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Cold Waves over northwest India and neighbourhood

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ABSTRACT. Based on 50 years (1915-16 to 1964-65) daily minimum temperature anomalies of meterological stations in Indo-Pakistan sub-continent north of 22½°N and west of 82½°E, a statistical study of duration, intensity and movement of cold waves in this region has been made. Duration of cold wave occasionally exceeds 10 days in Baluchistan, Kashmir and northwest Rajasthan whereas in east Uttar Pradesh, it lasts only for about 2–4 days. Maximum intensity of cold wave is also in Baluchistan, Kashmir and northwest Rajasthan. In the plains, Gujarat also experiences comparatively intense cold waves. The cold waves are comparatively mild in east Uttar Pradesh.

Probable duration of cold waves likely to be exceeded once in 5, 10, 25, 50 and 100 years has also been calculated and duration distribution charts prepared.

1. Introduction

During the winter season frequent spells of cold weather are experienced over the regions where cold northerly winds blow in the wake of western disturbances moving across the northern parts of Indo-Pakistan sub-continent. The cold spell with night temperature with departure $\leqslant -6°C$ from normal is known as cold wave. The cold wave is classified moderate if the night temperatures are 6 to 7°C below normal and severe if they depart by $\leqslant -8°C$ from normal. The above criteria have been maintained in this study.

On account of adverse effect of cold spells over the plant life and the discomfort to living beings, the study of their duration and intensity is of much importance. Their setting in over West Pakistan in the wake of western disturbances and then moving east to southeastwards has been of interest to synoptic meteorologists. Ramdas and Narasimhan (1937) and Barkat Ali and Naqvi (1931, 1941) studied the problem of prediction of minimum temperature over individual stations. Hariharan (1956) showed, that the progression of the cold wave in north India in the cases examined by him, was determined by the direction and speed of the wind at 3000 ft a.s.l. Rai Sircar and Datar (1963) also noticed cold wave movement in association with flow patterns at 0·6 and 0·9 km a.s.l. Raghavan (1967) discussed frequency, intensity, development and decay of severe cold waves over different sub-divisions in India.

Though on a few occasions these cold waves have penetrated quite deep in the Deccan Plateau in the south and moved eastward across the country upto Assam, they are much more frequent and severe in the northwestern parts of the country. The present study has, therefore, been confined to the region consisting of West Pakistan and northwest India, north of 22½°N and west 82½° E and is based on 50 years (1915-16 to 1964-65) minimum temperature data of the winter season (December to February) for the stations shown in Fig. 1. During the analysis of minimum temperature data, it has been noticed that on some occasions a small break of a day or two occurs in an otherwise prolonged cold wave. A break of one day in the cold spell, when such a spell prevailed for at least two days before or after the break, has been ignored and the spell presumed to have prevailed continuously. The longest spell of cold weather in the season has been classified as first cold wave and the next two cold spells in the order of their duration as the second and third cold waves.

2. Duration of cold waves

Table 1 gives the frequency distribution of duration of first three cold waves recorded during 50 winter seasons under study. Figures in brackets give the frequency distribution of the first three severe cold waves. Generally due to stagnation of cold air mass, cold waves over the hilly regions of Baluchistan and Kashmir have durations of 10–20 days in the season. Such long spells also occur over the northwest Rajasthan probably due to intense radiational cooling of the dry sandy soil during the nights. The duration of second cold wave generally does not exceed 10 days and that of the third is of less than 5 days in these areas. Over the rest of the region the duration of cold wave is comparatively very small. Except over and near the hills and in northwest Rajasthan the second and third severe cold waves generally do not occur.

Figs. 2 and 3 show the distribution of mean number of days per season with minimum temperature departure of $\leqslant -6°C$ from normal (cold wave) and of $\leqslant -8°C$ from normal (severe cold wave)

respectively. On the average about 8 to 10 days in the winter season record minimum temperature below normal by 6°C or more in Baluchistan and in east Kashmir. Over the plains, temperatures of such a subnormal order are recorded for 4 to 6 days per season over Rajasthan and southwest Uttar Pradesh. Over east and the plains of northwest Uttar Pradesh less than one day per season records minimum temperature 6°C below normal.

The average frequency of days with severe cold wave conditions is comparatively much smaller over whole of the area. Outside east Kashmir and Baluchistan less than 2 days per season experience severe cold wave conditions. Most parts of Uttar Pradesh record such subnormal temperatures only once in ten years.

