TRENDS AND PERIODICITIES IN RAINFALL AT WEST COAST STATIONS IN INDIA

P. KOTESWARAM AND S. M. A. ALVI
Meteorological Office, Poona-5, India

1. Introduction

THE secular trends and variations in rainfall of Indian stations have been studied by many workers, notably Pramanik and Jagannathan (1952) and Rao and Jagannathan (1963). The conclusions arrived at were that neither the annual nor the seasonal (monsoon) rainfall showed any general tendency for increase or decrease at any of the stations or sub-divisions (areas). The methods utilized by these workers were fitting of orthogonal polynomials up to the fifth degree and the ordinary moving averages, mostly of 10 years. All the calculations had to be done manually. The present authors have examined the data of a number of stations with data extending to 100–120 years, utilizing low pass and band pass filters and power spectrum analyses (WMO, 1966). The computations have been done with an IBM-1620 computer. Some of the results of the analyses of SW monsoon rainfall at selected stations along and near the west coast of India are given in the present communication. Fuller details will be published elsewhere.

TABLE I

Stations and rainfall data used in the analyses

	Station	Lat. ° N.	Long. ° E.	Elevation metres	Length of data
Coastal	Bombay (Colaba)	18° 54′	72° 49′	11	1847–1967
	Ratnagiri	16° 59′	73° 20′	35	1869–1967
	Vengurla	15° 52′	73° 38′	9	1871–1967
	Mangalore	12° 52′	74° 51′	22	1864–1967
	Cochin	09° 58′	76° 14′	3	1864–1967
	Trivandrum	08° 29′	76° 57′	64	1901–1967
Inland	Poona	18° 32′	73° 51′	559	1856–1967
	Belgaum	15° 51′	74° 32′	753	1864–1967
	Bangalore	12° 57′	77° 38′	897	1837–1967

2. Trend Analyses

In order to determine trends or long period variations, a low pass filter with 100 binomial weights was used. The effective number of weights, however, was 31 since the 35th and 65th members of the series carry only 1% of the central weight. The filter eliminates periodicities of 15 years or less and retains only longer periods. The computed rainfall curves obtained after applying the filter are given in Fig. 1. The sunspot curve for the period 1840–1967 treated with the same filter is also given in the figure.

2.1. *Coastal Stations*

The curves for stations north of 14° N—Bombay (Colaba), Ratnagiri and Vengurla—(Fig. 1, *b, c, d*) show a falling trend towards the end of the 19th century and a generally rising trend in the present century. The rise after 1920 is quite steep. The increase of average rainfall at these stations during the present century is 30–35%.

Stations south of 14° N—Mangalore, Cochin and Trivandrum—(Fig. 1, *e, f, g*) do not show any trend during the present century. A periodicity of 20–25 years is perceptible in these curves. The power spectrum analyses (Fig. 2), however, do not indicate this frequency.

2.2. *Inland Stations*

The curves for the inland stations—Poona and Bangalore—(Fig. 1, *h, j*) which are leeward of the Western Ghats also do not show any trend. Belgaum (Fig. 1, *i*) has a slow rising trend after 1920 and a steeper rise after 1935. The total increase in average rainfall is about 20%.

