Indian J. Met. Hydrol. Geophys. (1976), 27, 1, 23-28

551. 577 (540)=82

A study of trends and periodicities in the seasonal and annual rainfall of India

B. PARTHASARATHY and O. N. DHAR

Indian Institute of Tropical Meteorology, Poona

(*Received 30 September 1974*)

ABSTRACT. The seasonal and annual rainfall of India for each year of the 60-year period from 1901 to 1960 have been studied by subjecting them to the latest statistical techniques. This analysis has brought out that the mean annual rainfall is of the order of 119 cm with a standard deviation of 9·5 cm. Fisher's statistics have shown that the frequency distribution of time series of seasonal and annual rainfall are normal. Significant increase of 5 per cent in 30 years' mean is observed in the southwest monsoon and the annual rainfall but the increase of 6 per cent 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 10-15 years.

1. Introduction

Studies of large scale changes in atmospheric phenomena over wider areas especially in rainfall and temperatures are pre-requisite for the planning and development of a country's natural resources. Studies in fluctuations of rainfall were carried out in India as early as 1896 by Blanford who calculated the average annual rainfall and later by Walker (1910) who examined the monsoon rainfall (June to September). First systematic study of trends and periodicities in annual rainfall of India for the country as a whole by applying the statistical methods was studied by Pramanik and Jagannathan (1953) by examining the 10-year moving average as well as the orthogonal polynomial techniques with data of 30 stations.

Regional analysis of rainfall for the central India was attempted by Agarwala (1952), for Rajasthan by Pramanik *et al.* (1952) and Rao (1958), for Tamil Nadu by Krishna Rao and Jagannathan (1953) and for the different sub-divisions by Rao and Jagannathan (1963). After 1965, considerable work on trends and periodicities of India rainfall has been done by various research workers (Koteswaram and Alvi 1969, Bhargava and Bansal 1969, Jagannathan and Parthasarathy 1973 and Parthasarathy and Dhar 1974). However, all these studies are restricted to the analyis of rainfall data of a single or group of stations or of different meteorological divisions. In the present study seasonal and annual rainfall of the country as a whole has been undertaken for a detailed study by applying the latest statistical techiques.

2. Technique used for obtaining average rainfall

Mean seasonal and annual rainfall have been worked out for the entire country on the basis of about 3000 raingauge stations uniformly spread all over the country for each year of the 60-yr 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 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 (Table 1). It is observed that the mean annual rainfall of the contiguous Indian area is about 118·8 cm with a standard deviation of 9·5 cm and coefficient of variation is 8 per cent. It is also seen that about 75 per cent of mean annual rainfall occurs in the southwest monsoon season, and hardly 11 and 10 per cent respectively occurs in summer and post monsoon seasons. The winter months of January and February receive only 4 per cent of the mean annual rainfall. The coefficient of variation values are the highest for the winter and post monsoon seasons for the country.

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 method followed is that of Fisher's, which has been discussed in detail by Rao *et al.* (1971). The 60-yr series of seasonal and annual rainfall of the country were tested for normality by Fisher's

TABLE 1

Statistical parameters of Indian rainfall

	Season				Annual
	Winter	Summer	SW monsoon	Post monsoon	
Mean	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 with year	1·10	8·56	70·16	5·27	96·10
	(1902)	(1922)	(1918)	(1908)	(1918)
Highest value with year	7·20	16·89	106·61	20·86	144·64
	(1906)	(1933)	(1917)	(1956)	(1917)
Standard Deviation	1·48	2·14	7·78	3·60	9·55
Coeff. of variation (%)	35·6	16·8	8·6	29·4	8·0
Skewness	+0·160	+0·188	—0·382	+·0556	+0·154
Kurtosis	—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)	—0·392*	—1·566*	—0·618*	+0·055*	+0·392*

*Significant at 95 per cent level.

