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Trends and periodicities of monsoon and annual rainfall of districts of Haryana State and Delhi

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सार–वर्षा की प्रवृत्तियों और आवर्तिताओं का पता लगाने के लिए 90 वर्ष की अवधि (1901–1990) के लिए दक्षिण-पश्चिम मानसून और निश्चित संख्या वाले वर्षामापी स्टेशनों (36) पर आधारित हरियाणा और दिल्ली के 12 जिलों के वार्षिक वर्षा का विश्लेषण किया गया। यह देखा गया है कि मानसून और वार्षिक वर्षा में समान परिवर्तिता है और अधिकतम वर्षा के क्षेत्रों में यह न्यूनतम है। दो राज्यों अर्थात कुरुक्षेत्र और सिरसा में मानसून वर्षा की बारंबारता बंटन सामान्य नहीं पाई गई है। रोहतक और कुरुक्षेत्र की मानसून वर्षा और दिल्ली की वार्षिक वर्षा में सकारात्मक प्रवृत्ति पाई गई है। 45 वर्षों की अवधि के लिए माध्य वर्षा में वृद्धि से, पूर्वमध्य भागों में अधिकतम मान सहित राज्य के पश्चिम भागों के पूर्वमध्य से, प्रथम से द्वितीय तक प्रवणता का पता चलता है निम्न आवृत्ति फिल्टर के विश्लेषण से पता चलता है कि यह प्रवाह रैखिक नहीं है किन्तु ये दोलन हैं जोकि 10 वर्षों की अवधि या इससे अधिक के बने हुए हैं।

मानावलीय विश्लेषण से राज्य के मुख्यत: पूर्वी और दक्षिण-पश्चिम जिलों में 5.5 से 8.6 वर्षों के परास के सार्थक चक्र का पता चलता है। राज्य के कुछ जिलों के क्यू.बी.ओ. का भी प्रेक्षण लिया गया।

ABSTRACT. Analysis of southwest monsoon (June to September) and annual rainfall of 12 districts of Haryana and Delhi based on fixed number of raingauge stations (36) has been made for 90-year period (1901-1990) in order to search for trends and periodicities in the rainfall. It is seen that monsoon and annual rainfall have a similar variability and is least where rainfall is maximum. It is also observed that frequency distribution of monsoon rainfall is not normal in two districts, *viz*., Kurukshetra and Sirsa. Positive trend is noticed in monsoon rainfall of Rohtak and Kurukshetra and annual rainfall of Delhi. Increase in the mean rainfall for 45 years period showed a gradient from first to second from the eastcentral to the western parts of the State with a maximum value over the eastcentral parts. Low-pass filter analysis suggests that the trend is not linear but oscillatory consisting of periods of 10 years or more.

The spectral analysis indicates a significant cycle of range 5.5 to 8.6 years mainly in eastern and southwestern districts of the State. QBO is also observed over some districts of the State.

Key words — Trends and periodicities, Spectrum analysis, Frequency distribution, QBO, Gaussian low pass-filter, Red noise spectrum, White noise spectrum.

1. Introduction

Several studies have been undertaken in India to assess the rainfall variability. Blanford (1886) was the first meteorologist who made extensive studies of Indian rainfall. The studies of Koteswaram & Alvi (1970) and Jagannathan & Parthasarathy (1973) for different stations of India, Parthasarathy and Dhar (1974) for annual rainfall of 31 meteorological sub-divisions of India, Parthasarathy (1984) for monsoon rainfall of 29 meteorological sub-divisions of India, Raghavendra (1974, 1976 & 1980) for sub-divisions of Maharashtra, Andhra Pradesh and Kerala States, Chowdhury and Abhyankar (1979) for Gujarat, Parthasarathy and Mooley (1981) for Karnataka and Dhar *et al.* (1982) for Tamil Nadu showed the significant presence of different cycles ranging from 2 years to very low frequencies in the rainfall series of different regions/sub-divisions of India. Recent study of Soman *et al.* (1988) revealed a significant decreasing trend in the rainfall over major part of Kerala State barring the coastal belt. Sarker and Thapliyal (1988) have summarised the climate change and variability, with particular reference to the analysis, made by using Indian rainfall and temperature data for recent 100 years. In the present study the districtwise annual and monsoon rainfall data of Haryana and Delhi have been analysed to study the variability of annual and monsoon rainfall, the nature of frequency distribution the existence or otherwise of long term trends and periodicities.

