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Climatic changes in India—(I) Rainfall

S. K. PRAMANIK and P. JAGANNATHAN

Meteorological Office, Poona

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1. Introduction

It is often claimed that our climate is changing and that rainfall in particular is decreasing at certain places and increasing at certain others. The following are examples of such claims based on some recent studies of rainfall in different parts of the world : (*i*) Hesselberg (1950) from an examination of the 30-year moving averages of 60-70 years' rainfall data of 8 stations in Norway concluded that the annual amount has increased up to 20 per cent in the eastern parts of Norway while there is a large area with decreased precipitation (up to 20 per cent) on the western and northern slopes of the Central Mountain ridge. (*ii*) Lysgaard (1950) studied precipitation over the whole world in a general way and found that the variation from 1910 to 1940 was positive in certain areas including south India and southeast Asia and negative in some others. (*iii*) Walker (1910) examined the available monsoon rainfall data upto 1908 of India as a whole and of major rainfall divisions and concluded that the deficiency in the monsoon rainfall in northwest India after 1894 had not lasted long enough to justify the conclusion that there had been a permanent change of climate and that there were marked indications of return to good seasons. (*iv*) Satakopan (1936) from an examination of the southwest monsoon rainfall of Akola in Berar during the 65 years 1868 to 1932 by fitting polynomials of the 5th degree in time, found no significant trend in the seasonal rainfall. (*v*) Bose (1940) from an analysis of 43 years' rainfall from 1893 to 1935 of Calcutta by working the regression of monthly and annual rainfall, concluded that there was no secular trend in the rainfall of Calcutta. (*vi*) Ananthapadmanabha Rao (1936) from an analysis of 40 years' rainfall for the period 1893 to 1932 of stations in Mysore State observed an upward trend in the case of Kadur District. (*vii*) In the case of Rajasthan and neighbourhood, Pramanik, Hariharan and Ghose (1952) from an examination of the 10-year moving averages for about 60 to 70 years concluded that there was no accentuation of desert conditions there. (*viii*) Desai's (1952) conclusion in regard to the monsoon rainfall of Maha-Gujarat by means of polynomial analysis was also similar. The authors of this paper have found in an earlier study (1952) that there was no general tendency for increase or decrease in the annual rainfall of selected stations in the Deccan.

In this paper the rainfall trends in India and Pakistan as a whole have been studied.

2. Data

In India* even though observations of rainfall are supposed to have been made with the aid of instruments even in the 4th century B. C., the present data of rainfall of past years do not extend to periods earlier than the 19th century A. D. Up to the time when the whole system of meteorological organisation was centralised under the Government of India in 1875, the work of rainfall registration in the different parts of India was carried on by the different Provincial Governments. After the creation of the India Meteorological Department, the rainfall registration was placed on a more co-ordinated basis and at present, rainfall registration is being made from a number of departmental observatory stations and a much closer network of state raingauge stations. For the purpose of the present study, rainfall records of 30 selected observatory stations, for which long and continuous data are available have been utilised. The stations have been selected after scrutiny of

* The prepartition India including the present territory under Pakistan

the periodical inspection reports and records, keeping in view that

(*i*) the observations were made at the same site or if there was any change of site suitable corrections based on comparative observations at the sites, have been applied ;

(*ii*) the exposure of the instruments have remained satisfactory and not changed during the period at least after the India Meteorological Department took over.

However, even though at all regular observatories only Symon's gauge with rim placed at 1 foot above ground have been used, there might have been some slight diversity as to the type of instrument used and the method of observations prior to 1875.

The series of annual totals of rainfalls recorded at the 30 stations shown in Fig. 1 have been examined in the first instance and later the rainfall series relating to the four seasons January-March, April-May, June-September and October-December, at a few of the stations have been considered. In Table 1 are given the periods for which rainfall data have been used, the mean annual rainfall amounts, their standard deviation, co-efficient of variability, and the highest and lowest annual rainfalls expressed as percentages of the mean annual rainfall. The average rainfall of India as calculated from the sample of stations chosen works out to be 44·65″. The variation of mean rainfall from station to station is considerable and gives a standard deviation of 35·9″ for the spatial variation. Jacobabad has the lowest mean rainfall of 3·83″ and Silchar the highest with 128·4″*. Besides this spatial variation, there is variation from year to year to varying extent at the different stations as will be seen from the co-efficients of variability (column 5). The mean rainfall and the co-efficients of variability (*CV*) are shown in Fig. 2 and curves showing variation of annual rainfall are given in Fig. 3.

3. Distribution of annual rainfall

The frequency distributions of the observed samples of rainfall amounts have been examined to see if the scatter of the annual rainfall amounts about the mean rainfall of the place is random or if there is any significant deviation from the Gaussian normal curve so that they may be treated by the appropriate statistical methods. From the 3rd and the 4th moments, Fisher's (1950) g_1 and g_2 statistics and their standard errors have been calculated and these are given in Table 2 on page 299. The values of g_1 and g_2 indicate that the distribution of rainfall at some places is not strictly normal. Some of the g's are more than twice their standard errors and can be considered significant. The g_1 and g_2 values have been plotted on charts (Figs. 4 and 5) and it is seen that g_1 and g_2 values vary from station to station in a gradual manner indicating that the location of a station has a bearing on these characteristics. Stations in Deccan plateau and the northwest India consisting of Kashmir, Sind, Punjab and Rajputana show positive skewness signifying that in these regions deficiencies of rainfall are more common than they would be if the distribution were normal and that the average is made up by occasional large excesses, while those in the Sub-Himalayan regions of north and northeast India and the central parts of the country show slight negative skewness, indicating that excesses of rainfall are more common, with occasional large defects. The above would indicate that the rainfall is made up of at least two types with significantly differing means in the first mentioned of the areas, rainfall of the type with lower average is predominant while in the second rainfall of the type with higher average.

The figures for g_2 show that the frequency distribution of rainfall in the country with the exception mainly of northwest India, is more peaked than in the normal distribution indicating that the modal class is more frequent than can be normally expected, while in northwest India the significant negative values of g_2 at the stations indicate that the distribution gives curves more flat topped than normal.

* In fact available rainfall records have examples of stations with annual rainfall of barely 1½″ in Baluchistan and as much as 498·65″ in Khasi and Jaintia Hills