TABLE 2

Mann-Kendall rank and Student's t-test results

	Season				Annual
	Winter	Summer	SW monsoon	Post monsoon	
Mann-Kendall statistic value	−0·0604	+0·0903	+0·2169*	+0·1124	+0·244*
			Values during 1901 to 1930		
Mean fall (cm)	4·19	12·49	87·54	11·84	116·07
Standard deviation (cm)	1·557	2·286	8·365	3·815	9·572
Coeff. of variation (%)	37·1	18·3	9·6	32·2	8·2
			Values during 1931 to 1960		
Mean fall (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 (%)	34·1	15·1	7·0	26·4	7·2
Diff. of means (cm) of 1931-60 and 1901-1930	−0·07	+0·45	+4·33	+0·77	+5·49
Percentage of difference	−1·8	+3·6	+4·8	+6·4	+4·6
Student's t-value	+0·195	−0·811	−2·209*	−0·826	−2·287*

*Significant at 95 per cent level; **Significant at 99 per cent level.

statistics g_1 and g_2, and these have been compared with their respective standard errors (SE). The values of $g_1/\mathrm{SE}(g_1)$ and $g_2/\mathrm{SE}(g_2)$ are given in Table 1 and these values should be less than 1·960 for normality at 95 per cent level of significance. All these values in Table 1 are below 1·960 indicating thereby that the frequency distribution of seasonal and annual rainfall of India for the period 1901 to 1960 is normal for all practical purposes and as such normal statistical tests can be applied to these time series.

4. Trend analysis

The trend analysis of the averge seasonal/annual rainfall of India for the 60-yr priod from 1901 to 1960 was carried out using the following statistical tests.

4.1. *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 nonlinear. It is, therefore, necessary to use test of randomness to check the trend. Mann-Kendall rank method (WMO 1966) has been used and rank statistic values for all the four seasons and the year as a whole are shown in Table 2. It is seen that the southwest monsoon seasonal rainfall is significant at 95 per cent level wheres that of annual is at 99 per cent level. The other seasons do not show any significant trend.

4.2. *Student's t-test*

In the present study the rainfall series of the period 1901 to 1960 was broken into two equal periods, 1901-30 and 1931-60 as recommended by WMO. 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 2 gives the statistics regarding the means of the two periods, their differences, percentage of change per 30 years and student's *t*-value for the seasonal and annual rainfall of the country. It is observed that SW monsoon season and annual rainfall changes are statistically significant at 95 per cent level. Percentage of change varies from —2 to +6 per cent. Though the change for 30-yr mean is +6 per cent in post monsoon season, it is not significant because of very high coefficient of variation.

4.3. *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 (WMO 1966). 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 with actual rainfall of four seasons and annual rainfall are shown in Fig. 1.

5. 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 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). The method of removing the trend from the series and procedure of finding significance of power contributed in the spectrum has been discussed by Parthasarathy and Dhar (1974). Similar procedure has been followed in the present paper.

The post monsoon rainfall showed some persistence and rest of the series do not exhibit any persistence. The power spectrum analysis of original and filtered series results, which are significant at 90 per cent, 95 per cent and 99 per cent levels, are only shown in Table 3. It is seen that a cycle of 2·3 to 2·5 years is there in all the series of rainfall, which is more prominent in the filtered data. Another cycle of 10 to 15 years is also observed. 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 Landsberg (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-divisions of India by Rao *et al.* (1973). Thus the analysis made here supports the findings of the other research workers. Studies in the regional rainfall of Madras (Tamil Nadu) by Sen Gupta (1957) showed that an increase of sunspot actvity is