2. Data

The validity of any statistical analysis depends primarily on the quality of the data used. The raingauge network over Haryana like rest of the country has increased manyfolds. A straight forward algebraic average of rainfall for all the available stations over the districts would provide some inter-annual variability solely due to the sampling different stations during different years. To avoid this, rainfall records of 36 stations which are having continuous data beginning from 1901 have been examined for completeness and geographical coverage of the districts.

Fig. 1 shows the network of the selected stations over the region considered. The relevant rainfall

TABLE 1

Statistical parameters of districtwise rainfall of Haryana and Delhi

District		Mean (mm)	S.D. (%)	Coeff. of variation	Coeff. of skewness	Coeff. of Kurtosis	g_1/SE (g_1)	g_2/SE (g_2)	Chi-square value
Ambala	Monsoon	778.8	215.8	27.9	0.117	—0.623	0.580	—1.066	6.711
	Annual	952.2	227.2	23.9	0.384	0.159	1.540	0.474	5.822
Kurukshetra	Monsoon	466.8	161.6	34.6	1.228	3.479	4.909*	7.434*	15.244*
	Annual	577.3	177.9	30.8	0.861	1.824	3.454*	3.842*	8.844
Karnal	Monsoon	548.2	184.6	33.7	0.316	—0.216	1.357	—0.397	10.267
	Annual	668.7	198.6	29.7	2.300	—0.307	0.097	—0.509	2.622
Jind	Monsoon	364.4	146.7	40.3	0.818	0.940	3.977*	3.317*	9.556
	Annual	447.8	160.1	35.8	0.626	0.393	2.720*	1.604	9.911
Rohtak	Monsoon	433.3	176.0	40.6	0.275	—0.556	1.208	—1.022	7.067
	Annual	510.3	176.0	34.5	0.174	—0.270	0.698	—0.427	3.689
Sonepat	Monsoon	476.6	190.3	39.9	0.814	0.572	3.190*	1.306	8.844
	Annual	548.1	196.9	35.9	0.540	0.092	2.150*	0.454	4.578
Delhi	Monsoon	594.2	235.7	39.5	0.610	0.864	2.433*	1.957	4.400
	Annual	712.6	245.3	34.4	0.436	0.272	1.745	0.710	2.800
Faridabad	Monsoon	494.7	171.6	34.7	0.346	—0.137	1.386	—0.149	2.089
	Annual	581.4	185.3	31.9	0.187	—0.322	0.747	—0.538	5.822
Gurgaon	Monsoon	484.3	163.0	33.7	0.321	—0.245	1.284	—0.377	3.867
	Annual	560.7	169.3	30.2	0.528	0.488	2.131*	1.176	5.644
Mahendragarh	Monsoon	414.5	159.0	38.3	0.592	0.662	2.232*	1.451	4.756
	Annual	472.4	161.7	34.2	0.765	1.860	2.947*	3.320*	6.178
Bhiwani	Monsoon	351.9	142.3	40.4	0.397	—0.349	1.647	—0.603	3.867
	Annual	420.9	156.4	37.2	0.465	—0.150	1.861	—0.175	1.022
Hisar	Monsoon	310.4	124.8	40.2	0.624	0.316	2.333*	0.792	1.378
	Annual	384.8	136.0	35.3	0.823	1.404	3.168*	2.947*	5.111
Sirsa	Monsoon	253.3	145.4	57.4	1.258	2.889	5.038*	6.215*	11.333*
	Annual	316.1	151.9	48.1	1.300	4.970	5.985*	10.609*	8.844

*Frequency distribution of the series are not normal at 95% level.

