551.577.33

Trends and periodicities in sub-divisional rainfall

S. K. SUBRAMANIAN, S.V. PALANDE*, B.N. DEWAN*,

S. K. DIKSHIT* and LAWRENCE JOSEPH*

Regional Meteorological Centre, Madras

सार — वार्षिक वर्षा अनुक्रम और मानसून की प्रवृत्ति और आवर्तन के अध्ययन के लिए 35 मौसम वैज्ञानिक उपखण्डों के 87 वर्षों की अवधि (1901 - 1987) के मासिक और वार्षिक वर्षा आंकड़ों का प्रयोग किया गया । अयादृच्छिकता (नॉनरैंडमनेस) का परीक्षण करने के लिए वर्षा अनुक्रम के साथ बहुत से बटन निरपेक्ष सांख्यिकी परीक्षण प्रयुक्त किए गए हैं । दशकवार माध्यों की सम्पूर्ण अवधि के माध्यों से तुलना यह दर्शाती है कि समूचे देश के लिए वार्षिक वर्षा चार विभिन्न जलवायु विषयक अवधियों की ओर संकेत करते हैं । 1960 – 1965 और 1975 से आगे सामान्य वर्षा से अधिक की दो अवधियां और 1901 - 1915 और 1965 - 1975 से सामान्य वर्षा से कम की दो अवधियां, जबकि मानसून वर्षा दो विभिन्न जलवायु-विषयक अवधियां दर्शाती है — 1901 - 1920 से सामान्य वर्षा से कम की अवधि और 1920 से आगे सामान्य वर्षा से अधिक अवधि । यह अनुक्रम निम्न आवृति फिल्टर (लोपास फिल्टर) के अधीन भी आती थी जो कि कुछ उपखण्डों के लिए महत्वपूर्ण दीर्घ अवधि प्रवृत्ति की उपस्थिति दर्शाती थी । बहुत बड़ी संख्या के उपखण्डों के लिए वार्षिक और मासिक वर्षा अनुक्रम के लिए पॉवर मानावली (स्पेक्ट्रम) 2.1 - 3.6 वर्षा का महत्वपूर्ण आवर्तन दर्शाती है जो कि क्यू बी ओ की बारम्बारता अवधि के सदृश है । इसके अतिरिक्त अनेक उपखण्डों में 5.1 से 10.0 वर्षों और 19.3 वर्षों अथवा अधिक का आवर्तन भी महत्वपूर्ण है ।

ABSTRACT. The monthly and annual rainfall data for 35 meteorological sub-divisions for the 87-year period (1901-1987) have been used to study the trends and periodicities of monsoon and annual rainfall series. A number of distribution-free statistical tests have been applied to the rainfall series for testing non-randomness. Comparison of the decadewise means with the mean of the whole period showed that, for the country as a whole, the annual rainfall indicated four different climatic periods — two periods of above normal rainfall from 1960-1965 and from 1975 onwards and two periods of below normal rainfall from 1901-1915 and 1965-1975 whereas the monsoon rainfall showed two different climatic periods—a period of below normal rainfall from 1901-1920 and a period of above normal rainfall from 1920 onwards. The series were also subjected to low-pass filters which showed the presence of significant long term trend for a few sub-divisions. The power spectrum analysis for the annual and monthly rainfall series for a large number of sub-divisions showed significant periodicities of 2.1-3.6 years, which correspond to the frequency range of the QBO. In addition, periodicities of 5.1 to 10.0 years and 19.3 years or more were also significant for a number of sub-divisions.

Key words — Rainfall variability, Monsoon rainfall, Annual rainfall, Frequency distribution, Climatic variability, Trend, Power spectrum

1. Introduction

Studies on climatic changes over India on the basis of monsoon and annual rainfall have drawn the attention of all the scientists. The trends and periodicities in rainfall series, in a way, explain the changing climatic pattern that we experience over some of the meteorological sub-divisions though the change is not so alarming. Rao and Jagannathan (1963) studied rainfall data covering the period 1875-1955 over 25 meteorological sub-divisions. The study showed some oscillatory/increasing trend in part of series for certain sub-divisions. Parthasarathy and Dhar (1974) had a detailed study for 31 meteorological sub-divisions of India for the period 1901-1960 and they have found that there are a number of contiguous sub-divisions along the western part of the Peninsula which showed an increasing trend in mean annual rainfall. Joseph (1976) identified 3 different rainfall periods in Indian monsoon rainfall during 1891-1974 — two deficient rainfall periods: 1891-1920 and 1965-1974 and one good rainfall period, 1931-1960. Mooley and Parthasarathy (1984) using the residual mass-curve technique of All India

Summer Monsoon for the period 1871-1978 have found four different climatic periods increasing tendency in rainfall during 1878-1898 and 1933-1964 and decreasing tendency in rainfall during 1899-1932 and 1965 onwards. The trends and periodicities of monsoon and annual rainfall have also been studied for some of the states or regions independently by Raghavendra (1973, 1974, 1976, 1980) for NW India, Maharashtra, Andhra Pradesh and Kerala, Parthasarathy et al. (1976) for NW India, Rao (1958) for Rajasthan, Chowdhury and Abhyankar (1976, 1979) for Gujarat, Parthasarathy and Mooley (1981) for Karnataka, Dhar et al. (1982) for Tamilnadu, Koteswaram and Alvi (1969) for the west coast and Soman et al. (1988) for Kerala. All these studies do not indicate any long term climatic change but only random year to year fluctuations in rainfall. A significant evidence for the presence of different periodicities in rainfall series over a wide range of frequencies (very low to high) has, however, been indicated. An attempt has been made in this study, based on the annual and monsoon sub-divisional rainfall series covering the period 1901-1987, to see the prevailing trend in rainfall pattern.