3. Intensity of cold waves

Table 2 gives the frequency distribution of seasonal extremes of minimum temperature anomaly during the cold waves. Fig. 4 shows the distribution of mean of these lowest minimum temperature anomalies. Fig. 5 shows the distribution of lowest temperature anomalies ever recorded during the 50-year period under study. The examination of Table 2 and Figs. 4 and 5 shows that the maximum intensity of cold waves occur in Kashmir and Baluchistan and decreases progressively towards south and east. Intensity of cold waves, however, increases again in the south over Gujarat area. This is due to the fact that during a cold wave, even though the minimum temperatures over Gujarat are not lower than those over the areas north to it, they depart much more from the normal simply because normal temperatures over this area are quite high.

4. Movement of cold waves

To find the average direction and speed of cold wave movement, the dates of onset of 15 cold waves recorded during the period with a well defined movement over the region were noted for each station. The dates of onset of these cold waves over each station were ranked giving rank 1 to the date on which the cold wave first appeared over the region. These ranks were averaged for each station and the average isochrones so drawn show the average movement of cold wave (Fig. 6). The cold waves which first set in over Baluchistan move eastwards across West Pakistan and west Rajasthan by the third day. By this time the cold waves start affecting stations of the hills of west Uttar Pradesh and the cold air is brought down the slopes by katabatic action in the valleys of east Punjab and northern parts of west Uttar Pradesh after the lag of a day. By the fourth day, the cold waves approach east Uttar Pradesh. This average sequence of cold wave movement can be of much help in forecasting further progression of cold wave once it has appeared over Baluchistan.

5. Maximum probable duration of cold waves with different return periods

Besides the above statistics, an idea of maximum probable duration of cold wave with return periods of different durations can be of interest from point of view of assessing their probable effect on vegetation etc. The frequency distribution law of extreme values of meteorological elements as developed by Jenkinson (1955) has been utilised for calculating the probable duration of longest cold wave of the season with various return periods.

The theoretical consideration of the method are briefly as follows—

If $f(x) = e^{-y}$ is the average number of daily values greater that x and N, the total number of days during the period, then the probability P of all values in a year (here season) being less than x is

$$\{1 - f(x)/N\}^N \approx \exp[-f(x)] = \exp(-e^{-y}) \quad (1)$$

Hence the probability that an annual maximum value exceeds x is $[1 - \exp(-e^{-y})]$.

Assuming that the same value is exceeded once in T year, we get $1/T = 1 - \exp(-e^{-y})$

Hence we get—

$$y = -\log_e \log_e \frac{T}{T-1} \quad (2)$$

The general equation of (y, x) curve as suggested by Jenkinson is $x = a(1 - e^{-ky})$, where y is given by Eq. (2), and a is constant.

Then the annual maximum value likely to be exceeded once in T year is given by—

$$\frac{x - \xi_1}{\sigma_1} = \frac{k! - \{\log_e (T/T-1)\}^k}{\pm \{(2k)! - (k!)^2\}},$$

where the denominator has the sign of k and $\sigma_1/\sigma_2 = 2^k$ and ξ_1 and σ_1 are average and standard deviation of annual maxima respectively and σ_2 is the standard deviation of greater number in series of 2 annual maxima.

The values ξ_1, σ_1 and σ_1/σ_2 were worked out for all the stations for duration of first cold wave. From these the maximum duration of cold wave likely to be exceeded once in 5, 10, 25, 50 and 100 years were calculated for each station utilising the Table 4 of Jenkinson's paper (extending the table where found necessary). The values were plotted on the charts and isolines drawn at suitable intervals. Figs. 7 to 11 show the distribution of probable duration

of cold wave likely to be exceeded once in 5, 10, 25, 50 and 100 years. It may be seen that once in five years cold wave in Baluchistan, east Kashmir and northwest Rajasthan is likely to exceed 6–8 days duration, whereas in east Uttar Pradesh and parts of Pakistan there can be 5-year periods when no cold spell occurs. Similar patterns of probable duration of cold wave observed for 10, 25, 50 and 100 years return periods are given in Figs. 8–11. Once in 100 years cold wave may exceed 16–20 days in Baluchistan, east Kashmir and southwest Rajasthan whereas in east Uttar Pradesh this duration may be only 4–6 days.

The period of 50 years is too short for making return period study of second and third cold wave as well as of severe cold waves.

