The values of $g_1/\sigma g_1$, and $g_2/\sigma g_2$ are smaller than 1.96. Hence it can be inferred that g_1 and g_2 are not significantly different from zero. For seven degrees of freedom, at the 5% level, the value of chi-square is 14.10, whereas the chi-square statistic obtained is 9.95. The chi-square statistic is not significant at 5% level. From these tests, it can be inferred that the long homogeneous series is normal. Hence, the southwest monsoon rainfall of India can be considered to be normally distributed and statistical tests which imply normality can be applied to this time series.

d. Years of bad and good monsoons

The years when monsoon rainfall was below the 10th percentile and above the 90th percentile of the normal distribution fitted to the long homogeneous rainfall series of India, have been considered bad and good monsoon years, respectively. These are listed in Table 2 along with corresponding rainfall and its percentage deviation from the mean. When rainfall was below and above the 95th percentile, monsoon performance was considered as very bad and very good, respectively. There are six very bad and three very good years. Years of very bad and very good monsoons have been indicated in Table 2. The worst monsoon year on record during the period 1866–1970 is 1877, though 1918 is

TABLE 2. Bad and good years of monsoon rainfall for the 105 year period (1866–1970).

Serial no.	Bad years: Year	Bad years: Rainfall (cm)	Bad years: Percentage deviation from the mean	Good years: Year	Good years: Rainfall (cm)	Good years: Percentage deviation from the mean
1	1868	78.72	−11.3	1892	98.58	11.1
2	1877	70.09	−21.0*	1916	100.13	12.8
3	1899	70.30	−20.0*	1917	106.61	20.1†
4	1901	77.91	−12.2	1933	100.58	13.3
5	1904	78.87	−11.1	1942	102.25	15.2†
6	1905	76.28	−14.1	1956	99.58	12.2
7	1911	78.05	−12.1	1959	99.71	12.3
8	1918	70.16	−20.9*	1961	103.63	16.8†
9	1920	75.01	−15.5*			
10	1941	78.53	−11.5			
11	1951	74.53	−16.0*			
12	1965	71.81	−19.1*			
13	1966	76.54	−13.8			
14	1968	78.12	−12.0			

* Very bad year.
† Very good year.

almost equally bad. The best monsoon year is 1917. It is a strange coincidence that two successive years, 1917 and 1918, are characterized by such an extreme contrast with respect to the performance of the summer monsoon.

4. Trend analysis

The trend analysis of the monsoon rainfall was carried out by utilizing the following statistics:

a. Student's t-test and the Mann-Whitney rank test statistics

For this study, the data were considered for the two periods, i.e., 1866–1917 and 1918–70. The significance of the difference between the means for these two periods has been tested (Snedecor and Cochran, 1967). The calculated statistics are given in Table 3. It is observed that the coefficients of variation for these two periods are the same and that there is a general increase of 2% in the mean. This increase from the first half to the second half is not statistically significant.

The data series was further examined for the standard blocks of 30 years as recommended by WMO. The present 105 years consists of three standard 30-year blocks, (i) 1871–1900, (ii) 1901–30 and (iii) 1931–60. For all these blocks, various statistics were calculated and are given in Table 3. The mean rainfall varies from 87.53 to 91.81 cm, the increase in the mean from the block 1901–30 to the block 1931–60 being statistically significant at the 5% level.

It can also be seen that the mean for the standard 30-year period 1931–60 is also significantly higher than that for the standard 30-year period 1871–1900.

The three standard 30-year block averages were tested with the 105-year mean. The calculated t values of the blocks 1871–1900, 1901–30 and 1931–60 are −0.635, −1.012 and +2.386, respectively. The value for the block 1931–60 is significant at 5% level. This shows that the average of the block 1931–60 is significantly higher than the overall mean.

It is thus seen that the standard 30-year period, 1931–60, which has been adopted by WMO for working out normals of meteorological elements is one with significantly higher rainfall as compared to the 105-year mean as far as India is concerned.

