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Does precipitation pattern foretell climatic shift over Punjab state ?

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सार — पंजाब राज्य में वर्षा रिकार्ड करने के 27 केन्द्रों द्वारा 82 वर्षों (1901-1982) में दर्ज किए गए वर्षण के रिकार्ड का सांख्यिकी विश्लेषण, राज्य में जलवायु परिवर्तन का निर्धारण करने के लिए किया गया। इस अध्ययन का मुख्य उद्देश्य प्रदेश के विभिन्न केन्द्रा में वार्षिक, मानसूनी और शीतकालीन वर्षा की प्रवृत्ति और मानावली (स्पैक्ट्रम) विश्लेषण करना है। यह ज्ञात हुआ कि वर्षा के 81 अनुक्रमों में से 19 अनुक्रमों का आनुपातिक वितरण सामान्य रहा। कुछ वर्षा अनुक्रमों में मारकोव-लीनियर (मारकोव रैखिक) प्रकार की निरन्तरता पाई गई। मान-केंडाल परीक्षण से प्रकट हुआ कि सभी केन्द्रों में शीतकालीन वर्षा में कमी की प्रवृत्ति आई है और अमृतसर, तरण-तारण, टंडा, लुधियाना और रानिकी में यह प्रवृत्ति अधिक स्पष्ट रूप में पाई गई। निम्न आवृत्ति फिल्टर से पता चला कि यह प्रवृत्ति रैखिक नहीं है बल्कि दोलक है जिसमें 10 वर्ष या अधिक की अवधि सम्मिलित है। अधिकांश केन्द्रों की शीतकालीन वर्षा में 1935-1940 से 1965-1970 की अवधि के दौरान कमी आने की प्रवृत्ति का पता चला। निम्न आवृत्ति फिल्टर वक्रों से पता चला कि सभी केन्द्रों में 1960 से अध्ययन की अवधि तक शीतकालीन वर्षा सामान्य से कम रही।

मानावलीय (स्पैक्ट्रल) विश्लेषण से कुछ केन्द्रों में 4.1 से 27 वर्षों तक का सार्थक चक्र और अनेक केन्द्रों में अर्ध द्विवर्षी (क्यू० बी० ओ०) दोलनों का पता चला।

ABSTRACT. Statistical analysis of 82-years (1901-1982) record of precipitation from 27 rain-recording stations in Punjab state of India has been carried out to assess the climate shift, if any, in the state. The central part of the study is the trend and spectrum analysis of annual, monsoon and winter rainfall of different stations in the region. It is seen that frequency distribution of 19 rainfall series out of 81 series is normally distributed. Markov linear type of persistence is observed in some of the rainfall series. Mann-Kendall test indicates the decreasing trend in winter rainfall of all the stations and is found to be significant in case of Amritsar, Taran Taran, Tanda, Ludhiana and Ranike. Low-pass filter reveals that trend is not linear but oscillatory consisting of periods of 10 years or more. It is seen that winter rainfall of most of the stations exhibits the decreasing trend from 1935-40 to 1965-70. It is also revealed by the low-pass filter curves that winter rainfall of all the stations remained below average from 1960 till the end of the study period.

The spectral analysis indicates a significant cycle of 4.1 to 27 years in some of the stations and Quasi-Biennial Oscillations (QBO) over many stations.

Key words — Auto-correlation, Frequency distribution, Persistence, Periodicity, Red-noise, Spectrum analysis, Trend, White-noise.

1. Introduction

In recent years, contemporary changes in climate have become the focus of scientific efforts in many aspects. Numerous studies have been made on global, hemispheric, sub-continental and regional scale precipitation and temperature changes. Mitchell (1963), Brinkmann (1976), Angell *et al.* (1978), Hansen *et al.* (1981) and Jones *et al.* (1982) have studied the long term variation in surface air temperature. Their studies indicated a warming in the Northern Hemisphere between 1880 and 1940 and cooling thereafter. Hingane *et al.* (1985) in their study found a slight but definite warming trend in the mean annual Indian temperatures.