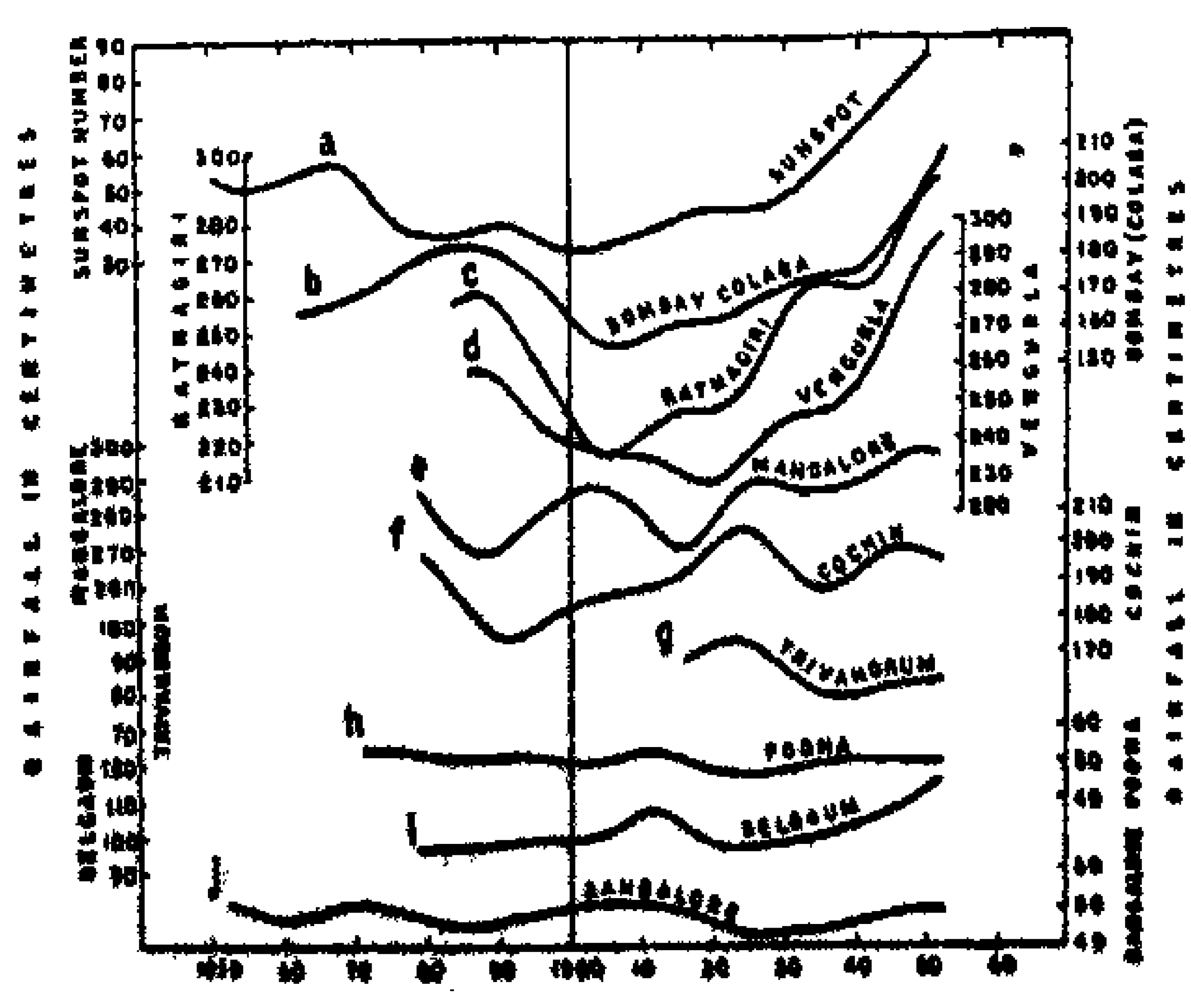

FIG. 1

2.3. *Statistical Significance*

In order to see whether the indicated long period trends are statistically significant, Mann-Kendall test for trend against randomness (Mann, 1954; Kendall and Stuart, 1961) was performed, taking the basic data of the concerned periods into account. The results of the test are given in Table II. If the numerical value in column 5 is greater than that in column 6, the trend is considered to be significant. It can be seen from the table that the increasing trends for the concerned periods during the present century are significant for Bombay (Colaba), Ratnagiri, Vengurla and Belgaum while for the rest of the stations the trends are not significant. The test confirms the conclusions by low pass filter analyses.

TABLE II

Mann-Kendall test of randomness against trend

Sl. No.	Station	Period From	Period To	Rank statistics (r)	Significance $(r)_t = 0 \pm t_g \sqrt{\frac{4N+10}{9N(N-1)}}$
1	2	3	4	5	6
1.	Bombay (Colaba)	1851	1900	·030	·183
	,,	1901	1967	·267*	·163
2.	Ratnagiri	1869	1908	·091	·215
	,,	1901	1967	·296*	·163
3.	Vengurla	1871	1917	—·036	—·197
	,,	1918	1967	·369*	·191
4.	Mangalore	1864	1914	·014	·189
	,,	1915	1967	·000	·185
5.	Cochin	1866	1893	—·181	—·252
	,,	1894	1967	·142	·155
6.	Trivandrum	1901	1967	·062	·163
7.	Poona	1856	1924	—·012	—·161
	,,	1925	1967	·116	·207
8.	Belgaum	1864	1900	·162	·225
	,,	1901	1967	·180*	·163
9.	Bangalore	1837	1924	—·003	—·142
	,,	1925	1967	·193	·207

* Significant.