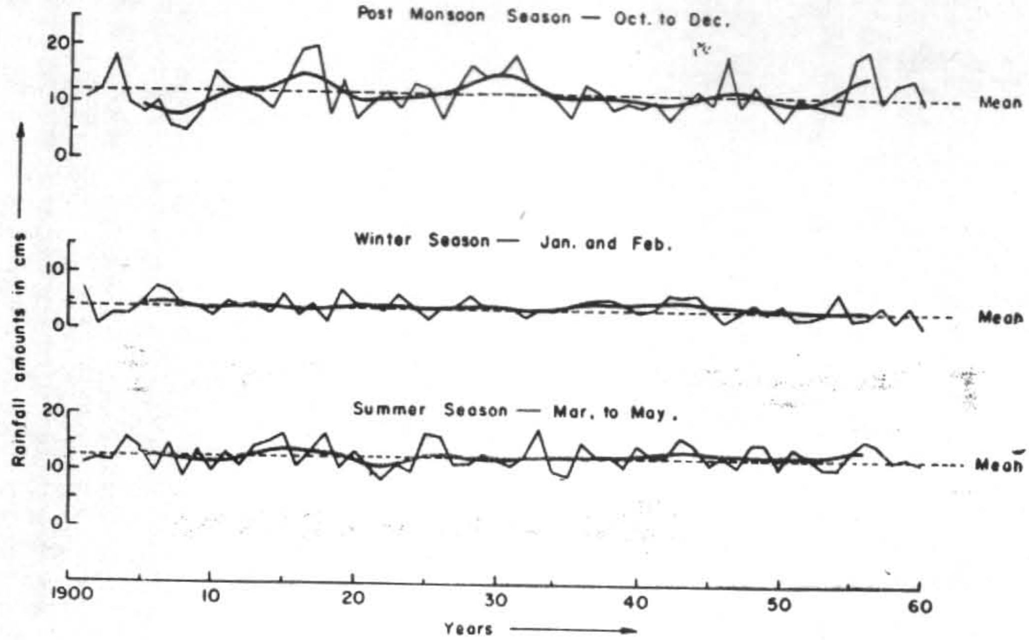

Fig. 1(a)

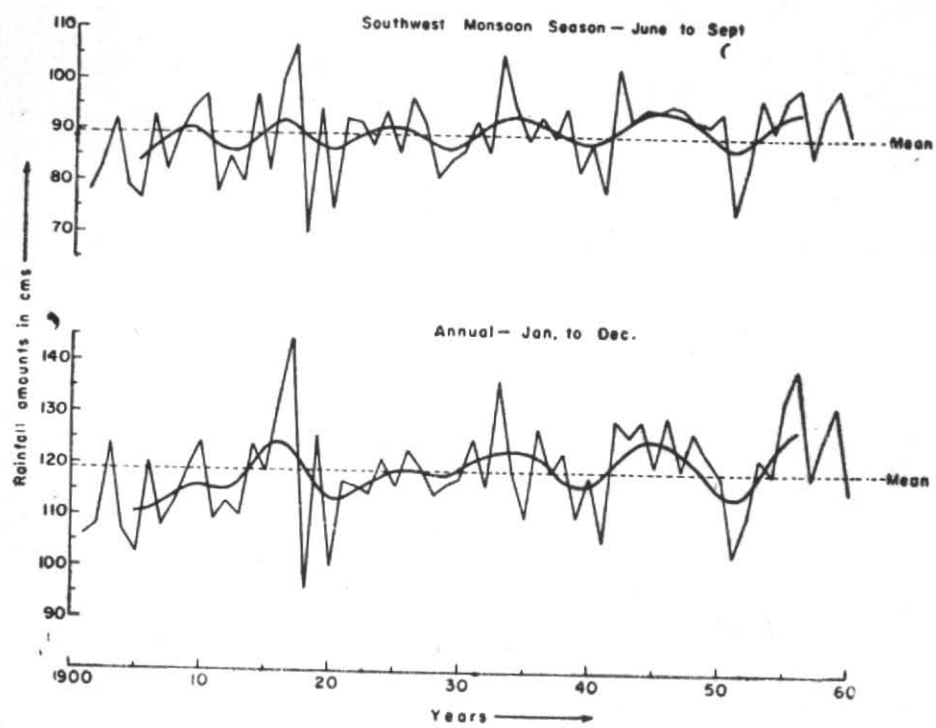

Fig. 1(b)