6. Conclusion

The above study shows that —

(1) The prolonged and severe cold waves prevail over Baluchistan, Kashmir and Rajasthan during the winter season. The intensity of cold wave, in east Uttar Pradesh is very mild.

(2) Severe cold spells generally do not recur during the winter season over the plains.

(3) The cold waves first set over Baluchistan and then move in east to southeast direction reaching east Uttar Pradesh by about the fourth day.

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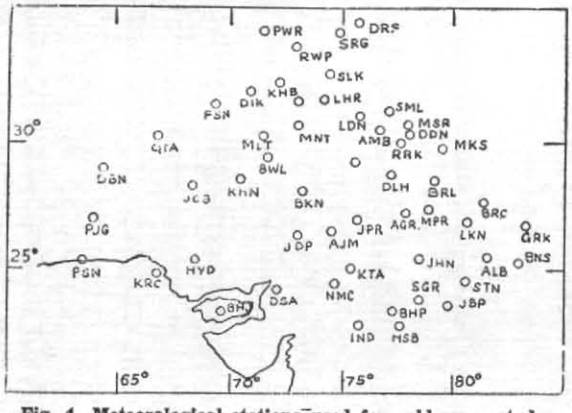

Fig. 1. Meteorological stations used for cold wave study

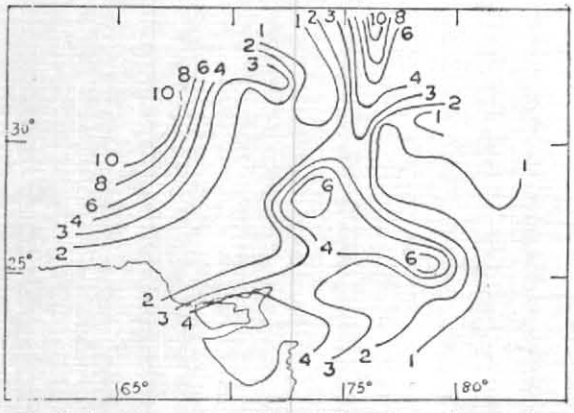

Fig. 2. Average number of days with minimum temperature departure ≤—6°C per winter season (Dec—Feb)

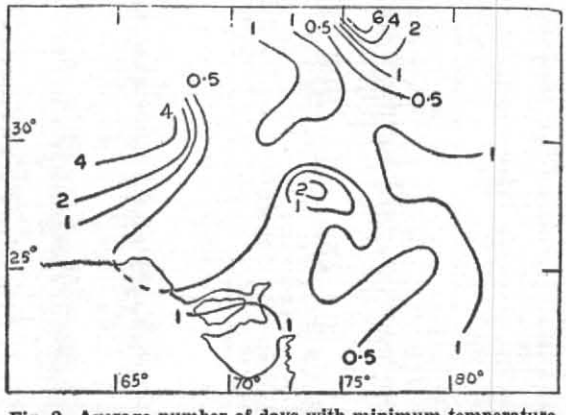

Fig. 3. Average number of days with minimum temperature departure ≤—8°C per winter season (Dec—Feb)

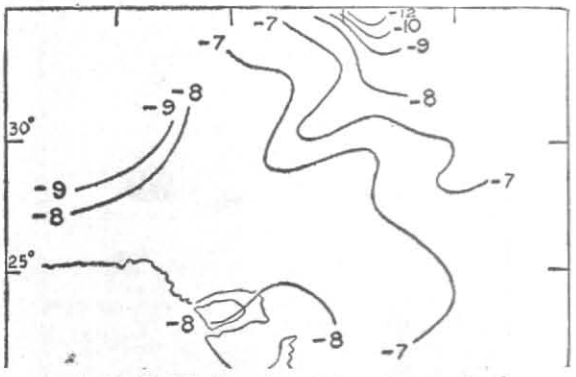

Fig. 4. Distribution of mean lowest anomaly of minimum temperature

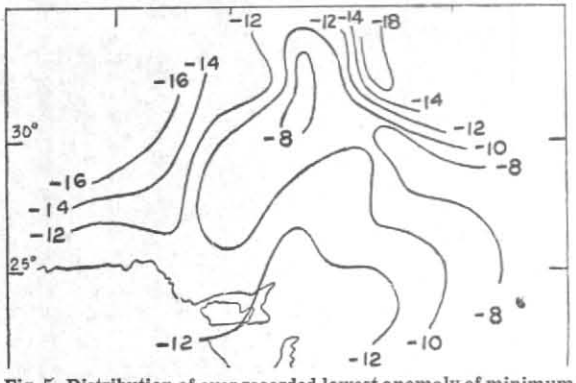

Fig. 5. Distribution of ever recorded lowest anomaly of minimum temperature during 50 years (1915-16 to 1964-65)