3. POWER SPECTRUM ANALYSES

Figure 2 shows the power spectrum analyses of Colaba (Bombay), Vengurla, Cochin and Trivandrum. A lag of 40 years was adopted for all stations except Trivandrum for which the lag of 20 years was chosen in view of the shortness of the data series. The null continuum as well as the 95%, 90%, 5% and 10% of significance continuum have been shown on each of the figures.

The following are the salient features:

3.1. *Colaba (Bombay)* (Fig. 2, a)

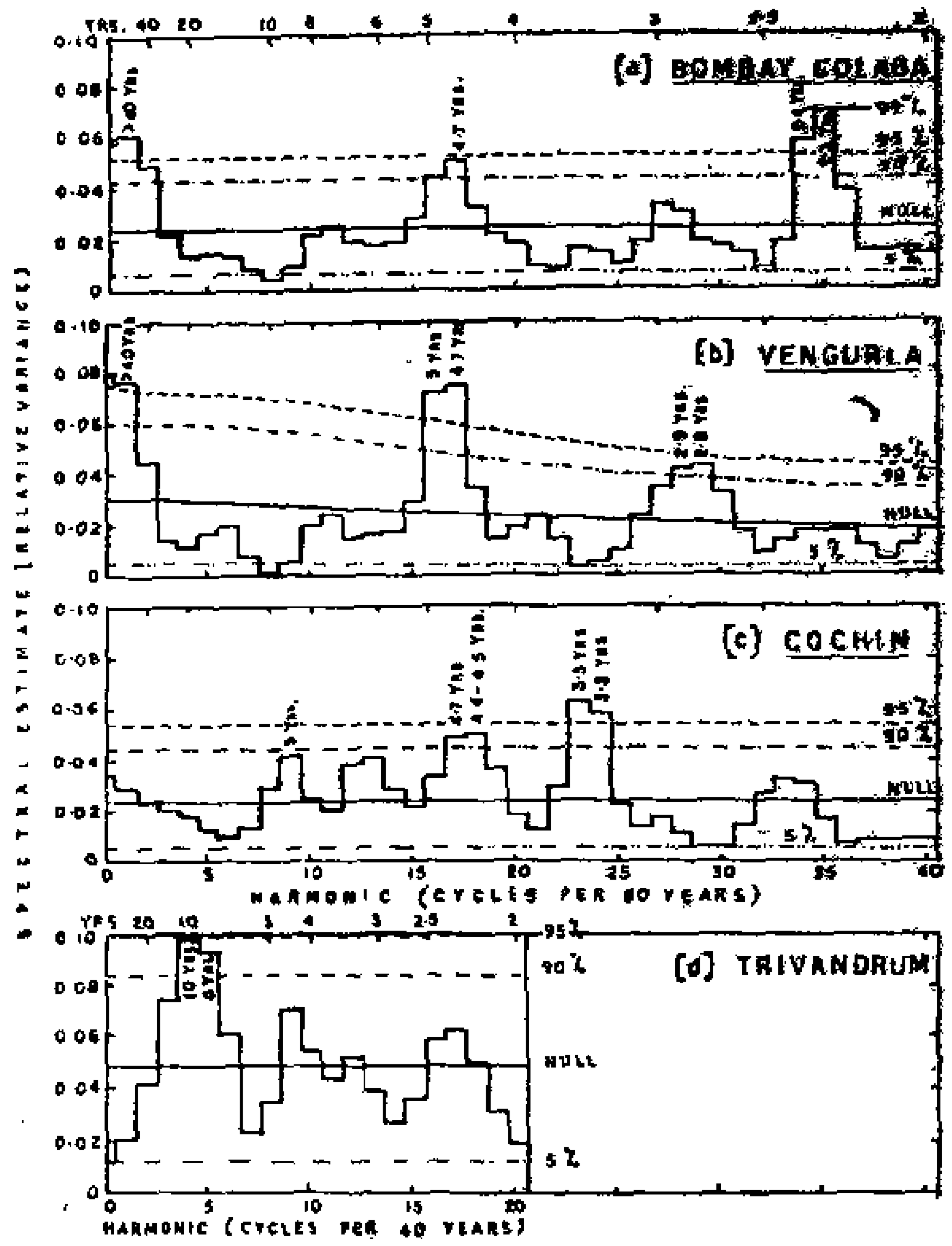

FIG. 2

The null continuum for the station is that of white noise.

