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A study of the Northeast Monsoon Rainfall of Tamilnad

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ABSTRACT. A mainly statistical study of the northeast monsoon (October to December) rainfall of Tamilnad has been made utilising the rainfall data for the 80 years, 1870 to 1949. A grouping of the districts on the basis of average rainfall has been indicated. The distribution of the rainfall has been studied and the probability of occurrence of rainfall within certain specified limits has been given. The normality of distribution of the district rainfalls has been tested. The occurrence of abnormalities has been discussed with reference to the incidence of depressions and cyclonic storms in the south Bay of Bengal. It is found that large excesses of rainfall occur when depressions and cyclonic storms strike or come very near to the Coromandel coast and large defects occur when such depressions and storms do not strike the coast although they may occur in the south Bay of Bengal.

An examination has also been made as to how far the influence of "World Factors" on the northeast monsoon rainfall of Tamilnad shown by Doraiswamy Iyer could account for the abnormalities. The secular variation in the seasonal rainfall in the Tamilnad districts has been examined but no significant changes during the past 80 years could be found. The inter-district correlation co-efficients for the northeast monsoon rainfall have been calculated and it is found that all the correlation co-efficients are positive and except for a few all are significant indicating that the whole of Tamilnad is a fairly homogeneous region as far as northeast monsoon rainfall is concerned.

1. Introduction

Over most of India, June to September, the southwest monsoon period, is the principal rainy season. Over Tamilnad*, however, the principal rainy season is October to December, the northeast monsoon period, and the rainfall in this season determines the agricultural production in the area. During the years 1947 to 1949 and also in 1950 the northeast monsoon rains were below normal and is reported to have caused considerable decrease in agricultural production. It was, therefore, considered worthwhile to examine the northeast monsoon rainfall over Tamilnad over a long period of years by suitable statistical methods, to see to what extent the years 1947 to 1950 were exceptional, what the abnormalities in the past were and whether they were related to any general or specific causes.

Tamilnad, consisting of the eleven districts Chingleput, North Arcot, South Arcot, Tanjore, Tiruchirapalli, Madurai, Ramnad, Tirunelveli, Salem, Coimbatore and the Nilgiris comprises mainly of the Carnatic plains and stretches as an extensive tract running southwest to northeast between latitudes 8° and 14°N, flanked on the west and northwest by the Western and Eastern Ghats respectively and bounded on the east and southeast by the Bay of Bengal and the Gulf of Mannar respectively. The land drops rather abruptly near the hills and thereafter slopes gradually towards the sea. The Eastern and the Western Ghats meet in the Nilgiris where *Dodabetta* (8640 ft) is the highest peak. In the long range of the Western Ghats which are 3000 to 5000 ft high there is a marked break of about 20 miles in width to the south of the Nilgiris known as the Palghat Gap. The Annamalais and the Palni hills are formed by the broadening of the Western Ghats to the south of the Palghat Gap. The *Anaimudi* peak (8837 ft) in the Annamalais is the highest peak in South India. Besides these, there are several isolated hills, the chief among them being the Shevroys in Salem district, the Pachaimalais and the Kollumalais in Salem and Tiruchirapalli

* Tamilnad is a new meteorological subdivision and is the same as the old division, *Southeast Madras*, used in India Meteorological Department publications with the district of Chittoor omitted. Chittoor district is now included in the new subdivision *Rayalaseema*

districts and the Javadi hills in the North Arcot district. The principal rivers which traverse the region are the Palar, Ponnaiyar, Cauvery, Vaigai and Thamraparni, all flowing from west to east into the Bay of Bengal. There are neither large lakes nor forests big enough tc produce climatic reactions.

The entire region is hidden by the Western Ghats from the full blast of the rain bearing winds of the southwest monsoon. There is, therefore, not much rain over the region in that season. With the retreat of the southwest monsoon and the reversal of the pressure distribution, which occurs in the beginning of October, a trough of low pressure gets established in the south Bay of Bengal. This trough, which is occasionally intensified by the passage westwards of low pressure waves, directs over the eastern parts of the South Indian Peninsula equatorial maritime air (*Em*) in sufficient depth which, interacting with the mixed Tropical Maritime (*Tm*) and diverted Tropical Continental (*Tc*) air already there, causes the northeast monsoon rains over Tamilnad. Depressions and cyclonic storms form occasionally in the trough of low pressure over the south Bay of Bengal and some of them moving west or northwest strike the Tamilnad coast causing widespread and locally heavy rain, especially over the coastal districts. These depressions and cyclonic storms occur mainly in October and November, which are the principal cyclone months in the Bay of Bengal. Some of them move north or northeast causing very little or no rain in Tamilnad.

The Autumn rainfall, *i.e.*, the northeast monsoon rainfall of the Carnatic was studied by Blanford (1886) on the basis of 20 years (1864—1883) rainfall data. More recently, Ramamurthi has studied the variation of rainfall in Tamilnad by calculating the "median" rainfall at half monthly intervals and their 5 per cent confidence limits from rainfall recorded at 54 provincial raingauge stations in Tamilnad during the 35 years 1903 to 1937. In this paper, a mainly statistical study of the northeast monsoon rainfall of Tamilnad during the 80 years 1870 to 1949 has been made. The spatial and time distribution of the northeast monsoon rainfall and the mechanism of its occurrence is being discussed in a separate paper.

2. Normal rainfall of the Northeast Monsoon

The data utilised in this investigation have been extracted from the provincial rainfall records. The positions of the raingauge stations whose data have been utilised are shown in Fig. 1. The number of raingauge stations in each district, the areas they represent, the normal rainfall in each district, during each of the months October, November and December as well as the annual normal rainfall are given in Table 1. It is seen that the northeast monsoon rainfall is about 60 per cent of the annual rainfall in the coastal districts and about 40 per cent in the interior districts. Most of the rainfall in the period occurs during October and November. There is more rain in October in the interior districts and more in November in the coastal districts.

The average rainfall in each of the 11 districts during the period October—December in the 81 years 1870 to 1950 is given in Table 2. These are also represented graphically in Fig. 2. The average rainfall for Tamilnad given in the penultimate column of Table 2 is the weighted average of the average rainfall of the districts.

In Table 3 are given for each of the districts the arithmetic mean (M) of the rainfalls, their mean deviation (M_d) being the average numerical departure of the actual rainfall from the normal, the standard deviation (S), the co-efficient of variability ($C.V. = 100\ S/M$) and the median rainfall as well as the upper and lower limits for the 5% random chance for the median. The highest and lowest rainfall recorded and the year in which it occurred has also been given.

Even a cursory examination of the mean rainfall amounts indicates that the rainfall of the season is not uniform throughout the

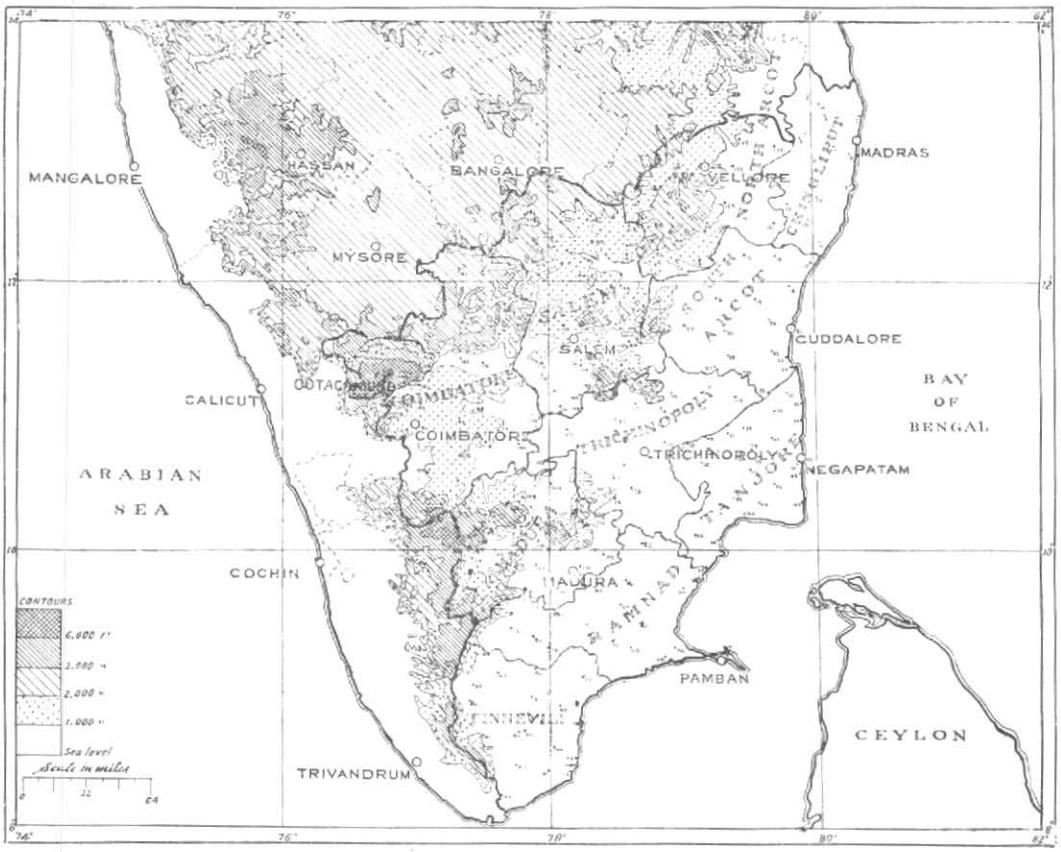

Fig. 1. Map of Tamilnad

region. The significance of the differences between the different means was tested by the *t—test.* This enabled the following grouping of the districts in terms of the mean rainfall—

(*i*) The north coastal districts—

Chingleput, South Arcot and Tanjore—with a mean rainfall of about 25 inches

(*ii*) The South coastal districts—

Ramnad and Tirunelveli—with a mean rainfall of about 18 inches

(*iii*) The interior districts—

Madurai, Tiruchirapalli and North Arcot—with a mean rainfall of about 15 inches

(*iv*) The sub-montane districts—

Salem and Coimbatore—with a mean rainfall of about 11 inches

(*v*) The hilly Nilgiris district—with a mean rainfall of 20 inches.

Ramamurthi has given an interesting grouping of the region linking the rainfall in the northeast and southwest monsoon periods. The above grouping agrees with the grouping indicated by him.

