

RESEARCH REPORT

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A STUDY OF TREND AND PERIODICITIES
IN THE SEASONAL AND ANNUAL
RAINFALL OF INDIA

by

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Abstract :

The seasonal and annual rainfall of India have been worked out for each year of the 60-year period from 1901 to 1960 by using the data of about 3,000 raingauges distributed uniformly all over the country. These time series of rainfall have been intensely studied by subjecting them to the latest statistical techniques. This analysis has brought out that the mean annual rainfall is 119 cms with a standard deviation of 9.5 cms. Fisher's measures of Skewness (g_1) and Kurtosis (g_2) are not significantly different from those for the normal distribution. Chi-square test also generally confirms that the frequency distribution of these time series is normal for the seasonal and annual rainfall distributions. Significant increase of 5 percent in 30 years' mean is observed in the southwest monsoon and the annual rainfall. However, the increase of 6 percent in the post monsoon rainfall is not statistically significant. Power spectrum analysis has revealed the presence

of 2.3 to 2.5 years' cycle and a weak cycle of about 10 to 15 years.

1. Introduction :

Studies of large scale changes in atmospheric phenomena over wider areas especially in rainfall and temperatures are pre-requisite for any planning and development of a country's natural resources. Regional variations of annual rainfall for British Isles were studied by Gregory (1956) and for Japan by Suzuki (1968). In this country, variations in the annual rainfall for some selected stations have been studied by Jagannathan and Parthasarathy (1973). Recently, Parthasarathy and Dhar (1974) have studied secular variations of annual rainfall of the 31 meteorological sub-divisions of India excluding the two island sub-divisions of Arabian sea and Bay of Bengal. In the present paper, seasonal and annual rainfall of the country as a whole has been taken up for a detailed study.

The year as a whole has been divided into four different seasons by the Indian meteorologists as per weather conditions prevailing in this country. The different seasons are (i) winter (January and February), (ii) summer (March to May), (iii) southwest monsoon (June to September) and (iv) post monsoon (October to December). The seasonal and annual rainfall have been worked out for the country as a whole for each year of the 60-year period from 1901 to 1960. The data of about 3,000 raingauges have been utilized in the

present study. This study could not be brought upto 1970 as rainfall data of all the 3,000 raingauges are not available in published form for all the meteorological sub-divisions of the country beyond 1960 or so.

2. Statistical parameters of seasonal and annual rainfall :

2.1 Mean rainfall and standard deviation :

Mean seasonal and annual rainfall have been worked out for the entire country on the basis of about 3,000 raingauge stations uniformly spread all over the country for each year of the 60-year period from 1901 to 1960. Taking into consideration all the rainfall stations in a meteorological sub-division for a particular season/year, average rainfall for that sub-division was first worked out for the different seasons as well as year as a whole. In this way, average rainfall of all the sub-divisions of the country (vide Fig.1) was worked out for each season/year of the 60-year period. Knowing the areas of each sub-division, weighted mean rainfall for different seasons and year as a whole were worked out for the entire country for each year of the 60-year period. From the 60-year series of seasonal/annual rainfall of India, various statistical parameters were worked out and the same are given in Table-1. From this table, it is observed that the mean annual rainfall of the contiguous Indian area

is about 118.8 cms with a standard deviation of 9.5 cms and coefficient of variation is 8 percent. It is also observed that about 75 percent of mean annual rainfall occurs in the southwest monsoon season, and hardly 11 and 10 percent respectively occurs in summer and post monsoon seasons. The winter months of January and February receive only 4 percent of the mean annual rainfall. The coefficient of variation values are the highest for the winter and post monsoon seasons for the country as a whole.

Table-1 : Statistical parameters of Indian rainfall.

	Winter season	Summer season	Sw monsoon season	Post monsoon season	Annual
Mean (cm)	4.15	12.72	89.71	12.23	118.82
Percentage of annual	3.5	10.7	75.5	10.3	100.00
Lowest value (cm) corresponding year	1.10 (1902)	8.56 (1922)	70.16 (1918)	5.27 (1908)	96.10 (1918)
Highest value (cm) corresponding year	7.20 (1906)	16.89 (1933)	106.61 (1917)	20.86 (1956)	144.64 (1917)
Standard Deviation (cm)	1.48	2.14	7.78	3.60	9.55
Coeff. of variation	35.6 p.c.	16.8 p.c.	8.6 p.c.	29.4 p.c.	8.0 p.c.
Skewness (g_1)	+0.160	+0.188	-0.382	+0.556	+0.154
Kurtosis (g_2)	-0.597	-0.974	-0.444	-0.067	+0.121
$g_1/SE(g_1)$	+0.533	+0.626	-1.271	-1.850	+0.512
$g_2/SE(g_2)$	-0.892	-1.566	-0.618	+0.055	+0.392
χ^2 Statistic } Value	10.65	13.93	10.67	17.51*	1.70

Note : * shows significance at 5 percent level.