Parthasarathy and Dhar (1974) studied secular variations in annual rainfall for different meteorological sub divisions of India and Patnaik *et al.* (1977) examined the characteristic temporal variation of summer and winter monsoon rainfall over the country. The studies of Parthasarathy (1984) for monsoon rainfall of 29 meteorological sub-divisions of India, Raghavendra (1974, 1976) for meteorological sub divisions of Maharashtra, and Andhra Pradesh states, Parthasarathy and Mooley (1981) for Karnataka and Dhar *et al.* (1982) for Tamilnadu 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. The 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

TABLE 1

Statistical parameters of stationwise rainfall of Punjab state (1981-1982)

Station	Mean (mm)			Standard deviation (mm)			Coefficient of Variation			g^1 1981			g^2 1982		
	Annual	Mon-soon	Win-ter	Annual	Mon-soon	Win-ter	Annual	Mon-soon	Win-ter	Annual	Mon-soon	Win-ter	Annual	Mon-soon	Win-ter
Amritsar	546	433	66	177	168	49	32	39	74	1.664	1.741	3.963*	−0.805	−0.65	2.384*
Aznala	686	487	68	215	206	42	35	42	62	3.325*	3.263*	2.199*	1.093	1.011	0.263
Taran Taran	543	429	64	189	175	48	35	41	72	3.317*	1.657	3.302*	1.441	−0.857	0.967
Pathankot	1154	863	148	344	288	80	30	33	54	2.261*	2.614*	1.932	−0.222*	0.119	−0.421
Tibri	910	673	114	371	312	72	41	46	63	3.174*	2.882*	2.675*	3.103*	3.024*	0.389
Batala	751	571	83	355	235	49	34	41	59	1.292	4.954*	1.761	0.059	4.636*	−0.216
Dasuya	848	642	100	248	221	60	29	35	59	1.805	1.181	3.029*	−0.985	−1.513	0.706
Tanda	692	542	99	223	194	51	32	36	65	1.516	1.717	3.303*	−0.091	−0.068	1.141
Hoshiarpur	888	670	101	264	244	60	30	37	59	5.109*	4.664*	4.629*	6.739*	5.379*	4.282*
Garhshankar	830	636	105	287	234	81	35	37	77	3.133*	1.872	10.631*	2.482*	0.491	22.039*
Jalandhar	695	524	82	212	198	51	31	38	62	2.579*	3.266*	3.352*	0.041	1.134	1.292
Nakodar	558	429	66	185	174	43	33	41	65	2.443*	3.181*	2.948*	0.795	2.006*	1.024
Phillaur	657	503	76	199	190	45	30	38	59	0.971	0.895	2.008*	−0.494	−1.597	−0.684
Nawanshahar	778	600	93	240	225	58	31	38	62	3.382*	3.541*	3.759*	2.251*	1.979	1.072
Fazilka	313	245	32	148	145	24	47	59	77	3.219*	4.498*	3.151*	1.774	3.904*	0.542
Firozpur	444	347	48	161	165	33	36	48	67	3.813*	3.454*	3.665*	2.076*	0.909	1.273
Zira	479	396	54	177	196	37	37	50	69	1.761	3.671*	2.594*	0.739	1.573	−0.227
Ropar	800	628	102	220	283	69	28	32	68	1.638	1.238	7.407*	0.221	−0.608	12.166*
Kharar	754	594	88	286	184	50	27	31	58	0.948	1.107	2.921*	−0.635	−1.081	0.829
Muktsar	363	278	35	148	134	28	41	48	81	3.824*	4.585*	4.638*	2.881*	6.048*	2.913*
Moga	485	370	51	202	180	37	42	49	72	4.264*	4.493*	3.374*	2.791*	3.849*	0.524
Jagraon	601	440	61	292	196	38	49	45	62	12.261*	4.155*	2.509*	3.285*	3.728*	−0.638
Ludhiana	666	519	73	265	230	45	40	44	62	7.142*	6.269*	2.721*	11.895*	10.891*	0.006
Samrala	712	566	72	229	205	42	32	36	58	2.509*	1.709	2.731*	0.712	0.342	0.324
Bandher	439	348	41	230	206	31	53	59	75	3.712*	4.261*	5.284*	2.116*	3.656*	7.372*
Ranike	439	351	43	241	221	36	55	63	83	2.496*	2.771*	3.205*	−0.009	−0.615	−0.347
Bhartala	583	438	59	213	186	37	37	42	62	3.524*	3.374*	2.593*	1.526	1.001	−0.474

* Significant at 95% level

years. Srivastava *et al.* (1992) found that most of the hill stations indicate decreasing trend in rainfall particularly during the last 2 to 3 decades. Rupa Kumar *et al.* (1992) found the increasing trend in monsoon rainfall along the west coast, northwest India and north Andhra Pradesh, and decreasing trend over east Madhya Pradesh, Northeast India and parts of Gujarat and Kerala. The study of Bhukan Lal *et al.* (1992) revealed a significant cycle of range 5.5 to 8.6 years in the rainfall of eastern and southwestern districts of Haryana.