TABLE 1

Rainfall of Tamilnad

District	Area in sq. miles	Number* of rainguage stations	Normal rainfall†					
			Annual	October	November	December	October to December	
							Actual	%of annual
1. Chingleput	3079	14 (7)	46·70	10·39	12·17	4·66	27·22	58·3
2. South Arcot	5217	17 (6)	46·86	9·05	11·02	5·52	25·59	54·6
3. Tanjore	3710	26 (10)	44·39	8·09	11·31	6·69	26·09	58·8
4. Ramnad	2104	19 (6)	31·71	7·06	7·16	3·47	17·69	55·8
5. Tirunelveli	5389	21 (7)	29·83	6·56	7·89	4·30	18·75	63·2
6. Madurai	6597	19 (5)	31·92	7·21	6·04	2·29	15·54	48·7
7. Tiruchirapalli	3632	20 (3)	34·70	7·15	6·00	2·82	15·97	46·0
8. North Arcot	7386	14 (6)	38·01	6·51	6·30	2·32	15·13	39·8
9. Salem	7530	25 (8)	32·33	6·02	4·02	1·19	11·23	34·7
10. Coimbatore	7800	23 (7)	33·61	6·93	4·52	1·41	12·86	38·3
11. Nilgiris	958	11 (2)	74·45	9·93	6·92	2·64	19·49	26·2
Tamilnad			38·88	7·54	7·52	3·45	18·51	47·7

*The number of raingauge stations has not been constant for all the years. The lowest number is indicated within brackets

†The figures refer to the 1940 Normals published in India Meteorological Department Memoir Vol. XXVII. Pt. V. Figures for Nilgiris district have been obtained by averaging the values for the 11 stations in the district

TABLE

Northeast Monsoon Rainfall

	CHINGLEPUT		SOUTH ARCOT		TANJORE		RAMNAD		TIRUNELVELI		MADURAI	
Normal	27·2		25·6		26·1		17·7		18·7		15·5	
Year	Actual *in*	Dep %	Actual *in*	Dep %	Actual *in*	Dep %	Actual *in*	Dep %	Actual *in*	Dep %	Actual *in*	Dep %
1870	19·7	— 25	25·4	+ 5	21 2	— 20	11·3	—36	11·6	— 36	10·4	— 33
1871	28·0	+ 7	24·3	0	23·5	— 12	15·8	—11	14·5	— 20	15·5	0
1872	41·0	+ 57	32·2	+ 33	28·7	+ 8	16·0	—10	14·4	— 21	14·5	— 6
1873	17·5	— 33	19·2	— 21	23·5	— 12	11·4	—36	8·0	— 56	12·7	— 19
1874	27·9	+ 7	18·2	— 25	20·3	— 24	13·2	—26	15·9	— 13	16·4	+ 6
1875	13·4	— 49	10·5	— 57	17·0	— 36	13·9	—22	13·7	— 25	17·2	+ 11
1876	4·7	— 82	7·8	— 68	15·6	— 41	7·9	—55	10·1	— 44	6·0	— 41
1877	20·9	— 20	27·4	+ 13	38·1	+ 43	34·1	+92	37·7	+108	32·7	+111
1878	7·7	— 70	11·5	— 53	12·0	— 55	8·3	—53	8·5	— 53	8·4	— 46
1879	22·2	— 15	12·6	— 48	22·1	— 17	9·7	—45	13·7	— 24	6·9	— 56
1880	28·5	+ 9	29·9	+ 23	37·0	+ 39	25·2	+42	20·7	+ 14	18·7	+ 20
1881	16·9	— 36	11·2	— 54	25·3	— 5	14·7	—17	16·5	— 9	11·8	— 24
1882	30·2	+ 15	17·5	— 28	26·7	+ 1	16·8	— 5	12·9	— 29	12·7	— 18
1883	32·8	+ 25	24·8	+ 2	25·9	— 3	20·1	+13	17·3	— 5	21·1	+ 36
1884	57·4	+119	60·6	+150	53·1	+100	29·1	+64	27·3	+ 54	23·4	+ 51
1885	30·1	+ 15	19·3	— 20	34·0	+ 28	18·8	+ 6	19·1	+ 5	17·0	+ 9
1886	17·0	— 35	14·5	— 40	19·8	— 25	15·4	—13	12·7	— 30	5·1	— 67
1887	42·2	+ 61	43·1	+ 78	41·9	+ 57	21·7	+22	27·6	+ 52	18·2	+ 17
1888	32·7	+ 25	28·1	+ 16	31·2	+ 17	22·7	+28	28·3	+ 56	16·6	+ 7
1889	20·9	— 20	12·3	— 49	15·8	— 41	9·5	—47	9·3	— 49	9·5	— 39
1890	9·4	— 64	12·7	— 47	20·3	— 24	11·5	—35	9·7	— 47	15·1	— 2
1891	21·3	— 19	29·4	+ 21	37·5	+ 41	25·8	+45	28·7	+ 58	20·1	+ 30
1892	7·2	— 72	6·4	— 74	9·9	— 63	4·6	—74	4·9	— 73	9·4	— 40
1893	29·7	+ 11	30·7	+ 27	33·0	+ 24	17·7	— 1	15·9	— 13	16·3	+ 6
1894	20·3	— 23	16·7	— 31	18·8	— 29	17·7	0	11·2	— 39	12·7	— 18
1895	28·2	+ 8	34·9	+ 44	33·9	+ 27	19·2	+ 8	24·6	+ 36	18·8	+ 21
1896	41·0	+ 57	30·0	+ 24	36·6	+ 38	27·4	+54	29·4	+ 62	22·6	+ 46
1897	9·6	— 63	9·5	— 61	10·4	— 71	9·5	—47	9·3	— 49	8·5	— 45
1898	46·4	+ 77	46·0	+ 90	40·7	+ 53	26·9	+52	20·6	+ 13	19·0	+ 22
1899	21·3	— 18	22·3	— 8	27·1	+ 2	13·5	—24	13·3	— 27	9·1	— 41
1900	16·9	— 35	18·7	— 23	26·7	+ 1	18·1	+ 2	24·2	+ 33	12·2	— 21
1901	34·5	+ 32	22·1	— 9	21·3	— 20	22·8	+29	12·0	— 34	15·2	— 2
1902	38·5	+ 47	38·9	+ 61	35·7	+ 34	29·2	+65	32·4	+ 78	20·6	+ 33
1903	41·1	+ 57	23·1	— 5	29·2	+ 10	16·8	— 5	12·7	— 30	15·7	+ 1
1904	8·8	— 66	13·9	— 43	16·0	— 40	11·7	—34	11·5	— 37	9·4	— 39
1905	25·0	— 5	24·7	+ 2	20·9	— 21	15·2	—14	17·3	— 5	11·3	— 27
1906	26·3	0	35·3	+ 46	39·3	+ 48	17·1	— 4	21·7	+ 20	14·8	— 4
1907	28·5	+ 9	27·6	+ 14	25·8	— 3	15·4	—13	20·4	+ 12	13·0	— 16
1908	24·5	— 6	24·9	+ 3	19·1	— 28	10·9	—39	8·8	— 51	12·3	— 20
1909	5·5	— 79	6·1	— 75	7·1	— 74	12·1	—31	12·2	— 33	16·4	+ 6
1910	24·1	— 8	19·2	— 21	16·8	— 37	14·0	—21	11·3	— 32	20·0	+ 29
1911	23·2	— 11	23·9	— 1	31·5	+ 19	18·7	+ 5	20·1	+ 11	14·7	— 5
1912	33·5	+ 28	26·3	+ 9	26·2	— 1	22·6	+27	23·8	+ 31	18·5	+ 19
1913	42·9	+ 64	44·6	+ 84	44·0	+ 66	16·4	— 8	21·1	+ 16	11·7	— 25
1914	28·9	+ 10	36·1	+ 49	30·1	+ 13	25·1	+42	41·8	+130	17·7	+ 14

2

of Tamilnad (1870-1950)

