PERIODICITY OF DROUGHT OCCURRENCE IN INDIA

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To find out whether there is any periodicity or cycles in drought occurrence in India, accumulated drought index (Palmer) for monsoon season (June–September) was computed for twenty-three sub-divisions of the country for about 60 years. These Palmer index values were subjected to the 'Power Spectrum Analysis'. The study reveals persistence in drought occurrence in some sub-divisions of North India and in the central parts of the Peninsula. Besides quasibiennial oscillation, some other periodicities are also seen. Amplitude and phase of these waves are also studied.

INTRODUCTION

Drought has been a scourge of mankind since ancient times and still continues to be a major menace to food supplies. Hence, for proper assessment of droughts and to facilitate their scientific study, Palmer (1965) used a water budgeting concept for developing a numerical index of drought from the data of rainfall, soil moisture and evapotranspiration. The formula for computing Palmer Index is

$$X_i = 0.897\ X_{i-1} + Z_i/3$$

where X_i is the Palmer index value of month i and Z_i is the weighted rainfall anomaly of the month obtained from the hydrologic accounting procedure. Employing Palmer's technique, monthly values of Palmer index for different sub-divisions of India have been computed from 1901 onwards. The accumulated values of these drought index (Palmer) for the monsoon season (June–September) have been worked out for 23 sub-divisions (Table 1) of the country (Fig. 1).

Droughts in successive years or prolonging continuously for more than one year or two have devastating effect on food production and country's economy. Hence the interest in finding periodicity in drought incidence.

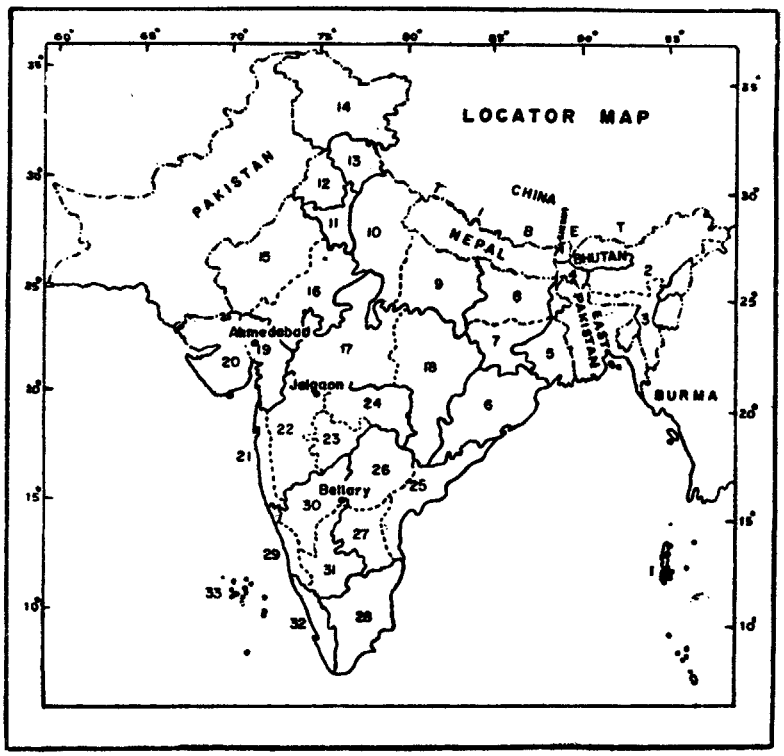
The discovery by Reed and Rogers (1962) of an oscillation in the zonal wind component in the equatorial stratosphere of slightly more than 24 months in length of the nature of quasi-biennial oscillation inspired workers in the field of meteorology and geophysics. In order to detect such an oscillation or periodicity in drought; drought index (Palmer) time series was subjected to power spectrum analysis. The method is described by Blackman and Tukey (1958) and in WMO Technical Note No. 79 (1966).