(*i*) Spectral estimates for 34th and 35th lag corresponding to a frequency of 2·3 to 2·4 years are significant at 95% level. The 35th lag spectral estimate is significant even at 99%.

(*ii*) Long period trends with a periodicity of greater than 40 years are also significant at 95% level.

(*iii*) Another periodicity of about 4.7 years also appears to be just significant at 95% level.

3.2. *Vengurla* (Fig. 2, b)

Since the lag one correlation coefficient is significant, the null continuum is partly that of red noise.

(*i*) The 28th and 29th lag spectral estimates corresponding to a frequency of 2·7–2·9 years are significant at 90% level.

(*ii*) The 16th and 17th lag spectral estimates are significant at 95% level corresponding to a periodicity of 4·7 to 5 years period.

(*iii*) The long period periodicity of greater than 40 years is also significant at 95% level.

3.3. *Cochin* (Fig. 2, c)

The spectrum is that of white noise. No long period trend is shown by the spectrum. However, it shows 23rd and 24th spectral estimates significant at 95% level corresponding to a periodicity of 3·5 and 3·3 years respectively. Further, it also shows 17th and 18th spectral estimates significant at 90% level corresponding to a periodicity of 4·7 and 4·4 years respectively. The ninth spectral estimate corresponding to a periodicity of nine years is almost significant at 90% level of significance.

3.4. *Trivandrum* (Fig. 2, *d*)

The spectrum is that of white noise. No long period trend is shown by the spectrum and although none of the spectral estimates reach the 95% significance level, the 4th and 5th spectral estimates are quite significant at 90% level corresponding to periodicity of 8 to 10 years.

3.5. In addition to the above stations power spectrum analyses have been done for Mangalore, Poona and Belgaum, but the figures are not reproduced here for want of space. Their salient features are given below.

3.5.1. *Mangalore*.—The spectrum is that of white noise. None of the spectral estimates is significant even at 90% level. Hence Mangalore does not show either any periodicity or long period trend.

3.5.2. *Poona*.—The spectrum dots not reveal any long period trend. However its 17th and 18th spectral peaks are significant at 95% level with reference to the null continuum which is that of white noise. The periodicities of these spectral peaks are equivalent to 4·4 to 4·7 years. The 4·4 years periodicity is even significant at the 99% level. A periodicity of 8 years is significant at the 90% level.

3.5.3. *Belgaum*.—The spectrum is that of white noise. The spectrum shows a long period variation of greater than 40 years which is significant at 95% level.

4. Summary of Results

The existence of a long period trend in the SW monsoon rainfall at west coast stations north of 14° N. is revealed by these analyses. No such trend is seen to the south of 14° N and at inland stations (except Belgaum).

A quasi-biennial oscillation (Q.B.O.) with a frequency of 2·3–2·9 years is also seen at west coast stations north of 14° N. A sub-harmonic of 4·4–5 years is present at Bombay (Colaba), Vengurla, Cochin and Poona. Cochin shows in addition a periodicity of 3·3–3·5 years. Bhargava and Bansal (1969) also found the Q.B.O. in their power spectrum analyses of Bombay (Colaba) rainfall.

5. Rainfall and Sunspot Numbers

Trivandrum which is the southernmost of the series shows a significant periodicity of 8–10 years (Fig. 2, *d*). When the rainfall series of Trivandrum and Cochin and the sunspot numbers for the corresponding periods were treated with a band pass filter tuned to eleven years, it is seen that in this century the rainfall series and sunspot numbers were in opposite phase, the former curve showing the maximum negative amplitude at the time when the latter had the maximum positive amplitude and *vice versa* (Fig. 3). There has been a shift in phase at both the stations after 1940.