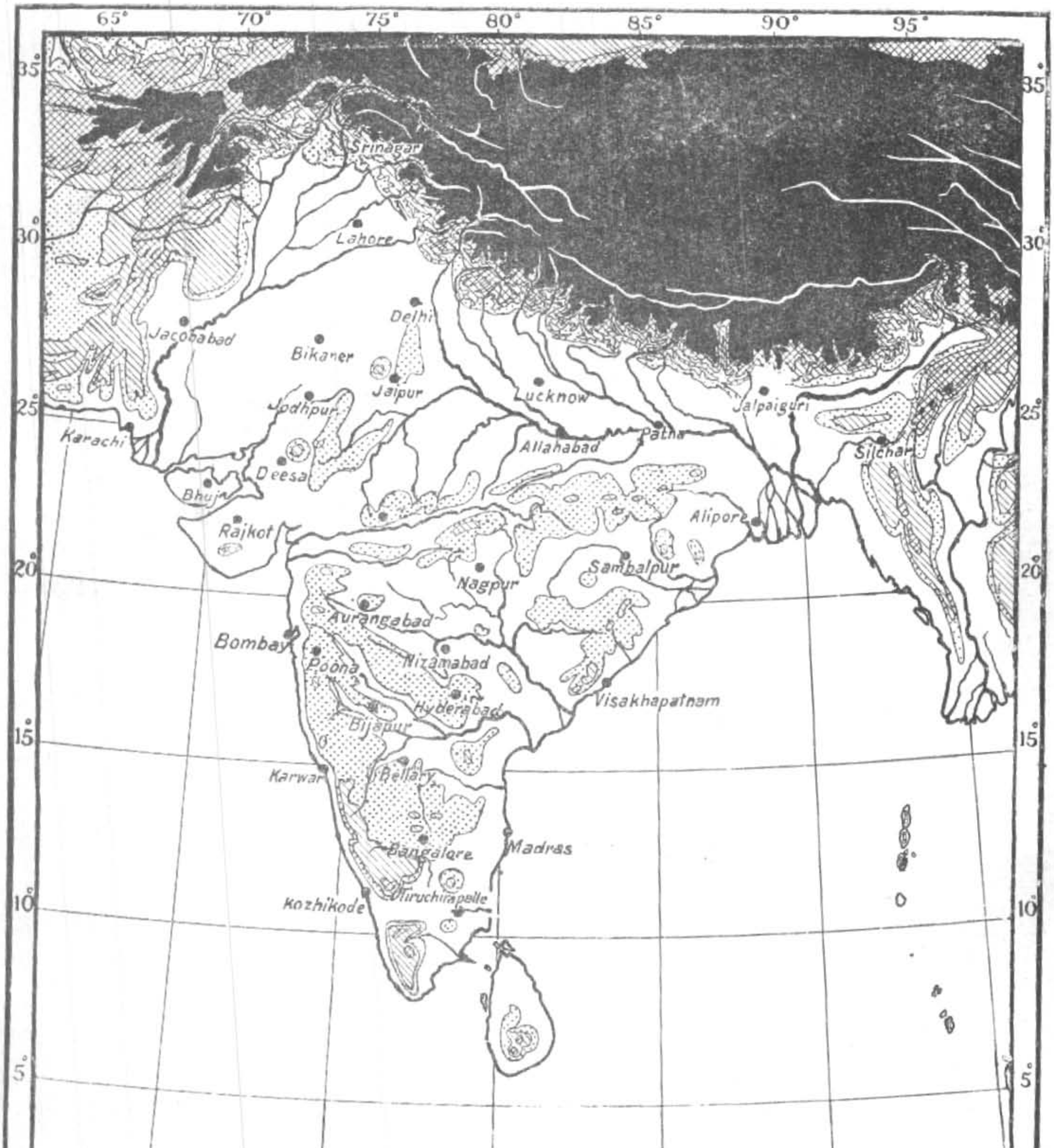

Fig. 1. Relief Map of India and neighbourhood, showing the position of selected stations

TABLE 1

Station	Data for period	Mean Rainfall (in)	Standard Deviation (in)	Co-efficient of variability %	Highest annual rainfall as percentage of mean %	Lowest annual rainfall as percentage of mean %
1. Alipore	1881-1950 (70)	63·25	10·82	17·1	141	57
2. Allahabad	1861-1950 (90)	39·04	10·97	28·1	195	40
3. Aurangabad	1876-1950 (75)	28·95	8·54	29·5	159	36
4. Bangalore	1837-1950 (114)	35·00	7·60	21·7	162	46
5. Bellary	1861-1950 (90)	19·43	5·85	30·1	192	42
6. Bikaner	1881-1950 (70)	11·69	5·66	48·4	260	10
7. Bhuj	1871-1950 (80)	13·60	8·21	60·4	341	6
8. Bombay	1847-1950(104)	71·71	17·16	23·9	160	47
9. Deesa	1870-1944 (75)	24·62	12·24	49·7	245	1
10. Delhi	1861-1950 (90)	27·13	9·03	33·3	223	30
11. Hyderabad (Dn)	1871-1950 (80)	30·38	9·00	29·6	185	54
12. Indore	1871-1950 (80)	35·52	9·46	26·6	181	44
13. Jacobabad	1862-1950 (89)	3·83	2·49	65·0	315	0·3
14. Jaipur	1871-1950 (80)	24·42	9·41	38·5	226	19
15. Jalpaiguri	1871-1950 (80)	127·92	20·91	16·3	124	53
16. Jodhpur	1876-1950 (75)	14·23	7·62	53·5	325	7
17. Karachi (Manora)	1857-1946 (90)	7·76	6·09	78·5	361	6
18. Karwar	1864-1938 (75)	118·20	25·31	21·4	163	61
19. Kozhikode	1866-1950 (85)	121·25	20·47	16·3	145	59
20. Lahore	1862-1946 (85)	19·09	6·30	33·0	198	46
21. Lucknow	1871-1950 (80)	39·49	11·95	30·3	176	37
22. Madras	1813-1950(138)	49·54	15·00	30·3	179	37
23. Nagpur	1856-1950 (95)	47·23	11·05	23·4	161	30
24. Patna	1871-1950 (80)	46·15	11·94	25·9	167	55
25. Poona	1856-1950 (95)	27·50	7·71	28·0	207	38
26. Rajkot	1871-1950 (80)	24·78	12·38	50·0	209	25
27. Sambalpur	1871-1950 (80)	65·00	9·47	14·6	140	57
28. Silchar	1871-1950 (80)	128·40	22·92	17·9	172	72
29. Srinagar	1892-1950 (59)	25·93	5·65	21·8	144	61
30. Visakhapatnam	1866-1950 (85)	39·67	11·45	28·9	200	43