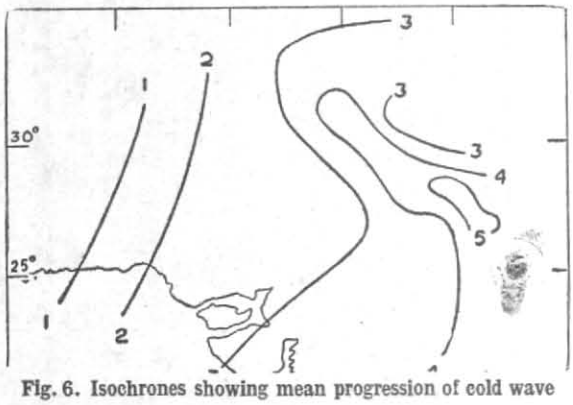

Fig. 6. Isochrones showing mean progression of cold wave

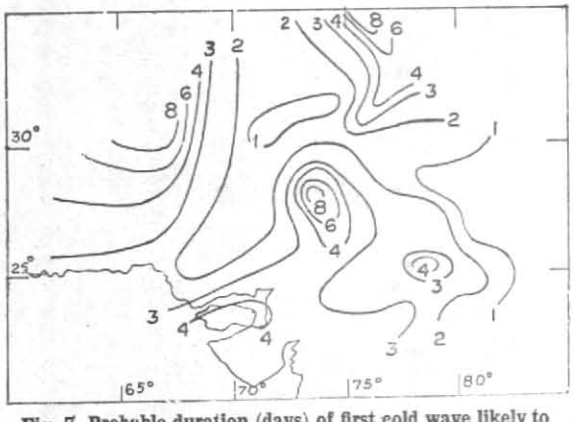

Fig. 7. Probable duration (days) of first cold wave likely to be exceeded once in a 5-year period

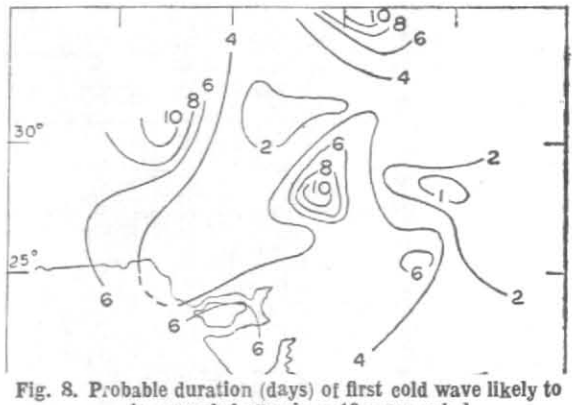

Fig. 8. Probable duration (days) of first cold wave likely to be exceeded once in a 10-year period

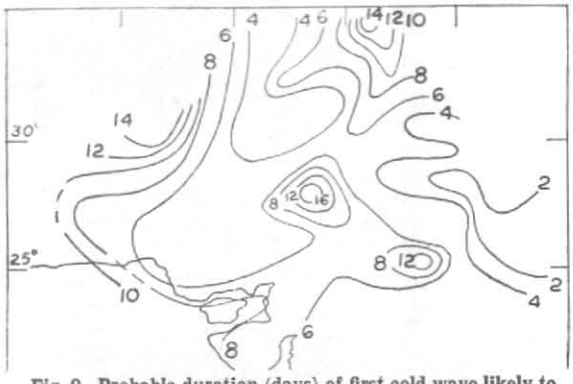

Fig. 9. Probable duration (days) of first cold wave likely to be exceeded once in a 25-year period

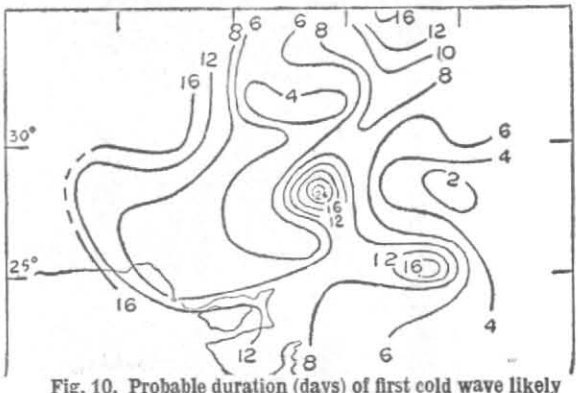

Fig. 10. Probable duration (days) of first cold wave likely to be exceeded in a 50-year period