METHODS OF ANALYSIS

(*I*) *Power Spectrum Analysis*—Analysis is carried out in three steps using drought index (Palmer) time series of N equally spaced values: (i) computation of

TABLE I

S. No.	Sub-division	Number of years of data used	Periodicity	Level of significance %	Lag No.	No. of degree of freedom [(2N-m/2)/m]	Type of spectrum
1.	Gangetic West Bengal	67(1902–1968)	04.6	95	10	5	White noise
			03.53	90	13		
2.	Orissa	67(1902–1968)	03.83	90	12	6	,, ,,
3.	Bihar Plateau	66(1902–1967)	46.00	95	1	6	,, ,,
			03.14	95	14		
4.	Bihar Plains	66(1902–1967)	02.3	90	20	5	Red noise
5.	Uttar Pradesh East	65(1902–1966)	07.33	95	6	6	,, ,,
			06.28	95	7		
			02.20	90	20		
			02.10	90	21		
6.	Uttar Pradesh West	65(1902–1966)	08.80	90	5	6	,, ,,
			02.90	90	15		
7.	Punjab & Haryana	66(1902–1967)	09.20	95	5	5	,, ,,
			03.53	90	13		
			02.87	90	16		
8.	Rajasthan West	62(1908–1969)	10.50	95	4	6	White noise
			04.18	90	11		
9.	Rajasthan East	64(1903–1966)	Nil	—	—	6	Red noise
10.	Madhya Pradesh West	66(1902–1967)	14.66	95	3	6	,, ,,
			11.00	95	4		
11.	Madhya Pradesh East	66(1902–1967)	02.20	90	20	6	,, ,,
12.	Gujarat	64(1903–1966)	4.66	90	9	6	White noise
13.	Saurashtra & Kutch	63(1904–1966)	3.66	90	12	5	Red noise
			3.38	90	13		
14.	Madhya Maharashtra	63(1904–1966)	4.90	90	9	5	Red noise
15.	Marathwada	64(1903–1966)	8.40	95	5	6	,, ,,
			6.00	95	7		
			5.40	90	8		
16.	Vidarbha	66(1902–1967)	Nil		—	6	,, ,,
17.	Coastal Andhra Pradesh	66(1902–1967)	23.00	90	2	5	White noise
			06.60	90	7		
18.	Telengana	66(1902–1967)	08.80	90	5	6	White noise
19.	Rayalaseema	66(1902–1967)	02.40	90	18	6	Red noise
20.	Tamil Nadu	67(1902–1968)	06.60	90	7	6	White noise
			03.07	90	15		
21.	Interior Mysore North	64(1904–1967)	05.50	95	8	6	Red noise
			02.75	95	16		
22.	Interior Mysore South	65(1903–1967)	07.50	90	6	6	Red noise
23.	Kerala	66(1902–1967)	04.60	90	10	5	White noise



STATES	SUB-DIVISIONS
	1. Bay Islands
Assam, Nagaland & Meghalaya	2. North Assam 3. South Assam
West Bengal	4 Sub-Himalayan West Bengal *5. Gangetic West Bengal
Orissa	*6. Orissa
Bihar	*7. Bihar Plateau *8. Bihar Plains
Uttar Pradesh	*9. East Uttar Pradesh *10. West Uttar Pradesh
Haryana	*11. Haryana
Punjab	*12. Punjab
Himachal Pradesh	13. Himachal Pradesh
Jammu and Kashmir	14. Jammu and Kashmir
Rajasthan	*15. West Rajasthan *16. East Rajasthan

STATES	SUB-DIVISIONS
Madhya Pradesh	*17. West Madhya Pradesh *18. East Madhya Pradesh
Gujarat	*19. Gujarat Region *20. Saurashtra & Kutch
Maharashtra	*21. Konkan *22. Madhya Maharashtra *23. Marathwada *24. Vidarbha
Andhra Pradesh	*25. Coastal AndhraPradesh *26. Telangana *27. Rayalaseema
Tamil Nadu	*28. Tamil Nadu
Mysore	29. Coastal Mysore *30. North Interior Mysore *31. South Interior Mysore
Kerala	*32. Kerala
	33. Arabian Sea Islands

FIG. 1. Periodicities of drought calculated for sub-divisions marked with asterisk.

auto-correlation coefficient for Lags zero to m ($m < N$); (ii) computation of the cosine transform of these $m+1$ auto-correlation coefficients to obtain $m+1$ raw

estimates of power spectrum; and (iii) smoothing the raw estimate by three term weighted moving averages and obtaining the final spectral estimate.