2.2 Extreme rainfall and the corresponding years :

The average annual rainfall of the 60-year period was examined in order to have an idea of the extreme values of annual rainfall of the country. From these statistics, the five wettest and driest years have been picked out and these are shown in Table-2.

Table-2 : Wettest and driest years of the country.

Serial Number	Wettest years			Driest years		
	Year	Annual rainfall (cms)	Percentage of mean annual	Year	Annual rainfall (cms)	Percentage of mean annual
1.	1917	144.6	121.7	1918	96.1	80.9
2.	1956	139.6	117.5	1920	100.4	84.4
3.	1933	136.3	114.7	1905	102.8	86.5
4.	1955	133.8	112.6	1941	105.6	88.9
5.	1959	132.7	111.7	1901	106.2	89.4

From Table-2, it is seen that the wettest year of 1917 was immediately followed by the driest year of 1918. In the case of five wettest years the percentage excess of rainfall varies from 12 to 22 while in the case of driest years the percentage deficiency varies from 11 to 19 of the mean annual. More details regarding monthly and annual statistics of Indian rainfall are available in the studies of Dhar, Parthasarathy and Ghose (1974).

2.3 Frequency distribution of seasonal/annual rainfall :

It is essential to know the nature of the frequency distribution of any time series under consideration for the application of different statistical tests. The series of seasonal and annual rainfall were tested for normality by Fisher's statistics g_1 and g_2 , where $g_1 = m_3^{3/2}$ (skewness) and $g_2 = m_4 / m_2^2$ (Kurtosis), m_2 , m_3 and m_4 being second, third and fourth moments, and these were compared with their respective standard errors (SE) as shown in the equations (1) and (2) below :-

$$\frac{g_1}{SE(g_1)} = \frac{m_3}{m_2^{3/2}} \sqrt{\frac{(N+1)(N+3)}{6(N-2)}} \dots (1)$$

$$\frac{g_2}{SE(g_2)} = \left[\frac{m_4}{m_2^2} - 3 + \frac{6}{(N+1)} \right] \sqrt{\frac{(N+1)^2 + (N+3)(N+5)}{24N(N-2)(N-3)}} \dots (2)$$

In all the cases, the values of $g_1/SE(g_1)$ and $g_2/SE(g_2)$, given in Table-1, are found to be less than 1.96. Hence none of these values of g_1 and g_2 is significant at 5 percent level. Thus as judged by the significance of g_1 and g_2 , the seasonal and annual rainfall of India as a whole is normal.

To confirm the normality of the time series, Chi-Square test (χ^2 test) has also been applied to the annual and

seasonal rainfall data of India. The equation used in applying Chi-Square test is as follows :-

$$\chi^2 = \sum \frac{(o_i - e_i)^2}{e_i} \text{ or } \sum \frac{o_i^2}{e_i} - N \quad \dots (3)$$

In Eq.(3) χ^2 is Chi-Square statistic, o_i is observed and e_i is expected frequencies of the i th class. The time series of seasonal and annual rainfall have been normalised (i.e. with zero mean and standard deviation as one) and their corresponding frequencies have been arranged into 10 different classes and their respective

χ^2 statistic have been worked out and are given in Table-1. The degrees of freedom are 7 and χ^2 value at 5 percent level should be 14.1. However, the χ^2 values for all the seasons except for post-monsoon season and for the annual rainfall are less than 14.1. For the post-monsoon season, the chi-square value is 17.5 which is significant at 5 percent level. Hence, for all practical purposes the Indian rainfall for the period of 1901 to 1960 is normal and as such all statistical tests which imply normality of distribution can be applied to these time series.

3. Trend analysis :

The trend analysis of the average seasonal/annual

rainfall of India for the 60-year period from 1901 to 1960 was carried out using the following statistical tests :-

3.1 Mann-Kendall rank statistic :

The most likely alternative to randomness in a climatic time series, is some form of a trend which may be linear or non linear. It is, therefore, necessary to use tests of randomness to check the trend. Mann-Kendall rank method has been suggested as a powerful test by Kendall and Stuart (1961). In this case the statistic τ was computed by using the following equation :-

$$\tau = \pm \frac{4 \sum_{i=1}^{i=N-1} n_i}{N(N-1)} - 1 \quad \dots (4)$$

where n_i is the number of values larger than i -th values in the series subsequent to its position in the time series. For N more than 10, τ is distributed normally with mean zero and standard deviation is :

$$\sqrt{\frac{4N + 10}{9N(N-1)}} \quad \dots (5)$$

The significance of τ was tested. As τ could be positive or negative, a two-tailed significance test was applied.

