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Climatic changes in India—(II) Temperature

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1. Introduction

In a previous paper (Pramanik and Jagannathan 1953), the authors have studied the rainfall trends at a number of places in India. In this note a similar study of temperature trends in India has been made.

Angstrom (1942) from a comparison of mean annual temperature for 1870-1900 and 1901-1930 found that there was an increase in temperature in northern and eastern Europe and a decrease over southwestern corner of Europe and northwestern Africa.

Willet (1950) considered mean temperature records of 50 years or more of 129 stations and of shorter records for 54 more stations over the world. He obtained temperature trend curves for the year as a whole as well as for the winter season by plotting pentad averages for each station and then obtained trend curves for each 10° square zones by averaging the values of each pentad over all the stations in the zone. He found an increasing tendency in temperature since about 1885. This trend is most pronounced in the higher and polar latitudes of the northern hemisphere decreasing southwards with latitude and apparently with no counterpart in the higher latitudes of the southern hemisphere. He also did not find any evidence that growth of population or industry was significantly reflected in the records of temperature used by him.

Leo Lysgaard (1949) compared the January and July 30-year averages of temperature, 1881 to 1910 and 1911 to 1940. He found that in January there was rise of temperature of 2° to 3°C in Greenland, North Asia and northern parts of America, but the increase became less further south and in East Asia and Australia, there was actually a decrease. In July he found an increase of over 1°C in higher northern latitudes, with a fall in Central Asia and the monsoon districts of South Asia. It may, however, be mentioned that the methods employed by him have been criticised by Dr. Bijl (1951) as being not very suitable and also as not having been applied properly.

Hasselberg and Birkland (1940) studied the climatic changes in Norway taking into account data of 60-70 years by means of 30-year moving means. They found that the mean annual temperature was on the average in the winter more by about 6°C, the mean being more in winter than in summer.

Vialar (1952) from a study of annual mean temperature at Paris Saint Maur, found that a rise in annual temperature began in 1888 of about 2°C per century and a rise of 5°·5 C has occurred in summer mean temperature since 1914. He was of the view that the existence of periodicities in temperature was not likely.

Eythorsson (1949) considered 30 years moving averages of temperature data from 1881 of some stations in Iceland and found that the mean temperature during 1914—1943 was about 1°C higher than that in 1881—1910.

It will be seen from the above that there is general agreement as regards the tendency for increase in mean temperature over the higher northern latitudes. So far as conditions in India are concerned apart from the very general remarks by Willet* and Lysgaard*

* Loc. Cit.

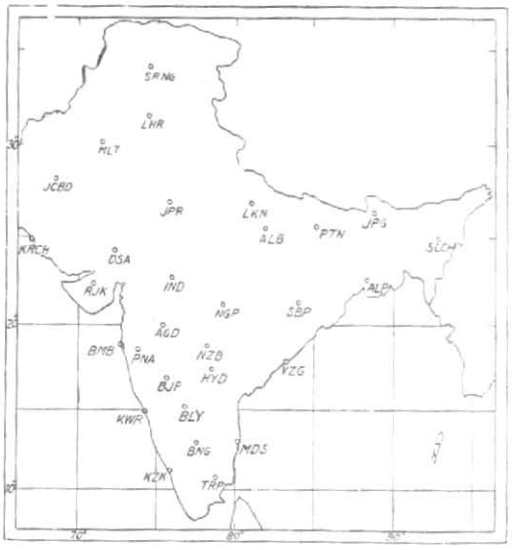

Fig. 1. Map of India and neighbourhood, showing the position of selected stations

some work has been done by Pramanik, Hariharan and Ghose (1952). They found from an examination of moving decade averages of maximum and minimum temperature data† for a number of stations in and around Rajasthan that during the last sixty to seventy years there has been no general tendency for accentuation or extension of desert conditions in and around Rajasthan.

The present authors (1952) on an examination of maximum and minimum temperatures data of stations in the Deccan Plateau for 60 to 75 years by fitting orthogonal polynomials found that there was no secular trend except a slight one in the case of a few stations, but further examination of 10-year moving averages confirmed a slight decreasing trend only in the case of maximum temperature at one station, *viz.*, Bellary in Rayalaseema, while at the other stations there was no appreciable trend either in maximum or minimum temperature.

2. Data

For the purpose of the present study, annual mean maximum and minimum temperature data of 30 meteorological observatory stations, distributed over India and Pakistan, for which long and continuous records are available, have been selected after scrutiny of the periodical Inspection Reports of Departmental Inspecting Officers and other records. In selecting the stations the following were also kept in view—

(1) the stations could be taken as representative of the different parts of the country ;

(2) the exposure of the thermometers have remained satisfactory throughout ;

(3) wherever there have been any change in the location or method of exposure of the thermometers, suitable corrections have been applied after necessary comparative observations.

The stations so selected are given below. They are also shown in Fig. 1.

Alipore	Jacobabad	Nagpur
Allahabad	Jaipur	Nizamabad
Aurangabad	Jalpaiguri	Patna
Bangalore	Karachi	Poona
Bellary	Karwar	Rajkot
Bijapur	Kozhikode	Sambalpur
Bombay	Lahore	Silchar
Deesa	Lucknow	Srinagar
Hyderabad (Dn)	Madras	Tiruchirapalli
Indore	Multan	Visakhapatnam

It may be mentioned that there was a change in the method of exposing the thermometers, when the India Meteorological Department decided to instal the thermometers in the standard Stevenson Screen instead of in the old type thatched "sheds". This change was introduced about the year 1926, but comparative observations of temperature readings in the "shed" and the "Screen" were made at least for two years at all the stations and corrections to be applied to the old set of readings were derived from the data of comparative observations. These corrections have been applied to the old data prior to the change for making them

† It should be mentioned that Pramanik, Hariharan and Ghose considered maximum and minimum temperatures separately whereas the other writers had considered only the mean temperature

comparable to the new series of data. The maximum and minimum thermometers have throughout been exposed at a height of 4 ft above ground, and as such the data refer to the temperature of the air in the shade at 4 ft above ground level. The thermometers in use have also been frequently compared with standard thermometers during inspections, and corrections obtained therefrom have been applied to the daily readings before entry in the records. The data of maximum and minimum temperatures can, therefore, be taken as reasonably accurate and homogeneous, and that any trends noticed in them are likely to be genuine and not due to changes in correction of instruments or changes in exposure and method of observation.

The stations, the periods of data, the mean daily maximum and minimum temperatures, their standard deviations and the co-efficients of variability are given in Table 1. It will be seen that the co-efficients of variability of mean daily maximum and minimum temperatures are very small being only about 1 to 2 per cent. It is, however, necessary to examine whether the variations in the mean maximum and minimum temperatures at the different stations, though small, are purely random in the sense that the series of observed values could have occurred due to random sampling from a homogeneous population. If the variations are not entirely random, they may be due to the existence of one or more of the following causes—

(*i*) long term trends,

(*ii*) short period oscillations (of more or less regularity) and

(*iii*) random or unsystematic components.