*Address : Meteorological Office, Pune-411005

2. Data

The monthly and annual rainfall data for 35 meteo-rological sub-divisions (Fig. 1) prepared by the India Meteorological Department for the 87—year period (1901-1987) have been made use of for this study. Continuous data for 87 years are available for most of the sub-divisions except the Bay islands and Arunachal Pradesh which have got the data of only 83 and 64 years respectively. Hence for the later part of the discussion which warrant a continuous data set, these two sub-divisions have not been considered.

As these individual sub-divisions are meteorologi-cally homogeneous, it is assumed that the monthly and annual rainfall series obtained for each sub-divisions on the basis of data of a fairly large number of raingauge stations are almost homogeneous though there may be small variations in the actual number of stations consi-dered for individual years.

3. Pattern of sub-division wise rainfall distribution

As per the criterion followed by the India Meteoro-logical Department, a sub-division is said to receive excess rainfall if the percentage departure is 20% or more, normal if the value is between —19% & +19%, deficient if it is between—20% &—59% and scanty if it lies between — 60% & —99%. For a no rainfall situa-tion, the percentage departure will be—100 %.

From the data of individual years for all the sub-divisions, the percentage frequencies were calculated showing the pattern of rainfall distribution for the annual (Jan-Dec) and monsoon (Jun-Sep) periods and have been presented for the three main types of rainfall realisations (excess, normal and deficient) in Table 1.

The noteworthy features are summarised below :

(a) Saurashtra & Kutch (S & K) was the only sub-division whose frequency of excess rain fall is the maximum (>30%), of normal rainfall the minimum (<40%) and of scanty rainfall the maximum (5%) for both the periods.

(b) 16 Sub-divisions had the frequency of excess rainfall between 10 & 20% and 17 sub-divisions had the frequency of normal rainfall between 60 & 80% for both the periods.

(c) If we examine the pattern of changes from monsoon period to annual it may be seen that, there lies an apparent tendency for the annual rainfall in the country to be normal than becoming either excess or deficient as evident from the increase in the number of sub-divisions which had a percentage fre-quency of excess rainfall less than 10% and a corresponding decrease in the number of sub-divisions which had the percentage frequency of deficient rainfall greater than 20%. If the rainfall over the country is exceptionally good during the monsoon period, it is some-what balanced by relatively poorer rain-fall during other seasons or a bad monsoon rainfall is adjusted suitably by a better per-formance in the remaining seasons.
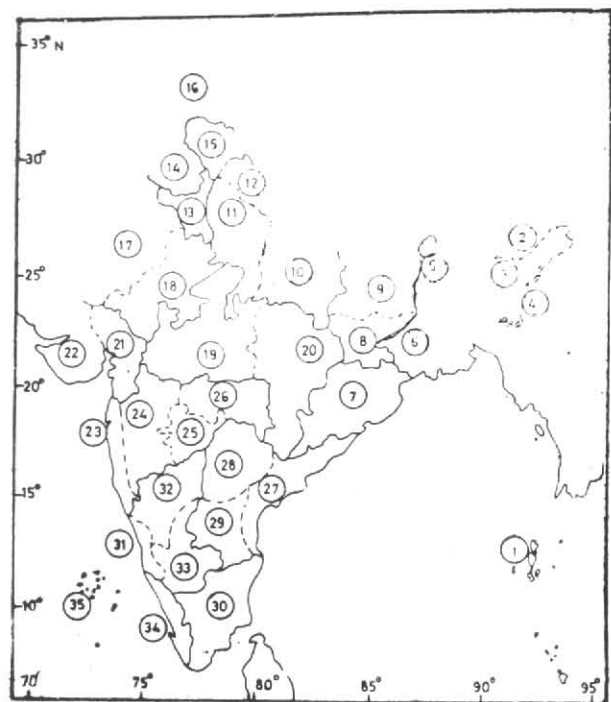

Fig. 1. 35 meteorological sub-divisions of India

TABLE 1

Rainfall type	Percentage frequency (%)	No. of sub-divisions	
		Annual	Monsoon
Excess	>30	1	1
	20 — 30	8	12
	10 — 20	16	16
	<10	10	6
Normal	>80	11	5
	60 — 80	17	17
	40 — 60	6	12
	<40	1	1
Deficient	20 — 30	7	14
	10 — 20	19	15
	<10	9	6

TABLE 2

Period		Sub-division	CV (%)	Mean rain-fall (mm)
Annual	Low	Assam & Megha-laya	9	2443.08
	High	West Rajasthan	39	311.47
Winter	Low	J & K	44	178.96
	High	Konkan & Goa	235	2.10
Pre-monsoon	Low	Assam & Megha-laya	22	619.76
	High	Saurashtra & Kutch	209	8.29
Monsoon	Low	Assam & Megha-laya	9	1594.24
	High	West Rajasthan	41	275.64
Post-monsoon	Low	Kerala	26	522.46
		Tamilnadu	26	477.53
	High	Saurashtra & Kutch	152	24.87

TABLE 3

Month		Sub-division	CV (%)	Mean monthly rainfall (mm)
Jun	Low	Assam & Meghalaya	18	464.8
	High	Saurashtra & Kutch	86	84.1
Jul	Low	Assam & Meghalaya	18	449.5
	High	Rayalaseema	65	91.5
Aug	Low	Assam & Meghalaya	20	379.5
	High	Saurashtra & Kutch	77	122.6
Sep	Low	Assam & Meghalaya	26	300.4
	High	Punjab	108	83.0

4. Variability of annual & seasonal rainfall

The coefficient of variation (%), which is the ratio of the standard deviation to the mean expressed as a percentage, is a good measure of the variability of rainfall.