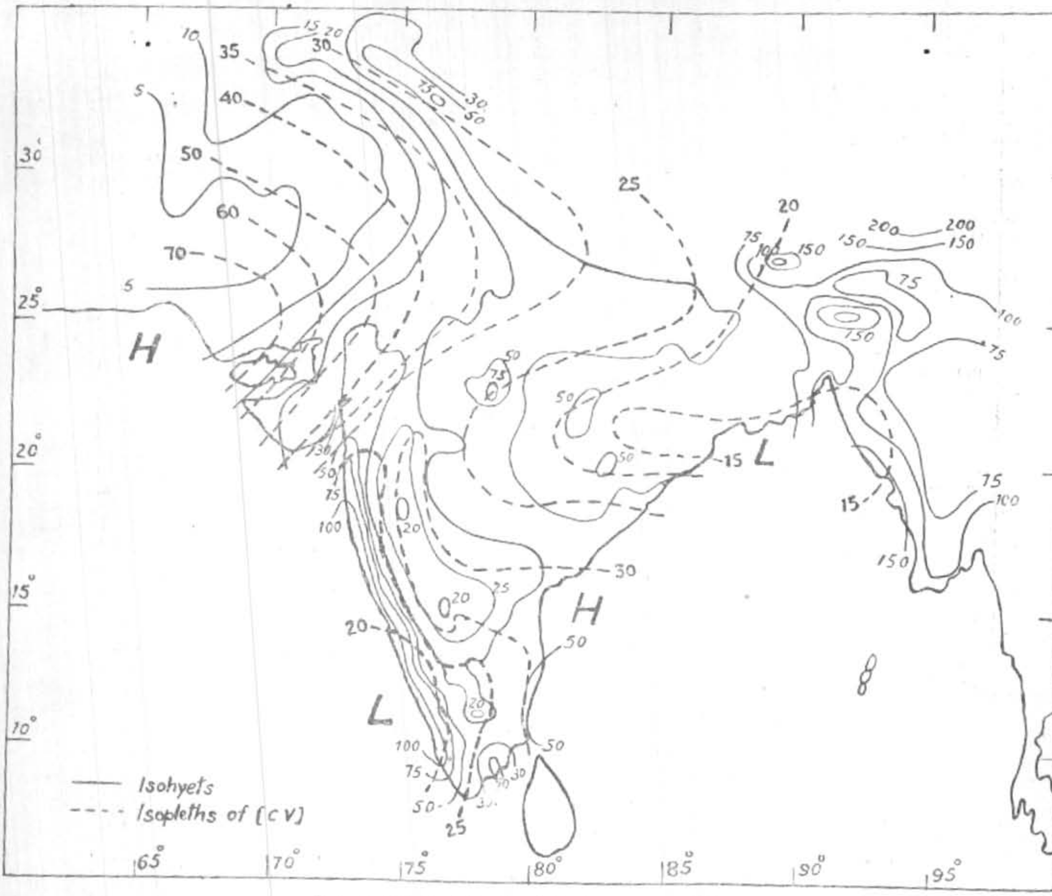

Fig. 2. Mean annual rainfall and variability

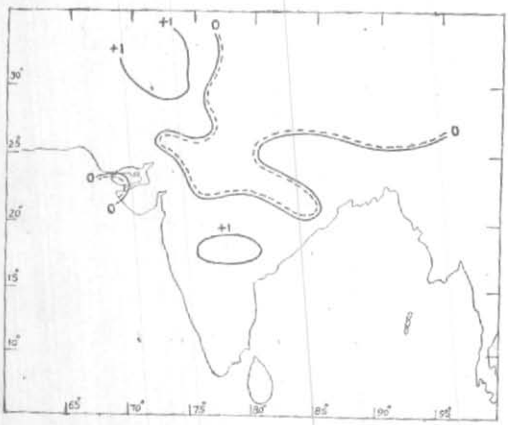

Fig. 4. Skewness (g_1) of annual rainfall

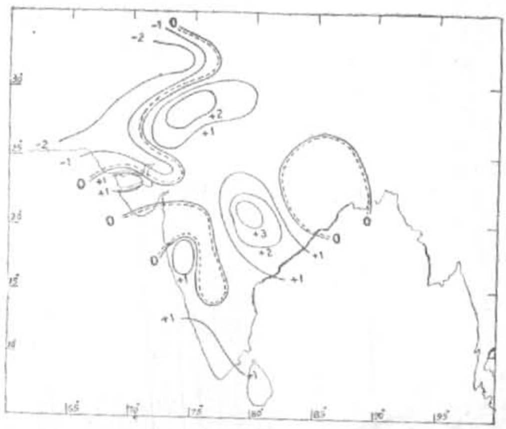

Fig. 5. 'Kurtosis' (g_2) of annual rainfall

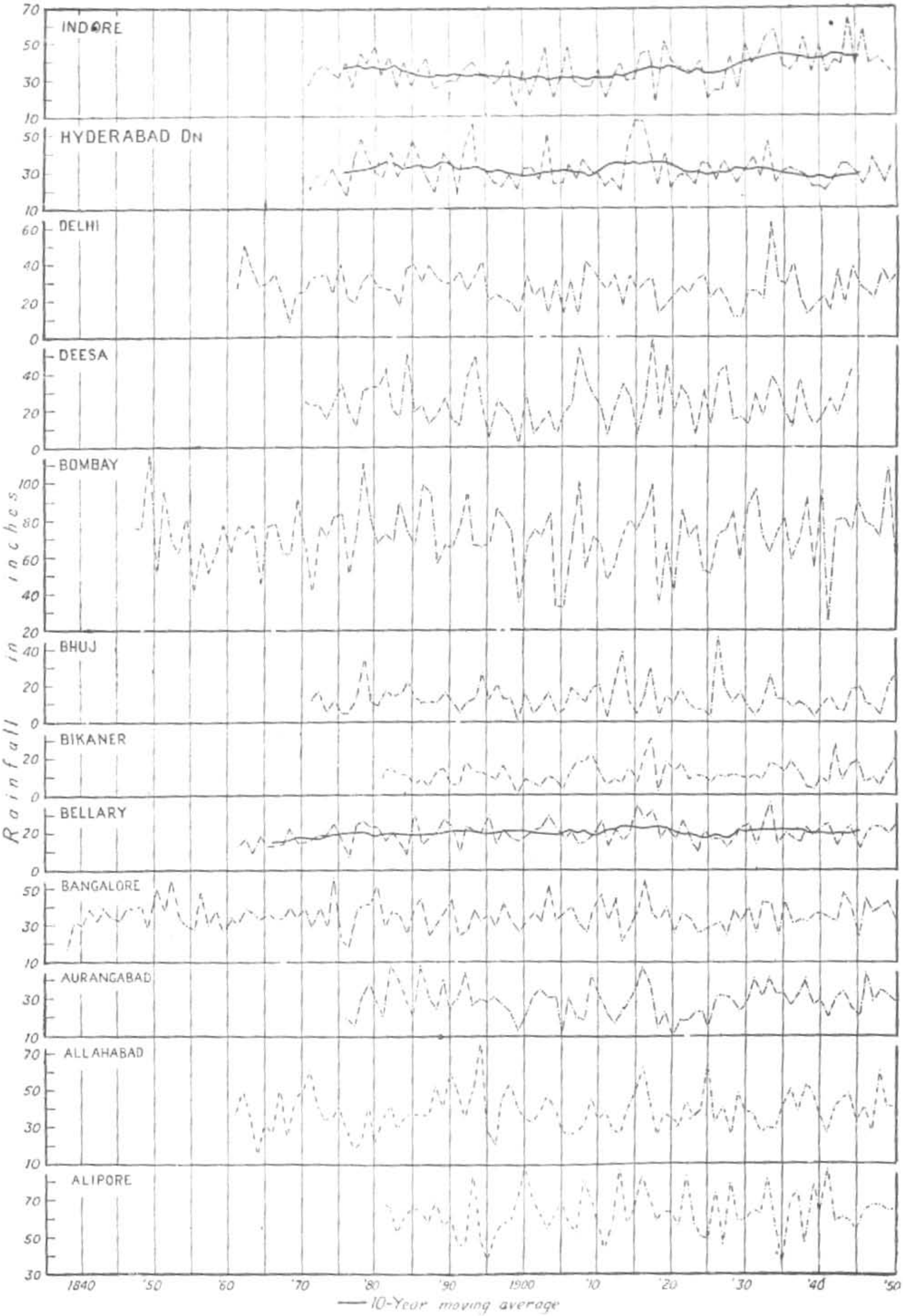

Fig. 3. Annual rainfall

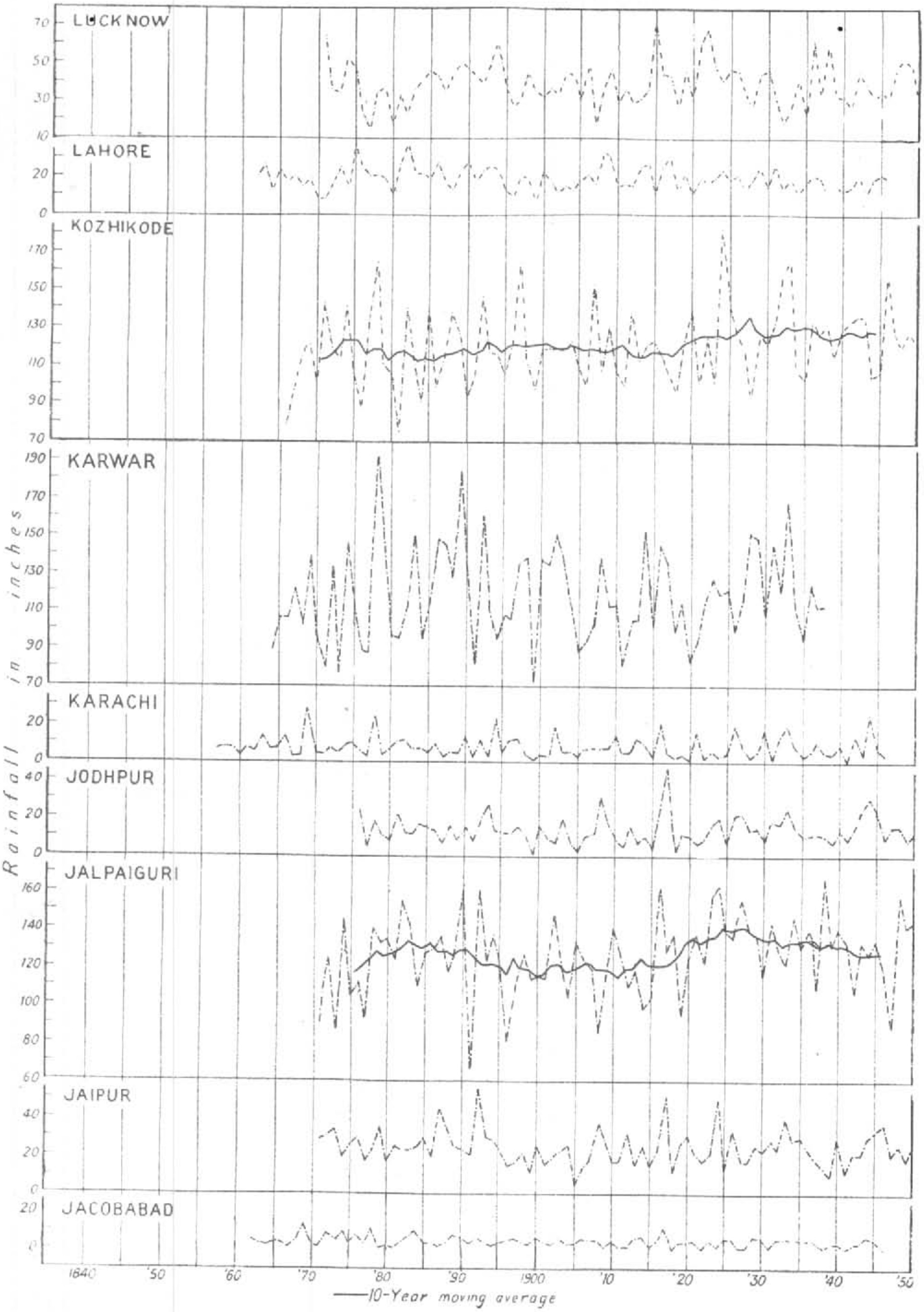

Fig. 3. Annual rainfall

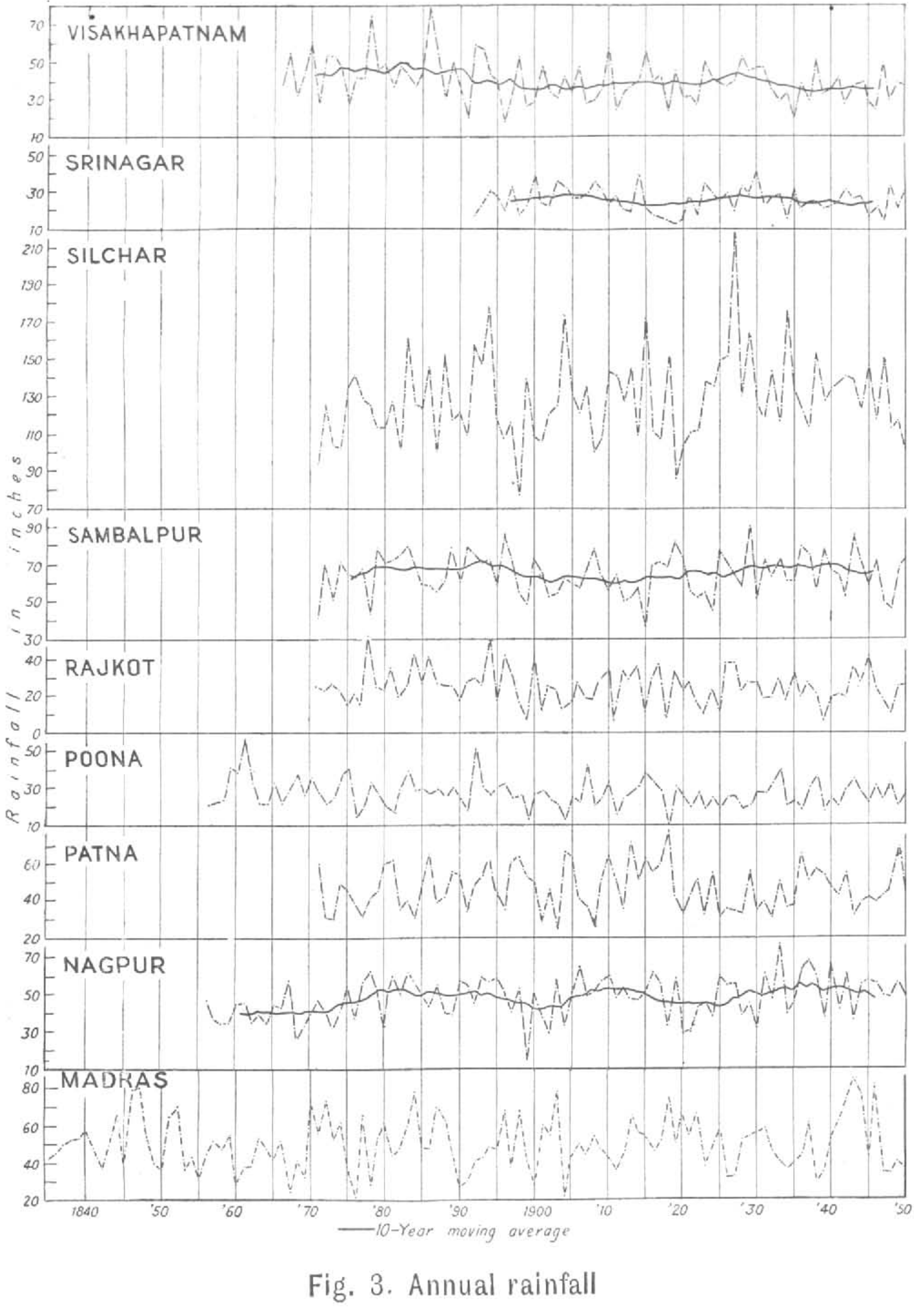

Fig. 3. Annual rainfall

TABLE 2

g_1, g_2 and their standard deviations

Station	g_1	SE(g_1)	g_2	SE(g_2)
1. Alipore	+ ·26	·29	— ·07	·57
2. Allahabad	+ ·22	·25	+ ·25	·50
3. Aurangabad	+ ·08	·28	— ·47	·55
4. Bangalore	+ ·36	·23	+ ·45	·45
5. Bellary	+ ·50	·25	— ·89	·50
6. Bikaner	+ ·55	·29	+2·66	·57
7. Bhuj	— ·17	·27	+1·79	·53
8. Bombay	+ ·23	·24	— ·89	·47
9. Deesa	+1·12	·28	—1·17	·55
10. Delhi	— ·68	·25	+1·94	·50
11. Hyderabad (Dn)	+1·00	·27	+ ·77	·53
12. Indore	— ·29	·27	+ ·72	·53
13. Jacobabad	+ ·25	·26	—1·72	·52
14. Jaipur	+ ·07	·27	+ ·99	·53
15. Jalpaiguri	— ·41	·27	+ ·25	·53
16. Jodhpur	— ·43	·28	+1·09	·55
17. Karachi	+ ·66	·25	— ·81	·50
18. Karwar	+ ·58	·28	+ ·38	·55
19. Kozhikode	+ ·61	·26	+1·38	·52
20. Lahore	+1·37	·26	—2·26	·52
21. Lucknow	— ·10	·27	+ ·58	·53
22. Madras	+ ·41	·21	+ ·49	·41
23. Nagpur	+ ·16	·25	+3·54	·49
24. Patna	+ ·32	·27	— ·71	·53
25. Poona	+ ·60	·25	+1·77	·49
26. Rajkot	+ ·43	·27	+ ·50	·53
27. Sambalpur	— ·21	·27	— ·56	·53
28. Silchar	+ ·53	·27	+ ·40	·53
29. Srinagar	+ ·04	·31	+ ·12	·62
30. Visakhapatnam	+ ·73	·26	+1·42	·52

4. Randomness of the rainfall series

We will examine further whether the variations in the rainfall at the various stations from year to year are purely random, in the sense that the series of rainfall could have occurred in the observed order by random sampling from a homogeneous population, or they have occurred according to some cyclical or periodical effects. Two tests for randomness developed by Kendall (1946) and Wallis and Moore (1941) have been applied to the rainfall series. In the first test, the number of turning points in the different series have been counted and the significance of their deviations from the expected number, on the assumption of the randomness of the series, have been tested. In the second test, the distribution of phase lengths were examined, and the significance of the deviations of the frequencies from those calculated on the assumption of the randomness of the series, were tested, by Wallis and Moore's criterion.

The actual number of turning points, the expected number and its standard deviation, as also the distribution of phase lengths and the " χ^2 values " are given in Table 3. The first test shows significantly smaller number of turning points only in the case of Bhuj, while at all other stations there is no evidence against randomness. In the second test also only Bhuj showed significantly high values of χ^2, which is mainly due to preponderance of phase lengths of 2 and 3 years or over at the expense of 1 year phase lengths. Thus only in the case of Bhuj, these tests indicate a possibility of some cyclical movement of length about 8 to 12 years and in the other stations there is no evidence against randomness of the rainfall series.