The deviation of the r^{th} term from the mean could then be expressed in the form :

$$U_r = T_r + C_r + E_r$$

where T_r is the contribution by the long term trend and C_r by the oscillatory term, and E_r is a purely random contribution for which no definite reasons could be attributed.

The series of maximum and minimum temperatures data at the 30 stations are examined in Section 3 to see if the fluctuations are purely random and, if not random, whether there are any short period cyclical tendencies and in Section 4 the series are examined for long-term trends.

3. Tests for Randomness

The mean daily maximum and minimum temperatures at the different stations have occurred in a particular order, and the values are bounded as they do not increase or decrease indefinitely. The question arises as to whether the variations have occurred at random or according to some cyclical effects.

If the n terms of a series are plotted against time and consecutive points joined by straight lines, the distribution of the ' peaks ' and ' troughs '* in the resulting curve gives an indication of any cyclical effects present in the series.

In a series of n randomly ordered terms, the expected number of turning points is $2(n-2)/3$. For sufficiently large n, the number of turning points may be taken as normally distributed about this mean value with a standard deviation of $\sqrt{(16n-29)/90}$. Any significant deviation from this can be considered as indicating the possibility of some cyclical effects. This can be used to test randomness in a series (Kendall 1946).

The actual number of turning points in the different series of maximum and minimum temperature data for the stations, the number expected on the assumption of randomness and their standard deviations are given in Table 2. It may be seen that the number of turning points in the case of Aurangabad, Bangalore, Karachi, Lucknow, Madras, Patna and Tiruchirapalli for maximum temperature, and in the case of Hyderabad (Deccan), Kozhikode, Nagpur, Nizamabad for minimum

* The 'peak' is a point where the value is higher than neighbouring values on either side of the curve and the curve on either side bends downwards and 'trough' is a point where the value is lower than the values on either side and the curve on either side turns upwards

TABLE 1

Mean maximum and minimum temperatures and their variations

Station	Data for period	Maximum temperature			Minimum temperature		
		Mean (°F)	Standard deviation (°F)	Co-efficient of variation (%)	Mean (°F)	Standard deviation (°F)	Co-efficient of variation (%)
Alipore	1881-1950 (70)	88·5	0·89	1·0	70·4	0·93	1·3
Allahabad	1876-1950 (75)	90·1	1·02	1·1	66·6	0·95	1·4
Aurangabad	1892-1951 (60)	90·5	1·07	1·2	66·7	0·84	1·3
Bangalore	1876-1950 (75)	83·8	1·02	1·2	64·1	1·08	1·7
Bellary	1876-1950 (75)	92·7	0·98	1·1	71·2	0·76	1·1
Bijapur	1892-1951 (60)	90·4	1·33	1·5	68·1	0·89	1·3
Bombay	1881-1950 (70)	86·9	0·74	0·9	73·9	0·79	1·1
Deesa	1880-1944 (65)	94·3	1·36	1·4	66·6	1·24	1·9
Hyderabad (Dn)	1876-1950 (75)	90·4	0·87	1·0	68·1	1·10	1·6
Indore	1881-1950 (70)	88·6	1·00	1·1	63·1	0·63	1·0
Jacobabad	1887-1946 (60)	95·6	1·45	1·5	67·1	0·95	1·4
Jaipur	1881-1950 (70)	89·8	1·16	1·3	64·3	1·07	1·7
Jalpaiguri	1891-1950 (60)	84·2	0·96	1·1	66·3	0·99	1·4
Karachi (Manora)	1882-1946 (65)	84·8	1·78	2·1	71·2	0·82	1·1
Karwar	1879-1938 (60)	86·4	0·60	0·7	72·6	0·67	0·9
Kozhikode	1892-1950 (60)	87·1	1·01	1·2	74·6	0·48	0·6
Lahore	1877-1946 (70)	88·6	1·28	1·4	61·8	1·02	1·7
Lucknow	1876-1950 (75)	89·9	1·10	1·2	66·1	0·85	1·3
Madras	1876-1950 (75)	92·1	0·78	0·8	74·5	0·73	1·0
Multan	1876-1946 (70)	90·1	1·58	1·7	64·9	1·25	1·9
Nagpur	1876-1950 (75)	92·1	1·08	1·2	68·5	0·86	1·3
Nizamabad	1892-1951 (60)	91·7	1·64	1·8	69·1	1·03	1·5
Patna	1876-1950 (75)	87·7	1·15	1·3	68·9	0·67	1·0
Poona	1881-1950 (70)	89·4	0·91	1·0	64·5	0·73	1·1
Rajkot	1891-1950 (60)	93·7	1·09	1·2	66·5	0·95	1·4
Sambalpur	1876-1950 (75)	90·7	1·00	1·1	69·6	0·91	1·3
Silchar	1876-1950 (75)	86·0	0·96	1·1	67·6	0·56	0·8
Srinagar	1892-1950 (59)	67·6	1·50	2·2	44·0	0·97	2·2
Tiruchirapalli	1876-1950 (75)	94·0	0·93	1·0	74·6	0·75	1·0
Visakhapatnam	1896-1950 (55)	87·0	0·88	1·0	75·5	0·68	0·9

TABLE 2

Turning points in the series

Station	Maximum temperature			Minimum temperature		
	No. of turning points		S.D.	No. of turning points		S.D.
	Actual	Estimated		Actual	Estimated	
Alipore	40	40·3	3·48	40	45·3	3·48
Allahabad	46	48·3	3·61	49	48·3	3·61
Aurangabad	29	38·7	3·22	37	38·7	3·22
Bangalore	36	48·7	3·61	44	48·7	3·61
Bellary	44	48·7	3·61	47	48·7	3·61
Bijapur	34	38·7	3·22	35	38·7	3·22
Bombay	40	45·3	3·48	42	45·3	3·48
Deesa	40	42·0	3·35	47	42·0	3·35
Hyderabad (Dn)	44	48·7	3·61	39	48·7	3·61
Indore	44	45·3	3·48	52	45·3	3·48
Jacobabad	36	38·7	3·22	41	38·7	3·22
Jaipur	42	45·3	3·48	41	45·3	3·48
Jalpaiguri	37	38·7	3·22	35	38·7	3·22
Karachi (Manora)	35	42·0	3·35	43	42·0	3·35
Karwar	35	38·7	3·22	38	38·7	3·22
Kozhikode	34	38·7	3·22	31	45·3	3·48
Lahore	41	45·3	3·48	48	48·7	3·61
Lucknow	38	48·7	3·61	41	48·7	3·61
Madras	38	48·7	3·61	42	48·7	3·61
Multan	47	45·3	3·48	46	45·3	3·48
Nagpur	44	48·7	3·61	40	48·7	3·61
Nizamabad	33	38·7	3·22	31	38·7	3·22
Patna	37	48·7	3·61	42	48·7	3·61
Poona	40	45·3	3·48	48	45·3	3·48
Rajkot	33	38·7	3·22	36	38·7	3·22
Sambalpur	44	48·7	3·61	45	48·7	3·61
Silchar	45	48·7	3·61	43	48·7	3·61
Srinagar	40	38·0	3·19	39	38·0	3·19
Tiruchirapalli	41	48·7	3·61	42	48·7	3·61
Visakhapatnam	34	35·3	3·06	31	35·0	3·06

temperature are significantly smaller than expected on the assumption of randomness the deviations being more than twice the standard deviations, indicating that the variations in the maximum and minimum temperatures at the above stations are not quite random but have a tendency to increase or decrease in the same way as in the previous years.