Power spectrum analysis revealed that oscillations of the periods ranging from 2.1 to 2.75 years of the type of quasi-biennial oscillations were observed in Bihar plains, Uttar Pradesh East, Madhya Pradesh East, Rayalaseema and interior Mysore North. Similarly periods ranging from 10.5 to 11 years, corresponding to 11 year sunspot cycle were observed in Rajasthan West and Madhya Pradesh West. The power spectrum studies are limited to the detection in a qualitative way of the presence or otherwise, of a particular oscillation.

(II) Numerical Filters and Fourier Analysis—In order to determine the presence of a particular oscillation in a quantitative manner a numerical filter and Fourier analysis were used. The monthly values of drought index (Palmer) from 1901 to 1960 for Bihar Plains, Uttar Pradesh East, Madhya Pradesh East, Rayalaseema and Interior Mysore North were utilised after removal of persistence from these values. These series have been subjected to a 97 point band-pass filter designed by Behannan and Ness (1965) for 24 ± 4 units. The response curve of the 97 point filter is represented in Fig. 2.

Similarly, annual drought index (Palmer) values from 1901 to 1960 for Rajasthan West and Madhya Pradesh West after removing the persistence have been subjected to 43 point band-pass filter designed for 11 years sunspot cycle (W.M.O.

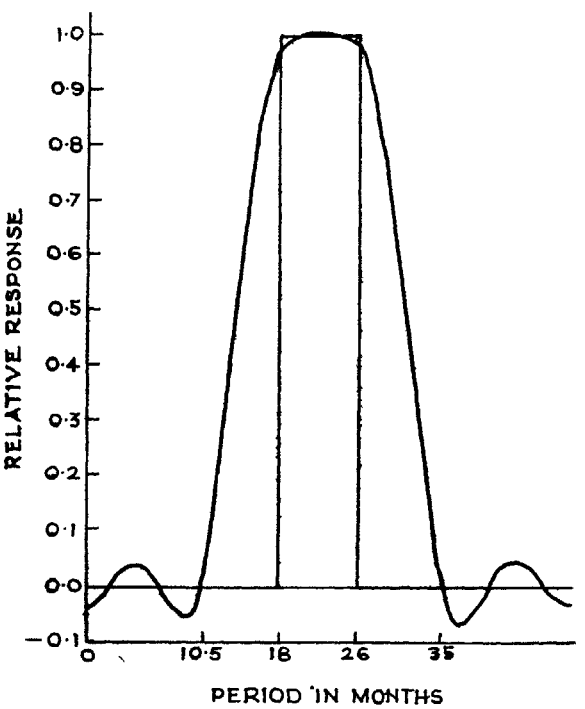


FIG. 2. The frequency response profile of 97 point numerical filter for 24 plus or minus, 4 months pass band.

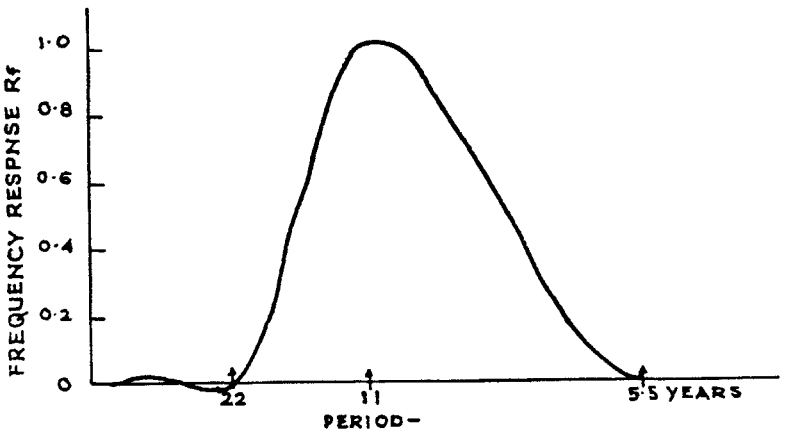


FIG. 3. Frequency response of the "Band Pass" moving average filter for eleven year cycle.