The values of T and their significance are given in Table-3. It is seen that T is significant for south-west monsoon seasonal rainfall at 5 percent level and for annual rainfall at 1 percent level. In both these cases an increasing trend is seen.

Table-3 : Mann-Kendall rank statistic test and student's t-test results.

	Winter	Summer	SW- monsoon	Post- monsoon	Annual
Man-Kendall rank Statistic value	-0.0604	+0.0903	+0.2169*	+0.1124	+0.2440**
<u>Value of 1901 to 1930</u>					
Mean (cm)	4.19	12.49	87.54	11.54	116.07
Standard Deviation (cm)	1.557	2.286	8.365	3.815	9.572
Coeff. of Variation	37.1 p.c.	18.3p.c.	9.6p.c.	32.2p.c.	8.2 p.c.
<u>Values of 1931 to 1960</u>					
Mean (cm)	4.12	12.94	91.88	12.62	121.57
Standard Deviation (cm)	1.405	1.959	6.471	3.333	8.701
Coeff. of Variation	34.1p.c.	15.1p.c.	7.0p.c.	26.4p.c.	7.2p.c.
Diff. of means of 1931-60 and 1901-30 in cms	-0.07	+0.45	+4.33	+0.77	+5.49
Percentage of Dff.	-1.8	±3.6	±4.8	±6.4	±4.6
Student's t-value	+0.195	-0.811	-2.209*	-0.826	-2.287*

Note : ** Significant at 1 percent level.

* Significant at 5 percent level.

3.2 Student's t-test :

The World Meteorological Organization (WMO) have recommended the use of 30-year averages (i.e. 1871-1900, 1901-30 and 1931-60, etc.) for the interpretation of climatological normals. In the present study the rainfall series of the period 1901 to 1960 was broken into two equal periods, 1901-30 and 1931-60. The significance of difference of the mean between the first and the second period was tested by Student's t-test and the magnitude of the gradient ascertained. Table-3 gives the statistics regarding the means, standard deviation, coefficient of variation of the two periods, the differences of the means for the two periods, percentage of change per 30 years and Student's t-value for the seasonal and annual rainfall of the country. From Table-3 it is observed that SW monsoon season and annual rainfall changes are statistically significant at 5 percent level. Percentage of change varies from -2 percent to +6 percent. Though the change for 30-year mean is +6 percent in post monsoon season, it is not significant because of very high coefficient of variation.

3.3 Decadal Averages :

The decade averages have been examined to see if they differ from the mean for the entire period by applying Gramer's test. Table-4 gives the following statistical parameters for

each decade. (i) Average (\bar{x}_k), (ii) Standard deviation (s_k), (iii) coefficient of variation and (iv) Cramer's test statistic (t_k) where

$$t_k = \left[\frac{n(N-2)}{N-n(1+A_k^2)} \right]^{\frac{1}{2}} A_k \dots (6)$$

where n is number of years in sub-group i.e. 10 years in present case and S is standard deviation of whole series.

$$\text{and } A_k = \frac{\bar{x}_k - \bar{x}}{s}$$

From the Table-4 it is observed that there is a gradual increase of decadal averages in SW monsoon and annual rainfall from first to last decade except the last decade (1951-60). The standard deviation of decade 1911 to 1920 is very high in the case of SW monsoon and annual rainfall because of the occurrences of extreme rainfall (i.e. wettest and driest years) in this decade. Decadal coefficient of variation are large in winter and post monsoon seasons indicating thereby the unreliability of rainfall in these two seasons. Cramer's test value

t_k (i.e. comparison of decadal average with the mean of the whole series), is slightly smaller than the value significant at 10 percent level in decade 1951-60 of winter, 1941-50 of SW monsoon, and in 1901-10 of post monsoon and annual rainfall.

Table-4 : Statistical parameters for each decade.