Based on the sub-divisionwise values of the coefficient of variation for the annual and the four seasons the summarised results for the winter (January-February), pre-monsoon (March - May), monsoon (June-September), post monsoon (October - December) periods and the annual period are given in the Table 2.

Assam & Meghalaya (A & M) sub-division had the minimum variability in respect of pre-monsoon, monsoon & the annual periods, Jammu & Kashmir (J & K) had the minimum variability in case of winter season and Tamilnadu and Kerala, which get bulk of post monsoon (northeast monsoon) rainfall, had the lowest variability for that season.

S & K had the highest variability in the case of pre-monsoon and post-monsoon seasons, west Rajasthan had the highest variability in respect of annual and monsoon periods and Konkan & Goa, which is practically dry during winter months, had the maximum variability for that season.

Monsoon rains form the principal component of rainfall in our country. From the sub-divisionwise values of C.V. for the monsoon months (June-September), a summarised picture for the four months of the monsoon season is given in Table 3.

A & M sub-division had the minimum variability for all four months and the values ranged between 18 & 26%. S & K had the maximum variability of 86 and 77 % in case of June & August rainfall. Rainfall of Rayalaseema sub-division was most variable (65%) in July and Punjab had the maximum variability (108%) in September.

5. Seasonal rainfall contribution towards annual rainfall

The mean percentage contributions of the rainfall of the four seasons to the annual rainfall were worked out for all the sub-divisions.

For the winter season, J & K share 18 % of annual rainfall, the sub-divisions of Himachal Pradesh (HP), Punjab, Haryana and hills of west Uttar Pradesh had the value of about 7-10% and for rest of the sub-divisions, the value was less than 5%.

During the pre-monsoon period J & K contributed 26% to its annual rainfall and Arunachal Pradesh, A & M, Nagaland-Manipur-Mizoram & Tripura (Nagaland etc) had their share in the range 20-25%. Bay islands, Sub-Himalayan West Bengal (SHWB), Gangetic West Bengal (GWB), HP, Rayalaseema, Tamilnadu, north and south interior Karnataka, Kerala and Arabian Sea islands accounted for about 10-15% of their annual rainfall. For rest of the sub-divisions, the values were below 10%.

For all the sub-divisions except Tamilnadu, the monsoon rainfall accounted for bulk of the annual rainfall. 18 subdivisions contributed more than 80%, 15 sub-divisions shared about 50-80%. J & K and Tamilnadu accounted for 46% and 34% respectively for their annual rainfall from this season.

In the post monsoon season, Tamilnadu accounted for 47% of its annual rainfall, coastal Andhra Pradesh and Rayalaseema about 31-32%, Bay islands, north interior Karnataka & Arabian Sea islands about 20-25%, Orissa, J & K, Madhya Maharashtra, Marathwada, Telangana & Kerala about 10-20%. west Rajasthan had the least share of 3% for its annual rainfall from this seaon.

6. Test for normality in sub-divisional rainfall

The first important step in any climatological time series analysis is to establish the probable form of the frequency distribution of the variables in the series. In most cases where the variable does not pertain to an extreme climatological event, the distribution will approach the Gaussian 'Normal' form (WMO 1966).

To test the rainfall series for normality, the procedure is followed using Fisher's statistics g_1 and g_2 which represent the skewness and kurtosis respectively of the frequency distribution (Snedecor and Cochran 1968). It is seen that for the annual rainfall series, the ratios of g_1/S.E. (g_1) and g_2/S.E. (g_2) were significant at 5% level for the sub-divisions Orissa, west Rajasthan and coastal Karnataka which implied that the frequency distribution of these sub-divisions were not normal. In addition, the ratio g_1/S.E. (g_1) was significant for Haryana, Punjab, J & K and Rayalaseema sub-divisions which suggested that the frequency distribution for these sub-divisions were somewhat skewed. The ratio g_2/S.E. (g_2) was significant for SHWB and its positive value indicated that the frequencies near the mode and in the tails were greater than those in the normal distribution.

For the monsoon rainfall series, both the ratios were significant for Nagaland etc, west Rajasthan, Rayalaseema and coastal Karnataka sub-divisions. g_1/S.E.(g_1) was significant for Andaman and Nicobar islands (A & N Islands), Madhya Maharashtra and Kerala and g_2/S.E.(g_2) was significant for A & M, SHWB, Bihar plains and north interior Karnataka sub-divisions.

The rainfall series for other seasons showed significant departure from normality for most of the sub-divisions.

7. Test for randomness

In climatological studies one is concerned with identifying the precise nature and extent of non-randomness and any evidence against randomness is related to some form of climatological fluctuation. So our ability to clearly specify the nature and extent of non-randomness improves our knowledge of the nature of these fluctuations. In time series analysis there is no unique single statistical method that is efficient for identifying all possible alternatives to randomness, *viz.*, persistence, trend, periodic fluctuations etc. A number of tests for randomness (WMO 1966) have, therefore, been applied on the monsoon and annual rainfall series and are described below. Many of these tests are robust and distribution-free and can be used to those frequency distributions that show departure from Gaussian Normal form also.

(a) *Mann-Kendall rank statistic*

This is a powerful test for randomness against trend. The T-values were significant at 5% level for H.P., Telangana, north interior Karnataka and Kerala sub-divisions for both the monsoon and annual rainfall series. In addition the monsoon rainfall series of A & M, SHWB and J & K sub-divisions were also significant.

(b) *Test based on Spearman's rank statistic*

This is another widely used test for randomness against the alternative of trend. For the annual and monsoon rainfall series, it was significant at 5% level for A & M, HP, Telangana, north interior Karnataka and Kerala. It was also significant for monsoon rainfall in respect of Nagaland etc and J & K sub-divisions.