TIRUCHI-RAPALLI		NORTH ARCOT		SALEM		COIMBA-TORE		NILGIRIS		TAMILNAD		Normal
16·0		15·1		11·2		12·9		19·5		18·5		
Actual *in*	Dep %	Actual *in*	Dep %	Actual *in*	Dep %	Actual *in*	Dep %	Actual *in*	Dep %	Actual *in*	Dep %	Year
15·1	— 1	14·4	— 4	9·7	—15	7·7	—37	12·9	—35	14·3	—21	1870
14·9	— 2	19·8	+ 32	9·1	—20	14·8	+21	27·3	+37	18·1	— 1	1871
16·5	+ 8	24·5	+ 63	12·2	+ 6	7·2	—41	22·8	+15	17·7	— 3	1872
16·6	+ 9	12·1	— 19	11·0	— 4	8·5	—31	16·6	—16	14·2	—22	1873
14·7	— 4	14·0	— 7	12·0	+ 4	10·2	—16	18·4	— 7	16·1	—12	1874
11·2	—27	6·4	— 57	8·2	—29	10·9	—11	23·2	+17	12·9	—29	1875
4·7	—69	3·3	— 78	1·9	—83	3·1	—75	11·9	—40	7·1	—61	1876
21·5	+41	14·8	— 1	16·3	+41	17·1	+40	30·7	+55	26·7	+47	1877
9·5	—37	10·9	— 27	9·1	—21	7·8	—37	14·3	—28	9·7	—47	1878
9·0	—41	8·5	— 43	6·4	—44	6·3	—49	18·9	— 5	12·2	—33	1879
22·9	+50	22·1	+ 47	18·0	+57	19·2	—57	29·9	+51	24·7	+36	1880
11·1	—27	9·0	— 40	6·4	—44	9·2	+25	17·5	—12	13·7	—25	1881
15·7	+ 3	19·3	+ 29	13·5	+17	12·8	+ 5	19·0	— 5	17·7	— 3	1882
18·1	+18	19·9	+ 32	18·3	+59	18·3	+50	21·7	+ 9	21·5	+18	1883
25·0	+64	36·4	+143	13·8	+20	17·2	+41	30·7	+54	33·4	+83	1884
17·6	+15	16·7	+ 11	16·5	+44	16·9	+38	27·9	+40	21·3	+17	1885
6·3	—59	8·5	— 43	6·1	—47	5·5	—55	11·5	—42	11·3	—38	1886
19·6	+29	27·0	+ 80	16·6	+45	15·1	+24	24·5	+23	26·9	+48	1887
12·6	—18	17·1	+ 14	10·4	—10	8·4	—32	14·9	—25	20·0	+10	1888
12·1	—21	14·6	— 3	9·0	—21	8·8	—28	18·9	— 5	12·3	—33	1889
15·2	0	11·0	— 27	10·2	—11	11·3	— 7	15·0	—25	13·0	—29	1890
15·2	0	14·7	— 2	7·8	—32	12·4	+ 1	29·1	+46	22·0	+21	1891
8·6	—44	6·2	— 59	5·2	—55	5·8	—52	14·0	—29	7·2	—61	1892
21·1	+39	18·1	+ 21	16·3	+42	16·1	+32	24·5	+23	21·7	+19	1893
9·3	—39	11·1	— 26	9·1	—21	9·2	—25	12·4	—37	13·5	—26	1894
16·5	+ 8	15·5	+ 3	12·4	+ 8	12·5	+ 2	20·5	+ 3	21·6	+19	1895
19·6	+29	13·8	— 8	11·0	— 4	12·7	+ 3	20·4	+ 3	24·0	+31	1896
7·8	—49	6·8	— 55	6·3	—46	7·6	—38	9·6	—57	8·6	—53	1897
23·3	+52	26·7	+ 78	19·2	+67	15·6	+27	22·2	+11	27·7	+52	1898
8·2	—47	7·7	— 49	4·8	—58	6·3	—49	8·2	—59	13·4	—26	1899
10·9	—28	9·9	— 34	7·1	—38	8·5	—31	15·2	—24	15·6	—14	1900
14·0	— 8	19·4	+ 29	12·0	+ 5	11·4	— 7	20·8	+ 5	18·0	— 1	1901
19·1	+25	15·9	+ 6	14·0	+22	20·6	+68	35·6	+79	26·9	+48	1902
17·2	+13	31·9	+112	19·8	+73	13·6	+11	20·3	+ 2	21·5	+18	1903
8·0	—47	7·4	— 51	4·8	—58	5·8	—53	8·9	—55	9·8	—46	1904
11·0	—38	15·9	+ 6	8·7	—24	9·7	—19	28·4	+43	16·4	—10	1905
17·2	+13	11·9	— 21	9·8	—15	13·9	+13	22·1	+11	21·7	+13	1906
16·0	+ 5	11·4	— 24	8·1	—30	12·7	+ 4	20·1	+ 1	17·9	— 2	1907
10·4	—32	8·9	— 40	6·5	—26	9·8	—20	13·7	—31	13·3	—26	1908
8·9	—42	3·9	— 74	10·1	—12	10·3	—16	17·5	—12	9·8	—45	1909
15·1	— 1	18·6	+ 24	17·2	+49	14·5	+18	24·9	+25	17·2	— 3	1910
13·6	—11	16·9	+ 13	10·4	—10	9·5	—22	22·5	+13	18·6	+ 1	1911
15·2	— 1	23·3	+ 55	15·4	+34	14·4	+18	20·8	+ 5	21·5	+19	1912
17·9	+17	14·1	— 6	10·0	—13	8·4	—32	18·7	— 6	22·8	+23	1913
16·1	+ 5	14·5	— 3	11·8	+ 3	11·7	— 5	22·9	+15	23·3	+27	1914

TABLE

	CHINGLEPUT		SOUTH ARCOT		TANJORE		RAMNAD		TIRUNELVELI		MADURAI	
Normal	27·2		25·6		26·1		17·7		18·7		15·5	
Year	Actual *in*	Dep %	Actual *in*	Dep %	Actual *in*	Dep %	Actual *in*	Dep %	Actual *in*	Dep %	Actual *in*	Dep %
1915	21·7	— 17	16·3	—33	17·5	—34	17·6	— 1	17·6	— 3	9·1	—41
1916	29·1	+ 11	26·5	+ 9	16·3	—39	10·1	—43	9·5	—47	9·4	—39
1917	24·5	— 6	14·8	—39	21·1	—20	13·8	—22	11·4	—37	14·9	— 4
1918	32·1	+ 23	28·3	+17	31·3	+18	20·6	+16	19·1	+ 5	18·7	+20
1919	28·8	+ 10	30·0	+24	43·9	+65	24·5	+38	18·6	+ 2	15·9	+ 3
1920	39·1	+ 50	33·8	+39	49·9	+84	23·3	+31	23·0	+27	17·1	+10
1921	23·3	— 11	17·6	—27	18·7	—30	15·7	—11	18·4	+ 1	16·7	+ 8
1922	40·5	+ 55	29·9	+23	29·9	—21	22·5	+27	27·6	+52	28·2	+82
1923	19·2	— 27	22·6	— 7	28·9	+ 9	19·7	+10	25·5	+41	13 0	—16
1924	19·1	— 27	15·1	—38	15·2	—43	22·3	+26	16·9	— 7	8·3	—46
1925	39·3	+ 50	36·0	+49	36·3	+37	13·8	—22	33·6	+85	20·8	+34
1926	16·9	— 35	17·5	—28	20·5	—23	11·1	—38	9·8	—46	12·1	—22
1927	18·4	— 29	16·2	—33	12·7	—52	13·6	—23	14·9	—18	13·6	—12
1928	23·5	— 10	34·2	+41	36·2	+36	17·2	— 3	19·4	+ 7	17·6	+14
1929	26·6	+ 2	25·6	+ 5	30·2	+14	20·8	+17	24·0	+32	13·4	—14
1930	44·7	+ 71	31·5	+30	36·9	+39	22·5	+27	15·9	—15	26·6	+71
1931	36·4	+ 39	39·9	+65	41·0	+54	27·7	+56	25·1	+38	21·7	+40
1932	27·0	+ 3	29·7	+23	39·7	+49	24·2	+36	18·6	+ 2	18·7	+20
1933	26·4	+ 1	23·5	— 3	20·4	—23	15·7	—11	15·5	—15	16·4	+ 5
1934	22·7	— 13	24·4	+ 1	20·3	—24	15·4	—13	14·5	—20	14·1	— 9
1935	22·9	— 12	25·9	+ 7	31·2	+17	15·0	—16	15·3	—15	15·7	+ 1
1936	19·3	— 26	20·3	—16	21·5	—19	19·5	+10	18·9	+ 4	16·9	+ 9
1937	38·3	+ 46	36·6	+51	28·9	+ 9	16·1	— 9	17·0	— 6	14·3	— 7
1938	6·9	— 74	8·8	—64	16·7	—37	8·2	—54	12·0	—34	7·9	—49
1939	22·5	— 14	25·1	+ 4	31·3	+18	18·4	+ 4	13·3	—27	15·6	+ 1
1940	31·6	+ 21	36·7	+52	36·9	+39	29·4	+66	32·2	+77	24·1	+55
1941	35·1	+ 34	26·7	+10	31·2	+17	18·6	+ 5	17·9	— 1	16·4	+ 6
1942	17·4	— 34	13·1	—46	14·5	—35	23·8	+34	17·7	— 3	16·6	+ 7
1943	38·1	+ 45	23·3	— 4	21·7	—18	17·8	0	17·6	— 3	16·1	+ 4
1944	38·7	+ 48	31·7	+31	36·9	+39	22·7	+28	24·3	+34	25·3	+63
1945	18·5	— 29	19·0	—22	20·1	—24	18·6	+ 5	22·0	+21	16·7	+ 8
1946	59·9	+129	43·2	+78	41·1	+55	26·0	+47	27·7	+53	19·5	+25
1947	9·3	— 64	10·9	—55	12·8	—52	9·7	—46	7·8	—57	13·8	—11
1948	18·5	— 29	20·4	—16	20·8	—22	17·3	— 3	20·0	+10	16·0	+ 3
1949	8·2	— 69	8·9	—63	12·7	—52	11·5	—35	11·0	—39	10·0	—36
1950	15·3	— 1	14·4	—42	19·6	—26	9·9	—44	13·5	—26	12·8	—17
Normal (1870-1949)	26·2		24·2		26·6		17·7		18·2		15·5	
									EXTREME			
Highest (Year)	+129 (1946)		+150 (1884)		+100 (1884)		+92 (1877)		+130 (1914)		+111 (1877)	
Lowest (Year)	—82 (1876)		—75 (1909)		—74 (1909)		—74 (1892)		—73 (1892)		—67 (1886)	

NOTE—(*i*) Normals given at the top of this table are the 1940 Normals vide India Meteorological
(*ii*) In the calculation of the various statistics

2 (*contd*)