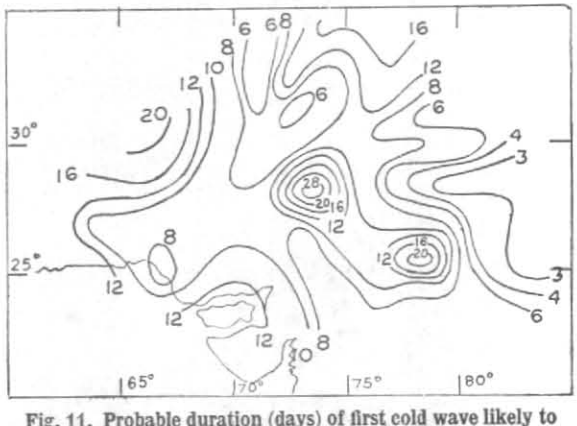

Fig. 11. Probable duration (days) of first cold wave likely to be exceeded once in a 100-year period

TABLE 1

Frequency distribution of first three cold waves recorded during 50 winter seasons (1915-16 to 1964-65)

(The figures in brackets refer to severe cold wave frequency)

Station	Cold wave	Duration of cold wave (days)										
		1	2	3	4	5	6	7	8	9	10	>10
Gorakhpur	I	8(1)	3	1								
	II	2										
	III	—										
Banaras	I	11	4									
	II	1										
	III	—										
Lucknow	I	6(2)	2	—	1							
	II	1										
	III	—										
Allahabad	I	8(1)	4	2	1							
	II	1	1									
	III	1										
Bahraich	I	9	2	3	—	2						
	II	2	1	—	1							
	III	2										
Jhanshi	I	11(5)	7(4)	4	4(2)	2	3(1)	6	2	—	1	1 (14 days)
	II	11(2)	3(1)	6	3	2	2	—	—	—	—	1 (12 days)
	III	4(1)	4	5	2							
Agra	I	8(3)	9(2)	4	2	1	2					
	II	6	3	—	1							
	III	—	1									
Mainpuri	I	11(4)	6(2)	5	—(1)	1	1	—	1			
	II	7	1(1)	—	—	—	1					
	III	1(1)	—	—	1							
Bareilly	I	9(2)	3(1)									
	II	—										
	III	—										
Roorkee	I	7(2)	3(1)	2	1	1	—	1	1			
	II	1	1	1	1							
	III	2										
Dehra Dun	I	9(4)	3	2	2	2						
(36 years data)	II	3	—	1								
	III	—	1									
New Delhi	I	5(2)	4(1)	2	2							
(44 years data)	II	1	1	1								
	III	1										
Hissar	I	8(4)	3(3)	2	6	2(1)	2	—	1			
	II	6(1)	3	2								
	III	1	1									
Ambala	I	9(3)	3	3	1	2						
	II	2	1									
	III	—										
Ludhiana	I	11(6)	4(1)	8(1)	5	1	3(1)	1	1		—	1 (11 days)
	II	4	7(1)	—	1	—	1	—	1			
	III	5	1	1								
Lahore	I	6(2)	1	1	1							
	II	—										
	III	—										
Sialkot	I	8(2)	3(1)	2	2	1	1	1	—	1		
	II	3	1	—	1							
	III	1										

TABLE 1 (*contd*)