Further if d is the interval between the consecutive turning points, the distributions of the values of d in a series of n randomly ordered terms, has a probability density given by :

$$\frac{6(d^2+3d+1)(n-d-2)}{(6+3)\,!\,(2n-7)}$$

Wallis and Moore (1941) have derived a test for randomness based on the distribution of phase lengths, d. The χ^2 derived for the observed distribution of phase lengths $d=1$, $d=2$ and $d\geqslant 3$ in accordance with the above can be used to test the randomness by a comparison with the standard χ^2 tables. The probability for a value of χ^2 larger than the one calculated can be read off from the table of χ^2 against $2\frac{1}{2}$ degrees of freedom if the value of $\chi^2\geqslant 6\cdot 3$, and for values of $\chi^2<6\cdot 3$ against 2 degrees of freedom for 6/7th of the χ^2 calculated. The actual and expected frequencies of phase lengths, the χ^2 and the probability P are given in Table 3. It is seen that in the case of maximum temperature the values for Alipore, Aurangabad, Bangalore, Karachi, Madras, Nagpur and Patna are high bringing down the values of the probability (P) to less than $0\cdot 05$. This is due to preponderance of phase lengths of 3 years or more in the case of Aurangabad, Karachi and Patna, and 2 and 3 or more years in the case of Alipore, Bangalore, Madras and Nagpur. For minimum temperature, Alipore and Kozhikode showed high values of χ^2 and low probability due to preponderance of 2-year phase lengths at the expense of 1-year lengths, and Hyderabad, Nizamabad and Patna due to preponderance of 2 and 3 or more years phase lengths at the expense of 1-year lengths.

Thus in the case of maximum temperature at Alipore, Aurangabad, Bangalore, Karachi, Madras, Nagpur and Patna and minimum temperature at Alipore, Kozhikode, Hyderabad, Nizamabad and Patna, there is an indication of a cyclical tendency with a period of about 8—12 years. However, the determination of the exact period of oscillation, if any, requires further examination.

4. Long term trends

Polynomials upto the 5th degree have been fitted to the series of data of maximum and minimum temperature at the places with a view to examine whether the series showed any long term trends. In Tables 4(a) and 5 (a) are given the co-efficients of the different degree orthogonal polynomials and in Tables 4(b) and 5 (b) are given the square roots of variances accounted for by the different orthogonal polynomials and the 5th degree polynomial as a whole, and the residual errors.

5. Maximum temperature

From Tables 4(a) and 4(b) it will be seen that in the case of maximum temperature :

(*i*) Allahabad, Hyderabad, Lahore, Lucknow, Rajkot and Srinagar do not show any trend upto the 5th degree

(*ii*) Alipore, Bangalore, Bombay, Karwar, Kozhikode, Multan and Patna show increasing linear trend

(*iii*) Aurangabad, Bellary, Jacobabad, Madras, Tiruchirapalli and Visakhapatnam show decreasing linear trend

(*iv*) Some significant higher degree trends are also noticeable at some of the stations.

6. Minimum temperature

From Tables 5 (a) and 5(b) it will be seen that in the case of minimum temperature :

(*i*) Jalpaiguri, Nagpur and Visakhapatnam show no trend upto 5th degree

(*ii*) Sambalpur shows decreasing linear trend

TABLE 3

Frequency of phase lengths, χ^2 for randomness hypothesis

Maximum temperature

Station	$d=1$		$d=2$		$d \geqslant 3$		χ^2	P
	A	E	A	E	A	E		
Alipore	17	24·55	18	10·65	4	3·80	7·4049	**·0422**
Allahabad	27	24·54	10	12·29	8	8·17	0·6768	·7500
Aurangabad	14	17·65	7	7·63	7	2·72	7·5412	**·0401**
Bangalore	12	22·03	17	9·56	6	3·41	12·3238	**·0016**
Bellary	25	27·06	14	11·74	4	4·60	0·2702	·8745
Bijapur	18	20·81	13	8·99	2	3·20	2·6180	·2741
Bombay	22	24·55	10	10·65	7	3·80	2·9993	·2272
Deesa	20	24·57	16	10·64	3	3·79	3·7148	·1642
Hyderabad (Dn)	24	27·06	14	11·74	5	4·60	0·4158	·8129
Indore	26	27·08	12	11·74	5	4·18	0·2097	·9015
Jacobabad	22	22·07	11	9·54	3	3·39	0·6863	·7100
Jaipur	22	27·08	16	11·19	3	2·73	3·0473	·2213
Jalpaiguri	24	22·70	6	9·81	6	3·49	3·3593	·1899
Karachi (Manora)	21	20·81	5	8·99	8	3·20	9·9710	**·0121**
Karwar	19	21·44	10	9·27	5	3·29	1·2240	·5491
Kozhikode	18	20·78	10	9·00	5	3·22	1·4670	·4677
Lahore	19	25·19	16	10·92	5	3·89	4·2010	·1292
Lucknow	19	23·29	11	10·10	7	3·61	4·0538	·1398
Madras	14	23·29	18	10·10	5	3·61	10·4200	**·0097**
Multan	28	28·97	14	12·55	4	4·48	0·2513	·8829
Nagpur	17	27·06	24	11·74	2	4·60	17·6127	**<·0010**
Nizamabad	16	20·18	10	8·72	6	3·10	3·7667	·1607
Patna	17	22·66	7	9·83	12	3·51	22·7640	**<·0010**
Poona	22	24·54	11	10·65	6	3·81	1·5330	·4713
Rajkot	16	20·18	9	8·72	7	3·10	5·7811	**·0576**
Sambalpur	22	27·06	15	11·74	6	4·20	2·6228	·2735
Silchar	27	27·69	11	12·01	6	4·30	0·7741	·6820
Srinagar	25	24·59	10	10·63	4	3·78	0·0569	·9721
Tiruchirapalli	21	25·17	11	10·92	8	3·91	4·9698	**·0876**
Visakhapatnam	25	20·82	5	0·99	3	3·19	2·6214	·2737

TABLE 3 (*contd*)