TIRUCHI-RAPALLI		NORTH ARCOT		SALEM		COIMBA-TORE		NILGIRIS		TAMILNAD		Normal
16·0		15·1		11·2		12·9		19·5		18·5		
Actual *in*	Dep %	Actual *in*	Dep %	Actual *in*	Dep %	Actual *in*	Dep %	Actual *in*	Dep %	Actual *in*	Dep %	Year
13·6	—11	13·5	— 10	12·7	+ 10	13·5	+ 10	19·7	— 1	15·6	—15	1915
10·8	—29	19·3	+ 29	18·5	+ 61	11·7	— 5	15·9	—20	15·8	—12	1916
12·2	—20	7·6	— 49	9·2	— 20	11·1	— 10	17·4	—13	14·2	—22	1917
18·2	+19	10·7	— 29	7·7	— 33	18·1	+ 48	28·6	+44	20·8	+15	1918
20·9	+37	17·8	+ 19	13·7	+ 19	12·6	+ 3	23·1	+16	23·1	+23	1919
23·2	+52	15·7	+ 5	14·4	+ 25	12·8	+ 5	16·7	—16	25·0	+33	1920
12·5	—18	7·5	— 50	10·4	— 9	13·2	+ 7	15·8	—21	15·4	—16	1921
19·7	+29	22·1	+ 48	20·9	+ 82	20·3	+ 65	28·3	+42	24·7	+39	1922
12·9	—15	9·5	— 37	5·6	— 51	6·8	— 45	14·8	—25	16·5	—12	1923
9·5	—37	9·9	— 34	6·6	— 43	9·9	— 19	15·4	—23	13·1	—27	1924
14·9	— 3	17·6	+ 17	9·1	— 21	13·5	+ 10	24·6	+24	23·3	+28	1925
9·9	—35	10·1	— 33	7·2	— 37	10·5	— 15	11·5	—42	12·5	—32	1926
8·6	—44	9·3	— 38	5·1	— 56	9·9	— 19	13·2	—34	12·0	—33	1927
17·6	+14	14·5	— 4	13·8	+ 20	14·3	+ 17	23·5	+18	21·3	+15	1928
16·5	+ 8	14·2	— 5	11·1	— 4	9·1	— 26	14·5	—27	18·9	+ 2	1929
26·9	+76	27·7	+ 85	19·0	+ 65	25·8	+111	31·0	+56	27·5	+53	1930
22·9	+50	20·7	+ 38	14·1	+ 23	14·6	+ 19	26·8	+35	26·3	+44	1931
24·5	+60	17·2	+ 15	18·1	+ 57	17·0	+ 39	26·7	+34	24·0	+29	1932
16·3	+ 7	13·5	— 10	12·9	+ 12	15·2	+ 24	16·3	—18	17·3	— 5	1933
17·5	+15	17·3	+ 15	15·1	+ 32	12·4	+ 1	18·2	— 9	17·2	— 5	1934
16·4	+ 8	18·0	+ 20	9·6	— 17	10·0	— 18	12·9	—35	17.7	— 5	1935
14·5	— 5	14·0	— 7	10·5	— 9	10·9	— 11	15·5	—22	16·5	—10	1936
17·3	+13	23·4	+ 56	11·5	0	11·5	— 6	20·1	+ 1	20·8	+16	1937
6·7	—54	2·9	— 81	2·5	— 78	3·3	— 73	10·5	—47	8·0	—57	1938
27·9	+83	17·8	+ 19	18·3	+ 59	16·7	+ 36	28·7	+45	21·3	+16	1939
20·8	+36	18·2	+ 22	13·0	+ 13	20·3	+ 66	21·4	+ 8	26·1	+41	1940
15·5	+ 2	16·4	+ 9	12·7	+ 10	13·1	+ 7	20·8	+ 5	20·2	+11	1941
12·5	—18	10·3	— 31	9·5	— 17	10·1	— 18	15·7	—21	14·5	—20	1942
17·5	+15	19·6	+ 31	15·6	+ 35	12·7	+ 4	17·3	—13	19·3	+ 7	1943
21·8	+43	18·2	+ 21	15·2	+ 32	22·4	+ 83	21·1	+ 6	25·2	+38	1944
11·0	—28	8·3	— 44	9·2	— 20	17·0	+ 38	19·7	— 1	16·4	—10	1945
24·2	+59	31·7	+111	24·0	+109	20·5	+ 67	31·0	+56	31·2	+73	1946
10·3	—33	8·1	— 46	9·5	— 17	9·8	— 20	12·4	—38	10·4	—43	1947
13·6	—11	14·2	— 5	11·9	+ 3	13·0	+ 6	23·5	+18	16·9	— 7	1948
11·4	—25	8·4	— 44	9·1	— 21	9·2	— 25	15·7	—21	10·5	—43	1949
13·2	—16	7·3	— 52	9·3	— 20	8·0	— 34	16·7	—16	12·6	—31	1950
15·3		15·0		11·5		12·3		19·9		18·2		

ABNORMALITIES (PERCENTAGE)

+83 (1939)	+143 (1884)	+109 (1946)	+111 (1930)	+79 (1902)	+83 (1884)
—69 (1876)	—81 (1938)	—83 (1876)	—75 (1876)	—59 (1899)	—61 (1876)

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only data upto 1949 have been utilised

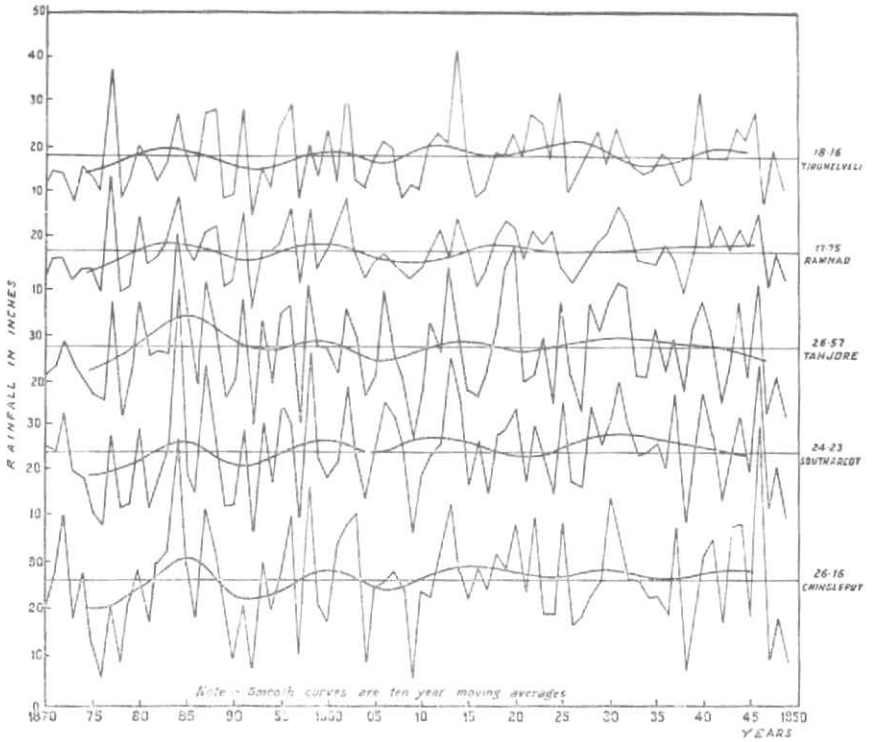

Fig. 2(a). Northeast Monsoon in Tamilnad (1870-1949)

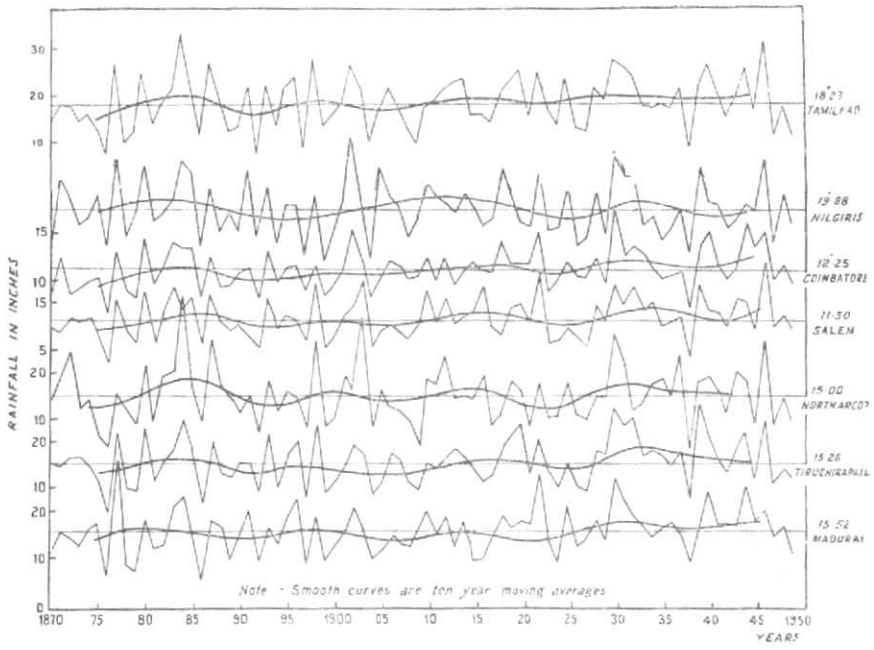

Fig. 2(b). Northeast Monsoon in Tamilnad (1870-1949)

TABLE 3

Rainfall Statistics for the Tamilnad Districts
(October to December : 1870—1949)

Districts	Arithmetic Mean (M)	Mean Deviation (M_d)	Standard Deviation (S)	Ratio M_d/S	Co-efficient of variability ($100\ S/M$)	Median	Savur's 5% limits for random chance		Highest rainfall		Lowest rainfall	
							Upper	Lower	Amount	Year	Amount	Year
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1. Chingleput	26·16	9·04	11·49	0·79	43·9	24·75	28·50	20·22	59·85	1946	4·75	1876
2. South Arcot	24·23	7·95	10·45	0·73	43·1	24·33	26·32	20·44	60·61	1884	6·12	1909
3. Tanjore	26·58	8·58	11·01	0·78	41·4	24·84	29·16	21·19	53·11	1884	7·09	1909
4. Ramnad	17·75	4·78	5·98	0·80	33·7	17·23	18·62	15·73	34.10	1877	4·64	1892
5. Tirunelveli	18·16	5·80	6·41	0·90	35·3	17·26	18·85	15·34	41·93	1914	4·94	1892
6. Madurai	15·52	3·82	5·08	0·75	32·7	15·69	16·44	13·63	32·75	1877	5·15	1886
7. Tiruchirapalli	15·26	4·07	5·12	0·79	33·6	15·18	16·44	13·63	27·95	1939	4·65	1876
8. North Arcot	15·00	4·95	6·61	0·75	44·1	14·41	16·39	13·52	36·41	1884	2·91	1938
9. Salem	11·50	3·63	4·51	0·80	39·2	11·01	12·43	9·79	24·04	1946	1·95	1876
10. Coimbatore	12·27	3·43	4·42	0·78	36·1	12·40	12·82	10·47	25·80	1930	3·07	1876
11. Nilgiris	19·88	4·95	6·08	0·81	30·6	19·70	20·84	17·46	35·58	1902	8·20	1899
Tamilnad	18·23	4·74	5·79	0·82	31·7	..	..	..	33·40	1884	7·11	1876

3. Distribution of rainfall

There is considerable variation in the northeast monsoon rainfall from year to year in all the districts as seen from Table 2 and Fig. 2 and from the high co-efficients of variability shown in Table 3. The co-efficients of variability are highest in the north coastal districts where the rainfall is also the highest. The variability decreases as we go from the coastal districts with higher rainfall to the interior districts with lower rainfall. It is known that, in general, rainfall is more variable in regions of lower mean rainfall than in regions of higher mean rainfall. It is seen that the northeast monsoon rainfall of Tamilnad is an exception to this general principle, the rainfall of the coastal districts with higher rainfall being more variable than the rainfall of the interior districts with lower rainfall. The reason for this apparently lies in the fact that the rainfall in the coastal districts is largely dependent on the occurrence of depressions and cyclonic storms in the south Bay of Bengal moving towards the Coromandel coast, which is a very variable factor. This point will be discussed further in the later paper on the distribution and mechanism of the northeast monsoon rainfall.