One of the methods to determine climatic shifts and to project a time series into future is the statistical analysis of the past behaviour of the sample. Now in the application of statistics it may be assumed that the series is composed of combination of two components, *viz.*, non-deterministic

Fig. 1. Locations of rainguage stations of Punjab state

component and deterministic component like trend, periodicities or persistence. The latter component is dealt in the paper. India as one unit, or even its isolated part/sub-divisions, is too big an area for practical purposes and averages mask much detail concerning climate shift of a single station. Therefore, it is felt that detailed study of stationwise rainfall behaviour would be quite relevant.

Punjab state of India during the course of the year, experiences two rainy seasons associated with monsoon (June to September) and winter (December to February). In this paper, an attempt has been made to bring out the salient features of monsoon, winter and annual rainfall variation, such as trends, periodicities and variability in the State.

2. Basic data

The most important factor, which is essential for a quantitative evaluation and understanding the characteristics of climatic shift, is the availability of continuous rainfall data for a very long period. In the present study 27 rain-recording stations, which have continuous data from 1901 to 1982, have been examined for completeness and geographical coverage of Punjab state. The data beyond 1982 could not be obtained from any source and as such the study could not be extended upto the recent period.

Fig. 1 shows the network of the selected stations over the region considered. The relevant rainfall data for the stations have been collected from the Hydromet. Directorate of India Meteorological Department (IMD), New Delhi and National Data Centre (IMD), Pune.

3. Analysis of data

The monthly rainfall is added-up to give seasonal and annual rainfall values. The seasons considered in this study are winter (December to February) and monsoon (June to September). For the winter season, the data period becomes shorter by one year, since December of the previous year is included while computing each year's winter mean.

The 81 data series of various rainfall stations in Punjab state are analysed statistically for the average and variability, type of frequency distribution, nature of trend and periodicities. The different aspects are discussed below.

3.1. *Statistical parameters*

Table 1 gives the statistial parameters of the rainfall series. It is seen that Pathankot receives the highest rainfall (annual 1154, monsoon 863 and winter 148 mm) and Fazilka the least (annual 313, monsoon 245 and winter 32 mm). Coefficient of Variation (C.V.) is highest (83%) in respect of winter of Ranike and lowest (27%) for annual rainfall of Kharar.

In order to examine whether the frequency distribution of various rainfall series is normal or not, Fisher's test has been applied. Fisher's statistics g^1 and g^2 are computed and shown in Table 1. It is seen from the table that both annual and monsoon rainfall of Amritsar, Dasuya, Tanda, Phillaur, Ropar & Kharar; annual of Batala & Zira; monsoon of Taran Taran, Garhshankar & Samrala and winter of Pathankot & Batala is normally distributed for their frequencies. Rest of the rainfall series are not normally distributed for their frequencies.

4. Trend in the rainfall

Computation of trend values provides with a tool to ascertain, if a locality is getting drier or wetter. In case the rainfall series show a positive trend, the area would be considered to be getting wetter year-by-year, and if it is negative, they would imply possible approach of drier condition.