TABLE II

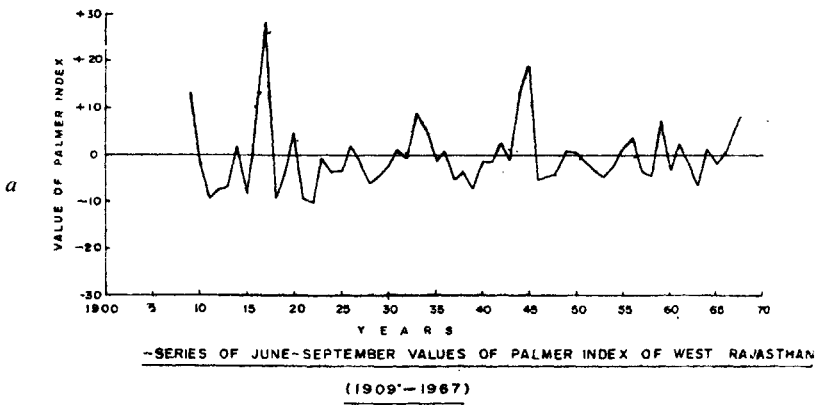
Quasi-biennial oscillation in the Drought Index (Palmer)

Sub-division		Period months	Details of Cycle	Amplitude cm	Phase
(1) Bihar Plains	1	24	May 1907 to May 1909	2.00	—59° 6′
	2	23	April 1909 to April 1911	1.71	53°18′
(2) Uttar Pradesh East	1	22	Mar. 1911 to Jan. 1913	0.79	35° 36′
	2	24	Jan. 1913 to Jan. 1915	0.96	—48° 42′
(3) Madhya Pradesh East	1	23	June 1910 to May 1911	0.67	— 1° 12′
	2	25	July 1913 to Aug. 1915	0.72	—48° 42′
(4) Rayalaseema	1	25	July 1908 to Aug. 1910	3.86	—20° 6′
	2	24	Aug. 1910 to Aug. 1912	2.53	79° 6′
(5) Interior Mysore North	1	24	Aug. 1920 to Aug. 1922	1.69	57° 18′

Sunspot Cycle in Drought Index (Palmer)

Sub Division	Period Years	Details of Cycle	Amplitude	Phase
(1) Madhya Pradesh West	10	1931–1941	9.24	49° 18′
(2) Rajasthan West	11	1936–1947	7.99	—67° 36′

Technical Note 79). The response curve of the 43 point filter is represented in Fig. 3. The residual values from the earlier set of 97 point filter for quasi-biennial oscillation for the five sub-divisions mentioned above and 11 year sunspot cycle for Rajasthan West and Madhya Pradesh West have been subjected to Fourier analysis. The results are given in Table II.



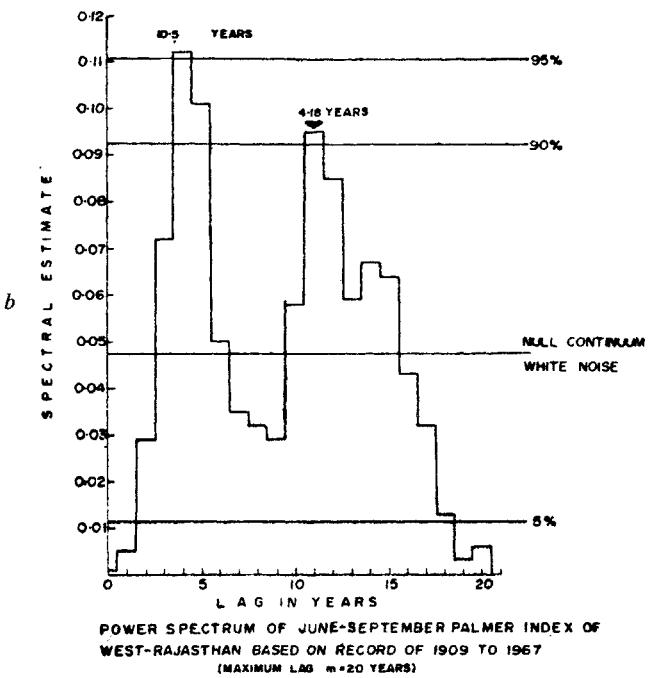


FIG. 4. Palmer Index Values with corresponding spectrum analysis for West Rajasthan and Interior Mysore North.