Minimum temperature

Station	$d=1$		$d=2$		$d\geqslant 3$		χ^2	P
	A	E	A	E	A	E		
Alipore	15	24·56	20	10·64	4	3·80	11·9600	**·0118**
Allahabad	29	30·21	16	13·11	3	4·68	1·2885	·5890
Aurangabad	23	22·70	6	9·81	7	3·49	5·0141	·0853
Bangalore	19	27·06	19	11·74	5	4·60	6·5247	·0942
Bellary	25	28·95	18	12·56	3	4·49	3·3894	·1877
Bijapur	17	21·44	11	9·27	6	3·29	3·4745	·1816
Bombay	22	25·82	15	11·19	4	3·99	1·8623	·4068
Deesa	34	28·98	9	12·55	3	4·47	2·3470	·3120
Hyderabad (Dn)	17	23·92	15	10·38	6	3·70	11·4877	**·0077**
Indore	38	32·11	12	13·92	1	4·98	4·5160	·1064
Jacobabad	30	25·22	4	10·90	5	3·88	3·5971	·1727
Jaipur	24	25·19	12	10·92	4	3·89	·1659	·9208
Jalpaiguri	17	21·44	13	9·27	4	3·29	2·5737	·2796
Karachi (Manora)	27	26·46	11	11·45	4	4·09	·0307	·9851
Karwar	24	23·33	8	10·08	5	3·59	1·0022	·6535
Kozhikode	12	18·91	15	8·18	3	2·91	8·2139	**·0296**
Lahore	20	23·30	10	10·10	7	3·60	3·6883	·1661
Lucknow	18	25·17	15	10·90	7	3·93	4·9829	·0864
Madras	20	25·80	13	11·20	8	4·00	5·5932	·0643
Multan	23	28·34	13	12·28	4	4·38	·0780	·9620
Nagpur	20	24·56	12	10·64	7	3·80	3·7149	·1642
Nizamabad	10	18·92	14	8·18	6	2·90	11·6599	**·0072**
Patna	23	28·80	10	11·20	8	4·00	12·2967	**·0099**
Poona	35	29·58	8	12·83	4	4·59	2·8868	·2409
Rajkot	20	22·07	10	9·54	5	3·39	·9809	·6204
Sambalpur	25	27·69	13	12·01	6	4·30	1·0149	·6103
Silchar	22	26·43	13	11·47	7	4·10	2·9978	·2738
Srinagar	25	23·96	9	10·35	4	3·69	·2473	·8846
Tiruchirapalli	19	25·80	15	11·20	7	4·00	5·3315	·0738
Visakhapatnam	15	18·93	11	8·17	4	2·90	2·2134	·3381

TABLE 4(a)

Distribution Constants—Maximum temperature

Station	Mean °F A_0	A_1 ($10^{-2}\times$)	A_2 ($10^{-4}\times$)	A_3 ($10^{-5}\times$)	A_4 ($10^{-6}\times$)	A_5 ($10^{-7}\times$)
Alipore	88·5	**2·76**	**—6·98**	—1·25	—0·10	—0·53
Allahabad	90·1	0·69	—1·93	—1·37	0·36	—6·41
Aurangabad	90·5	**—1·96**	**11·63**	1·16	1·19	**2·81**
Bangalore	83·8	**1·35**	**—6·72**	**—3·64**	**1·59**	—0·11
Bellary	92·7	**—5·75**	**—37·25**	**—1·58**	**3·43**	**—1·27**
Bijapur	90·4	—0·18	—7·32	**15·25**	**—4·87**	5·52
Bombay	86·9	**2·34**	—2·62	0·38	0·66	—0·29
Deesa	94·3	0·40	**—21·93**	1·32	—2·63	2·85
Hyderabad (Dn)	90·0	—0·70	—0·66	—0·47	0·11	0·63
Indore	88·6	—0·13	**—11·38**	3·37	0·98	0·29
Jacobabad	95·6	**—3·38**	1·37	**10·68**	—1·71	—1·98
Jaipur	89·8	—0·83	—6·13	**4·71**	0·34	—0·64
Jalpaiguri	84·2	0·07	**—17·91**	**—5·72**	—0·75	—0·02
Karachi (Manora)	84·8	—0·12	—8·43	7·81	—0·59	—0·71
Karwar	86·4	**1·34**	1·42	—0·57	**—4·35**	—0·51
Kozhikode	87·0	**2·38**	7·29	—11·45	—2·21	3·56
Lahore	88·6	0·07	1·92	1·82	1·57	—0·93
Lucknow	89·9	0·67	2·83	—2·62	—0·03	—0·83
Madras	92·1	**—1·33**	**—5·16**	—1·63	**—1·26**	—0·44
Multan	90·1	**3·24**	3·84	9·07	—0·44	1·44
Nagpur	92·1	—0·40	2·67	0·96	—0·38	—1·03
Nizamabad	91·7	—0·90	**—20·09**	6·75	1·67	2·80
Patna	87·9	**1·03**	**—11·41**	**—2·67**	**—1·60**	—7·55
Poona	89·4	—0·89	—11·68	**82·98**	—1·54	0·15
Rajkot	92·6	—0·02	3·28	1·64	—3·07	0·02
Sambalpur	90·7	—0·57	4·09	0·16	—2·85	—0·45
Silchar	86·0	0·69	**—5·87**	**3·00**	**—1·75**	0·10
Srinagar	67·6	—0·72	—14·01	—6·85	—5·97	—1·46
Tiruchirapalli	94·0	**—2·15**	—7·49	0·44	1·01	0·06
Visakhapatnam	87·0	**—2·80**	**9·31**	—0·05	10·15	**—7·20**

TABLE 4(b)

Square roots of variances contributed by different degrees of polynomials—Maximum temperature

Station	1st degree X_2	2nd degree X_3	3rd degree X_4	4th degree X_5	5th degree X_6	Polynomial	Residual
Alipore	**4·60**	**1·88**	0·63	0·09	0·88	**2·34**	0·65
Allahabad	1·28	0·40	0·96	0·47	1·60	1·04	1·02
Aurangabad	**2·63**	**2·41**	0·87	0·56	**2·00**	1·85	0·97
Bangalore	**2·53**	**2·46**	**2·51**	**2·07**	0·26	**2·15**	0·88
Bellary	**5·38**	**3·40**	**0·68**	**4·46**	**3·09**	**3·75**	0·18
Bijapur	0·24	1·52	**4·74**	**2·32**	**4·00**	**3·02**	1·05
Bombay	**4·13**	0·80	0·19	0·61	0·48	**1·91**	0·54
Deesa	0·60	**5·56**	0·54	0·17	1·02	**2·54**	1·20
Hyderabad (Dn)	1·32	0·24	0·32	0·14	1·54	0·93	0·86
Indore	0·21	**3·47**	1·71	0·93	0·48	**1·80**	0·91
Jacobabad	**4·53**	0·28	**3·31**	0·81	1·42	**2·62**	1·28
Jaipur	1·40	1·87	**2·40**	0·32	1·48	1·58	1·12
Jalpaiguri	0·09	**3·72**	**1·77**	0·36	0·01	1·70	0·86
Karachi (Manora)	0·18	0·64	**3·26**	0·41	0·78	1·54	0·82
Karwar	**1·80**	0·29	0·17	**2·06**	0·36	**1·25**	0·50
Kozhikode	**3·18**	1·51	**2·79**	1·05	**2·55**	**2·36**	0·78
Lahore	0·13	0·58	0·93	1·50	1·56	1·09	1·30
Lucknow	1·25	1·03	1·80	0·11	2·01	1·41	1·07
Madras	**2·48**	**1·87**	**1·12**	**1·60**	1·07	**1·72**	0·66
Multan	**5·48**	1·17	**4·62**	0·42	2·40	3·43	1·33
Nagpur	0·75	0·97	0·66	0·49	**2·50**	1·30	1·05
Nizamabad	0·11	**4·17**	2·09	0·80	2·00	2·30	1·50
Patna	**1·92**	**4·14**	**3·52**	**2·08**	1·54	**2·50**	0·98
Poona	0·12	0·30	**3·52**	1·46	0·25	**1·72**	0·81
Rajkot	0·02	0·68	0·51	1·64	0·13	0·83	1·11
Sambalpur	1·06	1·49	0·11	**3·80**	1·10	**1·92**	0·90
Silchar	1·30	**2·13**	**2·07**	**2·40**	0·24	**1·80**	0·87
Srinagar	0·94	2·79	2·03	2·64	0·95	1·95	1·44
Tiruchirapalli	**4·03**	**2·74**	0·30	**1·62**	0·15	**2·30**	0·81
Visakhapatnam	**3·30**	**1·59**	0·16	**3·27**	**1·82**	**2·34**	0·54