	Winter	Summer	SW Monsoon	Post Monsoon	Annual
<u>Decadal Averages</u>					
1901=1910	4.16	12.09	86.83	10.17	113.26
1911=1920	4.21	13.46	86.89	12.86	117.43
1921=1930	4.21	11.93	88.89	12.49	117.53
1931=1940	4.25	12.50	91.06	12.45	120.28
1941=1950	4.65	13.14	93.17	11.70	122.87
1951=1960	3.45	13.19	91.40	13.70	121.75
<u>Decadal Std. Dev.</u>					
1901=1910	1.99	2.06	7.55	3.80	7.64
1911=1920	1.45	2.06	11.39	4.14	14.04
1921=1930	1.07	2.39	4.51	2.77	2.68
1931=1940	0.83	2.28	5.37	2.68	7.59
1941=1950	1.40	1.82	5.59	3.22	7.06
1951=1960	1.57	1.62	7.93	3.69	10.80
<u>Decadal Coeff. of variation in p.c.</u>					
1901=1910	47.9	17.0	8.6	37.4	6.7
1911=1920	34.6	15.3	13.1	32.2	11.9
1921=1930	25.5	20.0	5.0	22.2	2.2
1931=1940	19.7	18.3	5.8	21.5	6.3
1941=1950	30.2	13.8	6.0	27.5	5.7
1951=1960	45.7	12.3	8.6	26.9	8.8

(Table 4 continued)

Decadal t_k value

1901-1910	+0.004	-1.010	-1.274	-2.015	-2.055
1911-1920	+0.122	+1.191	-1.250	+0.603	-0.497
1921-1930	+0.135	-1.275	-0.355	+0.243	-0.459
1931-1940	+0.220	-0.348	+0.595	+0.214	+0.522
1941-1950	+1.156	+0.682	+1.543	-0.502	+1.397
1951-1960	-1.560	+0.708	+0.697	+1.325	+0.988

Note : ♦ values slightly less than 10 percent significant level.

● significant at 5 percent level.

3.4 Low-pass filter :

To understand the nature of the trend, the series were also subjected to a 'low-pass filter' in order to suppress the high frequency oscillations. The weights used were nine ordinates of the Gaussian probability curve (i.e. 0.01, 0.05, 0.12, 0.20, 0.24, 0.20, 0.12, 0.05 and 0.01). The response curve of the Gaussian low-pass filter has a response function that is equal to unity at infinite wavelength and it tails off asymptotically to zero with decreasing wave lengths. The response is approximately given by the equation (WMO-1966) :

$$R(f) = \exp (- 2 \pi^2 \sigma_g^2 f^2) \quad \dots (7)$$

where σ_g is the appropriate standard deviation, i.e.

6 $\sigma_g = 10$ years. It is observed from the filtered series

that the trend is not linear but oscillatory consisting of periods of 10 years length or more. The low-pass filter curves along actual rainfall values of different seasons and annual rainfall are shown in Figure-2.

4. Power spectrum analysis :

Time series of average seasonal and annual rainfall were subjected to power spectrum analysis in order to see the periodicities, if any. The method followed is that of Blackman and Tukey (1958) as given in the WMO Technical Note No.79 (1966). The analysis is carried out in three steps on a given time series of N equally spaced values of the variate x.

- (i) Computation of auto-correlation coefficient of series for lags zero to m, is given by the formula :-

$$r_L = \frac{(N-L) \sum x_i x_{i+L} - (\sum x_i \sum x_{i+L})}{\sqrt{[(N-L) \sum x_i^2 - (\sum x_i)^2] [(N-L) \sum x_{i+L}^2 - (\sum x_{i+L})^2]}} \quad \dots (8)$$

where r_L = auto-correlation coefficient,

N = Number of years of data,

x_i = Variate in 'i'th term,

L = Period of lags = 0, 1, 2, 3, 4 ... m

(ii) The cosine transforms of these $m + 1$ auto-correlation coefficients, are computed to obtain $m + 1$ raw spectral estimates of power spectrum.

$$B_0 = \frac{1}{2m} (r_0 + r_m) + \frac{1}{m} \sum_{L=1}^{L=m-1} r_L \quad \dots (9a)$$

$$B_i = \frac{r_0}{m} + \frac{2}{m} \sum_{L=1}^{L=m-1} r_L \cos \left(\frac{\pi i L}{m} \right) + \frac{r_m}{m} (-1)^i \quad \dots (9b)$$

$$B_m = \frac{1}{2m} \left[r_0 + (-1)^m r_m \right] + \frac{1}{m} \sum_{L=1}^{L=m-1} (-1)^L r_L \quad \dots (9c)$$

where B_0 is spectral estimate for zero lag and B_m for the maximum lag of 'm' time units.

