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Trends and periodicities of rainfall in sub-divisions of Maharashtra State

V. K. RAGHAVENDRA

Meteorological Office, Poona

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ABSTRACT. The Maharashtra State of India is divided into four meteorological sub-divisions, *viz.*, Konkan, Madhya Maharashtra, Marathwada and Vidarbha. Of these, Madhya Maharashtra and Marathwada are prone to droughts. The principal rainy season is the monsoon season of June to September when over 80 per cent of the annual rainfall is received. The coefficient of variation is about 20 per cent for the annual and monsoon rainfall except in Marathwada where it is 25 per cent. The annual and monsoon rainfalls follow the normal distribution for their yearly frequencies. In this region the annual and the monsoon rainfall series are highly correlated. In the less drought prone sub-division of Konkan, the annual and monsoon rainfalls show a 100-year cycle. In all the sub-divisions the successive years' rainfalls are not dependent. The trend as revealed by fitting of orthogonal polynomials is shown as a quadratic curve for the annual and monsoon rainfalls of Konkan and Madhya Maharashtra, the sub-divisions on either side of the Western Ghats. The low pass filter and Mann-Kendall test against randomness confirmed the trend in Konkan rainfall. The power spectral analysis of the data indicates the existence of long term trend for monsoon rainfall of Konkan, 60 year cycle for the annual rainfall of Konkan and Madhya Maharashtra, 30-year cycle for the annual and monsoon rainfall of Vidarbha, 20-year cycle for the monsoon rainfall of Marathwada, 15-year cycle for the monsoon rainfall of Madhya Maharashtra, 7·5-year cycle for the annual and monsoon rainfall of Marathwada.

1. Introduction

The study reported in the present paper is based on the analysis of seasonal and annual rainfall of the four meteorological sub-divisions of Maharashtra (Konkan, Madhya Maharashtra, Marathwada and Vidarbha). In an earlier paper, a detailed discussion of the trend in rainfall of the stations in Western Himalayas was made by analysing the data of the individual stations in that area. It was generally concluded that there was no satisfactory evidence to support the existence of a general trend in the rainfall of the Western Himalayas. In another paper, the monsoon rainfall of the Peninsula (consisting of Maharashtra, Gujarat, Madhya Pradesh, Coastal Andhra Pradesh, Telangana, Interior Mysore North and Coastal Mysore excluding south Kanara) was analysed and discussed for general trend and periodicities. It was concluded that there was absence of any trend in the data but a weak indication of the existence of the Quasi Biennial Oscillation (QBO). In the present analysis the data of smaller regions—the meteorological sub-divisions—has been analysed to study the average and variability of the seasonal and annual rainfall, the nature of the frequency distribution, the existence or otherwise of long term trends and periodicities. The techniques adopted are the same as those applied to the monsoon rainfall of the Peninsula.

2. Data

Fig. 1 shows the State of Maharashtra with the district-wise distribution of raingauge stations having normals in the four meteorological sub-divisions. The stations started recording rainfall in different years. Therefore, the average and normal rainfall of the sub-divisions in each year has been arrived at by calculating the average actual monthly rainfall for the stations that recorded rainfall in that year and the corresponding average normal rainfall. From this, the year's departure of rainfall as percentage is computed. After computing the percentage departures for all the years, the rainfall series have been worked out

*This study is the first part of a report on trends and periodicities of the rainfall south of Vindhyas.

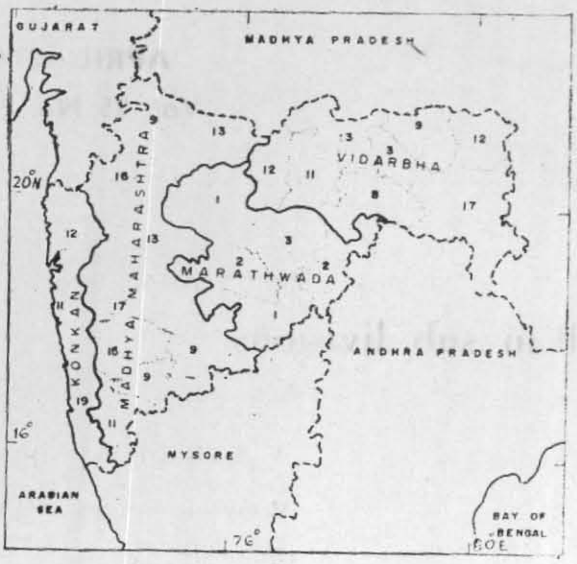

Fig. 1
Districtwise distribution of raingauge stati(ns having mormal

using the normal rainfall of the sub-division calculated on the basis of all raingauge stations having normals. The monthly rainfall data thus computed is added up to give the four standard seasonal rainfall and the annual rainfall values. The seasons are the Cold Weather season from January to February (CW), the Hot Weather season from March to May (HW), the Monsoon season from June to September (M) and the Post Monsoon season from October to December (PM). The numbers of stations having normals in Konkan, Madhya Maharashtra, Marathwada and Vidarbha are 42, 112, 9 and 85 respectively.

3. Analysis of Data

The five data series of the four sub-divisions are analysed statistically for the average and variability, type of frequency distribution, nature of trends and periodicities. The different aspects are discussed.

3.1. *Average and variability*

Table 1 gives the average, standard deviation, coefficient of variation (CV) and the mean deviation of the rainfall data. These are discussed below for each of the sub-divisions.

TABLE 1

Sub-divisional annual and seasonal rainfall averages and variabilities

Sub-divisions	Average rainfall (cm)	Average as per cent of annual	Standard deviation (cm)	Mean deviation (cm)	Coefficient of variation (per cent)
Annual					
Konkan (1878-1970)	303·6	100	52·3	41·1	17
Madhya Maharashtra (1878-1970)	101·9	100	18·1	14·1	18
Marathwada (1879-1970)	85·2	100	20·7	16·7	25
Vidarbha (1876-1970)	110·5	100	20·8	16·5	19
Cold Weather season (CW)					
Konkan	0·4	0·1	0·8	0·5	195
Madhya Maharashtra	0·5	0·5	0·8	0·5	157
Marathwada	1·0	1·2	1·4	1·0	143
Vidarbha	2·3	2·1	2·4	1·9	104
Hot Weather season (HW)					
Konkan	3·9	1·3	5·9	3·9	531
Mahya Maharashtra	4·9	4·8	3·5	2·6	71
Marathwada	3·2	3·8	2·9	2·2	91
Vidarbha	3·5	3·2	2·9	2·1	81
Monsoon season (M)					
Konkan	285·4	94	48·8	37·5	17
Madhya Maharashtra	85·0	83	14·8	11·2	17
Marathwada	72·4	85	18·3	15·0	25
Vidarbha	96·9	88	18·0	14·3	19
Post monsoon season (PM)					
Konkan	13·9	4·6	10·3	12·6	75
Madhya Maharashtra	11·6	11	6·2	5·1	54
Marathwada	8·6	10	6·1	4·9	71
Vidarbha	7·9	7·1	8·5	4·5	70

Konkan receives an annual rainfall of 304 cm of which 94 per cent is received in the monsoon season, 4·6 per cent in the Post Monsoon season, 1·3 per cent in the Hot Weather season and 0·1 per cent in the Cold Weather season. The CV is only 17 per cent for both the annual and the monsoon season, 75 per cent for PM, 153 per cent for HW and 195 per cent for CW season.