TABLE 5(a)

Distribution Constants—Minimum temperature

Station	Mean °F A_0	A_1 ($10^{-2}\times$)	A_2 ($10^{-4}\times$)	A_3 ($10^{-5}\times$)	A_4 ($10^{-6}\times$)	A_5 ($10^{-7}\times$)
Alipore	70·4	3·75	3·98	—0·97	—0·81	0·08
Allahabad	66·6	2·20	6·63	1·81	0·58	7·09
Aurangabad	66·7	3·33	—4·95	—2·92	1·90	—0·01
Bangalore	64·1	**2·81**	4·45	0·98	0·14	—0·64
Bellary	71·2	**4·11**	—3·85	—0·97	0·02	—0·88
Bijapur	68·1	**1·41**	—3·36	—3·39	1·36	—0·31
Bombay	73·9	**2·20**	—1·93	0·38	—0·70	—0·21
Deesa	66·6	—1·26	—0·86	8·55	—2·97	0·65
Hyderabad (Dn)	68·4	**2·84**	**—9·18**	**3·17**	0·25	—0·50
Indore	63·1	0·98	—7·38	4·08	0·45	0·01
Jacobabad	67·1	2·31	—3·34	3·41	0·70	0·36
Jaipur	64·3	**0·23**	0·56	6·10	—1·65	**—1·61**
Jalpaiguri	66·3	0·69	—2·07	0·26	—1·93	0·33
Karachi (Manora)	71·2	2·79	—1·57	2·59	—0·13	0·26
Karwar	72·6	0·82	—5·96	—0·88	—1·75	—1·94
Kozhikode	74·6	0·53	—1·84	4·83	0·06	—1·43
Lahore	61·8	1·48	2·34	1·98	1·65	—1·51
Lucknow	66·1	2·33	0·18	—3·65	0·81	0·17
Madras	74·5	**2·35**	**3·01**	—0·34	0·42	**—0·49**
Multan	64·9	3·61	—11·04	1·84	1·96	—0·95
Nagpur	68·5	—0·38	—1·80	2·05	—0·46	—0·14
Nizamabad	69·1	**2·39**	5·68	—7·11	0·64	0·99
Patna	68·9	**1·72**	—2·56	0·69	—0·15	0·78
Poona	64·5	2·61	25·26	**40·24**	0·31	0·41
Rajkot	66·5	2·68	3·25	—3·48	—2·63	2·39
Sambalpur	69·6	—1·51	2·45	1·35	0·87	—0·56
Silchar	67·6	**0·84**	**4·66**	1·33	0·15	—0·07
Srinagar	44·0	**1·96**	**0·93**	—4·00	—0·12	—2·19
Tiruchirapalli	74·6	**2·37**	—0·02	0·20	—0·70	**—0·69**
Visakhapatnam	75·5	0·98	—6·49	—0·28	1·96	0·10

TABLE 5(b)

Square roots of variances contributed by different degrees of polynomials—Minimum temperature

Station	1st degree X_2	2nd degree X_3	3rd degree X_4	4th degree X_5	5th degree X_6	Polynomial	Residual
Alipore	**6·34**	**1·22**	0·49	0·75	0·13	**2·92**	0·52
Allahabad	**4·12**	**2·40**	1·03	**2·22**	1·30	**2·47**	0·73
Aurangabad	**4·46**	1·02	0·28	0·90	0·00	**2·09**	0·61
Bangalore	**5·23**	1·62	0·65	0·18	1·58	**2·57**	0·87
Bellary	**3·85**	0·03	0·41	0·02	**2·15**	**1·98**	0·58
Bijapur	**1·88**	0·69	1·05	0·65	0·22	1·06	0·93
Bombay	**3·71**	0·59	0·19	0·66	0·35	**1·72**	0·59
Deesa	1·89	0·22	**3·57**	2·03	0·73	2·05	1·14
Hyderabad (Dn)	**5·32**	**3·36**	**2·19**	0·31	1·21	3·03	0·81
Indore	**1·65**	**2·25**	**2·08**	0·43	0·01	**1·57**	0·48
Jacobabad	**3·09**	0·69	1·05	0·33	0·80	1·54	0·88
Jaipur	**3·83**	0·05	0·98	1·56	**2·70**	**2·25**	0·91
Jalpaiguri	1·18	0·43	0·08	0·92	0·23	0·70	0·92
Karachi (Manora)	**4·21**	0·39	1·08	0·08	0·16	**1·95**	0·60
Karwar	1·09	**1·23**	0·27	0·88	1·39	1·05	0·62
Kozhikode	0·72	0·38	**1·50**	0·28	1·02	0·90	0·43
Lahore	**2·50**	0·71	1·01	1·57	**2·53**	1·83	0·93
Lucknow	**4·36**	0·06	**2·53**	1·06	0·40	**2·31**	0·63
Madras	**4·56**	**1·13**	0·23	0·51	**1·20**	**2·18**	0·47
Multan	**6·10**	**3·38**	0·94	**1·87**	1·60	**3·30**	0·90
Nagpur	0·70	0·66	1·41	0·60	0·33	0·82	0·85
Nizamabad	**3·21**	1·18	**2·21**	0·30	0·71	**1·85**	0·92
Patna	**3·22**	0·93	0·47	0·19	0·16	**1·11**	0·50
Poona	0·38	0·64	**1·71**	0·30	0·69	0·90	0·72
Rajkot	**3·60**	0·67	1·08	1·25	**1·75**	**1·96**	0·79
Sambalpur	**2·83**	0·89	0·91	1·14	1·32	1·60	0·83
Silchar	**1·58**	**1·70**	0·91	0·19	0·16	**1·11**	0·50
Srinagar	**2·56**	**1·86**	1·19	0·05	1·42	1·41	0·91
Tiruchirapalli	**4·44**	0·01	0·13	0·90	**1·70**	**2·16**	0·51
Visakhapatnam	1·15	1·08	0·06	0·63	0·04	0·76	0·67

(*iii*) All other stations except the stations mentioned in (*i*) and (*ii*) above show increasing linear trend

(*iv*) Some higher degree trends are also noticeable at some of the stations.