(iii) The final spectral estimates are obtained by smoothing the raw estimates by a 3-term weighted average. The weights are equal to 0.25, 0.50 and 0.25 (known as Wamming method). The smoothing formulas are respectively as under :-

$$S_0 = 0.50 (B_0 + B_1) \quad \dots (10a)$$

$$S_i = 0.25 B_{i-1} + 0.50 B_i + 0.25 B_{i+1} \quad \dots (10b)$$

$$S_m = 0.50 (B_{m-1} + B_m) \quad \dots (10c)$$

The trend analysis carried out earlier has shown that there is some trend in the series. This means that power is contained in a very few narrow bands. Such bands can cause errors in the spectral estimates where there is less power (Jenkins and Watts-1968). Hence, it may be advantageous to filter the data digitally in order to improve the spectral estimates at these frequencies. In this study the 'digital difference filter' has been employed to remove low frequency oscillations. A difference filter is defined by the following equation :-

$$y_t = x_t - x_{t-1} \quad \dots (11)$$

where y_t is the filtered series and x_t is the unfiltered series. The frequency response function of this filtered series is given by the following equation (Jenkins and Watts) :-

$$R(f) = 2 j \exp (- j \pi f) \sin \pi f \quad \dots (12)$$

where j is $\sqrt{-1}$ and f is the frequency. This acts as a 'high-pass filter.' The original rainfall series were filtered through this filter and the filtered series thus obtained were subjected to power spectrum analysis. To achieve satisfactory resolution in the spectrum, the maximum lag m has been chosen as 15. The null hypothesis for the purpose of the significance of power in the spectrum was considered in accordance with the fact whether the series revealed any persistence

or not. In most of the present series ~~there~~ is no 'Markow-linear' type persistence. If the lag one correlation coefficient was equal or greater in magnitude than the required value for significance but higher lag correlation did not taper off exponentially, the spectral estimates in the first half of the lags were tested with reference to the red-noise spectrum and the rest against white-noise spectrum. This was the case in the time series of post monsoon rainfall. In the absence of any persistence, the spectral estimates were tested against white-noise spectrum. All the filtered series and unfiltered series of Indian rainfall except post monsoon rainfall have been tested for significance against white-noise spectrum.

Table-5 : Power spectrum results

Season	Significant cycle in years	
	without filter	with using the filter
Winter	7.50*	2.30*
	6.00*	2.14*
	5.00	2.00*
	2.30	
Summer	3.75*	3.75*
	2.50	2.72*
		2.50*

SW Monsoon	10.00*	2.72*
	2.30*	2.50**
		2.30**
		2.14*
Post Monsoon	15.00*	3.33
	7.50	3.00*
	3.00*	2.50*
		2.30*
Annual	10.00	2.50*
	3.33	2.30**
	2.30	2.14*

Note : ** Significant at 1 percent level.
 * Significant at 5 percent level.
 Remaining values are significant
 at 10 percent level.

The results of the power spectrum analysis of original and filtered series results, which are significant at 10 percent, 5 percent and 1 percent levels, are only shown in Table-5. It is seen from the Table-5 that a cycle of 2.3 to 2.5 years is seen in all the series of rainfall, more prominently in the filtered data. Another cycle of 10 to 15 years is also observed in the original series for south west monsoon, post-monsoon and annual rainfall. There are two well known oscillations in the meteorological elements, they are (i) Quasi-biennial oscillation (QBO) and (ii) Solar cycle (Sunspot cycle). Existence of QBO as world wide phenomena in surface meteorological parameters is well established by Landsbers (1962).

In Indian rainfall, the QBO was observed for West Coast stations of India by Koteswaram and Alvi (1969), Bhargava and Bansal (1969), Jagannathan and Parthasarathy (1973). This QBO is also seen by Bhalme (1972) in annual frequencies of cyclonic disturbances (storms/depressions) of Bay of Bengal and in Palmer drought indices of various sub-division of India by Rao et al (1973). Thus the analysis made here supports the findings of the other ~~researchers~~ research workers. Studies in the regional rainfall of Madras (Tamil Nadu) by Sen Gupta (1957) showed that an increase of sunspot activity is associated with the decrease of rainfall and vice-versa. However, Jagannathan and Bhalme (1973) showed an increase in SW monsoon rainfall at a number of north Indian sub-divisions especially along the foot of the Himalayas. The studies of Koteswaram and Alvi (1969) for a few stations along the West Coast of India also show the effect of solar cycle on SW monsoon rainfall. Rao et al (1973) showed the presence of solar cycle in Palmer drought indices for certain sub-divisions of the country. This study also indicates the presence of a weak solar cycle (significant at 10 percent level) in Indian rainfall. Studies have also been made of time series of Indian rainfall and sunspot numbers by subjecting them to cross correlation analysis

of different lags which have not yielded any fruitful results. However, this fact requires further examination.