MAIN RESULTS

The present study has been made with a view to find out whether there is any periodicity in drought incidence, which can be identified with two of the well-known oscillations, (i) Quasi-biennial oscillation and (ii) Eleven year sunspot cycle. Drought

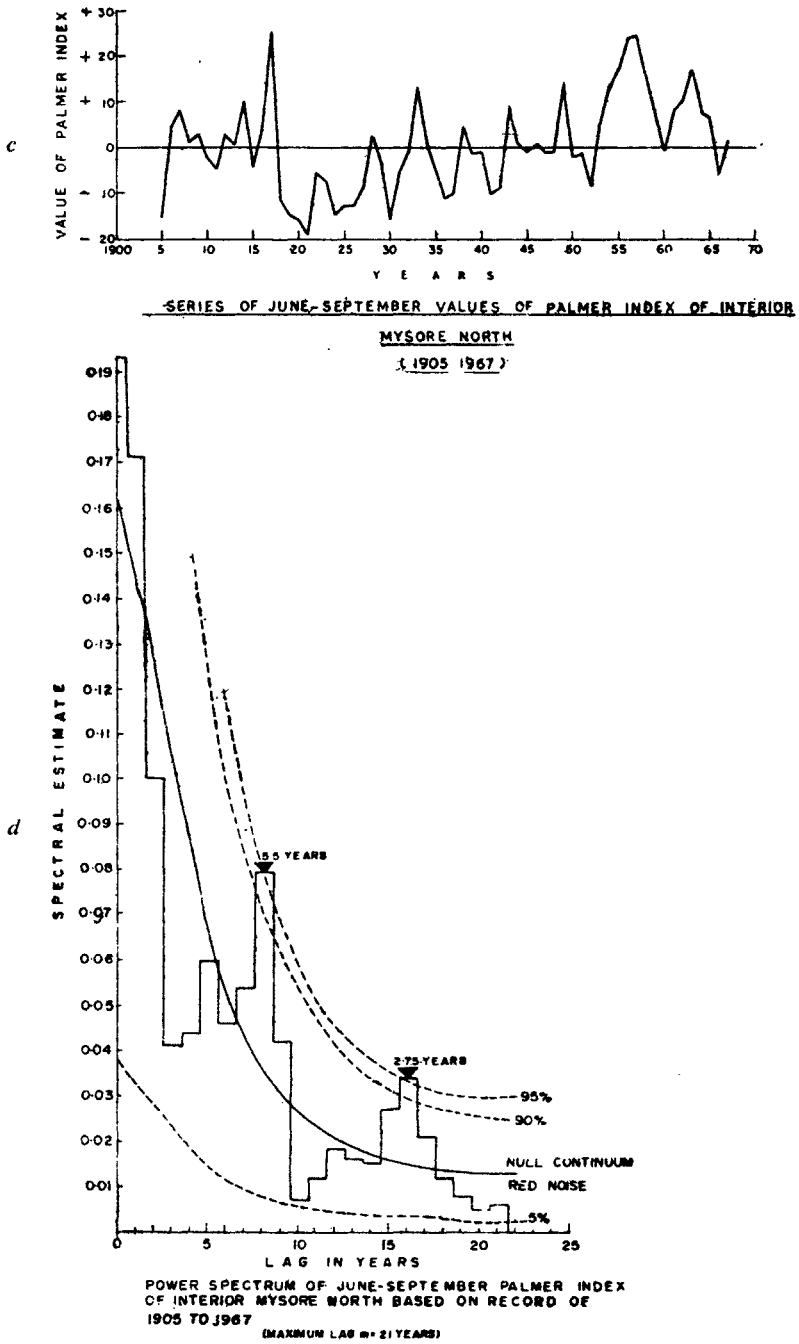


FIG. 4. Palmer Index Values with corresponding spectrum analysis for West Rajasthan and Interior Mysore North.