TABLE 2

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

District (1)	(2)	Mann-Kendall statistic (3)	Mean of 1901 to 1945 (4)	Mean of 1946 to 1990 (5)	Difference of col. 5 and col. 4 (6)	Difference as % of mean (7)	Student's *t*-value/ Mann-Whitney *U*-value (8)
Ambala	Monsoon	0.124	739.7	823.4	83.7	11.0	1.344
	Annual	0.109	918.0	966.3	68.3	8.0	1.434
Kurukshetra	Monsoon	0.141*	438.1	495.5	57.4	13.0	1.502
	Annual	0.032	561.5	593.1	31.6	6.0	0.841
Karnal	Monsoon	—0.037	543.4	552.9	9.5	2.0	0.242
	Annual	—0.048	667.8	669.6	1.8	1.0	0.043
Jind	Monsoon	—0.009	381.0	347.9	—33.1	—9.0	—1.072
	Annual	0.002	464.7	431.0	—33.7	—8.0	—0.998
Rohtak	Monsoon	0.183*	379.7	486.8	107.1	25.0	3.012*
	Annual	0.163*	461.5	559.1	97.6	20.0	2.724*
Sonepat	Monsoon	0.042	447.2	506.1	58.9	13.0	1.478
	Annual	0.014	529.6	566.7	37.1	7.0	0.894
Delhi	Monsoon	0.129	545.2	643.2	98.0	17.0	2.005*
	Annual	0.157*	651.5	773.8	122.3	18.0	2.327*
Faridabad	Monsoon	0.038	479.0	510.4	31.4	7.0	0.865
	Annual	0.008	573.2	589.6	16.6	3.0	0.419
Gurgaon	Monsoon	0.041	473.2	494.5	22.3	5.0	0.647
	Annual	0.029	554.0	567.3	13.3	3.0	0.371
Mahendragarh	Monsoon	0.078	392.1	436.9	44.8	11.0	1.342
	Annual	0.026	456.6	488.3	31.7	7.0	0.928
Bhiwani	Monsoon	—0.042	348.0	356.0	8.0	3.0	0.265
	Annual	—0.057	414.5	427.4	12.9	3.0	0.389
Hisar	Monsoon	—0.051	316.1	304.7	—11.4	—4.0	—0.032
	Annual	—0.055	394.0	375.7	—18.3	—5.0	—0.636
Sirsa	Monsoon	—0.036	260.9	245.7	—15.2	—6.0	—0.494
	Annual	—0.002	322.8	309.5	—13.3	—5.0	—0.414

*Value significant at 95% level.

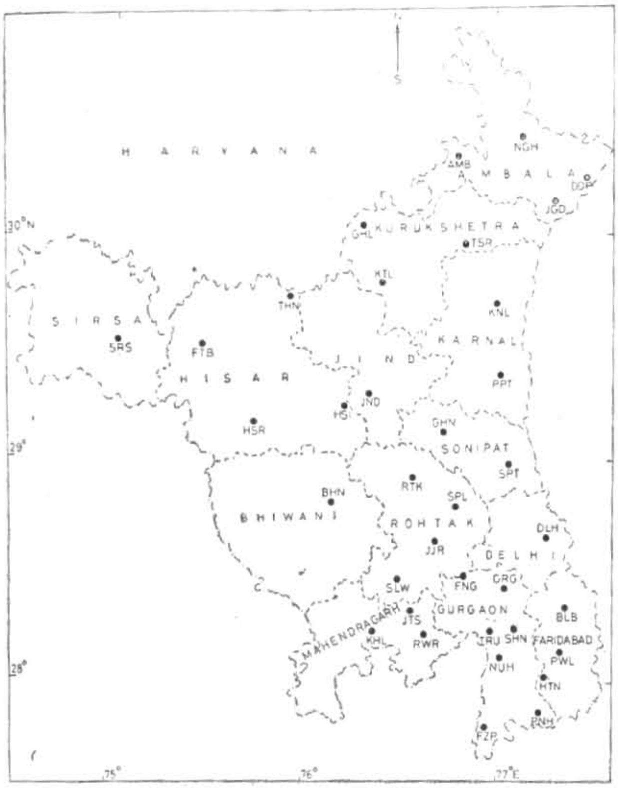

Fig. 1. Locations of raingauge stations and district boundaries of Haryana State

data for the stations have been collected from Hydromet· Directorate of India Met. Dept., New Delhi and National Data Centre, Pune. The missing rainfall values of some of the stations are interpolated as per the ratio method suggested by Rainbird (1967) by considering nearby stations or regional average of that area. The interpolated values taken into account are less than 2 per cent of the total.