5. Conclusions :

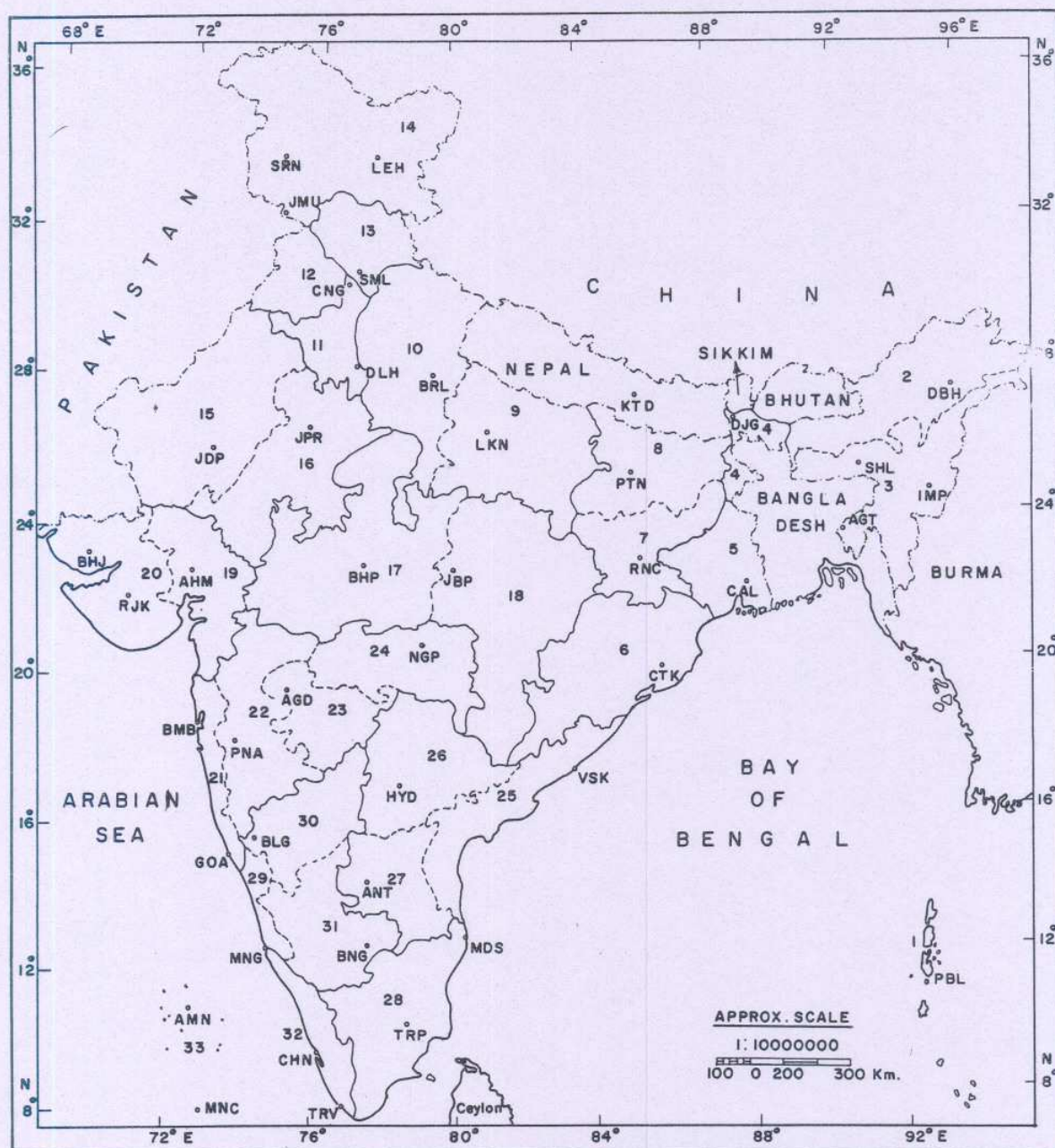
The analysis carried out with about 3,000 raingauges for the period of 1901 to 1960 has shown that the mean annual rainfall for the whole country is 119 cms with a standard deviation of 9.5 cms. 75 percent of the annual rainfall occurs in southwest monsoon season whereas 11 percent and 10 percent respectively occurs in summer and post monsoon seasons. The coefficient of variation is very high in winter and post monsoon seasons. The frequency distribution of time series of seasonal and annual rainfall are normally distributed. Significant increase of 5 percent in mean SW monsoon and annual rainfall in 30 years (Viz. 1931-60) has been noticed. However, 6 percent increase in post monsoon rainfall is not statistically significant because of high coefficient of variation in this season. Cramers' test indicates that the mean of the decade 1901 to 1910 for post monsoon and annual rainfall are significantly different from the overall mean for the 60-year period. Power spectrum analysis shows QBO and a weak solar cycle.