Station	Cold wave	Duration of cold wave (days) 1	2	3	4	5	6	7	8	9	10	>10
Rawalpindi	I	7(2)	5	3	0	—	—	—	—	—	1	
	II	3										
	III	—										
Khushab	I	10(5)	5(1)	5(3)	2	1	1	2	1	1	2	
(49 years data)	II	8(2)	3(1)	2	3	—	1					
	III	2	2									
Lyallpur	I	2	1	1	1							
(45 years data)	II	—										
	III	—										
Montgomery	I	9(3)	7(1)	2	3	1	1					
	II	3(1)	3	—	1							
	III	2										
Multan	I	11(3)	2	1	3	—	1	—	—	—	1	
	II	3										
	III	—										
Bahawalpur	I	9(3)	—(2)	1	—	1	1	1				
(30 years data)	II	1	2									
	III	2										
Khanpur	I	8(9)	6(1)	1	2	1	1	—	1			
	II	5	1	1	—	—	1					
	III	3										
Srinagar	I	7(7)	3(2)	—(1)	2(2)	1(1)	3	1	1	—	—	1 (11 days)
(45 years data)	II	5	1	2	—	—	1					
	III	2	1									
Dras	I	4(4)	3(4)	1(9)	3(1)	5(4)	3(2)	4(2)	4(3)	2(2)	3	*
(45 years data)	II	2(4)	3(7)	6(3)	5(3)	2(5)	3(1)	4(1)	2	1	—	†
	III	4(9)	4(5)	4(3)	4(1)	1	1(2)	1				
Leh	I	7(7)	5	3(1)	—(1)	3	2	2(1)	1(1)	1	—	**
(44 years data)	II	7(1)	1(1)	1	2	2(1)	2(1)	2(1)	1			
	III	1(1)	2(1)	2	1	1	1					
Peshawar	I	10(3)	2	2	2	—	2					
	II	3	1									
	III	1										
Dera I. Khan	I	8(4)	2(1)	3	2(1)	1						
	II	5	1	1								
	III	—	1									
Fort Sandeman	I	6(6)	5(1)	3	3(1)	1	1	1	3			
	II	5(1)	2	1	—	1						
	III	2	1									
Quetta	I	5(4)	5(8)	3(5)	3(3)	5(3)	2	2(1)	5(2)	1(1)	2	††
(42 years data)	II	6(12)	6(4)	5(1)	8	2	1(1)	1	—	1		
	III	7(3)	8(1)	3	2	—	1					
Dalbandin	I	7(8)	9(7)	3(1)	7(3)	4(2)	1(2)	1	2	2(1)	2	1(1)
	II	9(5)	7(1)	3(1)	2(1)	1(1)	2					(11 days)
	III	9(3)	3	1(1)	—	1						
Panjgur	I	7(8)	5(3)	2(2)	4(1)	7	—	1(1)	2	1		
	II	8(4)	3(1)	4	1							
	III	4(1)	3									

*1(11 days), 1(12 days), 1(13 days) —(1) (15 days) and 1 (18 days)

**1(1)(11 days), 1(19 days)

†—(1)(12 days), 1(15 days)

†† 1(12 days), 3(1) (13 days), 1(15 days), 1 (16 days)

TABLE 1 *(contd)*

Station	Cold wave	Duration of cold wave (days)										
		1	2	3	4	5	6	7	8	9	10	>10
Pasni	I	10(6)	4(1)	(1)	—	1						
	II	2	—	(1)	—	—						
	III	—										
Jacobabad	I	14(6)	8(4)	1	3	1	1	—	—	—	—	1 (12 days)
	II	3(1)	2	1	2							
	III	—	—	1								
Hyderabad	I	11(6)	3	1(1)	4	4						
	II	5	1	1								
	III	1	1									
Karachi	I	12(6)	5(1)	3(1)	4(1)	2	1					
	II	6	1									
	III	1										
Bikaner	I	10(2)	3(6)	4(2)	8(2)	3(2)	2	5	—	1	1	*
	II	14(4)	1(1)	2	3(1)	3(1)	1	—	—	—	1	1 (19 days)
	III	5	2(1)	1(1)	3	—	—	—	—	1		
Jodhpur	I	16(10)	8(5)	4(3)	6(1)	4						
	II	10(1)	4	1								
	III	1	1									
Jaipur	I	10(5)	10(5)	5(1)	4(3)	5(1)	2	—	1	1		
	II	13(3)	4	3(1)	2							
	III	4	3(1)									
Ajmer	I	13(8)	7(4)	8(1)	3	6	1	1	—	1	1	
	II	7(1)	10	3	1	1						
	III	5	3	—	1							
Kotah	I	11(6)	6(3)	3(2)	1	2	1	1	1	—	—	1 (11 days)
	II	6	1(1)	—	2							
	III	—	2									
Deesa	I	8(5)	5(3)	2(1)	6(1)	3	1	1	—	1	—	1 (12 days)
	II	7(2)	3(1)	1	2	1	—	—	—	1		
	III	3	2	1								
Bhuj	I	14(7)	5(9)	4(4)	4(2)	2	2	9	2	1		
	II	8(5)	5	5	5	1	4					
	III	5	8	2	—	3						
Neemuch	I	19(9)	7(2)	2(1)	4	—	3					
	II	6(1)	1	2								
	III	1										
Indore	I	11(12)	9(4)	7	5	2(1)	2					
	II	5(1)	8	1	—	1						
	III	5	—	—	1							
Bhopal (35 years data)	I	6(2)	11(4)	1(1)	5(1)	1	2					
	II	6	1	2								
	III	—	1									
Sutna	I	17(5)	9(2)	3(1)	4	3	—	1				
	II	6	2	2	2							
	III	2	1	1								
Hoshangabad	I	13(4)	9(1)	5	3	1						
	II	4	2	1								
	III	1										
Saugor	I	5(5)	9(2)	4(1)	4	—	—	—	—	—	1	
	II	7(1)	2	—	—	—	1					
	III	1	—	1								
Jabalpur	I	10(6)	6(1)	4(1)	1	1	—	1	—	—	1	
	II	3(1)	—	1	1							
	III	1	1									
Simla	I	18(7)	10(5)	2	1	1	—	1	—	—	—	1 (11 days)
	II	9(2)	—	1								
	III	1										
Mukteshwar	I	13(6)	4	3	2	1	—	—	—	1		
	II	3	1	1								
	III	—	1									
Mussoorie	I	7(5)	7	2(1)	2							
	II	6	1									
	III	1										