As the actual rainfalls in individual years vary much from the means even though the means have been derived from data for a large number of years, it is necessary to examine the nature of the distribution of the rainfall so that the probability of occurrence of a particular rainfall may be determined. The frequency distribution of the percentage departures from normal in the different districts in the 80 years is given in Table 4 (a). In Table 4 (b) are given the percentage of rainfalls falling within certain specified limits. These tables give an indication of what is ordinarily to be expected in a season. For example, the frequency data for Chingleput district shows that the departures from normal exceeded 20 per cent in 53 out of 80 years, *i.e.*, on about 2/3 the number of years and the departures exceeded the standard deviation on 27 out of 80 years, *i.e.*, on about 1/3 the number of years. The limits which are exceeded on

TABLE 4 (a)

Frequency table for Northeast Monsoon Rainfall of Tamilnad (1870-1949)

	Class limits percentage departure from normal	Number of occasions within specified limits										
		Chingle-put	South Arcot	Tanjore	Ramnad	Tirunel-veli	Madurai	Tiruchi-rapalli	North Arcot	Salem	Coim-batore	Nil-giris
Negative	100 – 90	..	..	..	..	..	..	..	..	..	..	..
	90 – 80	1	..	..	..	..	..	..	1	1	..	..
	80 – 70	4	2	2	1	1	..	..	2	1	1	..
	70 – 60	5	4	1	..	..	1	1	..	..	..	..
	60 – 50	..	4	4	3	4	1	1	5	5	3	3
	50 – 40	1	6	3	5	6	7	7	8	5	4	4
	40 – 30	6	5	7	8	11	6	7	7	4	4	6
	30 – 20	10	10	15	7	7	6	7	6	12	6	12
	20 – 10	10	2	6	9	7	8	8	2	8	11	8
	10 – 0	4	7	4	12	9	8	10	13	6	10	8
Positive	0 – 10	9½	11	7	9	8	17	10	5	8	12½	11
	10 – 20	5½	5	8	3	6	7	10	8	8	9½	9
	20 – 30	5	7	3	8	2	8	4	8	3	3	3
	30 – 40	3	3	8	4	6	4	3	4	4	5	3
	40 – 50	5	5	4	4	1	1	3½	2	5	2	6
	50 – 60	6	2	4	3	6	2	4½	2	4	3	5
	60 – 70	1	2	2	3	1	1	2	1	3	4	..
	70 – 80	2	2	..	..	2	1	1	2	1	..	2
	80 – 90	..	2	1	..	1	1	1	1	1	1	..
	90 – 100	..	..	1	1	..	..	..	..	..	..	..
	Over 100	2	1	..	..	2	1	..	3	1	1	..

TABLE 4 (b)

Frequency of occurrence of Northeast Monsoon Rainfall (1870-1949) within specified limits

Limits	No. of years	Percentage	No. of years	Percentage	No. of years	Percentage	No. of years	Percentage	No. of years	Percentage
	Chingleput		South Arcot		Tanjore		Ramnad		Tirunelveli	
$>+10\%$	29½	36·9	29	36·3	31	38·7	26	32·5	27	37·7
$<-10\%$	39	48·8	33	41·3	38	47·5	33	41·3	36	45·0
$>+20\%$	24½	30·6	24	30·0	23	28·7	23	28·7	21	26·4
$<-20\%$	29	36·3	31	38·7	32	40·0	24	30·0	29	36·3
$>+\sigma$	16	20·0	12	15·0	12	15·0	14	17·5	12	15·3
$<-\sigma$	11	13·7	14	17·5	10	12·5	15	18·7	11	13·7
$>+2\sigma$	2	2·5	2	2·5	2	2·5	1	1·3	5	6·3
$<-2\sigma$	..	..	..	..	..	..	1	1·3	1	1·3
$-10\%<r<10\%$	11½	14·3	18	22·5	11	13·7	21	26·3	17	21·3
$-20\%<r<20\%$	26½	33·1	25	31·3	25	31·3	33	41·3	30	37·5
$-\sigma<r<\sigma$	53	66·3	54	67·5	56	70·0	51	63·7	57	71·3
$-2\sigma<r<2\sigma$	78	97·5	78	97·5	78	97·5	78	79·5	74	92·5
Limits for 80% chance of success	±60%		±55%		±50%		±45%		±50%	
	Madurai		Tiruchirapalli		North Arcot		Salem		Coimbatore		Nilgiris
$>+10\%$	26	32·5	29	36·3	31	38·7	30	37·5	28½	35·6	28	35·0
$<-10\%$	29	36·3	31	38·7	31	38·7	36	45·0	29	36·3	33	41·3
$>+20\%$	19	23·7	19	23·7	23	28·7	22	27·5	19	23·7	19	23·7
$<-20\%$	21	26·3	23	28·7	29	36·1	28	35·0	18	25·0	25	31.3
$>+\sigma$	10	12·5	15	18·7	11	13·7	15	18·7	14	17·5	16	20·0
$<-\sigma$	14	17·5	14	17·5	11	13·7	12	15·0	9	11·3	12	15·0
$>+2\sigma$	3	3·7	2	2·5	3	3·7	2	2·5	2	2·5	2	2·5
$<-2\sigma$	1	1·3	1	1·3	..	..	1	1·3	..	..	..	..
$-10\%<r<10\%$	25	31·3	20	25·0	18	22·5	14	17·5	22½	29·4	19	23·7
$-20\%<r<20\%$	40	50·0	38	47·5	28	35·0	30	37·5	43	53·7	36	45·0
$-\sigma<r<\sigma$	56	70·0	51	63·7	58	72·5	53	66·3	56	70·0	52	65·0
$-2\sigma<r<2\sigma$	76	95·0	77	96·3	77	96·1	77	96·3	78	97·5	78	97·5
Limits for 80% chance of success	±40%		±45%		±50%		±55%		±45%		±45%	

20 per cent of the occasions are ± 60 per cent. Thus, with a knowledge of past rainfall alone, one would be able to forecast with an 80 per cent chance of success that the northeast monsoon rainfall of Chingleput will be within ± 60 per cent of the normal. But such " Standard 80% expectation " can scarcely be considered to be of much practical value as the range between the two limits is considerable.

It is well known that the distribution of rainfall at a single station is not always " normal " and is in general skew with the mode lower than the mean, *i.e.*, serious deficiencies of rainfall are commoner than they would be if the distribution were normal. The departure from normality may not be sufficiently high in respect of the southwest monsoon rainfall over the greater part of the plains of India as shown by Sankaranarayanan (1933). However, even if the distribution of rainfall at a single station is not exactly normal, the distribution of the mean rainfall over a region tends to normality as the number of stations in the sample is increased. Savur (1937) has stressed the utility of the median for analysing distributions which are not necessarily normal. The median rainfalls in the different districts and the upper and lower limits for the 5% random chance for the median given in Table 3 are also shown in Fig. 3. The significance of the median rainfalls of the different districts have also been tested in the manner suggested by Savur and it confirms the grouping of the districts already indicated in Section 2.

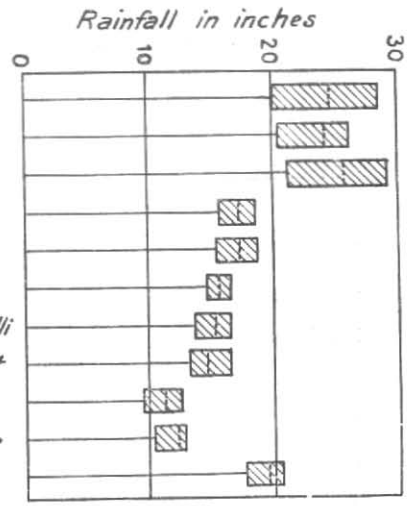

Fig. 3. Dispersion diagram for Northeast Monsoon Rainfall of Tamilnad

Note : Median rainfall indicated by dotted line and 5% limits by the length of the hatched rectangles

4. Normality of the distributions

The ratios of the mean deviation to the standard deviation in respect of the different districts are given in column 5 of Table 3. It is known (Kendall 1943) that for a normal distribution this ratio is $\sqrt{2/\pi} = 0{\cdot}80$ (approximately). As the ratio in respect of the different districts is of this order it suggests that the distributions of the northeast monsoon rainfalls in the different Tamilnad districts are not generally far different from the normal frequency distribution. A rigorous test for normality can be made following Fisher (1938) by calculating the two statistics g_1, g_2. The quantity g_1 which is calculated from the third powers is a measure of asymmetry and g_2 calculated from the fourth powers is a measure of departure from normality. The sampling variances of these quantities are functions depending only on the size of the sample (n) and are given by the relations—

$$\text{Variance of } g_1 = \frac{6n(n-1)}{(n-2)(n+1)(n+3)}, \text{ and}$$

$$\text{Variance of } g_2 = \frac{24n(n-1)^2}{(n-3)(n-2)(n+3)(n+5)}$$

The two measures of departure from normality and their standard errors have been calculated in respect of the different districts and are given in Table 5. It is seen that the values of g_1 for Madurai and Tirunelveli are just significant. These indicate that in these districts moderately dry northeast monsoons are more frequent than moderately wet northeast monsoons but very dry northeast monsoons are less frequent than very wet ones. All the other g_1 and g_2 are less than twice their standard errors indicating that the departure from normality of the distributions are not significant in the remaining districts.

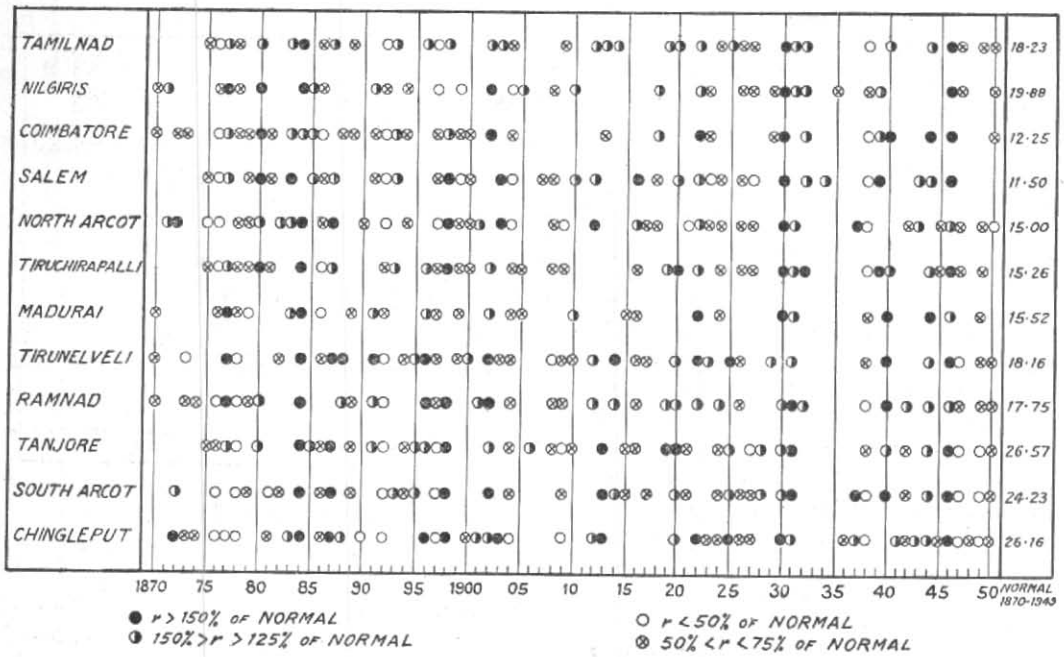

Fig. 4. Northeast Monsoon in Tamilnad (abnormalities)

5. Abnormalities of rainfall

The percentage departures from normal of the northeast monsoon rainfall in the 81 years 1870 to 1950 are given in Table 2 and Fig. 4 shows the prominent abnormalities. In Fig. 4 the years in which the actual rainfall was in moderate excess (*i.e.*, departure from normal +25 to +49 per cent) and in large excess (*i.e.*, departure from normal +50 per cent and above) and also those in which it was in moderate defect and large defect have been indicated distinctively.