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|---|---|---|---------------------------------------|
| 1 Bay Islands | 9 East Uttar Pradesh | 17 West Madhya Pradesh | 25 Coastal Andhra Pradesh |
| 2 North Assam (Including Nefu) | 10 West Uttar Pradesh | 18 East Madhya Pradesh | 26 Telangana |
| 3 South Assam (Including Nagaland, Manipur & Tripura) | 11 Haryana (including Chandigarh & Delhi) | 19 Gujarat Region (including Daman, Dadra & Nagar Haveli) | 27 Rayalaseema |
| 4 Sub-Himalayan West Bengal | 12 Punjab | 20 Saurashtra and Kutch (including Diu) | 28 Tamil Nadu including (Pondicherry) |
| 5 Gangetic West Bengal | 13 Himachal Pradesh | 21 Konkan (including Goa) | 29 Coastal Karnataka |
| 6 Orissa | 14 Jammu and Kashmir | 22 Madhya Maharashtra | 30 North Karnataka |
| 7 Bihar Plateau | 15 West Rajasthan | 23 Marathwada | 31 South Karnataka |
| 8 Bihar Plains | 16 East Rajasthan | 24 Vidarbha | 32 Kerala |
| | | | 33 Arabian Sea Islands |

FIGURE - I : METEOROLOGICAL SUB-DIVISIONS OF INDIA AS ON 1st. JANUARY 1971.

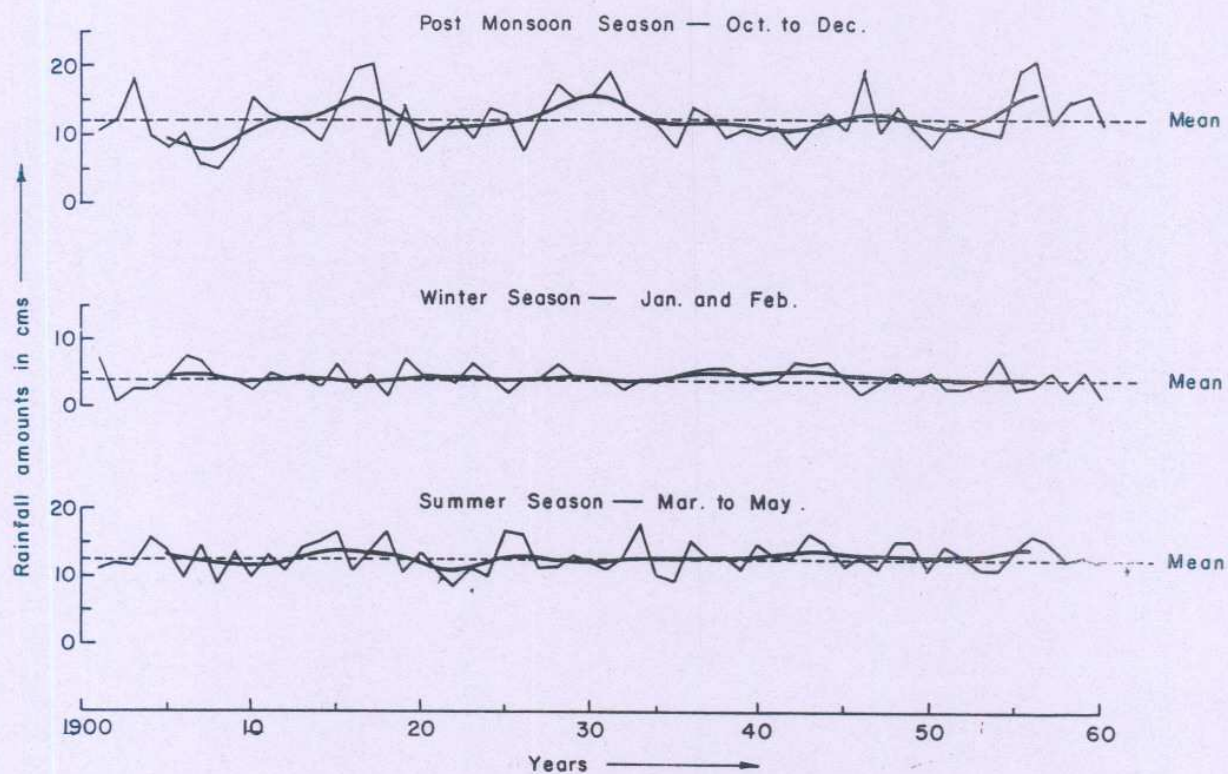


Fig. 2(a) : Actual and filtered (Low-pass) rainfall serie of India.