* 1 (12 days), (1) (17 days), 1 (21 days)

TABLE 2

Frequency distribution of lowest negative anomalies of minimum temperature recorded during cold wave condition in 50 winter seasons

Station	No. of seasons without cold wave	—6°	—7°	—8°	—9°	—10°	—11°	—12°	—13°	—14°	—15°	<—15°C
Gorakhpur	32	7	4	1								
Banaras	35	10	5									
Allahabad	40	7	2	0	1							
Lucknow	41	5	2	1	1							
Bahraich	33	10	7									
Jhansi	9	16	13	7	3	2						
Agra	14	12	9	4	1							
Mainpuri	25	16	4	3	2							
Bareilly	38	5	4	1	0	1	0	1				
Roorkee	33	8	7	1	1							
DehraDun	18	7	7	4								
New Delhi	31	7	4	1	1							
Hissar	25	8	7	5	2	2	0	1				
Ambala	32	13	2	3								
Ludhiana	15	14	12	6	3							
Lahore	40	4	3	2	0	1						
Sialkot	31	8	8	2	1							
Rawalpindi	34	10	4	2								
Khushab	26	11	5	3	2	0	2					
Lyalpur	36	4	3	1	0	1						
Montgomery	35	12	9	4								
Multan	31	8	8	2	1							
Bahawalpur	17	8	0	4	1							
Khanpur	30	7	3	7	3							
Srinagar	25	4	4	8	1	3						
Dras	9	3	1	4	1	5	2	6	6	4	2	2 (—18° C)
Leh	18	6	5	3	2	1	2	4	1	2		
Peshawar	32	10	5	1	1	0	1					
Dera I. Khan	32	8	5	3	1	0	0	1				
Fort Sandeman	38	8	5	7	0	1	0	1				
Quetta	12	3	6	7	6	7	4	0	3	1	1	
Dalbandin	11	7	7	7	5	2	5	0	3	1	2	
Panjgur	20	5	11	7	3	2	1	1				
Pasni	34	5	2	2	6	1						
Jacobabad	21	10	9	5	3	2						
Hyderabad	27	7	9	3	2	1	1					
Karachi	22	14	3	7	2	2						
Bikaner	11	10	12	5	3	7	2					
Jodhpur	12	9	10	7	6	3	3					
Jaipur	14	6	14	9	5	3						
Ajmer	13	9	15	8	2	3						
Kotah	22	4	13	7	2	1	0	1				
Deesa	22	8	8	3	2	3	3	1				
Bhuj	7	8	12	9	6	6	2					
Neemuch	16	15	7	7	2	3						
Indore	5	14	9	11	6	1	3	1				
Bhopal	24	9	9	2	4	1	1					
Sutna	16	17	11	5	1							
Hoshangabad	19	11	14	3	1	1	1					
Saugor	27	8	7	3	2	3						
Jabalpur	29	5	9	9								
Simla	14	17	6	3	3	2	0	2	1	0	1	1(—16°C)
Mukteshwar	26	11	7	3	2	1						
Mussoorie	17	8	4	4	1	0	0	1				