Actual and filtered (low-pass) rainfall series of India

TABLE 3

Power spectrum results

Seasons	Significant cycles in years	
	Without filter	With using difference 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 (r_1 significant)	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*

*Significant at 95 per cent level

**Significant at 99 per cent level

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 cost of India also shows the effect of solar cycle on SW monsoon rainfall. Rao *et al.* (1973) showed the presence of solar cycle in Palmer drought indices at certain sub-divisions of the country. This study also indicates the presence of a weak solar cycle (significant at 90 per cent 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.

6. Conclusions

The analysis carried out with about 3000 rain-guages for the period of 1901 to 1960 has shown that the mean annual rainfall for the whole country is 119 cm with a standard deviation of 9·5 cm. 75 percent of the annual rainfall occurs in south-west monsoon season whereas 11 per cent and 10 per cent respectively occurs in summer and post monsoon seasons. The frequency distribution of time series of seasonal and annual rainfall are normally distributed. Significant increase of 5 per-cent in SW monsoon and annual mean rainfall in 30 years have been noticed. However, 6 per cent increase in post monsoon rainfall is not statistically significant because of high coefficient of variation in this season. Significant presence of QBO and a weak solar cycle are observed by power spectrum analysis.

REFERENCES

Agarwala, K. S. 1952 *Indian J. Met. Geophys.*, **3**, pp. 229-230.

Bhalme, H. N. 1972 *Ibid.*, **23**, pp. 355-358.

Bhargava, B. N. and Bansal, R. K. 1969 *Ibid.*, **20**, pp. 127-128.

Blanford, H. F. 1886 *Mem. India met. Dep.*, **3**.

Jagannathan, P. and Parthasarathy, B. 1973 *Mon. Weath. Rev.*, **101**, pp. 371-375.

Jagannathan, P. and Bhalme, H. N. 1973 *Ibid.*, **101**, pp. 691-700.

Jenkins, G. M. and Watts, D. G. 1968 *Spectral analysis and its application*, Holden- Day Series in time series analysis, San Francisco.

Krishna Rao, P. R. and Jagannathan, P. 1953 *Indian J. Met. Geophys.*, **4**, pp. 22-44.

Koteswaram, P. and Alvi, S.M.A. 1969 *Curr. Sci.*, **38**, pp. 229-231.

Landsberg, H. E. 1962 *Beitr. Zur Phys. Atmos.*, **35**, pp. 184-194.

Parthasarathy, B. and Dhar, O. N. 1974 *Quart. J. R. met. Soc.*, **100**, pp. 245-257.

REFERENCES (contd)

Pramanik, S. K., Hariharan, P. S. and Ghose, S. K.	1952	*Indian J. Met. Geophys.*, **3**, pp. 131-140.
Pramanik, S. K. and Jagannathan, P.	1953	*Ibid.*, **4**, pp. 281-309.
Rao, K. N.	1958	*Ibid.*, **9**, pp. 97-116.
Rao, K. N. and Jagannathan, P.	1963	Climatic changes in India, Arid Zone Res. XX, Changes of Climate, Proc. Rome Symp., pp. 49-66.
Rao, K. N., George, C. J. and Abhyankar, V. P.	1971	*India met. Dep. Sci. Rep.* No. 168, pp. 1-8.
Rao, K. N., George, C. J., Moray, P. E. and Mehta, N. K.	1973	*Indian J. Met. Geophys.*, **24**, pp. 257-270.
Sen Gupta, P. K.	1957	*Weather*, **12**, pp. 322-324.
Walker, G. T.	1910	*Mem. India met. Dep.*, **21**, pp. 1-21.
WMO, Geneva	1966	*Climatic change*, WMO Tech. Note, 79, WMO No. 195-TP. 100.