3. Results and discussion

Monsoon and annual rainfall data series comprising Delhi and 12 districts of Haryana for a period of 90 years from 1901 have been analysed statistically for the variability and type of frequency distribution. Trends and periodicities have also been examined by various techniques like Mann-Kendall rank, Gaussian low-pass filter and power spectrum analysis methods as given in WMO Technical Note (1966). The different aspects of the analysis are discussed below.

3. 1. *Mean and variability*

Districtwise mean rainfall has been worked out by taking the arithmetic mean of all the stations available in each district for the period 1901 to 1990 and this is given in Table 1 together with data of other statistical parameters like standard deviation, coefficient of variation, coefficient of skewness and kurtosis.

It is observed from Table 1 that among all the districts of Haryana including Delhi considered in this study, average annual rainfall is highest (monsoon 778.8 and annual 952.2 mm) in respect of Ambala and lowest (monsoon 253.3 and annual 316.1 mm) in Sirsa. It is also seen that the coefficient of variations is lowest (monsoon 27.9 and annual 23.9%) in respect of Ambala and highest (monsoon 57.4 and annual 48.1%) for Sirsa.

3. 2. *Normality test for districtwise rainfall*

For the application of statistical tests for any time series, it is essential to know the nature of frequency distribution. The frequency distribution of monsoon and annual rainfall series for all the districts have been tested for normality by Fisher's statistics and Chi-square test. Fisher's statistics g_1 and g_2 are computed and these are compared with their respective standard errors (SE). Table 1 gives the values of two parameters, g_1/SE (g_1) and g_2/SE (g_2) for both the monsoon and annual rainfall.

In order to test the normality at 95% level of significance, the values of either g_1/SE (g_1) or g_2/SE (g_2) should be less than 1.960. It is evident from the Table 1 that for the districts of Kurukshetra, Jind, Sonepat, Mahendragarh, Hisar and Sirsa the values of g_1/SE (g_1) are greater than 1.960 for both the annual and monsoon rainfall series. It is also seen that the monsoon rainfall of Delhi and annual rainfall of Gurgaon is also not normally distributed for their frequencies. It is further observed that in case of monsoon rainfall of Sonepat, Delhi, Mahendragarh and Hisar and annual rainfall of Jind and Sonepat g_1/SE(g_1) is more than 1.960 but g_2/SE(g_2) is less than 1.960, which indicates that the peak of the series is slightly away from the normal. Thus, we see that 14 rainfall series are not normally distributed.

The Fisher's statistics is quite sensitive one for testing normality and as such the application of this test has revealed that more than 50% rainfall series considered in this study are not normally distributed for their frequencies. To test the normality of the time series, the Chi-square test which is lesser sensitive than the Fisher's statistics has been applied by considering eight equal probability class intervals. The results are shown in Table 1. For chi-square with five-degree of freedom the significant value at 95% level is 11.100. In view of this, there are only two rainfall series, *i.e.*, monsoon rainfall series of Kurukshetra and Sirsa in which the calculated chi-square values exceed 11.100 and indicate significance at 95% level. Therefore, except these two rainfall series, all the rainfall series under study can be regarded as normally distributed as per this test.

4. Trend analysis

4 .1. *Mann-Kendall rank statistic*

The most likely alternative to randomness in a climate time series is some form of trend, which need not be linear one. It is, therefore, advantageous to use tests of randomness to check the trend. The rank correlation methods are robust and departure from the Gaussian normal distribution will not be of much serious concern.

Mann-Kendall rank statistic has been suggested as a powerful test (Kendall and Stuart 1961), the most likely alternative to randomness is linear or non-linear