(c) *Von Neumann ratio V*

Whenever the frequency distribution of the series approximates to the Gaussian 'Normal' form, the test based on Von Neumann ratio is used as a test for randomness against unspecified alternatives (WMO 1966). For the annual and monsoon rainfall series, V values were significant at 5% level for Nagaland etc, Madhya Maharashtra, south interior Karnataka and Kerala sub-divisions. They were also significant for HP and north interior Karnataka for monsoon rainfall series.

(d) *Student's t-test*

This test is used to compare the mean values of the series in two different periods of record to detect any abrupt slippage of the mean. This test is robust and can be applied to any arbitrary frequency distribution (WMO 1966).

The rainfall series of 87 years was split into 2 periods, of 44 and 43 years length. This test showed that for the annual rainfall series, the increase in rainfall by about 7-12% during the second half for the sub-divisions of plains of west U.P., Punjab, Konkan & Goa, Telangana, coastal Karnataka and north interior Karnataka were significant at 5% level. These sub-divisions also showed a significant increase in monsoon rainfall by about 7 - 14%. Annual rainfall decreased by about 7 - 14% in the later half of the series in HP, Tamil Nadu and Kerala and monsoon rainfall decreased in HP and Kerala sub-divisions by 9% and 27% respectively which were statistically significant.

(e) *Test based on serial correlation coefficient*

The departure from randomness of a series may also be due to persistence which means that each value of the series is influenced by its immediately preceding value. The significance of the serial correlation coefficient (γ) for lag 1, is a good indicator for the presence of persistence in any time series (WMO 1966).

It is seen that the lag 1 serial correlation coefficient was significant at 5% level for Nagaland etc, J & K, Madhya Maharashtra and south interior Karnataka for annual and monsoon periods. Kerala showed persistence only for annual rainfall and SHWB and HP sub-divisions indicated persistence only for monsoon rainfall.

To summarise, it may be mentioned that the different methods used for testing randomness showed varying results in respect of some of the sub-divisions. This may be due to the fact that the alternative to randomness are not generally same for all these procedures and that for any sub-division, the alternative to randomness may be more than one. On the whole, the sub-divisions Assam & Meghalaya, Nagaland etc. SHWB, HP, J & K, Madhya Maharashtra, Telangana, north interior Karnataka, south interior Karnataka and Kerala showed some sort of non-randomness by at least two of the five methods used.

8. Test for homogeneity of variances

The homogeneity of the rainfall series was tested using Fisher's 'F' statistic defined as $F = s_1{}^2/s_2{}^2$ where $s_1{}^2$ and $s_2{}^2$ are sample variances of sizes n_1 and n_2. The data for 87 years was divided into two parts of sizes 44 and 43 years respectively. Overall changes in climatic variabilities due to inconstancy of the dispersion is reflected by the significance of the test based on variances (WMO 1966).

It is seen that for the annual rainfall series, the F-value was significant at both 5% and 1% level for Gangetic West Bengal, J & K and south interior Karnataka. It was significant at 1% level but not at 5% level for Assam & Meghalaya, Nagaland etc, SHWB, Orissa, Bihar plateau, hills of west Uttar Pradesh, east Rajasthan and coastal Karnataka sub-divisions. For the monsoon rainfall series the value was significant for Nagaland etc, J & K, and south interior Karnataka at both 5% and 1% level whereas it was significant for SHWB, GWB and hills of west Uttar Pradesh at 1% level only.

9. Trend in annual and monsoon rainfall

(a) *Test based on Chi-square*

As a qualitative method of finding whether any of the sub-divisions indicated an increasing or decreasing trend in rainfall distribution over the period in question, the actual frequencies of occurrences of different types

TABLE 4

Sub-division — Himachal Pradesh

Annual rainfall

[Frequencies — Observed and expected (in brackets)]

Period	Excess	Normal	Deficient	d.f.	Chi-square values
1901-1930	2(3)	20(21)	6(6)	2	0.369
1931-1960	5(3)	24(21)	1(6)	2	6.241*
1961-1987	0(3)	18(19)	9(5)	2	6.496*

* Significant at 5% level.   d.f. — degrees of freedom.

of rainfall (excess, normal etc) for every 30-year period (1901 - 1930, 1931 - 1960, 1961 - 1987) were compared with the expected frequencies calculated on the basis of the simple probability method from the data of the whole period. Chi-square values were obtained for these 3 periods and tested for its significance.

It is seen that for the annual rainfall the Chi-square values were significant at 5 % level for A & M (end period), HP (middle & end periods), Vidarbha (middle period) and north interior Karnataka (beginning period) and at 10 % level for GWB (beginning period), west Rajasthan (end period) and Madhya Maharashtra (middle period) sub-divisions. For the monsoon period, the Chi-square values were significant at 5% level for A & N Islands (middle period), HP (middle period) and Tamilnadu (beginning and middle periods and at 10% level for hills of west Uttar Pradesh (beginning period) and west Rajasthan (end period) sub-divisions.

The rainfall generally showed a decreasing trend during the beginning and the end periods (as indicated by the decrease in the frequency of excess rainfall and an increase in the frequency of deficient rainfall) and an upward trend for the middle period for most of the sub-divisions.

For an illustration of this method the distribution of actual and expected frequencies and the corresponding Chi-square values for the three periods for Himachal Pradesh sub-division in respect of annual rainfall distribution is given in Table 4. The test based on Chi-square was based on the frequencies of different types of rainfall realisations and not on actual rainfall values. Hence, only a general idea about variations in rainfall pattern can be arrived at by this method.