We next determined for which 30-year period the mean and standard deviation were highest and lowest; 1933–62 had the highest average rainfall of 92.40 cm and 1876–1905 the lowest average rainfall of 86.48 cm. As far as the standard deviation is concerned, the highest was 9.32 cm for the 30-year period 1891–1920, which included the four years (1899, 1917, 1918 and 1920) with large deviations of rainfall from normal and the lowest of 5.43 cm was for the period 1921–50.

b. Cramer's test for decadal averages

Decadal averages were examined to see if they differ from the mean of the entire period by applying Cramer's test. Table 4 gives the different statistical parameters for each decade. It is observed that the coefficient of variation is lowest in the decade 1881–1890 and the highest in 1911–20. There is a continuous increase of decadal mean from 1921–30 onward to 1941–50. These three decades were characterized by rather low coeffi-

TABLE 3. Student's t-test and Mann-Whitney rank statistic test for the period 1866–1970.

	Mean (cm)	Standard deviation (cm)	Coefficient of variation (%)	Student's t-statistic	Mann-Whitney statistic	Difference of means (cm)	Difference of means (percent)
1866–1917	87.81	7.50	8.5				
1918–1970	89.68	7.67	8.6	+1.250	+1.568	+1.87	+2.1
1871–1900	87.99	6.74	7.9				
1901–1930	87.53	8.36	9.6	−0.226	−0.147	−0.46	−0.5
1931–1960	91.81	6.37	6.9	+2.189*	+2.188*	+4.28	+4.6

* Significant at the 5% level.

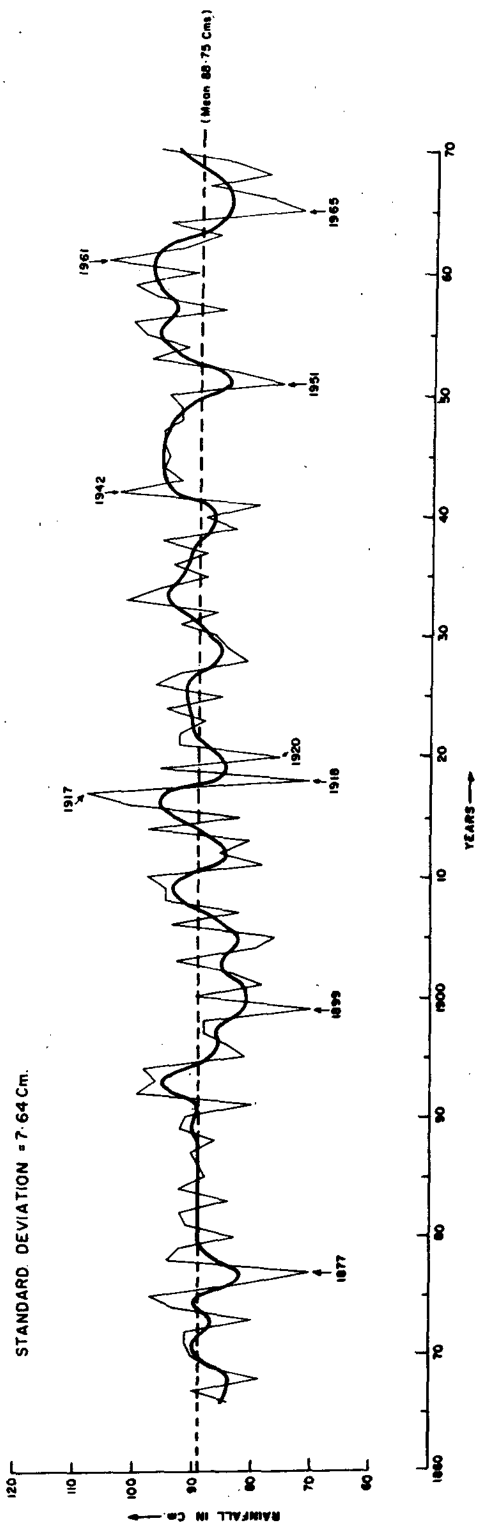

FIG. 6. Actual and filtered monsoon rainfall of India from 1866 to 1970—long homogeneous series.

cients of variation. The difference in the means for the decade 1941–50 and for the whole series is near the 5% significance level. The decade means are not significantly different from the overall mean.