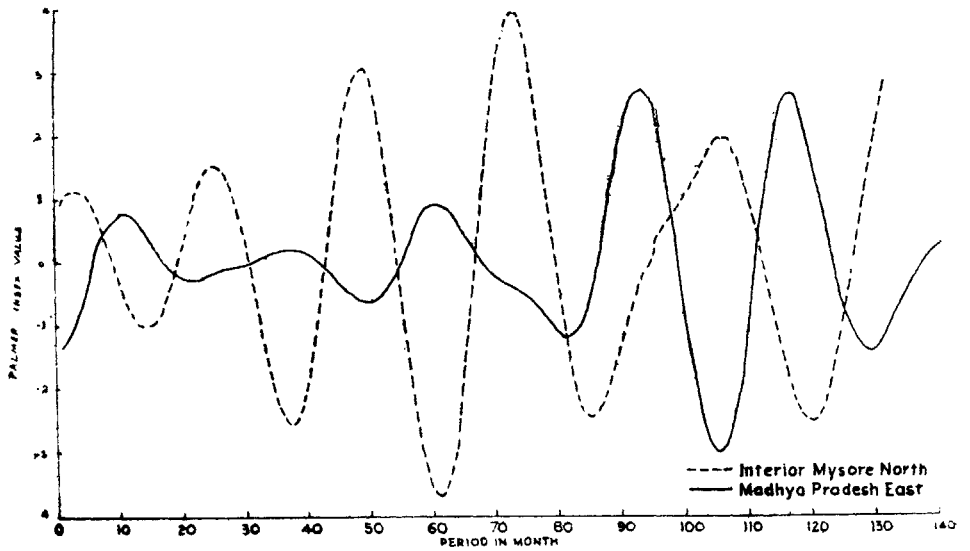


FIG. 5. Quasi-biennial wave in drought index (Palmer) for interior Mysore North (Jan. 1909–Dec. 1919) and Madhya Pradesh East (Jan. 1910–Aug. 1921).

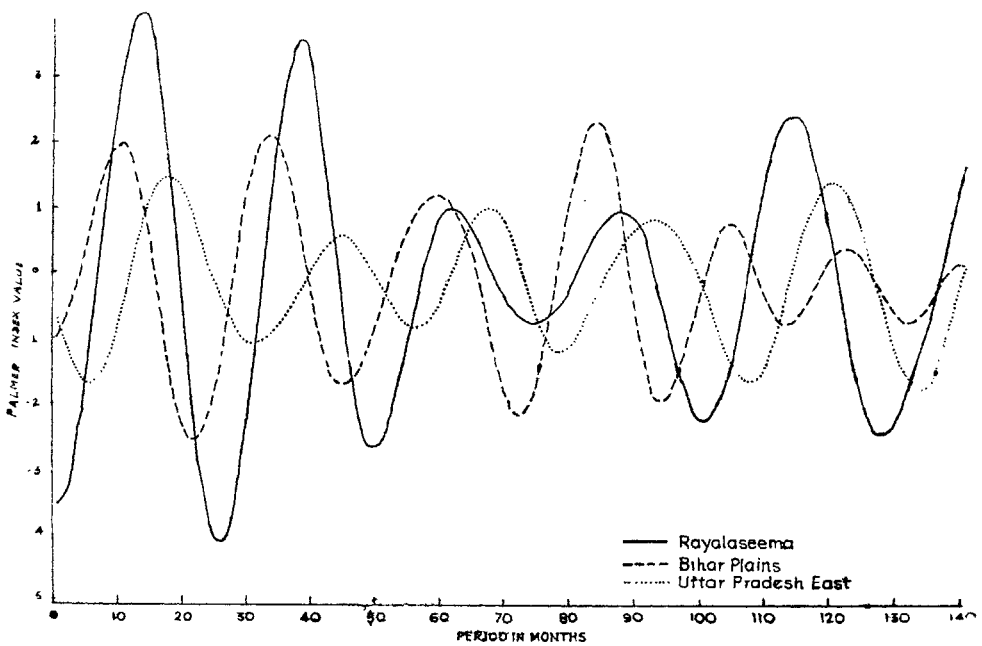


FIG. 6. Quasi-biennial wave in drought index (Palmer) for Rayalaseema (Jan. 1908 to Aug. 1919). Bihar plains (Jan. 1907 to Aug. 1918) and Uttar Pradesh East (Jan. 1908 to Aug. 1919).