Madhya Maharashtra receives an annual rainfall of 102 cm of which 83 per cent is received in the Monsoon season, 11 per cent in the PM season, 4·8 per cent in the HW and 0·5 per cent in the CW season. The CV is 18 per cent for the annual, 17 per cent for the Monsoon, 54 per cent for PM, 91 per cent for HW and 157 per cent for the CW season.

Marathwada receives an annual rainfall of 85 cm of which 85 per cent is received in the Monsoon season, 10 per cent in the Post Monsoon season, 3·8 per cent in Hot Weather season and 1·2 per cent in the Cold Weather season. The CV is 25 per cent for both the annual and the monsoon season's rainfall, 71 per cent for the PM season, 91 per cent for the HW and 143 per cent for CW seasons.

Vidarbha receives an annual rainfall of 111 cm of which 88 per cent is received in the Monsoon season, 7.1 per cent in the Post Monsoon season, 3·2 per cent in the Hot Weather season and 2·1 per cent in the Cold Weather season. The CV is 19 per cent for both the annual and Monsoon season's rainfalls, 70 per cent for the Post Monsoon, 81 per cent for the Hot Weather and 104 per cent for the Cold Weather seasons' rainfall.

In all the four sub-divisions, the Monsoon season accounts for the major portion of the annual rainfall and has a variability similar to that of the annual. The CV for both annual and monsoon rainfall is less than 20 per cent except in the case of Marathwada which has a CV of 25 per cent. The other seasons, except the Post Monsoon season, contribute very small percentages to the annual rainfall and are highly variable.

3·2. *Nature of frequency distribution*

The parameters defined by Fisher, *viz.* g_1, g_2 and their standard errors were computed for the data and the inferences are given below.

All the annual and Monsoon season's rainfalls are having a normal distribution for their frequencies. Therefore, there is only a five per cent chance that the annual rainfall and the monsoon rainfall of Konkan will lie outside $303 \cdot 6 \pm 2(52 \cdot 3)$ cm and $285 \cdot 4 \pm 2\ (48 \cdot 8)$ cm respectively.

In Madhya Maharashtra, there is only a five per cent chance that the annual and monsoon rainfall will lie outside $101 \cdot 9 \pm 2\ (18 \cdot 1)$ cm and $85 \cdot 0 \pm 2\ (14 \cdot 8)$ cm respectively.

In Marathwada there is only a five per cent chance that the annual and Monsoon rainfall will lie outside $85 \cdot 2 \pm 2(20 \cdot 7)$ cm and $72 \cdot 4 \pm 2\ (18 \cdot 3)$ cm respectively.

In Vidarbha there is only five per cent chance that the annual and the Monsoon rainfall will lie outside $110 \cdot 5 \pm 2\ (20 \cdot 8)$ cm and $96 \cdot 9 \pm 2\ (18 \cdot 0)$ cm respectively.

In the other seasons the distribtution is skew throughout and having kurtosis except for the CW season of Marathwada and Vidarbha and Monsoon season of Madhya Maharashtra, Marathwada and Vidarbha.

3·3. *Inter-correlation between seasonal and sub-divisional rainfall*

The correlation coefficients between the five seasonal and annual rainfall series of the four sub-divisions (20 data series) were computed. The correlation coefficents (82 out of 171) are significant.

The annual rainfall and monsoon rainfall are highly correlated whether it is between the sub-divisions or between the seasons. The Post Monsoon rainfall is also having a significant relationship with the annual rainfall. The seasonal rainfall are also correlated among themselves and between sub-divisions.

4. Trends in the data

For the study of trends, the data have been examined by more than one method so as to confirm the existence or otherwise of any general trend in the data series and these are discussed below :

4·1. *Comparison of short period means with the long period averages*

To study the changes in the data with respect to time, the decade averages were computed for the decades from 1881-1890 to 1961–1970. The decade averages were tested against the corresponding long period averages by the parameter 't_k' which is given by

$$t_k = \frac{\bar{x}_k - \bar{x}}{s} \left\{ \frac{k(n-2)}{n-k-k\left(\frac{\bar{x}_k - \bar{x}}{s}\right)^2} \right\}^{1/2}$$

where n is the number of values in the whole series, k the number of years in the short period and s the standard deviation. It can be shown that t_k is distributed as Student's t with $(n-2)$ degrees of freedom.

Table 2 gives the decade averages with the corresponding values of t_k for the annual and Monsoon season. For other seasons the values are computed and discussed.

To examine whether the most recent period data is significantly different from the complete data series, averages for the 25 years, 1946-70 were also computed and tested against the long period averages. The period averages for annual and monsoon season are given in Table 2 and the results are discussed.

4.1.1. *Annual* — In Konkan, the decade 1901–1910 has significantly low rainfall and 1951–1960 has significantly high rainfall. The recent period average for 1946–1970 is also significantly high,

TABLE 2

Period averages (cm)

	Konkan		Madhya Maharashtra		Marathwada		Vidarbha	
	Average	t_k	Average	t_k	Average	t_k	Average	t_k
Annual								
1881-1890	313·7	0·6	111·8	1·9	91·3	1·0	121·5	1·8
1891-1900	304·7	0·1	108·7	1·3	85·2	0·0	106·8	—0·6
1901-1910	267·8	—2·3	89·1	—2·4	82·8	—0·4	106·0	—0·7
1911-1920	281·3	—1·4	94·5	—1·3	79·6	—0·9	106·1	—0·7
1921-1930	282·8	—1·3	91·3	—1·9	71·9	—2·2	99·5	—1·8
1931-1940	313·4	0·6	106·9	0·9	89·9	0·7	126·7	2·7
1941-1950	299·2	—0·3	104·2	0·4	79·9	—0·9	112·3	0·3
1951-1960	347·8	2·9	104·2	0·4	94·9	1·6	110·2	0·0
1961-1970	315·1	0·7	104·4	0·5	92·8	1·2	108·8	—0·2
1946-1970	327·3	2·7	105·0	1·0	91·8	1·9	110·0	—0·1
Upto 1970	303·6	—	101·9	—	85·2	—	110·5	—
Monsoon season								
1881-1890	295·7	0·7	90·5	1·2	74·9	0·4	105·9	1·7
1891-1900	287·3	0·1	93·3	1·9	75·6	0·6	95·1	—0·3
1901-1910	255·8	—2·1	77·3	—1·7	72·6	0·0	95·4	—0·3
1911-1920	260·4	—1·7	78·3	—1·5	67·3	—0·9	91·1	—1·1
1921-1930	269·9	—1·1	78·2	—1·5	60·2	—2·3	86·8	—1·9
1931-1940	288·1	0·2	86·7	0·4	74·5	0·4	108·9	2·3
1941-1950	271·3	—0·3	87·6	0·6	68·4	—0·7	98·1	0·2
1951-1960	325·2	2·8	85·6	0·1	80·5	1·5	98·7	0·3
1961-1970	298·9	0·9	85·6	0·1	79·2	1·2	95·5	—0·2
1946-1970	307·6	2·7	86·3	0·5	78·3	1·9	97·1	0·1
Upto 1970	285·4	—	85·0	—	72·4	—	96·9	—

These might lead one to suspect a periodicity of 100 years and to infer that recent period rainfall is increasing, which is not the case as the 1961-1970 decade is already having a lower mean than 1951–1960.

In Madhya Maharashtra the decade 1901–1910 has significantly low rainfall. All other decades and recent period means are not significantly different from the long period average.