While the standard decade mean has increased from 1921 to 1950, it decreased after 1950, the maximum decrease being 4.41 cm from the decade 1951–60 to the decade 1961–70. Thus no significant increasing or decreasing trend in the standard decade mean has been found in the period 1871–1970.

We examined the series for the highest and lowest 10-year averages and standard deviations. The highest average is 95.22 cm for the 10-year period 1953–62 and the lowest, 82.88 cm, for the period 1896–1905. The highest standard deviation of 12.01 cm is for the period 1911–20 which included three years (1917, 1918 and 1920) with large deviation of rainfall from normal and the lowest of 2.95 cm for the period 1881–90.

c. Low-pass filter

It was observed from earlier studies that some changes in rainfall have taken place during the course of years. In order to understand these changes, the long homogeneous series has been passed through a low-pass filter as suggested in WMO Technical Note No. 79 (1966) and used by Tyson *et al.* (1975). The low-pass filter curve along with the actual rainfall of India is shown in Fig. 6. It is observed from this figure that the rainfall was much below normal for 13 years from 1895–1907. Rainfall was good in the years from 1878–1894 and from 1931–1964 except in one or two years when it was below normal.

5. Power spectrum analysis

The long homogeneous series was subjected to power spectrum analysis by following the procedure given in WMO Technical Note No. 79. To achieve satisfactory resolution in the spectrum we chose five different maximum lags m, i.e. 20, 25, 30, 35 and 40, and subjected the series to spectrum analysis. Fig. 7 shows the spectral results for a maximum lag m of 30 along with the correlogram. The correlogram indicates that the 14th autocorrelation is significant at the 5% level. The spectrum shows a significant (at 5% level) cycle in the class interval of 2.3–2.8 years. This cycle may be taken as the quasi-biennial oscillation (QBO). The presence of the QBO in Indian rainfall is not uncommon. Jagannathan and Parthasarathy (1973) have shown the presence of a QBO in the annual rainfall at many stations in India and Parthasarathy and Dhar (1974) have shown the existence of a QBO in the annual rainfall of some meteorological subdivisions of the country. The analysis made here of the monsoon rainfall of India as a whole supports this finding.

TABLE 4. Statistical parameters for each standard decade for the series 1866–1970.

Standard decade	Average (cm)	Standard deviation (cm)	Coefficient of variation (%)	Cramer's test statistic t_k	Difference of decadal mean from over-all average of 88.75 (cm)
1871–1880	87.07	8.32	9.6	−0.293	−0.68
1881–1890	89.61	2.94	3.3	+0.233	+0.54
1891–1900	87.01	8.51	9.8	−0.752	−1.74
1901–1910	86.83	7.95	9.2	−0.830	−1.92
1911–1920	86.89	12.01	13.8	−0.804	−1.86
1921–1930	88.90	4.76	5.4	+0.065	+0.15
1931–1940	90.87	5.23	5.8	+0.917	+2.12
1941–1950	93.17	5.90	6.3	+1.960*	+4.42
1951–1960	91.40	8.36	9.1	+1.150	+2.65
1961–1970	86.99	9.79	11.3	−0.761	−1.76

* Near significance point at the 5% level. This is defined as

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

where $A_k=(\bar{x}_k-\bar{\bar{x}})/s$, $\bar{\bar{x}}$ is the mean of the series 1866–1970, s the standard deviation of 1866–1970, $n=10$ years and $N=105$ years.

6. Relationship with sunspot cycle

The possible relationship of solar activity to various tropospheric phenomena such as the temperature, atmospheric pressure, precipitation, etc., has been a matter of interest to investigators. Here we have correlated the long homogeneous series with the Zurich relative sunspot number. The correlation coefficient between these two series is +0.168, a value which is close to the 5% significance level, *viz.*, +0.164.