(b) *Cramer's test by comparing the means of sub-periods with the mean of the whole period*

This test may be performed for any desired number and choice of sub-periods in the whole period (WMO 1966). In the present study, the sub-period is chosen at a decade (10 years) and t_k values have been calculated and tested for significance for all the decades from 1901 to 1980. The last sub-period is taken to

TABLE 5

Sub-period	Annual		Monsoon		Remarks
	$\bar{X}_k > \bar{X}$	$\bar{X}_k < \bar{X}$	$\bar{X}_k > \bar{X}$	$\bar{X}_k < \bar{X}$	
1901-1910	6	27(2)	9	24(2)	Low
1911-1920	20	13(1)	14	19(1)	
1921-1930	17(1)	16(2)	18(2)	15(2)	
1931-1940	22(3)	11	22(2)	11	
1941-1950	27(4)	6	25(5)	8	High
1951-1960	24(4)	9	22(5)	11	
1961-1970	15	18(4)	19	14(3)	Low
1971-1980	19(1)	14(4)	18(1)	15(4)	
1981-1987	27(18)	6(2)	25(10)	8(2)	High
Recent period					
1971-1987	25(11)	8(3)	23(8)	10(5)	High

Note : $\bar{X}_k$ — Sub-period mean $\bar{X}$ — Mean for whole series (figures give number of sub-divisions. Figures in brackets are the number of sub-divisions for which the difference is significant at 5% level).

cover 7 years from 1981 to 1987. In addition, the average for the recent period 1971-1987 (17 years) has also been tested with the mean of the whole series. The results for the annual and monsoon rainfall series showed no systematic variation for any particular sub-division.

When all the sub-divisions were taken together and the decadewise variations of rainfall examined, it is seen that for the annual rainfall series, the decade 1901-1910 indicated a very low rainfall with 27 out of 33 sub-divisions having mean decade rainfall less than the mean for the whole period, the difference being significant for 2 sub-divisions at 5% level. The decade 1941-1950, on the other hand, had good rainfall with 27 sub-divisions having mean decade rainfall more than or equal to the mean for the whole period, the difference of 4 sub-divisions being significant. Again the decade 1961-1970 was of slightly below average rainfall, though not as bad as the first decade. The period 1981-1987 showed very good rainfall with 27 sub-divisions having above normal rainfall, the difference in respect of 18 sub-divisions being significant. The recent period 1971-1987 also indicated a similar trend as the sub-period 1981-1987 with 25 sub-divisions (11 of which significant) having above normal rainfall. The consolidated decadewise results are presented in Table 5.

One of the advantages of the Cramer's test is that the value of n (size of the sub-period) can be changed suitably to find the exact period in which the rainfall over the country showed variations by considering the number of sub-divisions getting above/below normal rainfall.

From the results for values of n equal to 15, 20, 25 and 30 years composite graphs showing the number of sub-divisions getting sub-period rainfall more than the mean rainfall for the whole period for both the annual and the monsoon rainfall series were prepared (Fig. 3). For a qualitative assessment of these composite graphs, it was assumed that the country's rainfall would be above/below normal if the the number of sub-divisions getting rainfall more/less than the mean rainfall for the whole period.
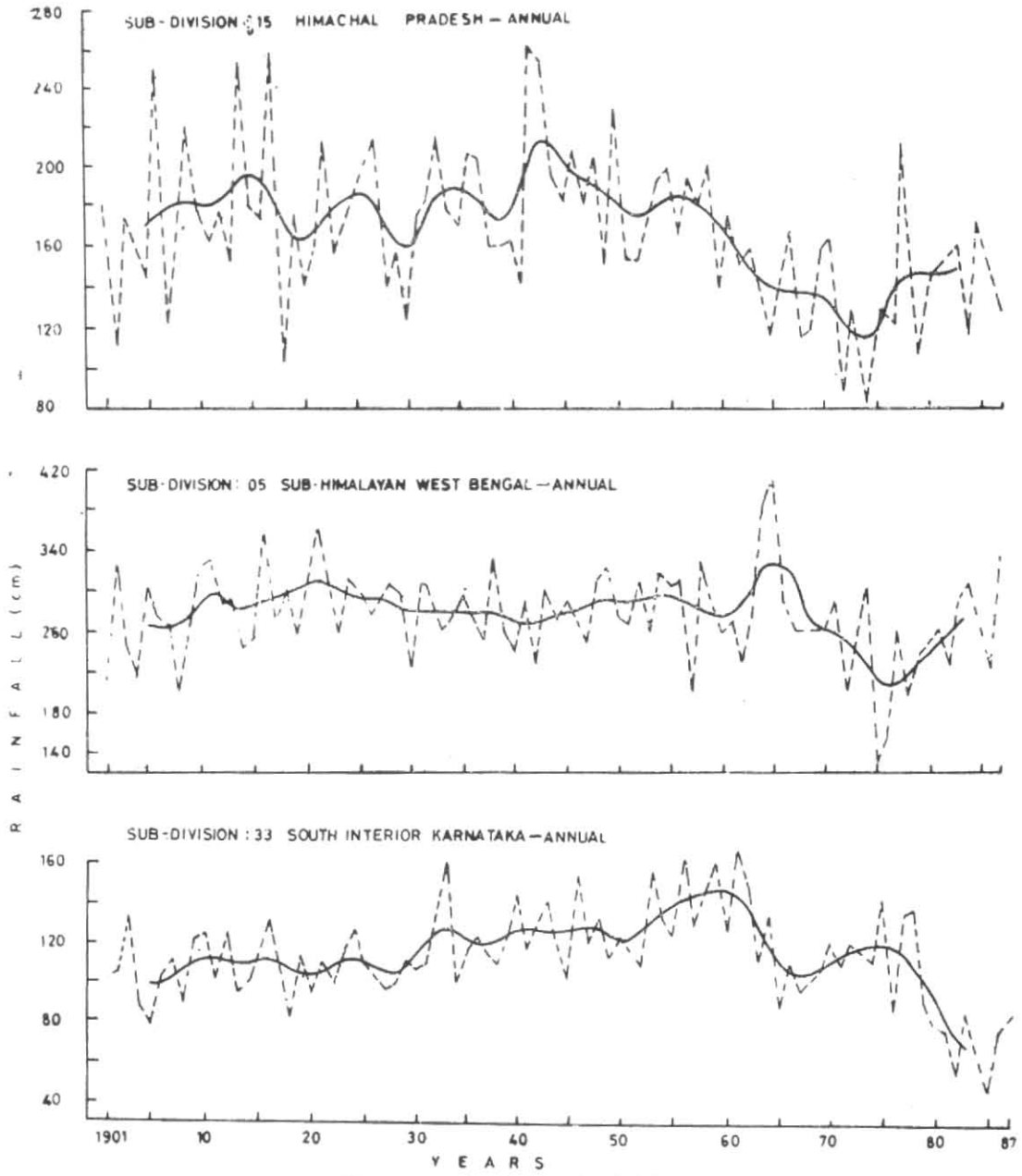
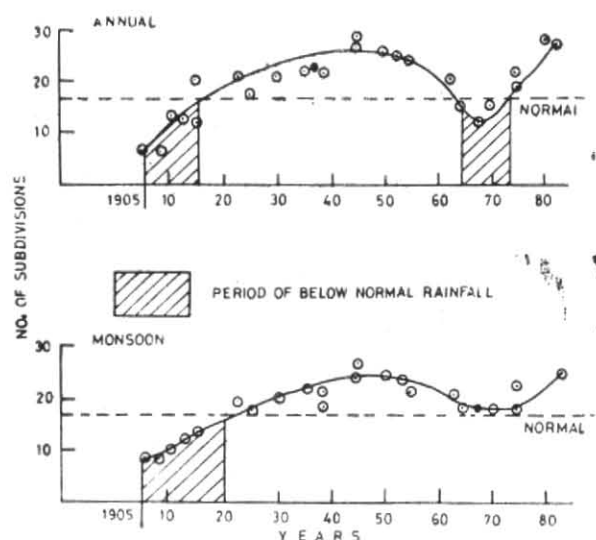Fig. 2. Actual and filtered rainfall series