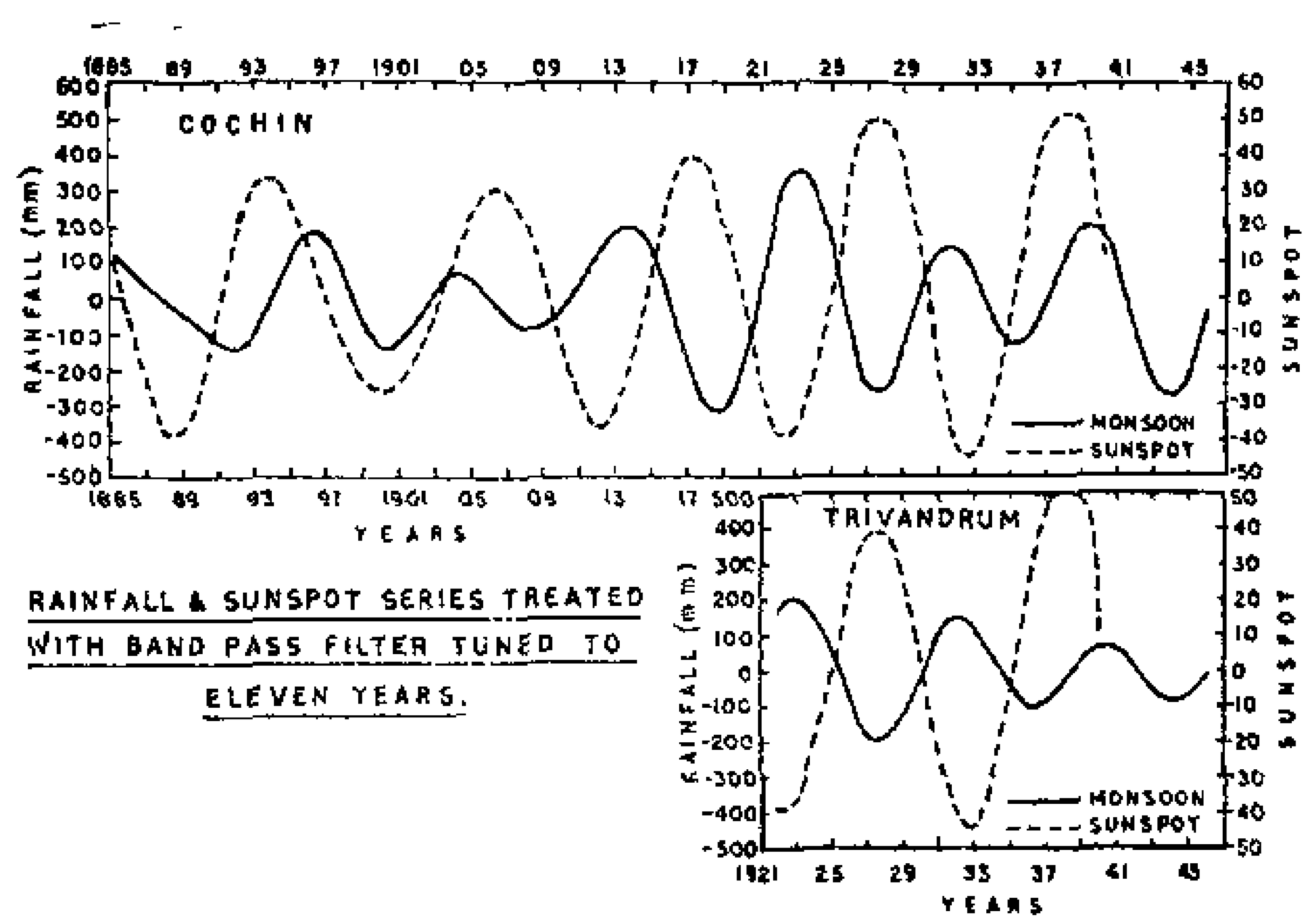

Fig. 3

The long period trends at Bombay, Ratnagiri and Vengurla follow the trend of the sunspot numbers during this century (Fig. 1). It would appear that the south-west monsoon rainfall along the west coast has been influenced by sunspot activities during the present century.

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