We examined the correlation between rainfall series

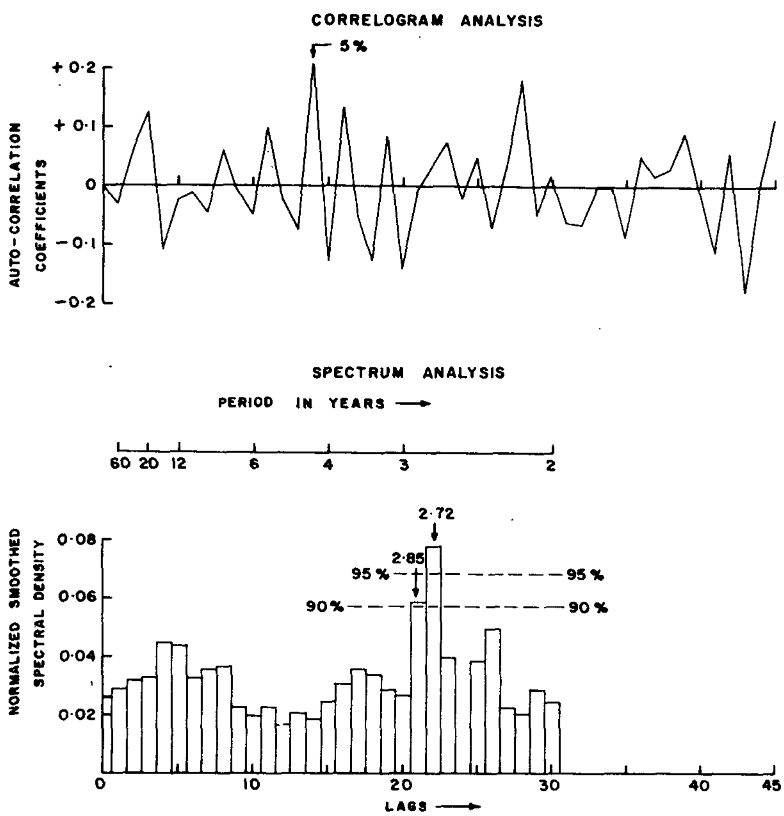

FIG. 7. Correlogram and spectral analysis of monsoon rainfall of India from 1866 to 1970—long homogeneous series.

and the index of solar activity as suggested by Xanthakis (1973) instead of the Zurich sunspot number. He is of the opinion that the relative sunspot number bears little relation to solar activity. Thus he devised a relative area index I_a, defined by $I_a=\frac{1}{2}(A^{\frac{1}{2}}+f^{\frac{1}{2}})$, where A and f are the total areas of sunspots and faculae corrected for foreshortening. He has calculated values of I_a from 1882–1960 which are presented in a table in his paper. The correlation coefficient between rainfall for the period 1882–1960 and I_a is $+0.145$, with a 5% significance of 0.183. However, the correlation coefficient between Zurich sunspot number and monsoon rainfall for the same period is $+0.170$.

It does not, therefore, appear to be possible to conclude that there is a significant relationship between solar activity and monsoon rainfall of India.

7. Conclusions

The following conclusions can be drawn from the statistical analysis of Indian monsoon rainfall for the 105-year period from 1866–1970:

1) The monsoon rainfall series is random and normally distributed, and there is no cause for fear of any disastrous decreasing trend in monsoon rainfall setting in over India.

2) The country had three very good monsoon years i.e., 1917, 1942 and 1961 and six very bad monsoon years, i.e., 1877, 1899, 1918, 1920, 1951 and 1965.

3) There is no significant change in the rainfall average from the first half of the period to the second half.

4) The mean for the standard 30-year block 1931–60 is significantly higher (at the 5% level) than the mean for the total period of 105 years (1866–1970) and the means of the preceding 30-years blocks, 1871–1900 and 1901–30.

5) The mean of the standard decade was very stable during the period 1871–1920, but increased steadily during the period 1921–50; thereafter, it decreased. None of the decade means was significantly different from the mean for the whole period.

6) Power spectrum analysis indicates the presence of a quasi-biennial oscillation.

7) There does not appear to be any significant relationship between solar activity and the Indian monsoon rainfall.

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