It is seen from this figure that in the years 1876, 1892, 1897 and 1938 the rainfall was in large defect in a number of districts as well as in the region as a whole. In the years 1878, 1886, 1904, 1909, 1927, 1947 and 1949 rainfall was in large defect in two or more districts while in the region as a whole it was in moderate defect. The rainfall was in large excess in most districts and in the region as a whole in the years 1884, 1930 and 1946 while in the years 1877, 1880, 1896, 1902, 1903, 1913, 1920, 1922, 1931 and 1940 it was in moderate excess in the region as a whole with large excess in two or more districts. It is seen that the years of abnormal rainfall do not follow any particular sequence but are distributed at random.

TABLE 5

Measures of departure from normality and their standard errors in respect of different districts

District	$g_1 \pm$S.E.(g_1)	$g_2 \pm$S.E.(g_2)
Chingleput	+·19±·27	—·72±·53
South Arcot	+·29±·27	—·38±·53
Tanjore	+·29±·27	—·48±·53
Ramnad	+·39±·27	—·18±·53
Tirunelveli	+·67±·27	+·05±·53
Madurai	+·61±·27	+·08±·53
Tiruchirapalli	+·40±·27	—·35±·53
North Arcot	+·51±·27	+·12±·53
Salem	+·34±·27	—·26±·53
Coimbatore	+·47±·27	+·42±·53
Nilgiris	+·35±·27	—·54±·53

The year with the least rainfall in the region as a whole was 1876, the worst famine year known in South India, when the rainfall in Tamilnad was in defect by 61 per cent. The highest percentage defects in any of the districts in that year was 82 per cent in Chingleput and 83 in Salem. The year with the highest rainfall was 1884 when the rainfall over Tamilnad was 83 per cent in excess of the normal, the highest percentage excess in any of the districts being 150 per cent in South Arcot district. In recent years, *i.e.*, in the last 25 years, the year with the least rainfall was 1938 and the year with the most rainfall was 1946. In the years 1947, 1949 and 1950, the northeast monsoon rainfall was in moderate defect in the region as a whole while in 1948 it was only in slight defect. While there have been years in the past when the northeast monsoon rainfall has been more deficient than in any of the years 1947 to 1950, the period 1947 to 1950 has been noteworthy in that in the 81 years 1870 to 1950, it is a period when the total deficiency of rainfall (*viz.*, 31 per cent) has been largest that has occurred in any consecutive four year period. The only other consecutive four year period when the total deficiency of rainfall was equally large was 1873 to 1876. It is thus seen that 1947 to 1950 has been, together with 1873-76, the worst consecutive four year period in the last 81 years.

It is interesting to examine the extreme abnormalities recorded in the 11 districts in the 81 year period, in order to get an idea of the limits within which abnormalities may be expected to lie. The extreme abnormalities are given at the bottom of Table 2. It is seen that while the extreme positive abnormalities range from +83 to +150 per cent, the extreme negative abnormalities range from —59 to —83 per cent. The maximum possible limit of negative abnormality is 100 per cent but it has actually not gone beyond —83 per cent in any district in the 81 years. It is seen that the positive abnormality also has in practice a limit and that it has not exceeded +150 per cent in the 81 year period. One can, therefore, draw the conclusion on the basis of 81 years records that even in the worst famine year the rainfall in any district of Tamilnad does not go below about 1/7th of the normal and even in the worst flood year, the rainfall does not exceed $2\frac{1}{2}$ times the normal in any district. In Tamilnad as a whole the extreme abnormalities have been —61 per cent and +83 per cent. The rainfall of Tamilnad has not, therefore, been below 1/3rd of the normal or above twice the normal in the last 81 years.

6. Depressions and cyclonic storms and the Northeast Monsoon Rainfall

In order to study how far the abnormalities of the northeast monsoon rainfall in Tamilnad are related to the occurrence or otherwise of depressions and cyclonic storms in the south Bay of Bengal and their movement, the depression and cyclone tracks published in the " Annual Summary " of the India Meteorological Department were examined. Table 6 gives the number of occasions during the 45 year period 1906—1950 when depressions and cyclonic storms occurred in October—December in the Bay of Bengal south of latitude 16°N and within specified ranges of longitude from the Coromandel coast which runs nearly along the 80°E meridian. The number which struck the Coromandel coast and the number which passed westwards across Tamilnad into the Arabian Sea are also shown. The percentage departures from normal of the northeast monsoon rainfall in Tamilnad in the different years are also shown in the last column of the table.

It is interesting to note from Table 6 that large excesses of rainfall occurred during the years when depressions and cyclonic storms occurring in the south Bay of Bengal struck the Coromandel coast or moved to within 2° longitude of the coast, while large defects of rainfall occurred during the years when such depressions and storms were absent or even when present did not move to within 2° of the Coromandel coast but moved north or northeast. There were, however, some rare years when rainfall was in moderate defect even though some depressions and storms crossed the Coromandel coast but it is found that in such years, the depressions

TABLE 6

Depressions and cyclonic storms in the Bay of Bengal south of latitude 16°N during October to December 1906-1949

Year	Number of depressions or storms in the Bay of Bengal south of Lat. 16°N and						Tamilnad rainfall % departure from normal (Oct-Dec)
	West of Long. 92°E	West of Long. 88°E	West of Long. 84°E	West of Long. 82°E	Crossed coast (80°E)	Passed across to Arabian Sea	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1906 ..	5	5	4	2	2	—	13
1907 ..	4	3	3	3	1	—	— 2
1908 ..	3	3	3	2	2	2	—26
1909 ..	4	1	—	—	—	—	—45
1910 ..	2	2	1	1	—	—	— 3
1911 ..	2	1	1	1	—	—	1
1912 ..	2	2	1	1	1	1	19
1913 ..	4	3	3	3	1	1	23
1914 ..	3	2	1	1	1	1	27
1915 ..	6	5	5	3	3	1	—15
1916 ..	5	4	3	2	1	1	—12
1917 ..	1	1	—	—	—	—	—22
1918 ..	4	4	4	2	1	—	15
1919 ..	4	4	3	2	1	—	23
1920 ..	2	2	2	—	—	—	33
1921 ..	4	4	2	2	2	—	—16
1922 ..	5	4	4	3	1	1	39
1923 ..	3	3	2	—	—	—	—12
1924 ..	5	3	1	1	1	—	—27
1925 ..	2	2	1	1	1	—	28
1926 ..	2	2	—	—	—	—	—32
1927 ..	2	1	1	1	1	—	—33
1928 ..	3	3	2	1	1	—	15
1929 ..	3	3	3	2	1	—	2
1930 ..	5	4	3	3	2	—	53
1931 ..	2	1	1	2	2	—	44
1932 ..	4	3	3	1	1	—	23
1933 ..	3	3	2	2	2	—	— 5
1934 ..	2	2	1	1	1	—	— 5
1935 ..	3	2	2	2	2	2	— 5
1936 ..	4	3	3	2	1	—	—10
1937 ..	3	3	2	2	2	1	16
1938 ..	2	1	1	1	—	—	—57
1939 ..	3	3	2	2	2	—	16
1940 ..	2	2	2	2	1	1	41
1941 ..	4	4	4	3	2	2	11
1942 ..	2	1	1	—	—	—	—20
1943 ..	4	4	3	3	3	1	7
1944 ..	4	3	3	2	1	1	38
1945 ..	5	5	4	2	—	—	—10
1946 ..	6	6	6	4	4	3	73
1947 ..	5	3	2	1	—	—	—43
1948 ..	3	3	2	1	—	—	— 7
1949 ..	1	1	1	1	—	—	—43
1950 ..	3	3	2	—	—	—	—31

or storms crossed the coast north of the latitude of Madras (13°N) and caused rain in the region to the north and northwest of Tamilnad. There was one year when rainfall over Tamilnad was in moderate excess without a depression or cyclonic storm striking the Coromandel coast or coming within 2 degrees of it. It should be remarked here that while depressions and cyclonic storms give widespread and locally heavy rain which may sometimes be concentrated over the coastal districts, low pressure waves with feeble depressional circulations which occasionally move from east to west in the northeast monsoon season across the south Bay of Bengal and Tamilnad into the Arabian Sea can cause widespread moderate to heavy rainfall. If a number of such active low pressure waves affect Tamilnad during the season there can be good northeast monsoon rains without a depression or cyclonic storm occurring.

Blanford (1886) has quoted and supported the view of Eliot that " a strong northeast monsoon on the Madras coast with heavy, or more or less continuous, rain over the land, is associated with an absence of cyclones in Bay " and states that " any partial failure of the Carnatic Autumnal rains coincides, in some cases certainly, probably as a rule, with an increased rainfall on the Bay ". This view would be correct so far as the northeast monsoon rainfall of Tamilnad is concerned if every depression or cyclonic storm which occurred in the south Bay of Bengal in the period October to December moved in a direction between northwest and northeast concentrating rainfall over the sea area and caused no rain over Tamilnad which would then be completely invaded by Tropical Continental air from North India drawn in the circulation to the western side of the atmospheric field surrounding the depression or cyclone in the Bay of Bengal. However, as seen from Table 6, a number of depressions and cyclonic storms in this season do move west or west-northwest and strike the Coromandel coast causing widespread and locally heavy rain.