TABLE 2

Mann-Kendall, autocorrelation and spectrum analysis results

Station	Mann-Kendall statistic			Autocorrelation Lag 1			Significant cycles in years		
	Annual	Monsoon	Winter	Annual	Monsoon	Winter	Annual	Monsoon	Winter
Amritsar	−0.112	0.038	−0.211*	0.116	0.141	0.199*	—	27	—
Aznala	0.086	0.232*	−0.092	0.058	0.152*	0.102	—	—	4.4
Taran Taran	−0.085	0.039	−0.159*	0.149	0.208*	0.18*	—	2.3	—
Pathankot	−0.051	0.078	−0.133	0.209*	0.202*	0.087	2.7	2.7	—
Tibri	0.033	0.005	−0.055	0.213*	0.152*	0.035	2.7	9.1	—
Batala	−0.255*	0.156*	−0.126	0.251*	0.183*	0.171*	—	—	4.1
Dasuya	−0.069	0.102	−0.118	−0.094	−0.201	0.081	2.7	2.5	—
Tanda	0.218*	0.251*	−0.165*	0.134	0.022	0.232*	—	—	6.1
Hoshiarpur	0.081	0.107	−0.117	−0.046	−0.133	−0.011	2.7	2.7	—
Garhshankar	0.024	0.041	−0.058	0.005	0.031	−0.055	—	2.7	—
Jalandar	0.103	0.106	−0.111	−0.025*	−0.161*	0.125	—	2.2	4.5
Nakodar	0.176*	0.181*	−0.123	−0.137	−0.096	0.089	—	—	—
Phillaur	0.042	0.053	−0.054	−0.079	−0.128	0.177*	—	—	—
Nawanshahar	0.062	0.111	−0.061	0.033	0.015	0.048	—	—	6.1
Fazilka	0.109	0.098	−0.047	−0.054	−0.049	0.098	—	—	4.4
Firozpur	0.068	0.095	−0.091	−0.052	−0.018	0.071	2.8	2.7	4.4
Zira	0.121	0.132	−0.123	0.078	0.278*	0.128	—	—	—
Ropar	−0.014	0.042	−0.081	0.084	0.027	0.217*	—	—	—
Kharar	0.095	0.114	−0.095	0.029	0.061	0.009	—	—	—
Muktsar	−0.043	0.015	−0.089	−0.055	−0.077	0.149	9.1	9.1	4.4
Moga	0.001	0.022	−0.146	0.029	0.095	0.166*	2.8	2.7	4.4
Jagraon	−0.013	0.026	−0.085	0.165*	0.061	−0.021	—	—	4.4
Ludhiana	−0.033	0.042	−0.177*	0.177*	0.175*	0.108	—	—	4.4
Samrala	0.041	0.086	−0.053	0.105	0.026	0.146	—	2.7	4.4
Bandher	0.087	0.103	−0.094	0.091	0.057	0.091	—	—	—
Rani-ke	−0.054	−0.014	−0.239	0.194*	0.145	0.263*	—	—	—
Bhartala	0.032	0.095	−0.103	−0.084	0.042	0.082	—	7.7	—

* Significant at 95% level.

4.1. *Mann-Kendall rank statistic*

It has been observed that most of the rainfall series are not normally distributed for their frequencies. As such the rank correlation method for finding trend has been applied since the rank correlation methods are robust and departure from the Guassian 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 trend. In this case the statistic is computed as per (WMO 1966). Table 2 shows the Mann-Kendall rank statistic values for all the stations and 95% significance levels are suitably marked. A significant increasing trend is noticed in both annual and monsoon rainfall of Batala, Tanda and Nakodar and monsoon rainfall of Aznala, whereas, decreasing trend is seen in all the winter rainfall series and it is significant in respect of Amritsar, Taran Taran, Tanda, Ludhiana and Ranike.

4.2. *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 (WMO 1966). The results of the analysis are summerised below.

(*a*) *Annual*

Nakodar rainfall has remained below average from the beginning of the study period till 1945 and then above average. Tanda rainfall indicated a dereasing trend from 1906 till 1920 and thereafter increasing trend till 1965. Jalandhar, Pathankot, Kharar and Hoshiarpur revealed a sharp increasing trend from 1930-35 to 1955-60 and then sharp decreasing trend till 1970-75. Garhshankar and Dasuya indicated decreasing trend from 1910 till 1930-35. Whereas, Ranike and Bandher revealed increasing trend.

(*b*) *Monsoon*

Tanda and Nakodar revealed the rising trend in the rainfall from 1920 to 1950-55 and the rainfall remained above average from 1940 onwards. Batala and Aznala rainfall is identical and remains below average from 1908 till 1945-50 and thereafter oscillatory and above average for most of the period. Jalandhar, Pathankot and Kharar indicate the sharp increase in rainfall from 1930 till 1960 and thereafter sharp decrease in the next decade. Dasuya, Hoshiarpur and Pathankot indicate decreasing trend from 1910 till 1930, whereas, Bandher shows increasing trend during this period.