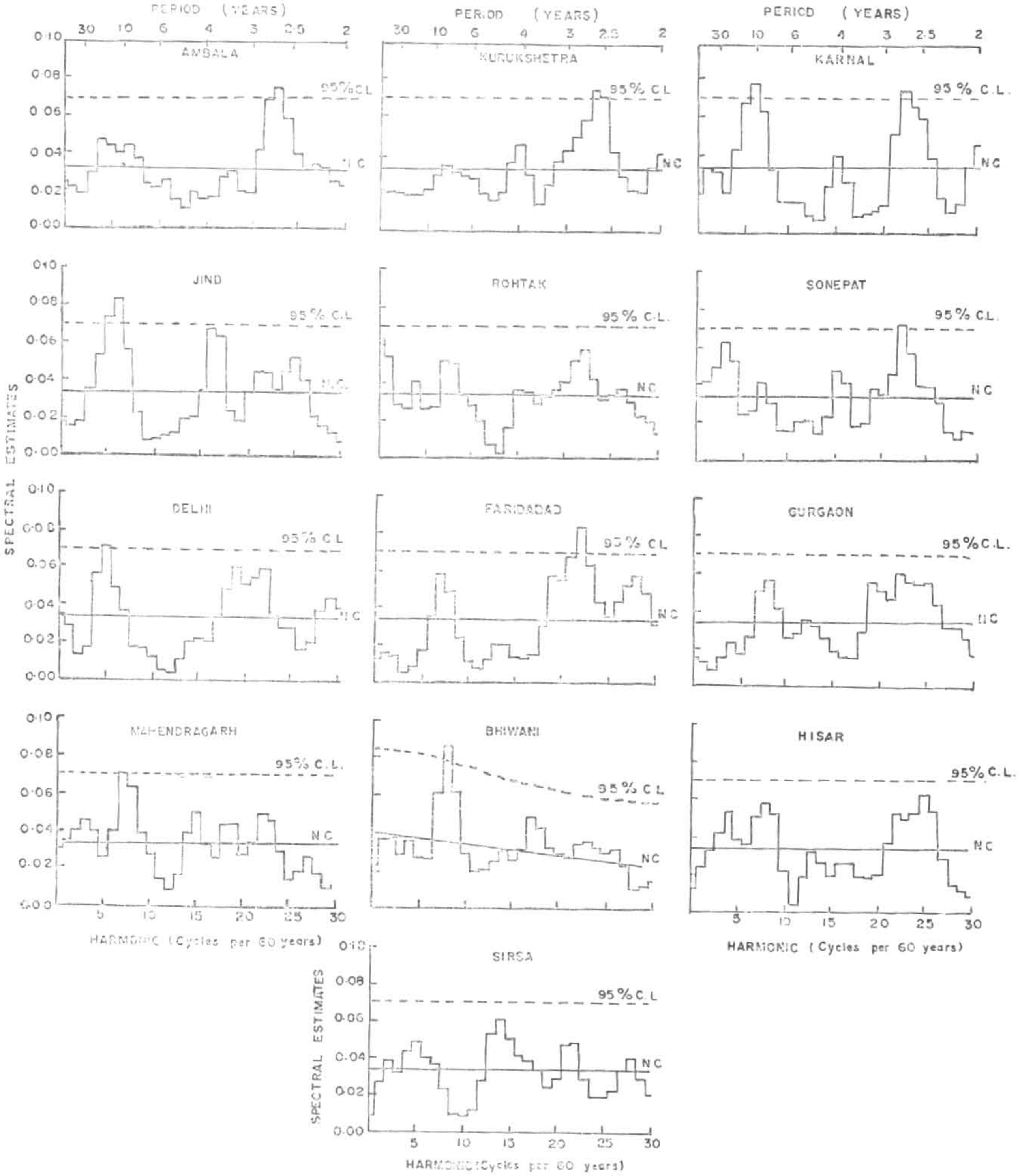

Fig. 2. Spectral analysis of monsoon rainfall (1901-1990)