In Marathwada, the decade 1921–1930 has significantly low rainfall and the recent period 1946–1970 is almost significantly high. No other decade or recent period means is significantly different from the long period average.

In Vidarbha, the decade 1931–1940 has a significantly high rainfall. No other decade or recent period mean is significantly different from the long period average.

4.1.2. *Cold Weather season* — In Konkan the decade 1891–1900, in Marathwada the decade 1921–1930 and in Vidarbha the decade 1941–1950 have significantly high rainfall. None of the other decade or recent period means is significantly different from the corresponding long period averages.

4.1.3. *Hot Weather season* — In Madhya Maharashtra the decade mean for 1961–1970 and the recent period mean 1946–1970 are significantly higher than the long period average.

In Konkan, Marathwada and Vidarbha none of the decade means or the recent period means is significantly different from the corresponding long period averages.

4.1.4. *Monsoon season* — In Konkan the decade 1901–1910 has significantly low rainfall and the decade 1951-1960 has significantly high rainfall

Also the recent period mean for 1946–1970 is significantly high. This is similar to the annual rainfall of Konkan.

In Madhya Maharashtra none of the short period means or recent period mean is significantly different from the long period average.

In Marathwada the decade 1921–1930 has significantly low rainfall. The recent period mean, 1946–1970 is almost significanly high.

In Vidarbha, the decade 1931–1940 has significantly high rainfall. No other decade mean or recent period mean is significantly different from the long period average.

4.1.5. *Post Monsoon season* — In Konkan, none of the decade means or recent period mean is significantly different from the long period average except the decade 1931–1940 which is significantly high.

In Madhya Maharashtra, the decades 1881–1890 and 1931–1940 have significantly high rainfall and the decade 1901–1910 has significantly low rainfall.

In Marathwada and Vidarbha the decade 1881–1890 has significantly high rainfall.

Out of 160 means only 21 are statistically different from the long period average and they do not adhere to any one single pattern of variation. There is no satisfactory evidence to show the existence of any systematic change in the data series.

4.2. *Analysis of long term trend by orthogonal polynomials*

To investigate the presence or absence of any long term trend in the data series, orthogonal polynomials as defined by Fisher (1938) and Rao *et al.* (1966) were fitted to the data series. The analysis of variance of the fitting of the polynomials is discussed below.

4.2.1. *Konkan* — The total contribution of all the six degrees of the polynomial is 16 per cent for the annual and 15 per cent for the Monsoon, 14 per cent for the Cold Weather (CW), 8 per cent for the Post Monsoon (PM) and 2 per cent for the Hot Weather (HW) season's rainfall. Of these the polynomials for the annual, Monsoon and CW seasons are significant. Of the individual terms the quadratic term contributes significantly in the annual and Monsoon season's rainfall, while for the CW season the linear and the fifth degree terms contribute significantly. Although for the PM season, the total contribution of the polynomial is not significant, the 3rd degree has a significant contribution.

As most of the rainfall is received during the Monsoon season, it may be inferred that the trend of rainfall of Konkan is of a quadratic polynomial during the period 1878 to 1970.

4.2.2. *Madhya Maharashtra* — The total contribution of all the six degrees of the polynomial is 15 per cent for the annual and 17 per cent, 15 per cent 9 per cent and 6 per cent for the PM, HW, M and CW seasons. Of these, polynomials for the annual, PM and HW seasons contribute significantly. Of the individual terms, the quadratic terms contribute significantly for the annual, HW and Monsoon season, while the 3rd degree and 6th degree contribute significantly for the PM season.

The general nature of the rainfall series appears to be of a quadratic curve during the period 1878-1970 but that of the PM season is a sixth degree curve.

4.2.3. *Marathwada* — The total contribution of all the six degrees of the polynomial is 11 per cent for the annual and 17 per cent, 14 per cent, 8 per cent and 7 per cent for the PM, CW, M and HW seasons. Of these, the PM and CW seasons' polynomials contribute significantly. Of the individual terms the quadratic term contributes significantly for the annual, CW and Monsoon seasons and the 3rd and 6th degree terms for the PM season.

As the annual and the Monsoon season's rainfall are most important, there appears to be absence of any trend in the rainfall of Marathwada. However the PM season's rainfall is of a sixth degree curve and the CW of a quadratic curve for the period 1879-1970.

4.2.4. *Vidarbha* — The total contribution of the six degrees of the polynomial is 11 per cent for the annual and 18 per cent, 12 per cent, 8 per cent and 1 per cent for PM, CW, Monsoon and HW seasons. Of these, the contribution of the PM season's rainfall is significant. Of the individual terms the quadratic contributes significantly for the CW season and the 5th degree and 6th degree terms for the PM season.

As the annual and Monsoon season's rainfalls are most important, here again there appears to be absence of a general trend in the rainfall of Vidarbha. However, the PM season's rainfall during 1876-1970 appears to follow a sixth degree curve.

Thus it is seen that the nature and trend of the rainfall of Konkan and Madhya Maharashtra is of a quadratic curve while there is no trend in the rainfall of Marathwada and Vidarbha.