5. Trends

(a) Polynomial analysis

In order to examine if there are any systematic variations in the rainfall at the different stations during the past century*, orthogonal polynomials up to the 5th degree have been

* It may be mentioned that data of all stations do not extend to full 100 years but most of them are for periods between 75 and 95 years and 3 for over 100 years

TABLE 3

Turning points and phase lengths

Station	No. of turning points			Phase lengths						$\frac{6}{7}\chi^2$	5% level
				1		= 2		⩾3			
	A	E	SD	A	E	A	E	A	E		
1. Alipore	40	45·3	3·48	19	24·55	15	10·64	5	3·81	2·9254	5·991
2. Allahabad	52	58·7	3·96	25	32·16	18	13·94	8	6·00	2·0605	,,
3. Aurangabad	44	48·7	3·61	24	27·16	11	11·74	8	4·29	3·2833	,,
4. Bangalore	84	74·7	4·40	5	52·11	21	22·72	4	8·17	2·5065	,,
5. Bellary	54	58·7	3·96	21	33·32	13	14·49	9	5·19	2·6671	,,
6. Bikaner	48	45·3	3·48	30	29·60	14	12·83	3	4·57	·5535	,,
7. Bhuj	43	52·0	3·73	15	26·42	19	11·47	8	4·11	11·5484	,,
8. Bombay	70	68·0	4·27	45	43·34	19	18·88	5	6·78	·4557	,,
9. Deesa	45	48·7	3·61	25	27·69	13	12·62	6	6·29	·8767	,,
10. Delhi	55	58·7	3·96	31	33·94	16	14·76	7	5·30	·7749	,,
11. Hyderabad (Dn	46	52·0	3·75	23	28·31	15	12·29	7	4·40	2·6829	,,
12. Indore	53	52·0	3·75	25	32·71	12	14·21	5	5·08	·4330	,,
13. Jacobabad	52	55·3	3·85	30	32·07	13	13·94	8	4·99	1·7251	,,
14. Jaipur	50	52·0	3·75	31	30·82	12	13·39	6	4·79	·3867	,,
15. Jalpaiguri	59	52·0	3·73	42	36·49	13	15·85	3	5·56	2·2484	,,
16. Jodhpur	47	48·7	3·61	26	28·95	14	12·56	6	4·49	·8244	,,
17. Karachi	64	58·7	3·96	42	39·60	19	17·22	2	6·18	2·7057	,,
18. Karwar	49	48·7	3·61	31	30·21	11	13·11	6	4·68	·6278	,,
19. Kozhikode	50	55·3	3·85	27	30·81	14	13·39	8	4·80	2·2561	,,
20. Lahore	61	55·3	3·85	39	37·73	20	16·40	1	5·87	4·1771	,,
21. Lucknow	46	52·0	3·73	22	28·31	16	12·29	7	4·40	3·4824	,,
22. Madras	82	90·7	4·92	49	50·81	18	22·19	14	8·00	4·5906	,,
23. Nagpur	64	62·0	4·07	42	39·60	15	17·23	6	5·17	1·3433	,,
24. Patna	49	52·0	3·73	28	30·20	14	13·11	6	4·69	·5028	,,
25. Poona	65	62·0	4·07	43	40·22	15	17·00	6	6·28	·4814	,,
26. Rajkot	57	52·0	3·73	38	35·23	16	15·39	2	5·47	2·0037	,,
27. Sambalpur	49	52·0	3·73	28	30·20	13	13·11	7	4·69	1·1134	,,
28. Silchar	56	52·0	3·73	40	34·60	9	15·63	6	5·37	2·8593	,,
29. Srinagar	41	38·7	3·22	26	25·22	12	8·18	2	6·60	3·4406	,,
30. Visakhapatnam	55	55·3	3·85	34	23·96	14	14·76	6	5·28	·1177	,,

fitted to the rainfall series in the manner developed by Fisher*, and the variances in the rainfall accounted for by the different degree polynomials have been examined and compared with the residual variances at each stage to test the significance of the changes indicated by the respective polynomials.

In Table 4 are given the co-efficients of the different degree orthogonal polynomials and in Table 5 the square root of variances accounted for by the different orthogonal polynomials, the 5th degree polynomials as a whole and the residual errors. It may be seen that the variances accounted for by the 5th degree polynomial as a whole are not significant except in the case of Bellary. However, some values of the square root of variances accounted for by a few orthogonal polynomials being greater than twice the residual errors suggest the possibility of trends representable by these polynomials. The cases in which one or more of the co-efficients of orthogonal polynomials are significant are given below—

Bellary	The 1st, 2nd and 5th degree orthogonal polynomials account for a significant part of the variation
Indore	The 2nd degree orthogonal polynomial accounts for a significant part of the variation. The variance accounted for by the 4th degree is also high, but the inclusion of this term decreases the residual error by only 1·5%, so that the contribution by this term is not significant
Jalpaiguri	The 1st and 5th degree orthogonal polynomial terms account for a significant part of the variation, but the variance accounted for by the 4th degree, though fairly high, is not significant
Hyderabad, Srinagar	The 5th degree orthogonal polynomial accounts for a significant part of the variation
Kozhikode, Nagpur, Visakhapatnam	The first degree orthogonal polynomial accounts for a significant part of the variation
Sambalpur	The 4th degree orthogonal polynomial accounts for a significant part of the variation

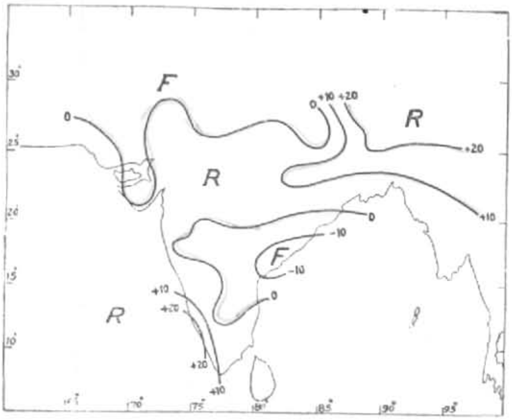

Fig. 6. Linear trend in annual rainfall

There are some cases in which the variance accounted for by some orthogonal polynomials are fairly high but not more than twice the residual error after fitting the 5th degree polynomial. These are the 5th degree orthogonal polynomials in the case of Bhuj, Bombay and Deesa, 4th in the case of Indore and Jalpaiguri, 5th in the case of Karachi, 1st in the case of Poona and 4th in the case of Silchar. These cases have been examined individually by omitting the other insignificant terms but the variance accounted for by these were still found not to be significant. The form of the polynomial fitted to the time series, the error accounted for by the polynomial and the residual error left over after fitting the polynomials are given in Table 6. The linear trends indicated in the case of Bellary, Kozhikode, Jalpaiguri and Nagpur are positive indicating increasing tendency for rainfall at these places and in the case of Visakhapatnam, the trend is negative indicating a decreasing tendency. The co-efficients for the 1st degree orthogonal polynomials have been plotted in Fig. 6. The variation of the co-efficient from station to station is fairly continuous and gradual and smooth contour lines demarcating the values have been drawn in this figure. This chart shows the regions with ' falling ' and ' rising ' tendencies. There are apparently two regions, one over north Madras coast, Hyderabad