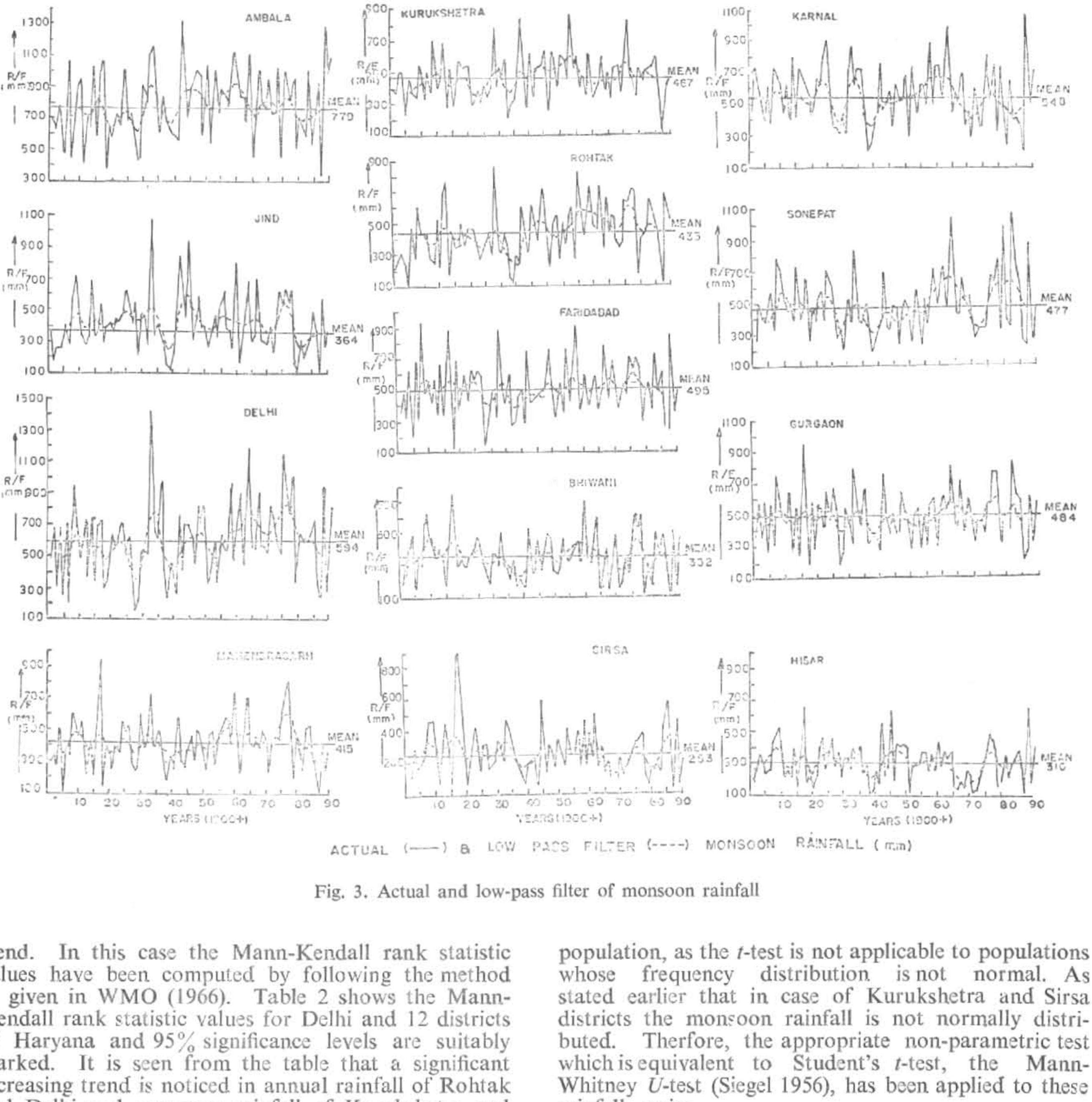

Fig. 3. Actual and low-pass filter of monsoon rainfall

trend. In this case the Mann-Kendall rank statistic values have been computed by following the method as given in WMO (1966). Table 2 shows the Mann-Kendall rank statistic values for Delhi and 12 districts of Haryana and 95% significance levels are suitably marked. It is seen from the table that a significant increasing trend is noticed in annual rainfall of Rohtak and Delhi and monsoon rainfall of Kurukshetra and Rohtak.

4. 2. *Student's t-test*

In the present study the rainfall series of the period 1901 to 1990 is divided into two equal periods, 1901-1945 and 1946-1990. The significance of the difference of the mean between the first and the second period has been tested by Student's *t*- test and the magnitude of the gradient ascertained. Table 2 shows the statistics regarding the means of the two periods, their differences, percentage as the long period mean and Student's *t*-values for all the districts.