series of twenty-three sub-divisions were subjected to the power spectrum analysis. Analysis reveals that various periodicities noticed were significant at 90 or 95 per cent level as given in Table I. Other particulars are also detailed in this Table. 'White

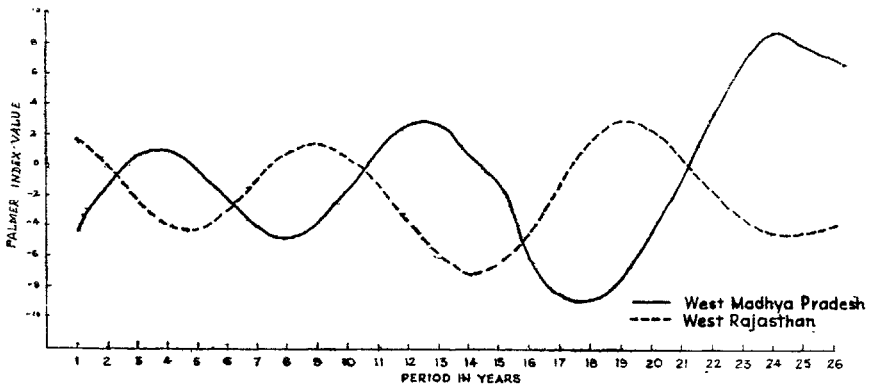


FIG. 7. Eleven year cycle for Palmer Index for West Madhya Pradesh (1924 to 1949) and West Rajasthan (1926 to 1951).

noise' spectrum of random series and a graph of season's drought index values for West Rajasthan are exhibited in Fig. 4*b* and 4*a*. Similarly, 'Red noise' spectrum of Markov type persistence of interior Mysore North and the plot of accumulated drought index values for monsoon season against years are shown in Fig. 4*d* and 4*c*.

Monthly values of the Palmer series for sub-divisions having quasi-biennial oscillation were subjected to the 97 point band-pass filter after removing the persistence. Residuals of the series for interior Mysore North and Madhya Pradesh East are presented in Fig. 5 and Bihar Plains, Uttar Pradesh East and Rayalaseema are presented in Fig. 6. Annual values of drought series for eleven year cycle for Rajasthan West and Madhya Pradesh West after removing the persistence were subjected to a 43 point band pass filter. Residuals of the series for these sub-divisions are represented in Fig. 7. Details of these oscillations are given in Table II.

SUMMARY AND CONCLUSIONS

Some persistence in drought occurrence is, however, seen in North India in the belt extending from Bihar Plains upto East Rajasthan. In peninsula, similar feature is seen in Madhya Maharashtra, Marathwada, Rayalaseema and Interior Mysore. Quasi-biennial oscillations were detected by Power Spectrum Analysis in Bihar Plains, Uttar Pradesh, East, Madhya Pradesh East, Rayalaseema and Interior Mysore North. Eleven year sunspot cycle in Rajasthan West and Madhya Pradesh West were also detected. These oscillations were further subjected to filters and Fourier analysis. The plots of the residuals indicate the presence of quasi-biennial oscillation in all the five sub-divisions mentioned above, whose amplitude is larger in Rayalaseema and Bihar. For Eleven year cycle residual plot indicates large amplitude for Rajasthan West.

From these results following conclusions are drawn:—

(1) The period of the quasi-biennial oscillation changes from one cycle to the next over a particular sub-division.

(2) In case of eleven year cycle, West Rajasthan is in lag with Uttar Pradesh West.

(3) There is a phase variation in quasi-biennial oscillation and in eleven year cycle.

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