* Loc. cit. pp. 151-153

TABLE 4

Distribution Constants—Annual Rainfall

Station	Mean	D_1 $(10^{-2}\times)$	D_2 $(10^{-4}\times)$	D_3 $(10^{-5}\times)$	D_4 $(10^{-6}\times)$	D_5 $(10^{-7}\times)$
1. Alipore	63·25	+ 4·62	— 7·00	— 7·60	+12·10	— 8·04
2. Allahabad	39·04	+ 2·86	+ 2·00	+ 6·90	+ 1·00	+ 0·43
3. Aurangabad	28·95	— 0·14	+34·40	+ 5·00	+ 2·80	+ 4·25
4. Bangalore	35·30	— 1·15	+ 2·80	+ 3·30	+ 0·002	+ 0·26
5. Bellary	19·43	+ 4·64	+19·00	+ 5·00	— 1·63	+ 1·51
6. Bikaner	11·69	+ 2·62	— 4·40	— 5·40	+ 7·37	— 0·59
7. Bhuj	13·60	— 0·34	— 4·92	+ 4·20	+ 3·69	+ 4·56
8. Bombay	71·71	+ 2·75	+24·90	+ 8·13	+·2·41	— 2·17
9. Deesa	24·62	+ 1·45	+ 8·50	— 4·70	— 0·72	+130·18
10. Delhi	27·13	— 4·00	+16·20	+ 4·20	+ 2·57	— 0·56
11. Hyderabad (Dn)	30·38	— 3·09	— 0·20	+ 9·10	— 1·96	+ 5·34
12. Indore	35·52	+ 6·50	+53·80	—13·80	— 9·68	+ 2·51
13. Jacobabad	3·83	— 1·24	+ 3·70	+ 0·40	— 1·41	+ 0·21
14. Jaipur	24·42	— 2·48	+ 1·90	+ 0·90	+ 3·37	+ 0·13
15. Jalpaiguri	127·92	+20·08	— 2·90	— 1·90	—22·25	+ 2·19
16. Jodhpur	14·23	+ 2·71	+11·90	— 8·30	— 0·41	— 0·75
17. Karachi	7·76	+ 1·21	+ 2·90	+ 2·20	+ 0·03	+ 0·33
18. Karwar	118·20	+ 8·71	—33·30	+57·30	—14·28	— 13·52
19. Kozhikode	121·25	+21·19	+10·20	+ 6·60	—10·22	+ 3·01
20. Lahore	19·09	— 3·67	—26·60	+ 2·20	— 1·68	+ 0·66
21. Lucknow	39·49	+ 3·34	—10·00	— 5·40	+ 8·38	— 2·56
22. Madras	49·54	+ 1·27	— 1·32	— 1·40	— 0·03	— 0·005
23. Nagpur	47·23	+ 8·89	—66·42	— 5·70	— 2·63	+ 1·29
24. Patna	46·15	— 0·67	—30·80	+14·80	+ 3·82	+ 0·86
25. Poona	27·50	— 5·64	+13·90	+ 0·80	+10·50	+ 0·02
26. Rajkot	24·78	— 5·57	— 1·20	+13·10	— 2·11	+ 0·13
27. Sambalpur	65·00	+ 0·91	+ 4·10	+ 9·60	—16·06	+ 1·82
28. Silchar	128·40	+15·95	—25·90	—21·60	—25·73	+ 1·19
29. Srinagar	25·94	— 2·84	— 5·79	+ 9·82	— 9·41	+ 19·04
30. Visakhapatnam	39·67	—12·63	+45·50	0·00	— 5·84	+ 2·80

TABLE 5

Square roots of variances contributed by different degrees of polynomial—Annual Rainfall

Station	X_2	X_3	X_4	X_5	X_6	Polynomial	Residual
1. Alipore	7·81	2·13	3·90	11·54	13·44	8·88	10·95
2. Allahabad	7·05	0·37	9·02	4·36	4·74	5·88	11·20
3. Aurangabad	0·26	12·59	3·45	3·64	10·42	7·64	8·60
4. Bangalore	4·04	2·87	9·93	0·02	6·29	5·71	7·68
5. Bellary	11·43	10·87	6·49	7·07	16·67	13·12	5·09
6. Bikaner	4·44	1·34	2·76	7·03	0·83	4·01	5·77
7. Bhuj	0·71	2·10	3·65	6·42	15·84	7·88	8·24
8. Bombay	7·66	20·47	17·61	13·67	32·45	24·60	16·70
9. Deesa	2·72	3·10	3·25	2·72	23·87	11·01	12·33
10. Delhi	9·25	9·27	5·47	11·19	6·17	8·67	9·05
11. Hyderabad (Dn)	6·39	2·62	8·09	3·49	18·54	9·69	8·95
12. Indore	13·41	22·06	11·96	16·82	8·73	15·30	8·93
13. Jacobabad	2·81	1·83	1·38	3·26	1·53	2·33	2·50
14. Jaipur	5·11	2·54	0·60	5·86	1·48	3·45	9·68
15. Jalpaiguri	41·47	1·21	1·60	38·73	45·78	32·62	19·86
16. Jodhpur	5·08	4·36	5·74	0·53	1·85	4·04	7·82
17. Karachi	2·97	1·65	2·84	0·14	3·59	2·55	2·12
18. Karwar	16·33	12·20	39·55	18·58	35·28	26·68	25·21
19. Kozhikode	48·21	1·70	7·10	22·16	14·67	24·83	20·16
20. Lahore	8·36	4·43	2·35	3·89	3·20	4·91	6·37
21. Lucknow	6·90	4·25	4·68	14·58	8·89	8·71	12·14
22. Madras	5·96	2·20	8·16	5·88	6·22	6·17	15·46
23. Nagpur	23·77	14·61	9·05	9·99	11·63	14·80	10·79
24. Patna	0·14	13·15	12·76	8·19	3·08	9·09	12·10
25. Poona	15·07	9·16	1·29	12·62	0·18	9·71	7·59
26. Rajkot	11·49	0·52	11·35	3·67	0·46	7·42	12·64
27. Sambalpur	1·88	1·74	8·27	27·95	6·33	13·39	9·16
28. Silchar	32·94	11·07	18·54	44·78	4·14	26·74	22·64
29. Srinagar	3·72	1·15	2·92	4·15	12·41	6·25	5·59
30. Visakhapatnam	29·33	7·58	0·03	13·43	13·65	16·03	11·10

and Deccan (Desh) and another over north-west India where the rainfall during the past century was decreasing. While in the rest of the country with two predominant centres one over the west coast of India and the other over Assam, the rainfall during the past century, was having a tendency to increase.

(b) Moving Averages

In the last Section we have seen that the rainfall in respect of some stations show some ' trend ', in the entire period considered. The question of trend is further examined by the method of moving averages. Ten-year moving averages in respect of these stations mentioned have been computed and plotted in Fig. 3 along with the curves of actual rainfall. The 10-year moving average curves show, apart from some oscillation* the following—

Bellary	In the beginning for about 20 years the rainfall was low but afterwards there was apparently no general tendency for increase
Hyderabad	No tendency for increase or decrease is noticeable
Indore	Rainfall since 1930 was slightly higher than before
Jalpaiguri	Rainfall between about 1890 and 1918 was lower and the rainfall later was higher than the mean rainfall, but no general increasing tendency is, however, noticeable
Kozhikode	Rainfall was lower up to 1917 and higher later. No general increasing tendency is, however, seen
Nagpur	In the beginning for about 20 years the rainfall was low, but afterwards though the rainfall is higher, there is no general tendency for the increase or decrease
Sambalpur	No tendency for increase or decrease is noticeable
Srinagar	No tendency for increase or decrease is noticeable
Visakhapatnam	Rainfall was higher from about 1870 to 1890 and lower later. No general tendency for decrease is, however, noticeable

(c) Decade averages

In Table 7 are given the average rainfall during the different successive decades for the stations mentioned in the previous paragraph. The significance of the difference between the mean rainfall in the different sub-groups made up of the ten-year periods and the general mean has been tested by the *t*-test developed by Cramer (1946). The significant† values have been indicated by thick type in the table. It may be seen that the average rainfall during 1861-1870 at Bellary and Nagpur were significantly lower than their respective mean rainfall while that for 1921-1930 at Jalpaiguri, for 1931-1940 at Indore and Nagpur and for 1941-1950 at Indore were significantly higher. Apart from these none of the decade averages for the stations was significantly different from the mean.

6. Trends in seasonal rainfalls

(a) Polynomial analysis

In the case of Bellary, Jalpaiguri, Kozhikode, Nagpur and Visakhapatnam, which showed linear trends by the polynomial analysis, the rainfall during the different seasons, have been examined separately for trend by fitting 5th degree polynomials in time to the series of seasonal rainfall. The mean rainfall of the places during the different seasons, their standard deviations and their co-efficients of variability as well as the proportion of seasonal rainfall as percentage of the annual rainfall are given in Table 8. The seasonal rainfall are plotted in Fig. 7.

The distribution constants are given in Table 9 and the errors accounted for the different degree orthogonal polynomials, the 5th degree polynomials as a whole, and residual errors are given in Table 10.