There have been quite a few years, and Blanford quotes 1876, the worst famine year, as one of such years, when well-marked depressions and cyclonic storms occurred in the south Bay of Bengal in October—December but the northeast monsoon rainfall over Tamilnad was deficient. Recent examples of this are the years 1923, 1926, 1927, 1938, 1942, 1945, 1947, 1948, 1949 and 1950. In these years the depressions or cyclonic storms did not cross the Coromandel coast and in the years 1923, 1926 and 1942 they did not come closer to the coast than longitude 84°E. In October 1949 a severe cyclone occurred in the Bay of Bengal and moving northwest struck the Circars coast at Masulipatam. This did not cause any rain over Tamilnad. In October 1950 also a cyclone which occurred in the southwest Bay of Bengal moved rapidly northwards and did not cause any rain over Tamilnad although it caused very heavy rain over Nellore and the neighbourhood.

It appears, therefore, necessary to modify Eliot and Blanford's conclusion and to state that while deficient northeast monsoon rains occur over Tamilnad when depressions and cyclonic storms occurring in the south Bay of Bengal move in some northerly direction and do not strike the Coromandel coast, copious northeast monsoon rains occur over Tamilnad when the depressions or cyclonic storms move westwards and strike the Coromandel coast. In most of the years when the northeast monsoon rainfall was above normal such depressions and cyclonic storms have struck the coast or come very near the coast. The uncertainty or variability in the northeast monsoon rainfall of Tamilnad is the reflection of the uncertainty or variability in the occurrence of depressions and cyclonic storms and what is more important, in their direction of movement.

The incidence of depressions and cyclonic storms in the different sections of the south Bay of Bengal and the percentage departures from normal of the Tamilnad northeast monsoon rainfall have been correlated and the correlation co-efficients are given below—

Correlation of the Northeast Monsoon Rainfall of Tamilnad with number of depressions in the south Bay of Bengal

	Correlation Co-efficient
(*i*) West of Longitude 92°E	0·23
(*ii*) West of Longitude 88°E	0·39
(*iii*) West of Longitude 84°E	0·42
(*iv*) West of Longitude 82°E	0·54
(*v*) Which crossed Coromandel coast	0·49
(*vi*) Which crossed coast and passed into the Arabian Sea	0·33

The values of the correlation co-efficients for different levels of significance as given by Fisher (1938) for $n = 43$ are 0·25 for $P = 0·1$, 0·29 for $P = 0·05$, 0·34 for $P = 0·02$ and 0·38 for $P = 0·01$. All the correlation co-efficients above are positive and further it is seen that all except the first are significant at the 5% level. This indicates clearly the dependence of the Tamilnad northeast monsoon rainfall with the occurrence of depressions and cyclonic storms in the south Bay of Bengal. The greater influence of storms which are nearer the coast is a point worth noting. The drop in the value of the correlation co-efficient in (*v*) and (*vi*) is due to the localisation as well as reduction in the rainfall after the depression or storm has crossed the coast.

7. Regression formula for foreshadowing Northeast Monsoon Rainfall

After examining correlation co-efficients between the northeast monsoon rainfall of southeast Madras and several likely factors, Doraiswamy Iyer (1941) evolved a regression formula for forecasting the rainfall from three factors, *viz.*,

(*i*) South American Pressure during June to August

(*ii*) Bangalore westerly upper winds between 3 and 5 km in September and

(*iii*) Agra westerly upper winds between 5 and 8 km in September,

with a multiple correlation co-efficient of 0·59.

This formula was later revised using data up to 1949 for the same three factors. The revised multiple correlation co-efficient was 0·61. To examine if the excesses and defects of actual rainfall are accounted for by this revised formula, the anomalies (*viz.*, actual *minus* calculated) of rainfall for this forecast formula have been calculated and plotted in Fig. 6 for the years 1915 to 1949. It is seen that the actual rainfall was much in excess of the calculated amount during the years 1920, 1922 and 1946, the years in which the rainfall of Tamilnad was in moderate or large excess and that the calculated values were over-estimations during the years 1926, 1927 and 1938, when the actual rainfall was much in defect of the normal. Thus, it appears that the contributions by the different factors used in the forecast formula do not satisfactorily account for the rainfall particularly during the years of extreme variation. This, as also the small value of the multiple correlation co-efficient, stresses the need for search for other causal factors.

8. Secular variation in rainfall

With a view to examine if the variability in the rainfall, which is particularly high, is only due to random variations from year to year or is due to any systematic changes, fifth degree polynomials of time have been fitted to the rainfall series.

$$r = A_1 f_0(t) + A_2 f_1(t) + A_3 f_2(t) + A_4 f_3(t) + A_5 f_4(t) + A_6 f_5(t)$$

where f_0, f_1, f_2 etc are orthogonal polynomials of time as evolved by Fisher and A_1, A_2, A_3 etc are regression co-efficients of the 0, 1, 2nd etc polynomial terms. The significance of the different regression co-efficients and of the polynomial as a whole were then tested to find out how far the changes indicated by the different degrees of the curve are really significant. For this purpose, the variance contributed by the different degrees of the curve as well as the variance accounted for the polynomial as a whole were compared with the "residual variance" and their significance tested by Fisher's *z–test*. Fisher and Yates (1943) Table XXIII has been utilised for this purpose.

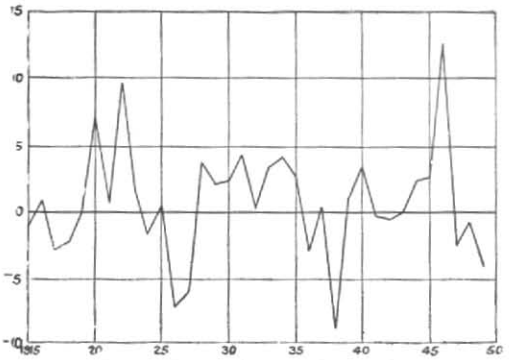

Fig. 5. " Anomalies " of rainfall for V. D. Iyer's formula for forecasting N. E. Monsoon Rainfall of S. E. Madras

As the series considered is a long one, to facilitate easier calculation, it has been divided into two consisting of the first and second series of 40 years and the polynomial co-efficients and the variances have been calculated in the usual manner for each of the two series and the significance tested as stated above, in the first instance. The statistics for the complete series of 80 years have been calculated by combining the above results by means of suitable combination formulae, which are given in Appendix I for use by interested readers.

The square roots of the variances contributed by the 1st, 2nd etc degrees of the curve, the fifth degree polynomial as a whole and the residual variance in the different series are given in Table 7. It is seen from Table 7 that there is practically no " Secular trend " that could be accounted for by fitting polynomials for time up to the fifth degree. However, a few of the co-efficients are significant or approaching significance even though collectively the polynomial is not so. For example, X_6 for North Arcot for the period 1870 to 1909 and X_6 for Coimbatore for the whole period are significant and a few of the co-efficients for Chingleput, North Arcot, Tanjore and Nilgiris though not significant are just approaching to be so. It may, therefore, be worthwhile to look into the cases of these districts a bit more closely.

Ten-year moving averages of the rainfalls have been calculated and shown in Fig. 2. These show the actual trend of variation of the 10-year averages and indicate a series of drier years between 1873 and 1879 in some of the districts and a series of wetter years between 1882 and 1887 and again between 1928 and 1935. It may be mentioned that the average rainfall during the years 1947 to 1950 has also been particularly poor in the coastal districts being about 13½ inches as against a normal of about 25 inches. However, only a few of the differences between the general mean and the 10-year moving averages were found to be significant at the 5% level as revealed by the *t-test*, *viz.*, those between 1884 and 1887 for Tanjore and between 1930 and 1934 for Tiruchirapalli. The average rainfalls and the standard deviations in the different districts as well as in the whole of Tamilnad during the three periods 1873 to 1879, 1882 to 1887 and 1928 to 1935 are given in Table 8. It is seen from this table that the rainfall of Chingleput, South Arcot and Nilgiris have been significantly lower during the period 1873 to 1879 and the rainfall of Chingleput and North Arcot have been significantly higher during the period 1882 to 1887 and that of Tiruchirapalli during 1928 to 1935. The years 1876—1878 was the period when the region and in fact the country as a whole was in the grip of a severe famine and the year 1884 was the year of high floods.

9. Inter-district Correlations

With a view to examine if the rainfalls in the districts are inter-related with each other and in order to group the districts, into coherent zones, if possible, correlation co-efficients between the series of rainfalls have been calculated and given in Table 9. It is interesting to note that all the correlation co-efficients are positive, indicating that the rainfall in the different districts generally vary in the same sense. The 5 per cent values of the correlation co-efficients for 78 degrees of freedom from Fisher's Table V-A is 0·22 and hence only correlation co-efficients higher than this can be taken to be significant according to that standard. It will be seen that, on this basis, all correlation co-efficients except that between Ramnad and Coimbatore are significant. According

TABLE 7

Secular changes in the Northeast Monsoon Rainfall in the districts of Tamilnad

District	Period	X_2	X_3	X_4	X_5	X_6	Polynomial	Residual error
Chingleput ..	I	3·387	—10·595	—10·559	— 2·473	—22·923	12·385	12.104
	II	—8·820	— 3·769	— 5·649	—16·507	—11·144	10·204	10·904
	III	7·852	—10·895	— 3·795	— 5·019	11·144	10·432	11·564
South Arcot ..	I	7·093	— 6·353	—11·707	1·078	—19·465	11·026	11·728
	II	—9·186	— 8·435	— 7·902	— 7·408	1·120	7·404	9·347
	III	7·967	—13·758	— 6·990	— 3·857	— 7·798	8·687	10·560
Tanjore ..	I	— ·693	—17·671	— 3 251	— 4·912	—17·170	11·315	9·885
	II	—8·172	—11·587	— 5·202	— 7·886	·610	7·624	8·823
	III	·984	—10·286	— 2·733	—17·459	17·521	12·050	9·861
Ramnad ..	I	2·870	—10·545	— 1·922	— 1·891	— 5·100	5·527	6·875
	II	— ·621	— 3·432	— 2·956	— 6·862	— 3·254	3·964	5·257
	III	6·837	— 4·858	1·892	— 8·449	— 8·034	6·478	5·947
Tirunelveli ..	I	3·578	—10·376	— ·956	— 5·455	— 1·766	4·999	8·042
	II	—5·560	— 1·475	1·320	— 8·142	— 5·212	5·065	7·210
	III	8·058	— 8·347	·706	— 6·103	8·832	7·077	7·413
Madurai ..	I	—1·144	— 3·600	1·800	— ·625	3·159	2·362	5·726
	II	— ·025	— 2·961	— 4·090	·064	— 2·999	2·626	4·877
	III	6·022	— ·380	— 2·790	— 6·154	3·589	4·358	5·128
Tiruchirapalli ..	I	—3·429	— 3·864	— 2·102	·354	— 5·627	3·513	5·230
	II	2·208	— 5·809	— 5·647	— 2·324	·960	3·922	5·238
	III	7·018	2·013	— 4·987	— 7·953	— 1·418	5·356	5·108
North Arcot ..	I	—5·013	— 7·561	— 5·916	— ·037	—17·427	9·175	7·060
	II	— ·453	·526	—10·261	1·443	— 1·827	4·716	5·994
	III	·515	1·881	— ·350	— 6·332	5·055	3·730	6·765
Salem ..	I	—1·827	— 4·677	·523	— ·949	— 4·307	2·998	4·582
	II	·576	3·254	— 4·390	— 1·007	— 1·780	2·622	4·725
	III	5·766	1·394	·925	— 3·018	3·184	3·326	4·574
Coimbatore ..	I	1·756	— 3·761	2·895	— ·683	— 5·508	3·359	4·357
	II	3·709	— 1·034	— 1·111	— 2·785	— 6·001	3·459	4·537
	III	5·853	·491	·569	— 5·712	—13·692	7·140	4·172
Nilgiris ..	I	—3·968	— 1·051	4·504	— 4·427	— 7·216	4·665	6·916
	II	1·173	3·235	·053	·934	— 5·153	2·802	5·798
	III	— ·399	3·906	1·283	— 1·202	10·699	5·157	6·135