(*c*) *Winter*

The striking feature of the winter rainfall is that the rainfall of all the stations except Garhshankar and Muktsar has been below normal from 1960 till the end of the study period. In case of these two stations the rainfall has been above average from 1970 onwards. Leaving aside the minor fluctuation, the rainfall series of Amritsar, Aznala, Pathankot, Taran Taran, Batala, Tanda, Dasuya, Hoshiarpur, Nakodar, Jalandhar, Nawanshar, Muktsar, Kharar, Jagraon, Moga, Ludhiana, Bandher and Bhartala indicates decreasing trend from 1930-35 till 1960-65.

Some of the curves of low-pass filter alongwith the actual annual, monsoon and winter rainfall are shown in Fig. 2. The horizontal line indicated by M depicts the mean rainfall.

5. Test for persistence

A non-parametric test for persistence in time series is given by auto-correlation coefficient (r_τ) which has been calculated as per WMO (1966)

$$r_\tau = \frac{1/(N-\tau) \sum_{i=1}^{N-\tau} (X_i-\bar{X})(X_{i+\tau}-\bar{X})}{1/N \sum_{i=1}^{N} (X_i-\bar{X})^2}$$

where, r_τ are the auto-correlations for all lags $\tau = 0$ to $\tau = m$ (where $m<N$), N the number of terms and $\bar{X}$ the mean of all X_i in the series. Gilman *et al.* (1963) have given the methods of finding persistence of first order, linear Markov process, which is dominant form of trend. Accordingly the auto-correlation at lag two (r_2) and lag three (r_3) were compared with r_1^2 and r_1^3 respectively. Due to lack of space only r_1 values are given in Table 2 with significant values suitably marked. It is seen that auto-correlation at lag one (r_1) is positive and significantly greater than test value (at 95% level) for both annual and monsoon rainfall of Pathankot and Ludhiana, monsoon and winter of Taran Taran and Batala, annual and winter of Ranike, annual rainfall of Tibri and Jagraon, winter rainfall of Amritsar, Tanda, Phillaur & Ropar and monsoon rainfall of Dasuya, Jalandhar and Zira. Markov linear type of persistence is observed only in annual rainfall of Tibri and Pathankot, monsoon rainfall of Batala, Zira, Pathankot and Ludhiana and winter rainfall of Amritsar, Taran Taran, Moga and Ropar.

6. Periodicities

For determining periodicities in the rainfall series, if any, the data series were subjected to spectrum analysis following Blackman and Tukey (1958) as given in WMO (1966). To achieve satisfactory resolution in the spectrum, a maximum lag limit 27, which is roughly one-third of the total length of the period (82). The null hypothesis for the purpose was considered in accordance with the fact whether the series revealed any persistence or not. In case of Markov-linear type persistence the approximate 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