Bellary	None of the co-efficients of the orthogonal polynomial terms in any of the seasonal rainfall series is significant, but the contribution by the 1st and 5th degree orthogonal polynomial terms in the case of the southwest monsoon rainfall are fairly high

* The entire oscillation cannot be attributed to oscillary character in the series as a part of the oscillation should be due to the process of smoothing the Slutzky-Yule effect

† The 5% level has been taken as usual

TABLE 6

Forms of Polynomials fitted to the Time Series of Annual Rainfall

Station	Form of fitted curve	t	Error accounted for by polynomial	Residual error
Bellary	$18{\cdot}1477+0{\cdot}1542t+10^{-3}\times 1{\cdot}90t^2-10^{-5}\times 33{\cdot}95t^3+10^{-7}\times 1{\cdot}51t^5$	Y–1905·5	13·25	5·41
Hyderabad	$30{\cdot}3800+0{\cdot}2379t-10^{-5}\times 94{\cdot}84t^3+10^{-7}\times 5{\cdot}34t^5$	Y–1910·5	18·54	8·81
Indore	$32{\cdot}6511+10^{-3}\times 5{\cdot}38t^2$	Y–1910·5	22·06	9·16
Jalpaiguri	$127{\cdot}9200+0{\cdot}3572t-10^{-5}\times 38{\cdot}89t^3+10^{-7}\times 2{\cdot}19t^5$	Y–1910·5	43·68	19·96
Kozhikode	$121{\cdot}2500+0{\cdot}2119t$	Y–1908·0	48·21	19·91
Nagpur	$47{\cdot}2300+0{\cdot}0889t$	Y–1903·0	23·77	10·83
Sambalpur	$61{\cdot}4815+10^{-3}\times 22{\cdot}01t^2-10^{-6}\times 16{\cdot}06t^4$	Y–1910·5	27·95	9·00
Srinagar	$26{\cdot}1802-10^{-5}\times 183{\cdot}74t^3+10^{-7}\times 19{\cdot}04t^5$	Y–1921·0	12·41	5·46
Visakhapatnam	$39{\cdot}6700-0{\cdot}1263t$	Y–1908·0	29·33	11·10

Y—Year

TABLE 7

Successive decade averages—Annual Rainfall

Decade	Bellary	Hyderabad	Indore	Jalpaiguri	Kozhikode	Nagpur	Sambalpur	Srinagar	Visakhapatnam
1861-70	**14·72**					**40·20**			
1871-80	19·83	29·47	35·98	118·36	122·89	45·69	62·20		45·59
1881-90	19·05	33·13	32·17	134·57	112·79	50·94	67·09		44·93
1891-00	19·14	29·90	31·84	117·38	120·21	47·85	69·20	26·32*	37·48
1901-10	20·81	30·38	30·90	122·69	120·42	48·61	62·22	28·51	38·16
1911-20	22·40	34·10	34·17	122·03	117·86	48·27	63·11	23·27	39·05
1921-30	18·59	28·45	33·61	**141·36**	124·59	43·97	62·30	27·84	41·06
1931-40	20·73	28·81	**43·51**	133·87	130·93	**55·30**	63·89	24·47	35·12
1941-50	20·01	28·80	41·97	129·62	129·25	47·62	64·85	25·25	35·29

* 1892-1900

Jalpaiguri	The only significant co-efficient is the one for the 5th degree orthogonal polynomial in the case of the October to December rainfall. It may be seen, however, that the variances accounted for by the 1st, 2nd and 4th degree orthogonal polynomials for April-May and the 1st degree for June to September rainfall are fairly high though not significant
Kozhikode	None of the co-efficients in any of the seasons are significant but those of the 1st and 4th degree orthogonal polynomials for April to May and the 1st degree for the June-September, the 1st degree in the case of October to December are fairly high
Nagpur	The rainfall during January to March has been significantly increasing and the rainfall during June to September and October to December have a slight tendency to increase, which are not, however, significant. There is no trend in the rainfall of April and May
Visakhapatnam	There is a significant linear decreasing trend for June-September rainfall. The variance accounted for by 4th degree orthogonal polynomial in the case of October to December, though high, is not significant. In the rest of the seasons there is practically no trend

(b) Moving averages

The ten-year moving averages in respect of the seasonal rainfalls where some trend were indicated have been prepared and shown in Fig. 7 along with the curves for actual rainfalls. The curves for ten-year moving means show—

Jalpaiguri	There was no general tendency for any increase or decrease in the October-December rainfall
Nagpur	There was no general tendency for any increase or decrease in the January to March rainfall
Visakhapatnam	The June to September rainfall during about 5 or 6 years in the beginning was higher and those for about 20 years at the end of the series were lower. There was, however, no general tendency to decrease or increase

(c) Decade averages

Average rainfall in the successive decades during the seasons considered above have been calculated and the significance of the difference between the mean rainfall in the different sub-groups and the general means have been tested by the t-test. In Table 11 are given the average seasonal rainfall during the successive decades. It is seen that the average rainfall of Visakhapatnam during June to September of the period 1931-40 was significantly lower and that of Nagpur during January to March of 1941-50 and of Jalpaiguri during October to December 1921-1930 were significantly higher than the respective means.

TABLE 8

Mean seasonal rainfall, standard deviation, etc

Station	Season	Mean rainfall	Per cent of annual	Standard deviation	Co-efficient of variability
Bellary	Jan—Mar	0·48	2·4	0·71	147·91
	Apr—May	2·73	14·1	1·62	59·34
	Jun—Sep	10·24	52·7	4·26	41·60
	Oct—Dec	5·97	30·7	3·60	60·30
Jalpaiguri	Jan—Mar	2·25	1·7	1·61	71·53
	Apr—May	16·09	12·6	5·98	37·17
	Jun—Sep	103·58	80·9	18·69	18·04
	Oct—Dec	5·86	4·6	4·94	84·30
Kozhikode	Jan—Mar	1·29	1·1	1·80	139·53
	Apr—May	13·42	11·1	9·08	67·66
	Jun—Sep	90·48	74·6	17·72	19·59
	Oct—Dec	16·53	13·7	6·70	40·53
Nagpur	Jan—Mar	1·71	3·6	1·62	94·73
	Apr—May	1·35	2·9	1·51	111·85
	Jun—Sep	41·06	86·9	9·31	22·67
	Oct—Dec	3·01	6·4	2·74	91·02
Visakhapatnam	Jan—Mar	1·34	3·4	1·66	123·88
	Apr—May	2·91	7·3	2·81	96·56
	Jun—Sep	20·52	51·7	7·23	35·23
	Oct—Dec	15·03	37·9	9·04	60·15

TABLE 9

Co-efficients of orthogonal polynomials—seasonal rainfall

Station	Season	D_1 ($10^{-2}\times$)	D_2 ($10^{-4}\times$)	D_3 ($10^{-5}\times$)	D_4 ($10^{-6}\times$)	D_5 ($10^{-7}\times$)
Bellary	Jan—Mar	— 0·06	— 0·03	— 1·12	+ 0·02	— 0·06
	Apr—May	+ 0·26	—11·52	+ 0·56	+ 0·08	— 0·07
	Jun—Sep	+ 2·90	—96·84	+ 2·72	— 0·61	+ 0·72
	Oct—Dec	+ 1·48	—80·78	+ 2·56	— 1·07	+ 0·50
Jalpaiguri	Jan—Mar	— 0·06	—17·52	—39·33	— 0·29	— 1·26
	Apr—May	+ 5·44	+24·48	+ 4·97	— 6·63	+ 0·84
	Jun—Sep	+12·43	—13·40	— 2·55	+ 1·51	+ 0·93
	Oct—Dec	+ 3·74	— 7·02	— 6·15	— 0·18	+ 3·31
Kozhikode	Jan—Mar	+ 1·13	+ 2·93	+ 0·25	+ 0·28	+ 0·07
	Apr—May	+ 5·82	+ 4·42	+ 3·31	— 6·30	+ 1·26
	Jun—Sep	+10·02	— 1·84	+ 2·95	— 0·28	+ 3·57
	Oct—Dec	+ 5·34	— 7·23	— 2·12	— 3·50	— 1·09
Nagpur	Jan—Mar	+ 1·29	+ 3·05	+ 0·15	— 3·43	+ 0·20
	Apr—May	— 0·001	+ 0·04	+ 1·65	— 0·12	— 0·03
	Jun—Sep	+ 6·44	—20·54	+ 4·94	— 0·11	— 0·23
	Oct—Dec	+ 1·76	— 5·21	+ 1·32	— 0·95	— 0·22
Visakhapatam	Jan—Mar	+ 1·02	— 2·66	— 2·05	— 0·21	— 0·19
	Apr—May	— 1·37	+ 3·74	+ 0·72	— 0·92	— 0·49
	Jun—Sep	— 8·60	— 4·29	— 3·85	+ 3·77	+ 1·26
	Oct—Dec	— 2·99	+13·84	— 0·41	— 7·23	+ 1·32