I—1870-1909, II—1910-1949, III—1870-1949

to Walker's criteria, as extended by Savur and Gopala Rao (1932), for a set of 55 correlation co-efficients, the 5 per cent random value for the highest correlation co-efficient is 0·38 and on this basis, it is found that all except three correlation co-efficients are significant. Before placing any reliance on the correlation co-efficients, it is necessary to see whether traces of slow changes observed in the previous section have any part to play on these correlation co-efficients. The correlation co-efficients after removing the effect of the slow changes are given in Table 10. For n =73, the 5 per cent value of the correlation co-efficient from Table V-A of Fisher is 0·23 and on the basis of Walker's criteria, the 5 per cent random value for the highest correlation co-efficient is 0·37. It can be seen that the order of the correlation co-efficients in the Tables 9 and 10 are not

TABLE 8

Average rainfall and the standard deviations for three periods

District	1873 to 1879		1882 to 1887		1928 to 1938	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Chingleput	16·34	8·24	34·95	13·62	28·78	7·27
South Arcot	15·33	6·74	29·79	18·14	29·34	5·30
Tanjore	21·22	8·32	33·56	18·01	32·00	7·57
Ramnad	14·07	9·14	20·31	4·85	19·80	4·42
Tirunelveli	15·39	10·26	19·60	6·82	18·53	3·82
Madurai	14·34	9·26	16·24	6·55	18·01	4·10
Tiruchirapalli	12·45	5·57	17·07	6·14	19·84	3·96
North Arcot	10·01	4·17	21·29	9·50	17·88	5·59
Salem	9·27	4·42	14·13	4·33	14·21	9·49
Coimbatore	9·12	4·38	14·33	4·63	14·81	4·74
Nilgiris	9·16	6·24	22·54	6·84	21·24	6·22
Tamilnad	14·16	6·27	22·01	7·80	21·27	4·17

Note—Means which are significant from the general means for 5% level are underlined

TABLE 9

Inter-correlation between October to December rainfall in the eleven districts of Tamilnad

District	Chingleput	South Arcot	Tanjore	Ramnad	Tirunelveli	Madurai	Tiruchirapalli	North Arcot	Salem	Coimbatore
South Arcot	0·85									
Tanjore	0·71	0·86								
Ramnad	0·64	0·61	0·72							
Tirunelveli	0·53	0·66	0·83	0·79						
Madurai	0·78	0·57	0·57	0·74	0·66					
Tiruchirapalli	0·73	0·71	0·79	0·70	0·49	0·73				
North Arcot	0·85	0·77	0·62	0·55	0·36	0·53	0·74			
Salem	0·67	0·54	0·48	0·53	0·31	0·63	0·79	0·81		
Coimbatore	0·62	0·56	0·53	0·05	0·47	0·80	0·78	0·61	0·76	
Nilgiris	0·59	0·60	0·59	0·60	0·54	0·69	0·72	0·61	0·63	0·77

Note—C.C s. which are insignificant are underlined

TABLE 10

Inter-correlation between October to December rainfall in the eleven districts of Tamilnad after removal of secular changes

District	Chingleput	South Arcot	Tanjore	Ramnad	Tirunelveli	Madurai	Tiruchirapalli	North Arcot	Salem	Coimbatore
South Arcot	0·86									
Tanjore	0·72	0·91								
Ramnad	0·67	0·61	0·77							
Tirunelveli	0·51	0·67	0·83	0·83						
Madurai	0·79	0·59	0·56	0·76	0·65					
Tiruchirapalli	0·76	0·73	0·83	0·71	0·50	0·72				
North Arcot	0·86	0·80	0·62	0·57	0·36	0·53	0·75			
Salem	0·63	0·56	0·48	0·55	0·29	0·62	0·80	0·81		
Coimbatore	0·72	0·58	0·65	—0·05	0·55	0·89	0·82	0·69	0·84	
Nilgiris	0·61	0·65	0·60	0·68	0·55	0·71	0·77	0·61	0·64	0·93

Note—C. Cs. which are insignificant are underlined

different, indicating that the slow changes indicated by some of the districts have no significant effect on their inter-relation and that the relationships indicated by the correlation co-efficients arise out of variations in rainfall in the different years. It may be seen that the interior districts of North Arcot, Salem and Coimbatore form a group, whose rainfall is not related with that of the south coastal districts. Except for this deviation, the region forms a fairly homogeneous unit where the rhythm and incidence of the northeast monsoon rainfall in the different parts are generally maintained. Thus, the whole of Tamilnad can be considered to be a fairly coherent region.

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APPENDIX I

If a complete series of 2n terms is divided into two component series of n terms each, then the distribution constants and the variances contributed by the 1st, 2nd etc degrees of the curves for the complete series are expressible in an elegant form in terms of the distribution constants and variances of the component series. In the following, a, a' and A are the distribution constants in the first, second n terms and in the complete series of $2n$ terms (corresponding to a' etc in Fisher's notation) and x^2, x'^2 and X^2 are variances contributed by the different degrees of the curve in the first, second and complete series, then

$$A_1=2^{-1}(a_1+a'_1)$$

$$A_2=2^{-1}(2n+1)^{-1}\left\{(n+1)(a_2-a'_2)-n(a_1-a'_1)\right\}$$

$$A_3=-2^{-2}(2n+1)^{-1}\left\{(n+2)(a_3+a'_3)-3n(a_2-a'_2)\right\}$$

$$A_4=2^{-2}(2n+1)^{-1}\left\{(2n+3)^{-1}(n+2)(n+3)(a_4+a'_4)-5n(n+2)(a_3-a'_3)+3n^2(a_2+a'_2)+n(n-1)(a_1-a'_1)\right\}$$

$$A_5=2^{-3}(2n+1)^{-1}(2n+3)^{-1}\left\{(n+3)(n+4)(a_5+a'_5)-7n(n+3)(a_4-a'_4)+10n^2(a_3+a'_3)+2n(n-2)(a_2-a'_2)\right\}$$

$$A_6=2^{-3}(2n+1)^{-1}(2n+3)^{-1}(2n+5)^{-1}\left\{(n+3)(n+4)(n+5)(a_3+a'_6)-9n(n+3)(n+4)(a_5-a'_5)+21n^2(n+3)(a_4+a'_4)-5n(n^2+5)(a_3-a'_3)-6n^2(n-2)(a_2+a'_2)-2n(n-1)(n-2)(a_1-a'_1)\right\}$$

$$X_2=2^{-\frac{1}{2}}(4n^2-1)^{-\frac{1}{2}}\left\{(x_2+x'_2)(n^2-1)^{\frac{1}{2}}-(a_1-a'_1)(3n^3)^{\frac{1}{2}}\right\}$$

$$X_3=2^{-3/2}(4n^2-1)^{-\frac{1}{2}}\left\{(x_3+x'_3)(n^2-4)^{\frac{1}{2}}-(x_2-x'_2)(15n^2)^{\frac{1}{2}}\right\}$$

$$X_4=2^{-3/2}(4n^2-1)^{-\frac{1}{2}}(4n^2-9)^{-\frac{1}{2}}\left[(x_4+x'_4)(n^2-4)^{\frac{1}{2}}(n^2-9)^{\frac{1}{2}}-(x_3-x'_3)\left\{35n^2(n^2-4)\right\}^{\frac{1}{2}}+(x_2+x'_2)(21n^4)^{\frac{1}{2}}+(a_1-a'_1)\left\{7n^3(n^2-1)\right\}^{\frac{1}{2}}\right]$$

$$X_5=2^{-5/2}(4n^2-1)^{-\frac{1}{2}}(4n^2-9)^{-\frac{1}{2}}\left[(x_5+x'_5)(n^2-9)^{\frac{1}{2}}(n^2-16)^{\frac{1}{2}}-(x_4-x'_4)\left\{63n^2(n^2-9)\right\}^{\frac{1}{2}}+(x_3+x'_3)(180n^4)^{\frac{1}{2}}+(x_2-x'_2)\left\{12n^2(n^2-4)\right\}^{\frac{1}{2}}\right]$$

$$X_6=2^{-5/2}(4n^2-1)^{-\frac{1}{2}}(4n^2-9)^{-\frac{1}{2}}(4n^2-25)^{-\frac{1}{2}}\left[(x_6+x'_6)(n^2-9)^{\frac{1}{2}}(n^2-16)^{\frac{1}{2}}(n^2-25)^{\frac{1}{2}}-(x_5-x'_5)\left\{99n^2(n^2-9)(n^2-16)\right\}-(x_4+x'_4)\left\{693n^4(n^2-9)\right\}^{\frac{1}{2}}-(x_3-x'_3)\left\{55n^2(n^2+5)^2\right\}^{\frac{1}{2}}-(x_2+x'_2)\left\{132n^4(n^2-4)\right\}^{\frac{1}{2}}-(a_1-a'_1)\left\{44n^3(n^2-1)(n^2-4)\right\}^{\frac{1}{2}}\right]$$