Student's *t*-values at 95% levels are suitably marked in Table 2. The Student's *t*-test strictly assumes that the observations have come from a normally distributed population, as the *t*-test is not applicable to populations whose frequency distribution is not normal. As stated earlier that in case of Kurukshetra and Sirsa districts the monsoon rainfall is not normally distributed. Therfore, the appropriate non-parametric test which is equivalent to Student's *t*-test, the Mann-Whitney *U*-test (Siegel 1956), has been applied to these rainfall series.

It is seen from Table 2 that significant positive trend is noticed in both the annual and monsoon rainfall series of Rohtak and Delhi. Student's test suggests significant increasing trend in the monsoon rainfall of Delhi but the Mann-Kendall statistic does not support this. Whereas in respect of monsoon rainfall of Kurukshetra Mann-Kendall test indicates a significant increasing trend but Mann-Whitney *U*-test does not support this. Table 2 also reveals that increase in monsoon rainfall in respect of Rohtak and Delhi are quite high and are of the order of 107.1 and 98.0 mm respectively. Gradient in rainfall is observed from eastcentral parts to the western parts of the State. Significant percentage change in the mean for 45 years varies from 11.0 to 25.0 %.

4.3. *Low-pass filter*

To understand the nature of trend, the series were 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 (0.01, 0.05, 0.12, 0.20, 0.24, 0.20, 0.12, 0.05 and 0.01). The response curve of Gaussian low-pass filter has a response function that is equal to unity at infinite wavelength and it tails of asymptotically to zero with decreasing wavelengths (WMO 1966). The low-pass filter curves for monsoon and annual rainfall of Delhi and 12 districts of Haryana are almost identical. Therefore, for the sake of brevity the low-pass filter curves only for monsoon along with actual rainfall curves are shown in Fig. 3.

It is observed from the low-pass filter curves that the trend is not linear but oscillatory consisting of periods of 10-year length or more.

Leaving aside the minor fluctuations, it is evident that except for Jind the rainfall series of all the districts of Haryana including Delhi exhibit an increasing trend from 1940 to 1960/1965, whereas Jind indicates decreasing trend during the period.

Further it is also seen that except Jind and Karnal rest of the districts of Haryana including Delhi indicate the decreasing trend from 1910/1915 till 1940.

5. Periodicities

For determining periodicities in the annual rainfall series, if any, the data series of Delhi and 12 districts of Haryana were subjected to spectrum analysis following the procedure of Blackman and Tukey (1958) as given in WMO (1966). To achieve satisfactory resolution in the spectrum, we chose a maximum lag limit 30, which is one third of the total length of the period (90). The null hypothesis for the purpose was considered in accordance with the fact whether the series revealed any persistence or not. If the persistence was of the 'Markov-linear type,' then the appropriate 'red-noise spectrum' and the associated 95% limits were calculated and the individual peaks tested with reference to these limits. In the absence of any persistence, the spectral estimates were tested against 'white-noise spectrum'.

Red-noise or persistence has been noticed in the rainfall series of Bhiwani only. Rest of the districts do not exhibit any persistence.

The annual and monsoon rainfall spectrum results are almost similar, therefore, for the sake of brevity, spectrum results of monsoon rainfall only have been depicted in Fig. 2. It is observed from the diagrams that there is a cycle of 8.6, 7.5, 6.0 and 5.5-year at the 95% significant level in the rainfall series of Mahendragarh, Bhiwani, Jind and Delhi. A cycle between 2 and 3 years, generally called quasi-biennial oscillation (QBO) is significant at 95% level in the rainfall series of Ambala, Kurukshetra, Faridabad and Karnal. The study by Raghavendra (1973) also showed the significant presence of QBO in northwest Indian regions.

6. Conclusions

(a) Ambala is the wettest and Sirsa is the driest district of Haryana State.

(b) There is a significant increasing trend in the mean annual and monsoon rainfall in Rohtak and Delhi from the first half to the second half of the period.

(c) The significant increase in the annual and monsoon rainfall shows a gradient from the eastcentral to the western parts of the State.

(d) Positive trend is noticed in the monsoon rainfall of Kurukshetra and Rohtak and in the annual rainfall of Delhi and Rohtak.

(e) The power spectrum analysis indicates a significant cycle of range 5.5 to 8.6 years mainly in eastern and southwestern districts of the State. QBO is also observed over some districts of the State.

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