Fig. 3.

It is seen that for the annual rainfall series, taken together for all the 33 sub-divisions, there were four different climatic periods - the periods from 1901 to 1915 and 1965-1975 which showed below normal rainfall and the periods from 1916 to 1965 and 1975 onwards which showed above normal rainfall.

The monsoon rainfall series, on the other hand showed below normal period from 1901 to 1920 and generally above normal rainfall from 1920 onwards. Even during the period from 1965 to 1975, when the annual rainfall was below normal, the monsoon rainfall over the country was nearly normal.

In fact, the conclusions arrived at by this method are too fine as the areal extent and geographical locations of different sub-divisions are not considered. However, the results are in general agreement with the published results (Joseph 1976, Mooley and Parthasarathy 1984).

(c) *Low-pass filters*

An idea about the long term trend present in a series can also be obtained if the variations in shorter wavelength of the series are suppressed by means of a "low-pass filter".

Two types of low-pass filters were used in this study. They were the Spencer's 15- point filter having unequal but symmetrical weights (Kendall and Stuart 1966) and the Gaussian 9 - point filter (WMO 1966) whose response function is unity at infinite wavelength and tapers assymptotically to zero as the wavelengths are decreased. It is found that the filtered series by both these methods are almost identical.

The actual and filtered annual rainfall series for some of the sub-divisions which indicated significant long term trend in some part of the series are given in Figs. 2 and 4 and are discussed below :

HP showed an increasing trend from 1930-1945, a decreasing trend from 1945-1974 and an increasing trend thereafter.

SHWB showed an increasing trend from 1901 to 1921 decreasing trend from 1921 to 1958, abrupt increasing trend from 1960 to 1965, a decreasing trend from 1965 to 1976 and an increasing trend in the later part of the series.

South interior Karnataka showed a gradual increasing trend from 1928 to 1958 and a decreasing trend in the later part of the series.

Konkan & Goa showed an increasing trend from 1920 to 1956, a decreasing trend from 1956 to 1968 and an increasing trend from 1968 onwards.

Coastal Karnataka depicted an increasing trend from 1919 to 1960, a sharp decreasing trend from 1960 to 1965 and an increasing trend thereafter.

Kerala showed a decreasing trend from 1923 to 1953, a sharp increasing trend from 1953 to 1960 followed by a sharp decreasing trend from 1960 to 1965.

The filtered series for monsoon rainfall for these sub-divisions showed similar features.

It is interesting to note that when coastal Karnataka and Konkan & Goa sub-division, which lie along the west coast of India, showed an increasing trend from about 1920 to 1960 Kerala, which is also on the west coast but to the south of the above two sub-divisions, showed a decreasing trend during the same period. This feature of contrasting rainfall trends over sub-divisions along the west coast is in agreement with the earlier published results (Koteswaram and Alvi 1969, Soman *et al.* 1988).

10. Periodicities in sub-divisional rainfall

In order to find significant periodicities in annual and monsoon rainfall series, power spectrum analysis using Blackman and Tukey's procedure (WMO 1966) was used for all the 33 sub-divisions. The maximum lag was varied from 23 to 29 so as to achieve satisfactory resolution in the spectrum of the series. Whenever the rainfall series showed persistence of "Markov" type, by virtue of its first serial correlation coefficient being significant, appropriate 'red-noise' spectrum was used to determine the significant peaks 'white-noise' spectrum was used for those rainfall series which were free from persistence.