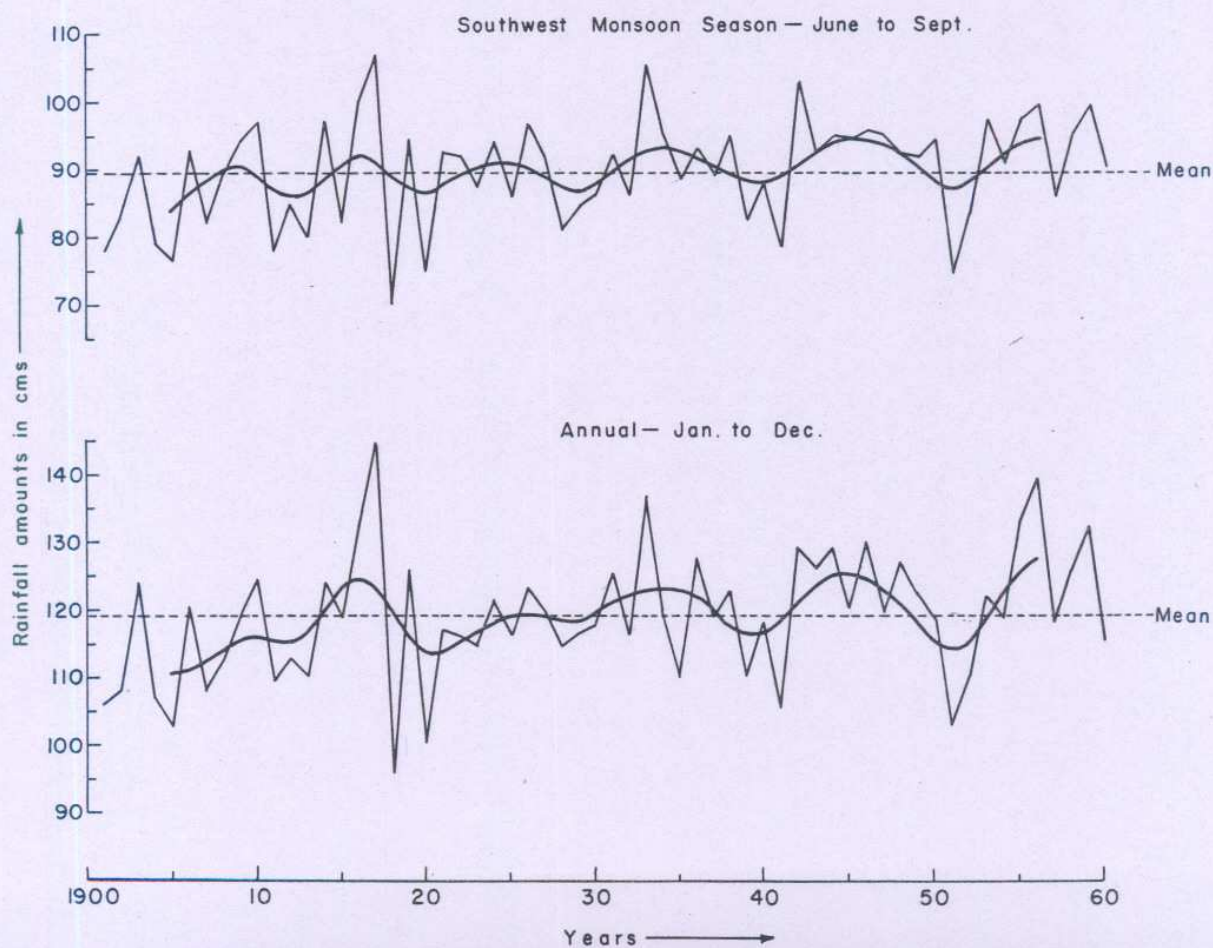


Fig. 2(b) : Actual and filtered (Low-pass) rainfall series of India.