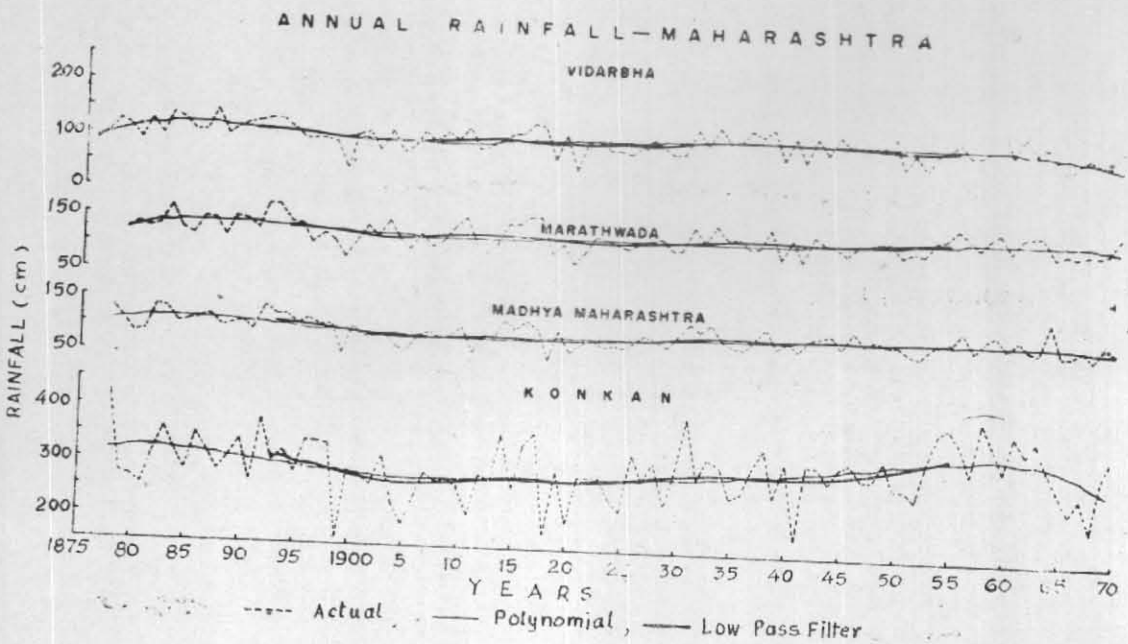

Fig. 2
Actual rainfall (cm), polynomial and low pass filrer

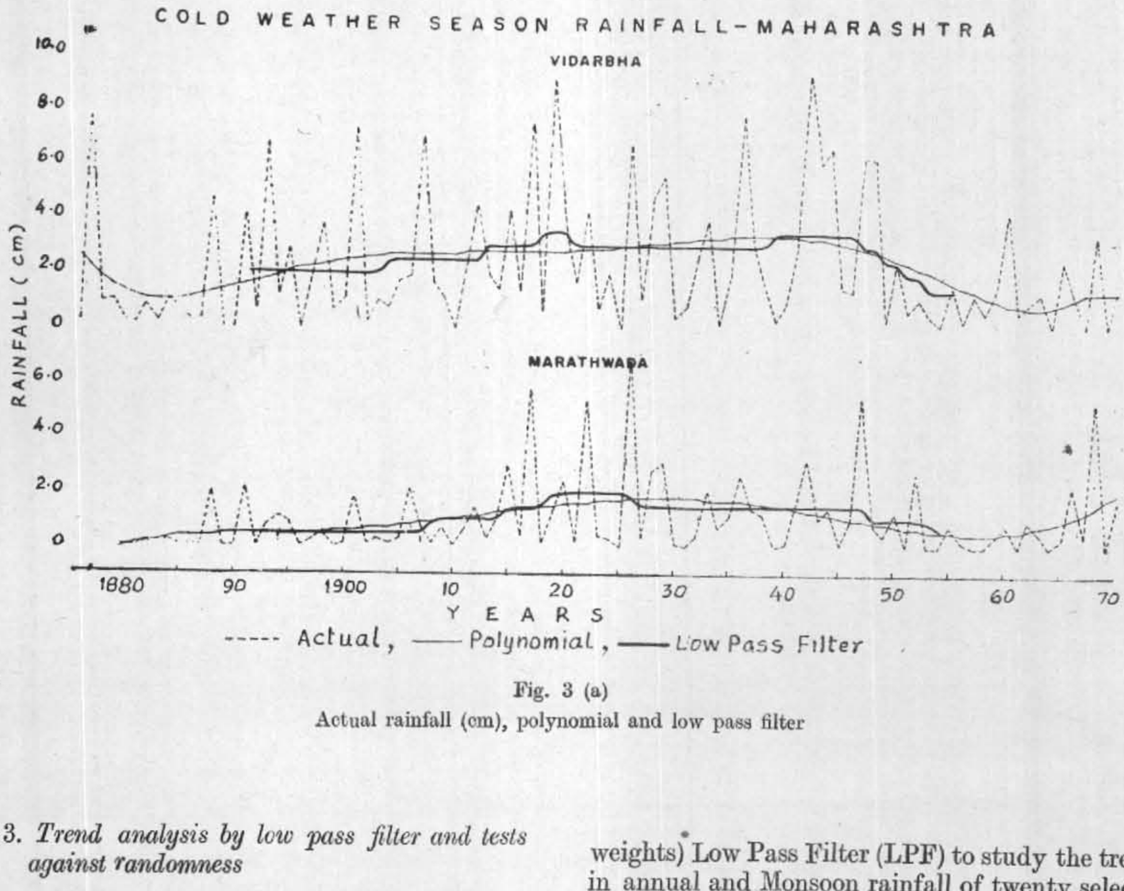

Fig. 3 (a)
Actual rainfall (cm), polynomial and low pass filter

4.3. *Trend analysis by low pass filter and tests against randomness*

Koteswaram and Alvi (1970) have applied the 100 binomial coefficient weights (effective 31 weights) Low Pass Filter (LPF) to study the trends in annual and Monsoon rainfall of twenty selected stations in India. The Mann-Kendall test for randomness was also applied for significance of

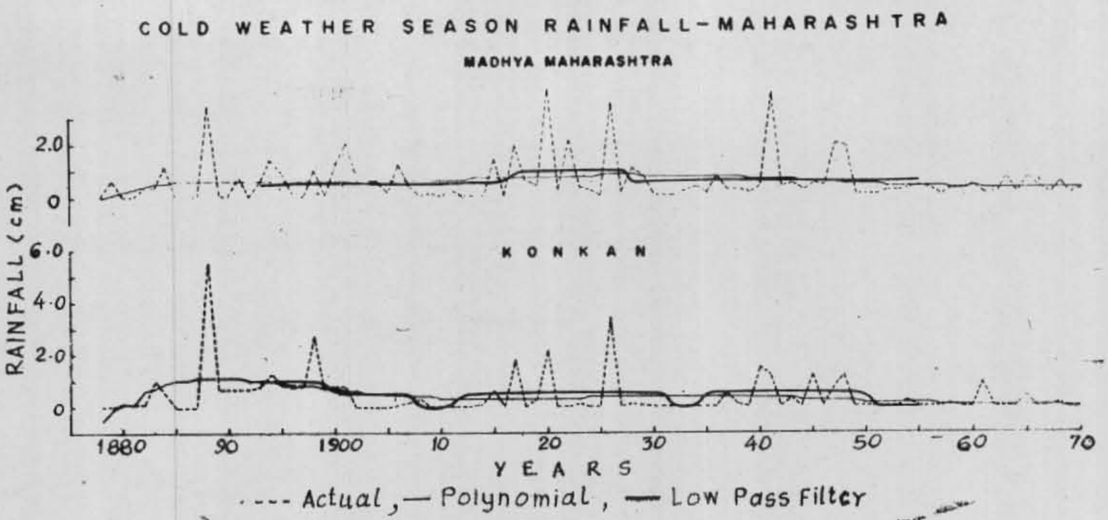

Fig. 3 (b)
Actual rainfall (cm), polynomial and low pass filter

trends indicated by the LPF. Similar LPF has been applied to annual and seasonal rainfall for the four sub-divisions of Maharashtra State. Figs. 2 to 6 give the actual rainfall, sixth degree polynomial fit and the LPF curve for the annual and four seasons CW, HW, M and PM respectively. The last section of LPF that showed an increase or decrease has been listed in Table 3. The period of increase or decrease, its percentage change, its corresponding percentage change for sixth degree polynomial and the increase or decrease for the last 15 years in the polynomial for which no LPF values are available are also given in the Table 3 along with the Mann-Kendall Test against randomness. The results are discussed below.

4.3.1. *Annual* — The last sections of LPF for the periods 1940-55, 1949-55, 1943-55 and 1952-55 show an increasing trend for Konkan, Madhya Maharashtra, Marathwada and Vidarbha respectively. A similar trend is also exhibited by the polynomial. However, the 15 years following 1955 in the polynomial showed decreasing trend. The Mann-Kendall test indicated that the trends for Konkan alone are significant. All changes indicated are about 1 per cent or less.

4. 3. 2. *Cold Weather season* — The last section of the LPF and the corresponding section of the orthogonal polynomial showed a decreasing trend. But the last fifteen years of the polynomial for 1956-70 also showed a decreasing trend except for Marathwada where it was increasing. The Mann-Kendall test indicated the trend in Konkan and Marathwada as significant. However, it is to be noted that this season contributes less than a few per cent to the annual rainfall.

4. 3. 3. *Hot Weather season* — The last section of the LPF and the corresponding section of the orthogonal polynomial showed an increasing trend. But the last fifteen years in the polynomial for 1956-70 showed a decreasing trend except for Vidarbha. The Mann-Kendall test indicated the trend in Marathwada as significant.