For the annual rainfall series the analysis revealed that at 90% confidence limit, the power concentration was found generally significant over the high frequency range corresponding to the period of 2.1-3.6 years (21 sub-divisions). This refers to the frequency range of the QBO as reported by many. In addition, significant peaks were also seen over the low frequency range corresponding to the period of 19.3 years or more (9 sub-divisions), and intermediate periods of 5.1 to 10.0 years (7 sub-divisions), and 11.5 to 16.7 years (4 sub-divisions). At 95 per cent limit the spectral peaks in the frequency band corresponding to the period 11.5-16.7 years were not significant.
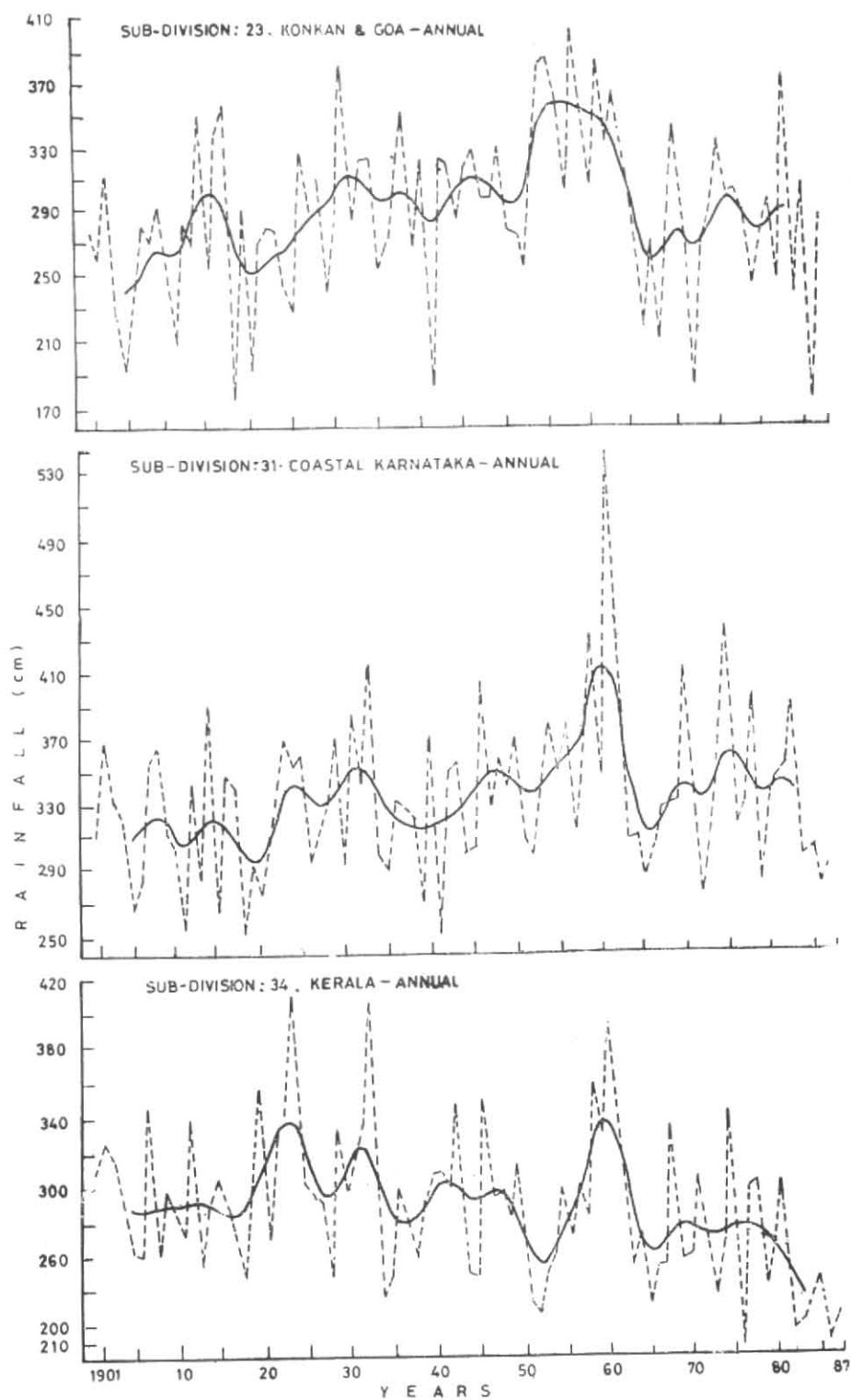
Fig. 4. Actual and filtered rainfall series

11. Conclusions

(a) Saurashtra & Kutch is the only sub-division which had the maximum frequency for excess rainfall (73%), the minimum frequency for normal rainfall (<40%) and the maximum frequency for scanty rainfall (5%) for both the annual and monsoon periods.

(b) There lies an apparent tendency for the annual rainfall in the country to be normal than otherwise.

(c) Assam & Meghalaya had the minimum variability in respect of premonsoon, monsoon and annual rainfall. J & K had the minimum variability for winter rainfall. Tamilnadu and Kerala had the lowest variability for post monsoon rainfall.

(d) Saurashtra & Kutch and west Rajasthan sub-divisions had the highest variability in respect of annual, monsoon and post monsoon seasons whereas Konkan & Goa had the maximum variability for winter rainfall.

(e) Assam & Meghalaya had the minimum variability for all the four months of the monsoon season (18-26%). Saurashtra & Kutch had the maximum variability of 86 % and 77% for June and August rainfall, Rayalaseema had the maximum variability of 65 % for July rainfall and Punjab had the maximum variability (108 %) for September rainfall.

(f) Winter and pre-monsoon rainfall for J & K contributed the maximum share toward annual rainfall (18% and 26%) among all the sub-divisions. Monsoon rainfall for 18 sub-divisions contributed more than 80% of their annual rainfall. The post monsoon rainfall of Tamilnadu contributed about 47% for its annual rainfall.