TABLE 10

Errors accounted for by the different degree orthogonal polynomials

Station	Season	X_2	X_3	X_4	X_5	X_6	Polynomial	Residual
Bellary	Jan—Mar	0·17	0·62	1·44	0·01	0·63	0·50	0·72
	Apr—May	0·66	0·66	1·72	0·35	0·80	0·65	1·71
	Jun—Sep	7·15	5·55	3·56	2·65	7·98	5·75	4·34
	Oct—Dec	3·65	4·62	3·31	4·64	5·53	4·42	3·54
Jalpaiguri	Jan—Mar	0·44	0·75	3·40	0·51	1·40	1·70	1·59
	Apr—May	11·25	10·44	4·31	11·54	2·87	8·89	5·73
	Jun—Sep	25·68	5·72	2·20	8·65	10·23	13·24	19·00
	Oct—Dec	7·30	2·99	5·32	0·30	11·50	6·67	4·70
Kozhikode	Jan—Mar	2·57	1·46	0·26	0·64	0·36	1·36	1·82
	Apr—May	13·24	2·21	3·54	14·37	6·14	9·32	9·07
	Jun—Sep	22·80	0·92	3·15	6·40	17·41	13·15	18·33
	Oct—Dec	12·17	3·61	2·26	8·00	5·25	7·18	6·71
Nagpur	Jan—Mar	3·44	2·01	0·09	4·12	1·80	2·69	1·59
	Apr—May	0·03	0·09	2·63	0·47	0·29	1·20	1·53
	Jun—Sep	17·21	13·55	7·81	4·22	20·69	13·32	9·03
	Oct—Dec	4·71	3·43	2·15	3·60	1·96	3·33	2·70
Visakhapatnam	Jan—Mar	2·31	1·34	2·18	0·48	0·91	1·61	1·67
	Apr—May	3·12	1·87	0·77	2·12	2·39	1·91	2·88
	Jun—Sep	19·57	2·14	4·11	8·67	6·15	10·17	6·99
	Oct—Dec	6·79	6·91	4·37	16·66	8·87	9·69	8·99

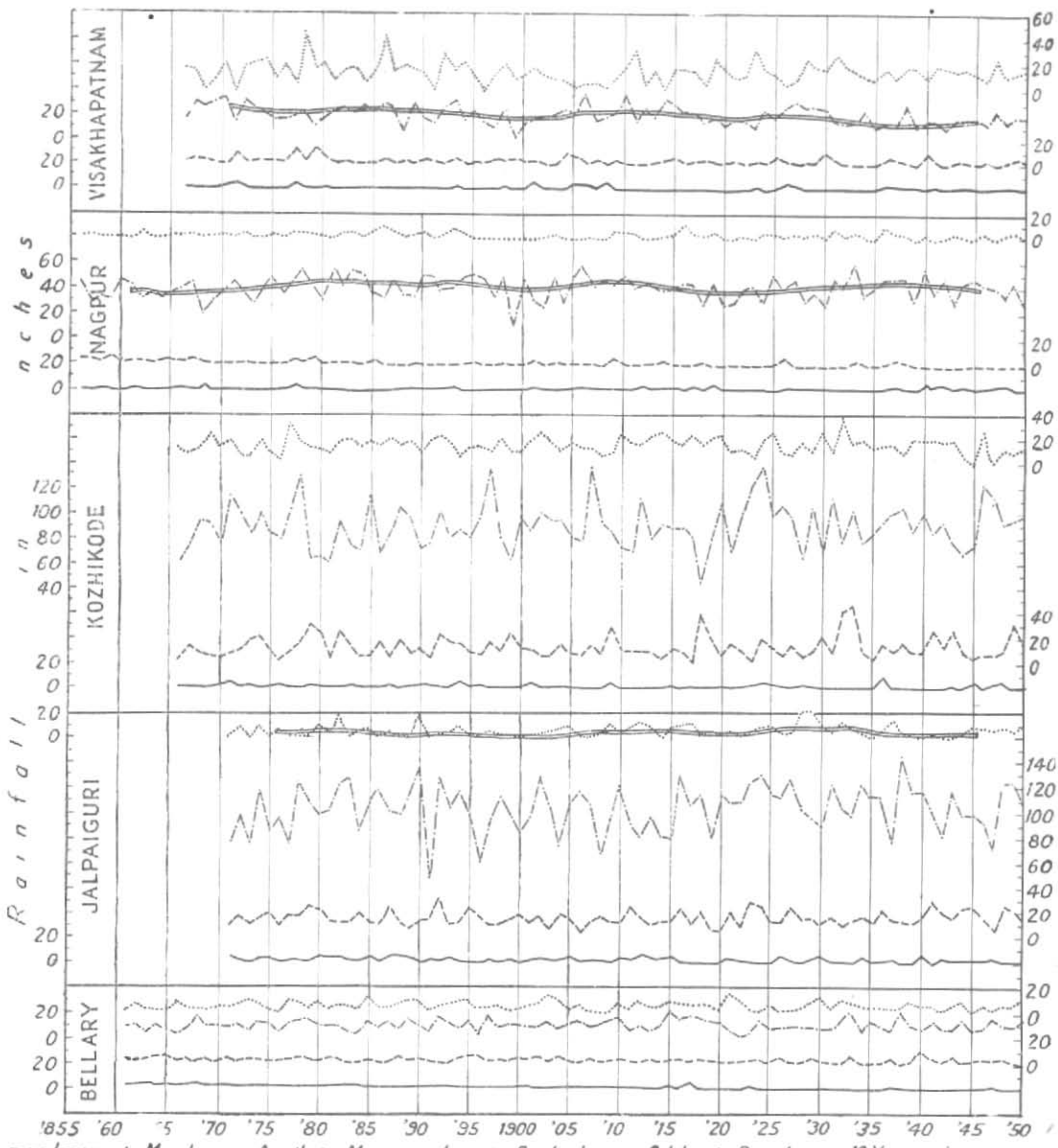

Fig. 7. Seasonal rainfall year by year

7. Conclusions

The examination carried out shows that—

(*i*) There appears to be no significant short period cyclical movement in the annual rainfall at the different stations except at Bhuj, where an oscillatory tendency of length about 8-12 years may be present

(*ii*) The distribution of rainfall in the major part of India, particularly in the arid and semi-arid regions of northwest India and the semi-arid regions of the Deccan, show that there is a general tendency for deficient rainfall to be more frequent than it would be if the rainfall distributions were normal, while in

TABLE 11

Successive Decade averages—Seasonal rainfall

Decade	Jalpaiguri Oct—Dec	Nagpur Jan—Mar	Visakhapatnam Jun—Sep
1871-80	4·10	1·18	19·47
1881-90	6·56	1·00	24·04
1891-00	3·06	1·39	19·01
1901-10	4·97	1·33	23·19
1911-20	6·98	2·41	21·09
1921-30	**9·63**	1·50	21·24
1931-40	6·01	1·86	**15·58**
1941-50	5·59	**2·99**	16·58

the sub-Himalayan regions of north and northeast India there is a slight tendency for rainfall in excess of the mean to be more frequent

(*iii*) Analysis by fitting polynomials to the annual rainfall series indicate increasing linear trends in the case of Kozhikode, Bellary, Nagpur and Jalpaiguri and decreasing trend in the case of Visakhapatnam. In addition trends of some higher order have been indicated in some of the stations

(*iv*) Further examination, with the aid of 10-year moving averages for the places showing trends by the polynomial analysis, show that there is no general tendency for increase or decrease in the case of any of the stations

(*v*) Polynomial analysis of seasonal rainfall at stations where annual rainfall indicated linear trends by polynomial analysis, show decreasing trend of southwest monsoon rainfall in the case of Visakhapatnam and a slight increasing trend in the case of the southwest monsoon rainfall of Kozhikode, Bellary, Nagpur and Jalpaiguri. There is significant increasing trend in the January to March rainfall of Nagpur

(*vi*) Examination of the 10-year moving averages of seasonal rainfall at the places show that there has been no general tendency for increase or decrease at any of the places, but the average June to September rainfall during 1931-1940 of Visakhapatnam was significantly lower than the mean rainfall and the January to March rainfall of Nagpur for 1941-1950 and October to December rainfall of Jalpaiguri for 1921-1930 were significantly higher than the mean rainfall for the season.

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