4. 3. 4. *Monsoon season* — Here also the last sections of the LPF show an increasing trend. The periods are 1939-55 for Konkan; 1950-55 for Madhya Maharashtra; 1942-55 for Marathwada and 1951-55 for Vidarbha.

A similar trend was also shown in the polynomial except for Madhya Maharashtra. In the last 15 years' period 1956-70, Konkan and Vidarbha showed a decreasing trend while Madhya Maharashtra and Marathwada showed an increasing trend. All changes indicated are about 1 per cent or less. The Mann-Kendall test indicated the trends in Konkan as significant.

4. 3. 5. *Post Monsoon season* — Here also the last section of LPF showed an increasing trend which was also seen in the polynomial. But the last fifteen years in the polynomial showed decreasing trend. The Mann-Kendall test indicated the trends as insignificant.

The trends for the annual and Monsoon rainfall for Konkan are significant.

4. 4. *Persistency in the data series* — To see whether any year's rainfall is having a direct relationship with the rainfall that occurred in the previous years, serial correlation coefficients were

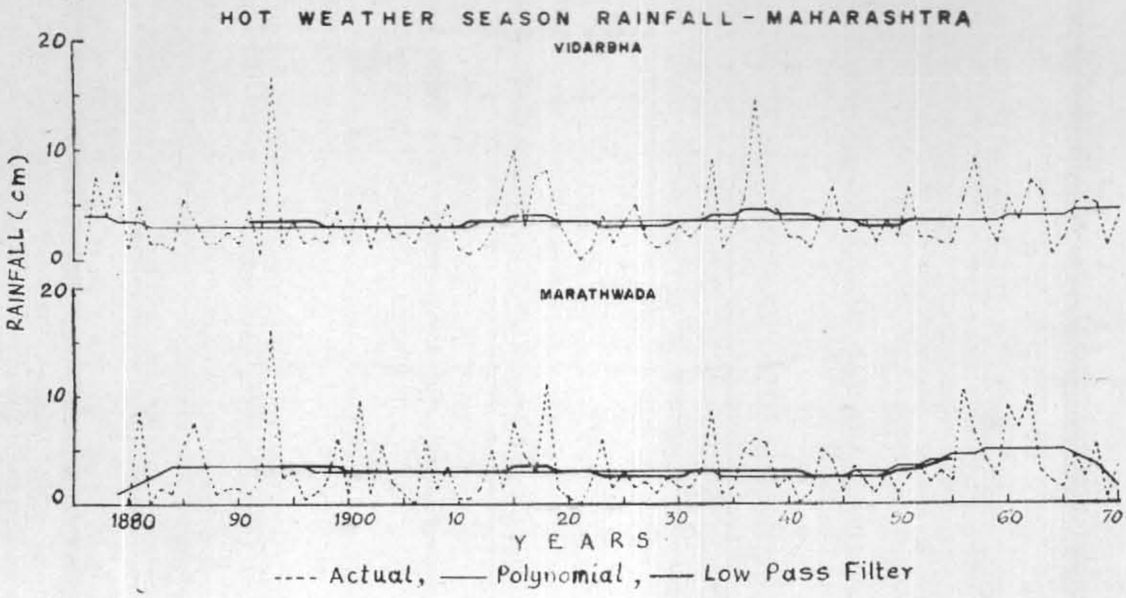

Fig. 4(a)
Actual rainfall (cm), polynomial and low pass filter

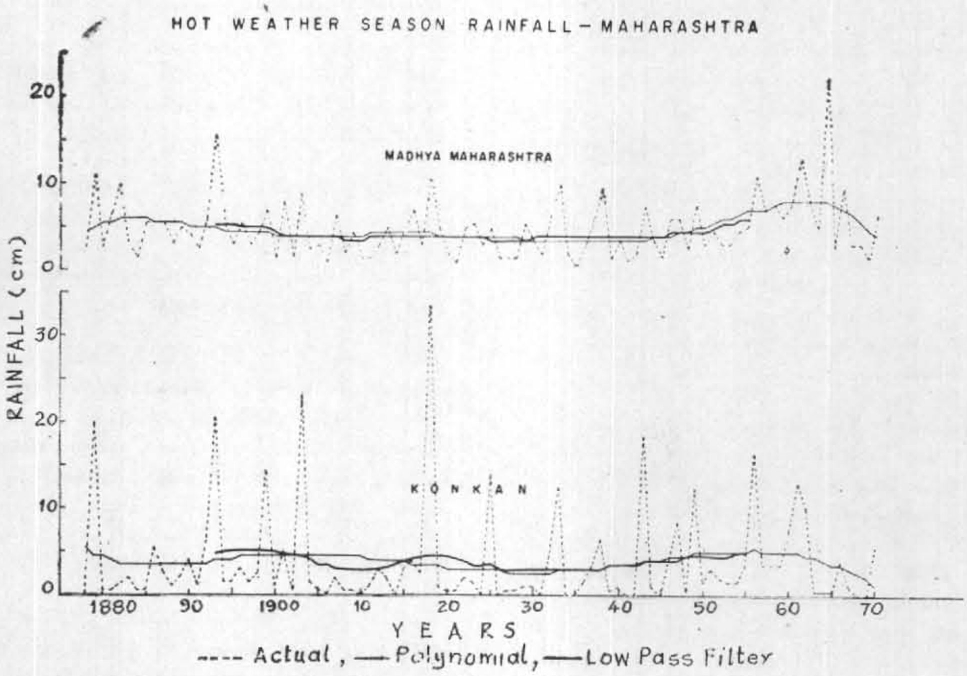

Fig. 4 (b)
Actual rainfall (cm), polynomial and low pass filter

computed upto lags 10 years. These are discussed seasonwise.

4.4.1. *Annual*—Of the 40 serial correlation coefficients, the fifth for Konkan, the first for Marathwada and the second for Vidarbha, are significant. There is a good chance that the sixth year may be similar to the current year for Konkan, the second year be similar to the current year for Marathwada and the third year may be similar to the current year for Vidarbha.

4.4.2. *Monsoon season* — Of the 40 serial correlation coefficients only the 5th for Konkan and 2nd for Vidarbha are significant. It is likely that the sixth year for Konkan may be similar to the current year and the third year for Vidarbha may be similar to the current year.