(g) The frequency distribution of the monsoon and annual rainfall series of most of the sub-divisions were normal. The rainfall series for other seasons showed significant departure from normality for most of the sub-divisions.

(h) Assam & Meghalaya, Nagaland etc, Sub-Himalayan West Bengal, Himachal Pradesh, J&K, Madhya Maharashtra, Telangana, north interior Karnataka, south interior Karnataka and Kerala sub-divisions showed some non-randomness.

(i) J & K and south interior Karnataka sub-divisions showed long-term climatic variability due to inconstancy of dispersion for both the annual and monsoon rainfall series.

(j) The decade-wise rainfall analysis for the country as a whole showed poor rainfall for the decades 1901-1910 and 1961- 1970 and good rainfall for the decade 1941-1950 and the period 1981-1987. Even considering the recent period 1971-1987, there was good rainfall activity in the country.

(k) For the country, taken as a whole, the annual rainfall showed four different climatic periods — two below normal periods from 1901 to 1915 and 1965 to 1975 and two above normal periods from 1916 to 1965 and 1975 onwards. The monsoon rainfall, on the other hand, showed a below normal period from 1901 to 1920 and a generally above normal period from 1920 onwards.

(l) The trend analysis using the "low-pass" filters indicated the presence of significant long-term trend in some part of the rainfall series for Himachal Pradesh, SHWB, Konkan and Goa, coastal Karnataka, south interior Karnataka and Kerala. For the remaining sub-divisions the filtered series were of oscillatory nature around the mean and no significant trend was indicated.

(m) The decreasing trend in the rainfall series of Kerala sub-division from about 1920-1960 was in contrast to the increasing trend noticed in the series of coastal Karnataka and Konkan & Goa for the same period.

(n) The power spectrum analysis showed that the monsoon and the annual rainfall series of a number of sub-divisions had a significant periodicity of 2.1-3.6 years in the higher frequency range. This roughly corresponds to the QBO. In addition, periodicities of 19.3 years or more (low-frequency) and of 5.1 to 10.0 years were also significant for a number of sub-divisions at 95 per cent limit.

References

Chowdhury, A. and Abhyankar, V.P., 1976, "An attempt to determine climatic shift in rainfall over Gujarat State", Proc. Symp. Tropical Monsoon, I.I.T.M. Pune, pp. 388-398.

Chowdhury, A. and Abhyankar, V.P., 1979, Does precipitation pattern foretell Gujarat climate becoming arid?, *Mausam*, **30**, pp. 85-90.

Dhar, O.N., Rakhecha, P.R. and Kulkarni, A.K., 1982, "Trend and fluctuations of seasonal and annual rainfall of Tamilnadu", *Proc. Indian Acad Sci. (Earth and Planet Sci.)*, **91**, pp. 97 - 104.

Joseph, P.V., 1976, "Climatic change in Monsoon and Cyclones 1891 - 1974", Proc. Symp. Tropical Monsoon, I.I.T.M., Pune, pp. 378 - 387.

Kendall, M.G. and Stuart, A., 1966, "*The Advanced Theory of Statistics*, Volume 3, Charles Griffin, London.

Koteswaram, P. and Alvi, S.M.A., 1969, "Trends and periodicities in rainfall at west coast stations in India", *Curr Sci.*, **38**, 10, pp. 229-231.

Mooley, D.A. and Parthasarathy, B., 1984, "Fluctuations in All-India Summer Monsoon rainfall during 1871-1978", *Climatic Change*, **6**, 287-301.

Parthasarathy B. and Dhar, O.N., 1974, "Secular variations of regional rainfall over India", *Quart. J.R. Met. Soc.*, **100**, pp. 245-257.

Parthasarathy, B., Joshi, P.K. and Zachariah, M., 1976, "A study of southwest monsoon rainfall over northwest Indian region", Proc. Symp. Tropical Monsoon, I.I.T.M., Pune, pp. 367-377.

Parthasarathy, B. and Mooley, D.A., 1981, "Hundred years of Karnataka rainfall", R-30, I.I.T.M., Pune, pp. 1-19.

Rao, K.N., 1958, "Some studies on rainfall of Rajasthan with particular reference to trends", *Indian J. Met. Geophys.*, **9**, pp. 97-116.

Rao, K.N. and Jagannathan, P., 1963, "Climatic changes in India", Proc. Synop. '*Changes of Climates*', UNESCO, pp. 53-66.

Raghavendra, V.K., 1973, "A statistical study of the southwest monsoon rainfall in the Indian Peninsula and southwest monsoon rainfall and winter precipitation in northwest India", Met. Monogr., India Met. Dep., **6**, pp. 1-14.

Raghavendra, V.K., 1974, "Trends and periodicities of rainfall in sub-division of Maharashtra State," *Indian J. Met. Geophys.*, **25**, pp. 197 - 210.

Raghavendra, V.K., 1976, "Long period aspects of monsoon rainfall in southern state of Andhra Pradesh in India", Proc. Symp. Tropical Monsoon, I.I.T.M., Pune, pp. 445-457.

Raghavendra, V.K., 1980, "Droughts in Kerala", *Vayu Mandal*, **10**, pp. 28-31.

Snedecor, G.W. and Cochran, W.G., 1968, '*Statistical Methods*, (6th addition), Oxford & IBH Publishing Company, New Delhi.

Soman M.K., Krishna Kumar, K. and Nityanand Singh, 1988, "Decreasing trend in the rainfall of Kerala", *Curr. Sci.*, **57**, 1, pp. 7-12.

World Meteorological Organisation, 1966, *Climatic change*, WMO Tech. Note No. 79.