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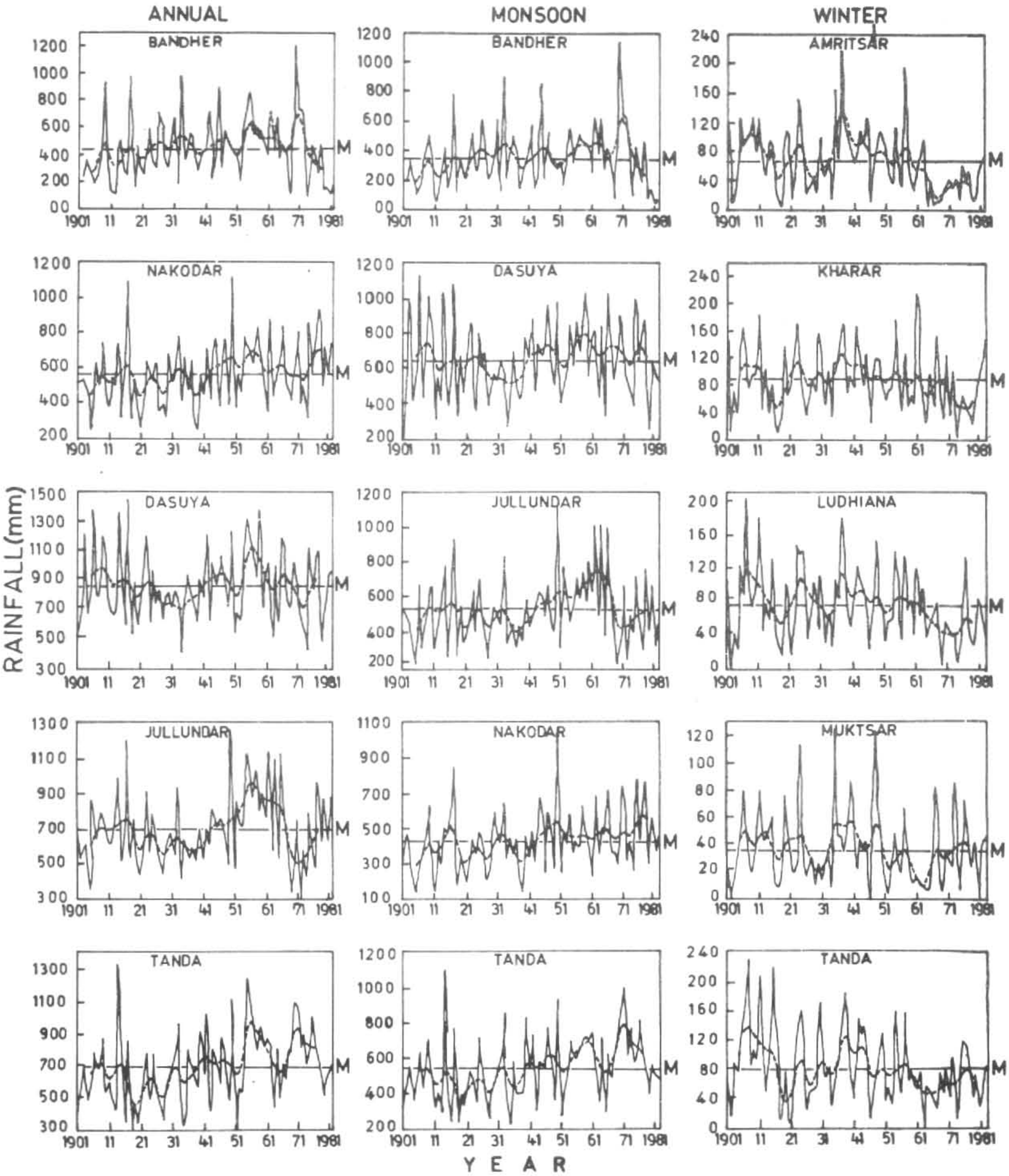

Fig. 2. Actual and Low-Pass filter rainfall curves (1901-1982)