TABLE 3

Average and percentage increase or decrease and randomness test against trends

Sub-divisions	Average rainfall (cm)	Period of the last section in LPF	Percentage increase or decrease in: LPF in the last section	Polynomial in LPF	Period 1956-1970 in the polynomial	Rank statistics: r	r(t)	Remarks
				Annual				
Konkan	303·6	1949-55	+0·95	+0·77	—1·39	—0·1529	0·1384	Significant
Madhya Maharashtra	101·9	1949-55	+0·47	+0·25	—0·54	0·0134	0·1384	Insignificant
Marathwada	85·2	1943-55	+1·18	+0·87	—0·59	—0·0836	0·1384	Do.
Vidarbha	110·5	1952-55	+0·43	+0·06	—0·96	0·0191	0·1384	Do.
				Cold Weather season				
Konkan	0·4	1944-55	—6·59	—2·27	—3·33	0·1572	0·1384	Significant
Madhya Maharashtra	0·5	1943-55	—7·00	—5·00	—1·20	0·0325	0·1384	Insignificant
Marathwada	1·0	1944-55	—3·18	—5·45	9·33	—0·2102	0·1384	Significant
Vidarbha	2·3	1943-55	—7·64	—2·42	—2·30	—0·0602	0·1384	Insignificant
				Hot Weather season				
Konkan	3·9	1931-55	+2·29	2·62	—6·38	—0·0105	0·1384	Insignificant
Madhya Maharashtra	4·9	1940-55	+2·97	4·49	—4·78	—0·0545	0·1384	Do.
Marathwada	3·2	1946-55	+5·66	5·19	—5·08	—0·1658	0·1384	Significant
Vidarbha	3·5	1949-55	+2·00	0·00	1·88	—0·1075	0·1384	Insignificant
				Monsoon season				
Konkan	285·4	1939-55	+0·90	0·78	—1·14	—0·1424	0·1384	Significant
Madhya Maharashtra	85·0	1950-55	+0·28	—0·12	0·14	—0·0024	0·1384	Insignificant
Marathwada	72·4	1942-55	+1·11	0·74	0·93	—0·0784	0·1384	Do.
Vidarbha	96·9	1951-55	+0·48	0·27	—1·13	0·0086	0·1384	Do.
				Post Monsoon season				
Konkan	13·9	1944-55	+1·18	0·07	—5·04	—0·0717	0·1384	Insignificant
Madhya Maharashtra	11·6	1945-55	+0·67	0·35	—3·79	0·0043	0·1384	Do.
Marathwada	8·6	1948-55	+1·73	1·80	—5·04	0·0167	0·1384	Do.
Vidarbha	7·9	1953-55	+0·44	+0·41	0·00	0·0812	0·1384	Do.

4.4.3. *Post Monsoon and Hot Weather seasons* — Of the 40 serial correlation coefficients none of them is significant.

4.4.4. *Cold Weather season* — Of the 40 serial correlation coefficients only the 6th for Madhya Maharashtra and fifth for Marathwada are significant. The contribution of rain in this season is very small. However, there is a likelyhood that the seventh year for Madhya Maharashtra and the sixth year for Marathwada are likely to be similar to the current year.

5. Search for periodicities by power spectral analysis

The data were subjected to power spectral analysis as described by Blackman and Tukey (1958). The power spectral study will bring out prominent periodicities in terms of $2m/i$ intervals where i will range from 0 to m. Thus if we are analysing data of the total number of occurrences for a year or total number of occurrences for a part of the year the time interval is a full year. Therefore, the periods brought out in fractions of a year will lead one to infer that the peaks in data are expected

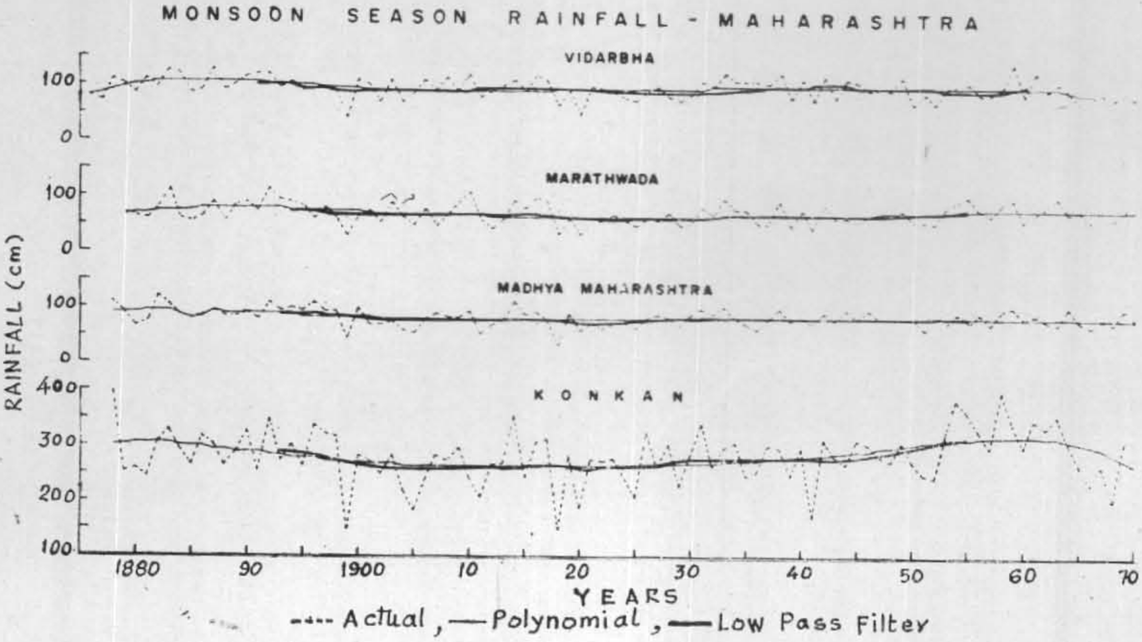

Fig. 5
Actual rainfall (cm), polynomial and low pass filter

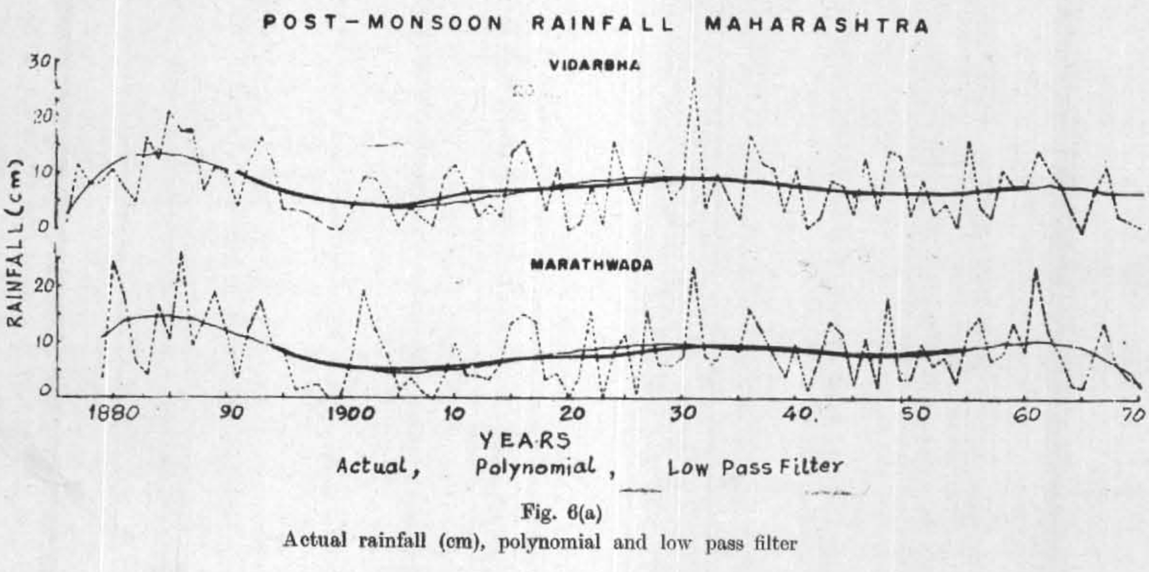

Fig. 6(a)
Actual rainfall (cm), polynomial and low pass filter

to occur in the particular portion of the year which the fraction indicates. *This is an erroneous interpretation.* The periods are to be interpreted in a way similar to drawing a graph with the periodicity brought out and picking up the relevant value for a particular year and that intermediate portion of the graph between two consecutive intervals of time (similar to the graph of the basic data) does not repesent the progress of the element during the interval of time but is only a connecting link of the points representing the value for the particular points of time. This is a very important aspect to be borne in mind when interpreting the periodicities in data.