When the co-efficients, say, of the 1st degree, 2nd degree etc, are plotted on a map, the manner in which the values even when they are not all statistically significant, change from station to station suggests that the occurrence of the different individual co-efficients are not entirely random but are to some extent dependent on their position on the map.

In Figs. 3 and 4 are plotted the co-efficient of the 1st degree orthogonal polynomial and lines demarcating different ranges of values, have been drawn. The stations on the west coast of India and the sub-Himalayan regions of north and northeast India have a tendency for increasing maximum temperature and those in the rest of the country extending in a northwesterly direction from north Madras coast to Baluchistan have a tendency for decreasing maximum temperature. In regard to minimum temperature, except for a small strip of the country extending from Orissa to the Vindhyas, the country has a tendency for increasing minimum temperature.

7. Moving averages

We will now examine by the method of moving averages whether the trends exhibited in the last section were due to any systematic increasing or decreasing tendencies or to some unusually higher or lower values at certain particular periods. 10-year moving averages, in respect of all the stations have been computed and plotted in Fig. 2. The 10-year moving average curves show apart from some oscillatory tendency the following main features:

Maximum temperature

Bangalore	Increasing from 1890 to 1925 and decreasing afterwards
Bellary	Decreasing tendency from 1912
Bombay	Slight tendency to increase up to 1920 and no tendency later
Jacobabad	High upto 1917—no general tendency
Jalpaiguri	Slight tendency to increase upto 1920 and decrease afterwards
Kozhikode	Slight increase after 1922 but no general tendency to increase or decrease
Madras	Slight tendency to decrease during last 25 years
Multan	Tendency to increase from 1922
Patna	Temperatures were rather low between 1905 and 1923. Otherwise there is no tendency
Sambalpur	Slight decreasing tendency up to 1915 and slight increasing tendency afterwards
Srinagar	Slight tendency to decrease during the last two decades
Visakhapatnam	Temperature high up to 1905. No general tendency.

At the other stations no tendency is noticeable.

Minimum temperature

Alipore	Slight increasing tendency
Bellary	Slight increase up to 1932, but no tendency later
Bangalore	Slight increasing tendency
Bombay	Very slight increase up to 1925, but no tendency later
Jaipur	Slight increasing tendency during last 20 years
Karachi	Slight tendency to increase
Kozhikode	Slight tendency to increase
Lucknow	Rather low up to 1915, but no tendency
Madras	Slight tendency to increase
Multan	Rather low up to 1895. No general tendency
Silchar	Slight tendency to increase during last 20 years
Srinagar	Slight tendency to increase during last 20 years

At the other stations no tendency is noticeable.