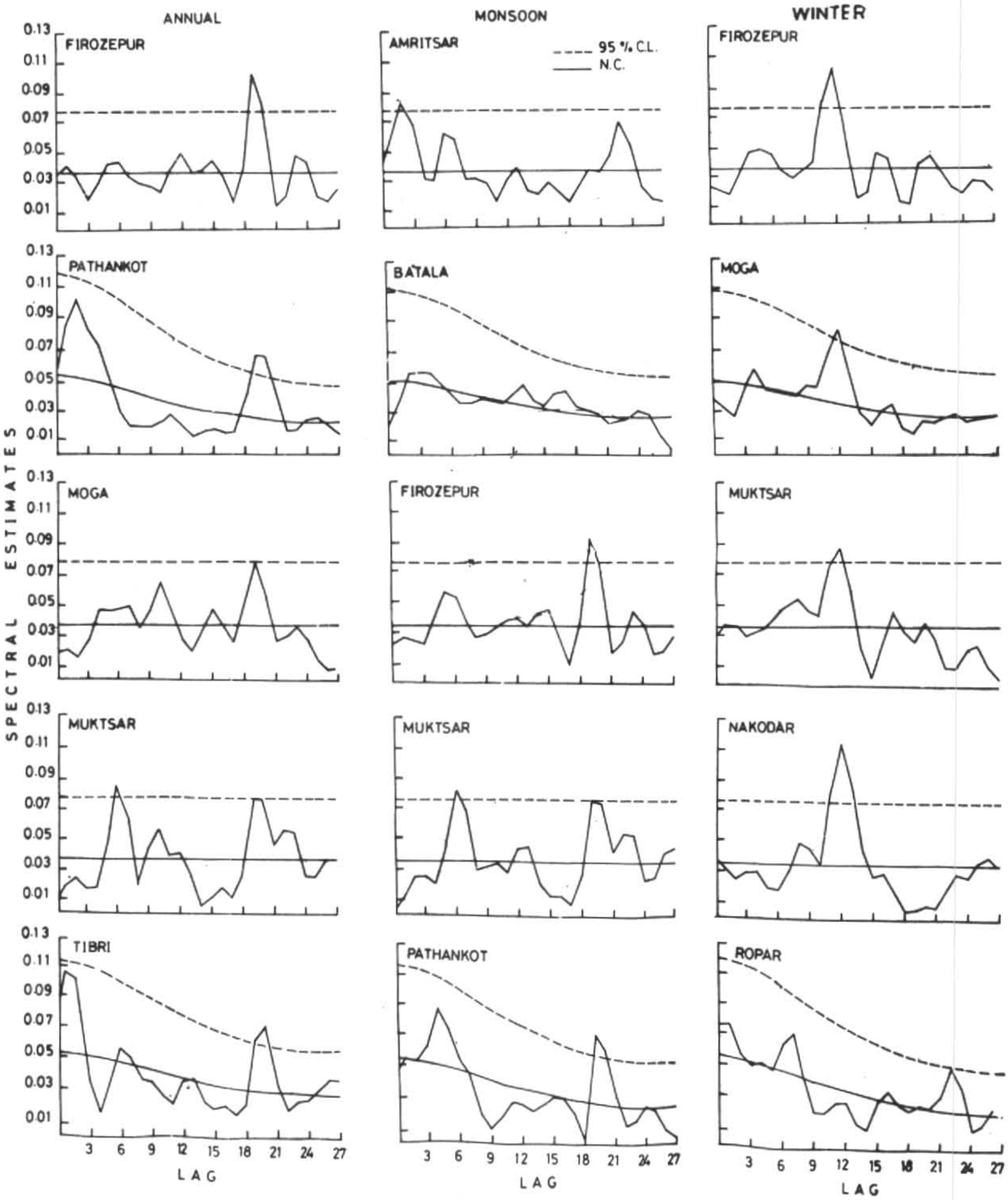

Fig. 3. Spectral analysis of annual, monsoon and winter rainfall (1901-1982)

persistence, the spectral estimates were tested against 'white-noise spectrum'.

The annual, monsoon and winter rainfall spectrum results of all the stations are given in Table 2 and for some of the selected rainfall series are shown in Fig. 3 for quick reference. It is seen that there is a cycle of 27, 9.1, 9.1, 7.7 year in monsoon rainfall of Amritsar, Tibri, Muktsar and Bhartala respectively. Annual rainfall of Muktsar estimates a cycle of 9.1 year. There is a cycle of 6.1 year in winter of Tanda and Nawanshar. 4.1 to 4.5 year cycle is observed in winter rainfall of Aznala, Batala, Jalandhar, Fazilka, Firozpur, Muktsar, Moga, Jagraon, Ludhiana and Samrala. A cycle between 2 to 3 years generally called quasi-biennial oscillation

(QBO) is significant at 95% level in both the annual and monsoon rainfall of Pathankot, Dasuya, Hoshiarpur, Firozpur & Moga; annual rainfall of Tibri and monsoon rainfall of Taran Taran, Garhshankar, Jalandhar and Samrala.

7. Conclusions

(*i*) Pathankot is the wettest and Fazilka is the driest station of Punjab state.

(*ii*) Frequency distribution of most of the rainfall series is not normal.

(*iii*) Mann-Kendall tests, low-pass filter analysis reveals the increasing trend in both the annual and monsoon rainfall of Batala, Tanda and Nakodar.

(*iv*) The striking feature of the study is that almost all the winter rainfall series exhibit a rainfall below average from 1960 till the end of the study period and decreasing trend from the year 1935-40 till 1965-70. This is perhaps due to decrease in number of active western disturbances affecting the region. This aspect needs in-depth study separately.

(*v*) Spectrum analysis revealed the existence of cycle of 4.1 to 27 years in some of the stations and QBO in many.

(*vi*) The pricipitation pattern except winter rainfall does not suggest that the climate shift is occurring in Punjab.

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