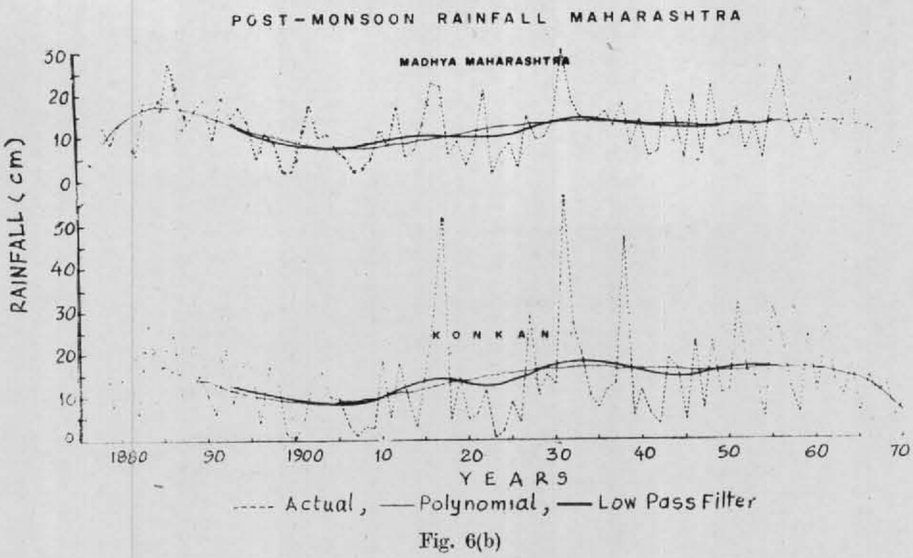

Fig. 6(b)
Acutal rainfall (cm), polynomial and low pass lter

5·1. *Spectral analysis of the data*

Power spectrum analysis as described in the previous section was made for all the data series using lag limit 30, which is roughly one third the total number and is expected to bring out the periodicities clearly. The results are discussed below seasonwise.

5.2.1. *Annual* – Fig.7 shows the spectral estimates with the Null Continuum (NC) and the 95 per cent Confidence Limit (CL).The peaks that have spectral estimate exceeding 95 per cent CL are for 60-year cycle in Konkan and Madhya Maharashtra and the 30-year cycle for Vidarbha. No spectral estimate exceeds the 95 per cent CL for Marathwada although the 7·5 years cycle peak and the 2.3 years cycle peak are near the 95 per-cent CL. Therefore, the prominent periodicities are the long term cycle of 60 years for Konkan and Madhya Maharashtra and the 30-year cycle for Vidarbha and 7·5 and 2·3 years cycle for the Marathwada region.

5.2.2. *Monsoon season* — Fig. 8 shows the spectral estimates together with the NC and the 95 per cent CL for Monsoon season for all the four sub-divisions. The peaks exceeding the 95 per cent CL are that pertaining to the long term cycle of the Konkan, I5 years cycle of Madhya Maharashtra and the 30-year cycle for Vidarbha. The other peaks that are very near 95 per cent CL are 2·3 years for Konkan, 7·5 years and 20 years for Marathwada and 2·3 and 2·1 years for Vidarbha. There appears to be a very slow trend and the QBO for Konkan, a cycle of 15 years for Madhya Maharashtra, a cycle of 30 years and the QBO for Vidarbha and the 7·5 years and 20 years for Marathwada.

5·2·3. *Post Monsoon season* — Fig. 9 shows the spectral estimates together with the NC and the 95 per cent CL for the Post Monsoon season for all the four sub-divisions. The peaks that exceed the 95 per cent CL are corresponding to the 3-year cycle for Vidarbha, 2·6 years for Madhya Maharashtra. The other peaks near 95 per cent CL are the 3-year cycle of Marathwada and the 30 years cycle of Madhya Maharashtra. The QBO near the 3-year cycle is the most prominent in this season.

5·2·4. *Hot Weather season* — Fig. 10 shows the spectral estimates together with the NC and the 95 per cent CL for the Hot Weather season.The only peak exceeding 95 per cent CL is for the 2 years cycle of Vidarbha and the peak near about 95 per cent CL is that corresponding to 2 years cycle for Marathwada. We may expect alternate years to be good and bad for Marathwada and Vidarbha.

5·2·5. *Cold Weather season* — Fig. 11 shows the spectral estimate together with NC and the 95 per cent CL for the Cold Weather season for all the four sub-divisions. The peaks exceeding 95 per cent CL are corresponding to 2·3 years for Marathwada only. The peaks having a value near about 95 per cent CL are for 30-years cycle for Konkan only. There appears to be no evidence of any cycle in this season of very low rainfall.

6. Summary and Conclusions

(1) Konkan receives an annual rainfall of 304 cm, Madhya Maharashtra 102 cm, Marathwada 85 cm and Vidarbha 111 cm respectively. The Monsoon season accounts for above 80 per cent of the annual rainfall in the sub-divisions. The other seasons

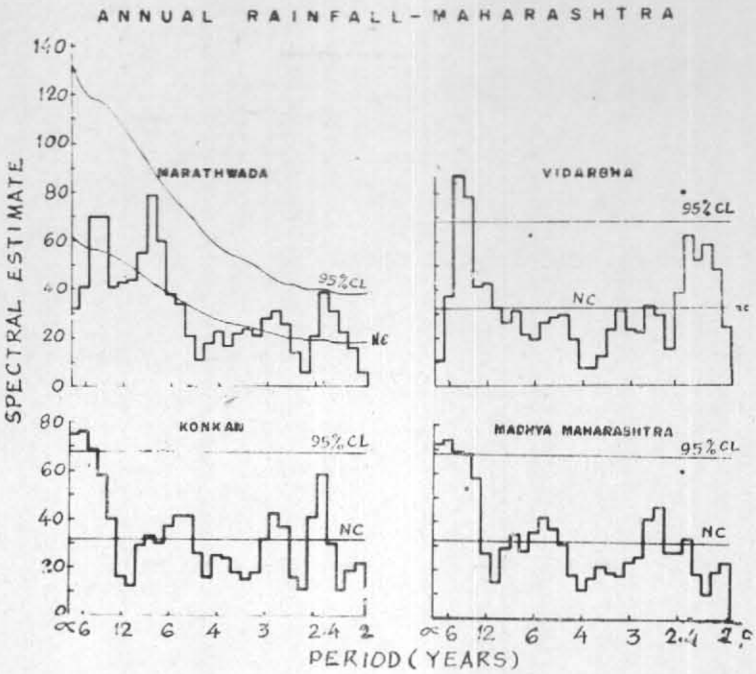

Fig. 7
Spectral analysis

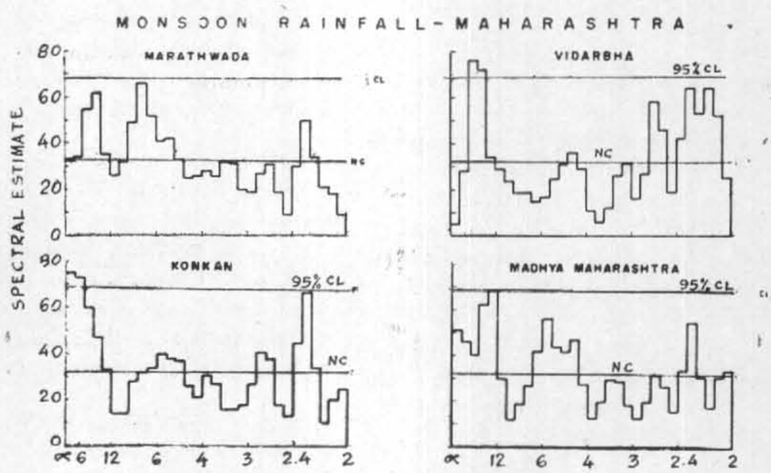

Fig. 8
Spectral analysis

except the Post Monsoon contribute very small percentages. The annual and Monsoon rainfall have CV of 20 per cent except that in Marathwada where the CV is 25 per cent. The other three seasonal rainfall series are very highly variable.