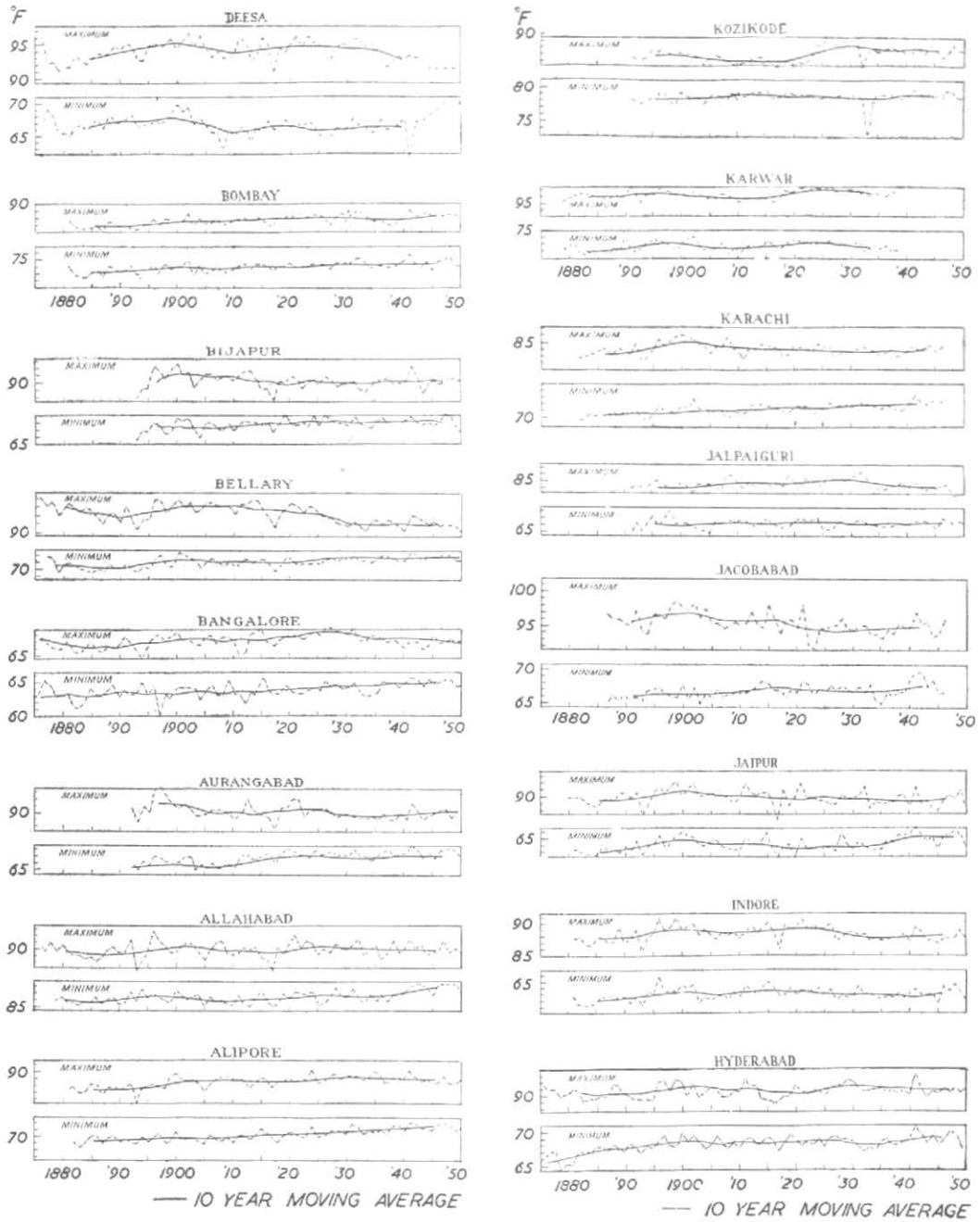

Fig. 2. Temperature in India

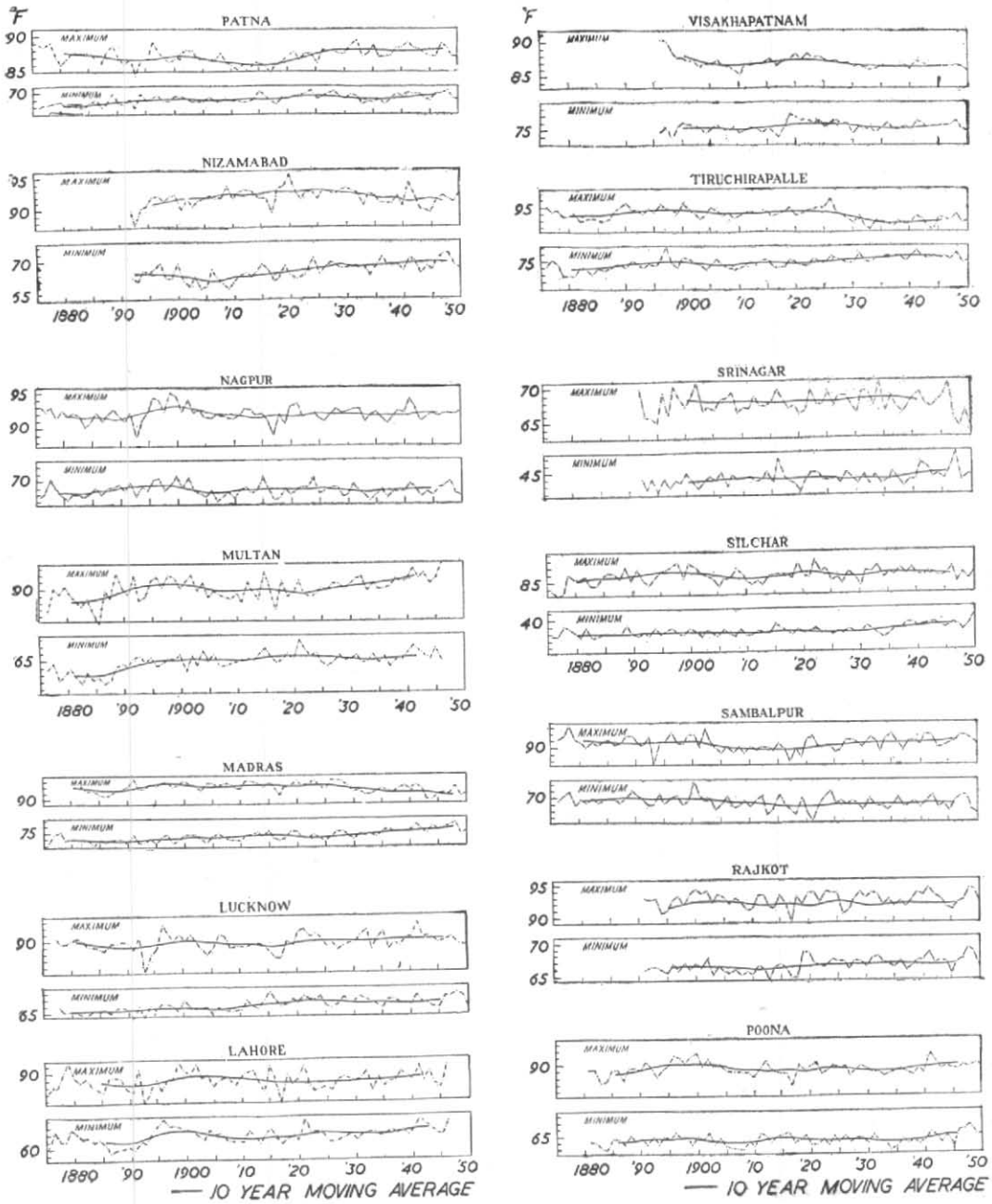

Fig. 2. Temperature in India

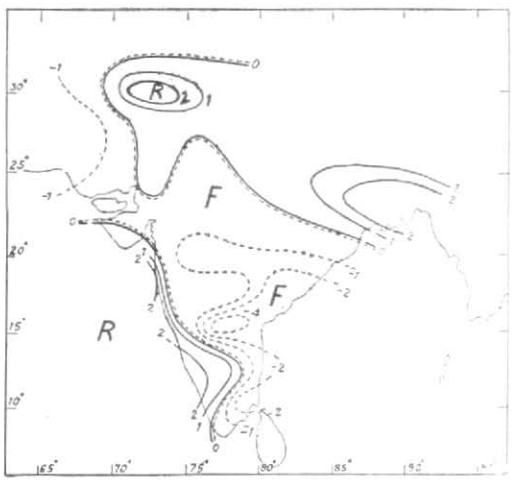

Fig. 3. Trend in Maximum temperature

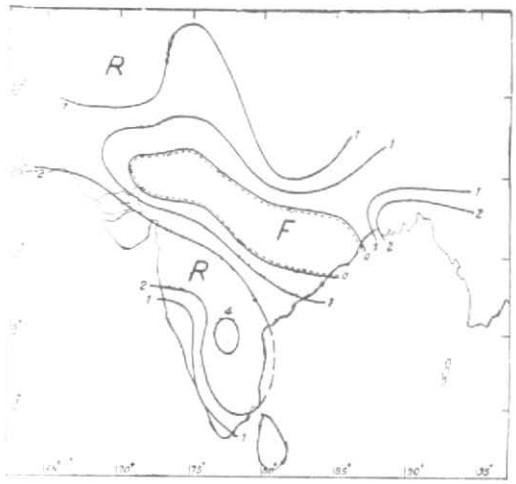

Fig. 4. Trend in Minimum temperature

In Tables 6 (a) and 6(b) are given the averages of maximum and minimum temperature in the different decades. These give an idea of the trend in the maximum and minimum temperature in the successive decades. The deviation of these decade averages from the general means have been tested by the usual t-test and the significant values of the decade averages have been indicated in thick types in the table.

Alipore — Maximum temperature was low in 1891—1900 and high during 1921—1930 and 1931—1940 ; minimum temperature was low in the 3 decades preceding 1910 and high in the last two decades

Allahabad — Maximum and minimum temperatures were low during 1881—1890 ; minimum temperature was high during the last 10 years

Aurangabad — Maximum temperature was low in 1931—1940 ; minimum temperature was low during 1901—1910 and high during the last 10 years

Bangalore — Maximum temperature was low in 1931—1940 ; minimum temperature was low during 1901—1910 and high during the last 10 years

Bellary — Maximum temperature was high during the first three decades of the present century and low during the last two decades ; minimum temperature was low during 1881—1890 and high during the last 2 decades

Bombay — Maximum temperature was low during the two decades preceding 1900 and high during 1921—1930 and 1941—1950 ; minimum temperature was low during 1881—1890 and high during the last two decades

Deesa — Maximum temperature was low in 1881 — 1890 ; minimum temperature was high in 1891—1900

Hyderabad — Maximum temperature was high in 1901—1910 and 1921—1930 ; minimum temperature was low in 1881—1890

Indore — Minimum temperature was low in 1881—1890 and high in 1911—1928

TABLE 6(a)