(2) The annual and Monsoon seasons rainfall are having a normal distribution for their frequencies. The other season's rainfall are distributed skewishly with kurtosis.

(3) The annual and Monsoon rainfall are very highly correlated whether it is the rainfall of the same sub-division and different season or the same season and different sub-division. The Post Monsoon season is also having a high significant correlation with the annual rainfall.

(4) The annual and Monsoon rainfall of the Konkan appear to have a weak indication of a 100-year cycle. There is no other satisfactory evidence

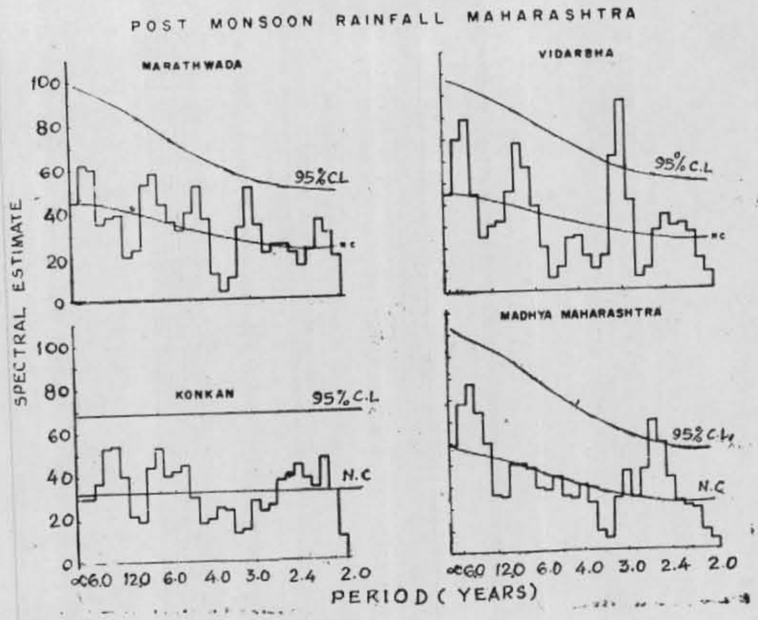

Fig. 9
Spectral analysis

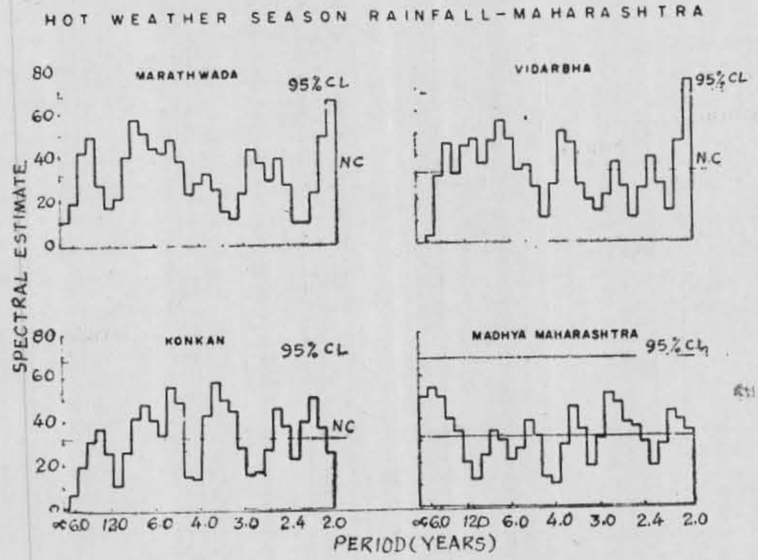

Fig. 10
Spectral analysis

to show the existence of any systematic change in the data series.

(5) An examination of trend by fitting orthogonal polynomials upto sixth degree indicate the general trend in the rainfall of Konkan and Madhya Maharashtra is of a quadratic curve for the annual and Monsoon season's rainfall (which accounts for about 80 per cent of the annual rainfall). The absence of any trend in the rainfall of Marathwada and Vidarbha is also indicated.

(6) The LPF and the Mann-Kendall test against randomness indicated the trends in the data of annual and Monsoon season's rainfall of Konkan as significant. The increase or decrease indicated by the last section of the LPF was also shown by the corresponding section of the orthogonal polynomial but the last 15 years of the period where there was no LPF value invariably indicated an opposite trend except for the Cold Weather season which was decreasing throughout (This is not very significant

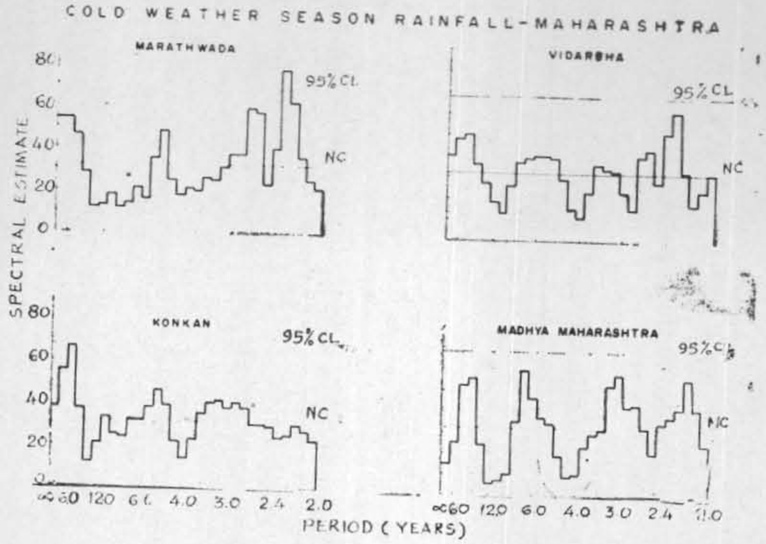

Fig. 11
Spectral analysis

as this season's contribution to annual rainfall is the least).

(7) The power spectral estimates of the data indicate the existence of a long term slow increasing trend for the Monsoon rainfall of Konkan 60-year cycle for the annual rainfall of Konkan and Madhya Maharashtra, 30-year cycle for annual and Monsoon rainfall of Vidarbha, 20-year cycle for Monsoon rainfall of Marathwada and 15-year cycle for the Monsoon rainfall of Madhya Maharashtra, 7·5 year cycle for the annual and Monsoon rainfall of Marathwada and a QBO for Post Monsoon rainfall of Madhya Maharashtra and Vidarbha, Hot Weather rainfall of Vidarbha and Cold Weather rainfall of Marathwada.

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