Decade averages of maximum temperature

Station	1881-1890	1891-1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950
Alipore	87·47	**87·88**	88·61	88·56	**89·10**	**89·20**	89·00
Allahabad	**89·47**	90·10	90·27	89·74	90·60	**90·31**	90·28
Aurangabad			90·33	90·39	90·47	**89·59**	90·39
Bangalore	**82·85**	83·62	83·97	83·81	**84·95**	83·93	83·69
Bellary	92·89	93·17	**93·79**	**93·54**	92·59	**91·20**	91·39
Bijapur			91·05	90·42	90·32	90·07	90·47
Bombay	**86·09**	**86·45**	86·80	87·06	**87·33**	87·13	**87·79**
Deesa	**93·43**	94·72	94·68	94·49	94·99	94·21	
Hyderabad (Dn)	90·14	90·65	**91·40**	90·29	**90·95**	90·51	90·18
Indore	87·96	88·98	88·82	89·15	89·18	88·08	88·33
Jacobabad		96·43	96·23	95·40	**94·73**	**94·67**	
Jaipur	89·54	90·26	90·25	89·79	89·81	89·51	89·50
Jalpaiguri		84·09	84·34	84·71	**85·10**	84·69	83·85
Karachi (Manora)		84·72	84·98	84·24	84·15	83·96	
Karwar	86·14	86·52	86·09	86·07	**87·20**		
Kozhikode		87·02	**86·33**	**84·87**	**87·91**	**87·67**	**87·66**
Lucknow	89·63	89·76	89·72	89·34	90·12	90·26	90·28
Lahore	88·31	88·36	88·89	88·48	88·20	88·57	
Madras	91·68	**92·58**	92·34	92·48	92·53	**91·60**	**91·09**
Multan	**88·78**	90·72	89·97	89·51	90·13	90·84	
Nagpur	91·73	92·65	92·18	91·66	92·14	91·84	92·09
Nizamabad			91·75	**92·64**	92·52	91·53	91·43
Patna	87·89	87·30	87·40	**86·26**	88·01	**88·51**	**88·49**
Poona	88·87	**90·37**	89·43	89·20	89·98	88·83	89·86
Rajkot		93·13	92·14	92·62	93·00	92·88	93·05
Sambalpur	91·04	91·06	90·20	**89·84**	90·54	90·90	91·11
Silchar	85·91	86·45	86·04	85·90	85·93	86·41	85·96
Srinagar			67·77	67·49	67·76	68·05	66·99
Tiruchirapalli	94·00	**94·87**	**94·78**	94·32	94·60	**92·85**	**93·15**
Visakhapatnam			86·66	87·03	87·22	86·31	86·57

TABLE 6(b)

Decade averages of minimum temperature

Station	1881-1890	1891-1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950
Alipore	**69·56**	**69·72**	**69·68**	70·27	70·70	**71·19**	**71·72**
Allahabad	**65·74**	66·68	66·09	66·19	66·79	67·95	**68·08**
Aurangabad			**65·63**	66·97	67·14	67·10	**67·39**
Bangalore	**63·19**	**63·46**	63·98	63·94	64·32	**64·81**	**65·34**
Bellary	**70·31**	70·91	71·23	71·25	71·28	**71·71**	**72·03**
Bijapur			67·62	68·18	68·30	68·27	68·30
Bombay	**73·07**	73·63	73·62	74·06	74·02	**74·46**	**74·60**
Deesa	66·74	**67·58**	66·56	66·26	66·13	66·64	
Hyderabad (Dn)	**67·19**	68·26	68·33	68·71	68·72	68·12	69·00
Indore	**62·24**	63·31	62·94	**63·70**	63·21	62·98	63·33
Jacobabad		66·83	66·60	67·37	67·50	66·95	
Jaipur	**63·30**	64·49	64·83	64·18	64·11	64·63	**65·37**
Jalpaiguri		66·25	66·25	66·44	66·54	66·49	66·66
Karachi (Manora)		70·90	71·15	71·52	71·55	**71·72**	
Karwar	**72·15**	72·75	72·55	72·70	72·98		
Kozhikode		**74·27**	74·40	**74·92**	74·62	74·56	**74·89**
Lahore	**60·80**	62·30	61·63	61·62	61·88	62·08	
Lucknow	**65·24**	65·68	**65·47**	66·35	**66·68**	66·38	66·74
Madras	**73·77**	**74·06**	74·28	74·80	74·50	**75·08**	**75·58**
Multan	**63·02**	65·16	65·01	65·53	**65·63**	65·24	
Nagpur	**68·28**	**69·25**	68·20	68·44	68·66	68·13	68·46
Nizamabad			**67·81**	68·91	69·28	69·53	69·84
Patna	**68·30**	68·80	68·77	68·83	**69·52**	68·91	**69·64**
Poona	64·40	64·72	64·10	64·83	64·38	**64·07**	**64·98**
Rajkot		66·29	**65·89**	66·38	60·86	66·33	67·42
Sambalpur	70·09	70·13	69·64	69·13	69·31	69·24	69·39
Silchar	67·38	67·50	67·29	67·52	67·32	67·67	**68·22**
Srinagar			43·75	43·95	44·06	43·77	**44·88**
Tiruchirapalli	**73·76**	74·62	74·33	74·54	73·30	**75·32**	75·43
Visakhapatnam			75·23	75·49	76·02	75·32	75·68

Jacobabad	Maximum temperature was low in 1921—1930 and 1931—1940
Jaipur	Minimum temperature was low in 1881—1890 and high in 1941—1950
Jalpaiguri	Maximum temperature was high in 1921—1930
Karachi	Minimum temperature was high in 1931—1940
Karwar	Maximum temperature was high in 1921—1930; minimum temperature was low in 1881—1890
Kozhikode	Maximum temperature was low in 1901—1910 and 1911—1920 and high in the last 3 decades; minimum temperature was low in 1891—1900 and high in 1911—1920 and 1941—1950
Lahore	Minimum temperature was low in 1881—1890
Lucknow	Minimum temperature was low in 1881—1890 and 1901—1910, and high in 1921—1930 and 1941—1950
Madras	Maximum temperature was high in 1891—1900 and low during last two decades; minimum temperature was low in the two decades preceding 1900 and high during the last two decades
Multan	Maximum temperature was low in 1881—1890, minimum temperature was low in 1881—1890 and high in 1921—1930
Nagpur	Minimum temperature was low in 1881—1890 and high in the next decade
Nizamabad	Maximum temperature was high in 1911—1920; minimum temperature was low in 1901—1910 and high in 1941—1950
Patna	Maximum temperature was low in 1911—1920 and high during last two decades; minimum temperature was low in 1881—1890 and high in 1921—1930 and 1941—1950
Poona	Maximum temperature was high in 1891—1900 and 1941—1950; minimum temperature was low in 1931—1940 and high in 1941—1950
Rajkot	Minimum temperature was low in 1901—1910 and high during last two decades
Sambalpur	Maximum temperature was low in 1911—1920
Silchar, Srinagar	Minimum temperature was high during last decade
Tiruchirapalli	Maximum temperature was high in 1891—1900 and 1921—1930 and low during last 2 decades; minimum temperature was low in 1881—1890 and high during last two decades

8. Conclusion

Thus from the above it would appear that there is no general tendency for a systematic increase or decrease in maximum and minimum temperatures at any of the places examined, but at some of the places there are variations of an oscillatory character with a period of 30—40 years.

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