

Cold Wave/Severe Cold Wave Events during Post-Monsoon and Winter Season over Some Stations of Eastern Uttar Pradesh, India

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Abstract: A cold wave is a weather phenomenon that is distinguished by marked cooling of the air, or with the invasion of very cold air, over a large area. In the present study, cold and severe cold wave frequencies have been studied for the post-monsoon and winter season over some stations of eastern Uttar Pradesh for the period 1971-2010 and also for the four decades. The highest number of cold wave days are found in Kheri during recent decade during October. During post-monsoon season, Varanasi experienced a significant number of cold wave days during all the four decades. The significant severe cold wave days were found in recent two decades for each month and season over Kheri.

Keywords: Extreme events; Cold wave; Severe cold wave; Decades.

Introduction

The cold wave is defined in the occurrence of extremely low temperature in association with the incursion of dry cold winds from the north into the sub-continent (De et al., 2005). The northern parts of India, specially the hilly regions and the adjoining plains, are influenced by transient disturbances in the mid-latitude westerlies which often have weak frontal characteristics. These are known as western disturbances.

Jagannathan and Parathasarathy (1973) analysed the time series of mean annual temperature over a set of eight Indian stations. Pramanik and Jagannathan (1954) studied about secular trends in the annual mean maximum and minimum temperature over India and concluded that there is no general tendency for an increase or decrease in this temperature. The study by

Srivastava et al. (1992) gave the first indications that the diurnal asymmetry of temperature trends over India is quite different from that observed over many other parts of the globe. Karl and Easterling (1999) studied negative effects of weather and climate extremes on society and found it can harm ecosystem in many obvious ways (e.g. floods, droughts, extreme cold and heat etc.) resulting into large losses of human life, agriculture, engineering structure such as dams and exponentially increasing costs associated with them. Mason et al. (1999) studied the theoretical, modelling and empirical analysis and suggested the remarkable changes in the frequency and intensity of extreme events, including floods, may occur when there are only small changes in climate. Arora et al. (2005) studied the trends in temperature time series of 125 stations distributed over the entire India. Easterling et al. (2000) study the impact

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on human society and the natural environment due to changes in frequency and intensity of extreme weather and climate. Bhatla and Tripathi (2014) studied the extreme temperature and rainfall events over Varanasi using 30 years daily surface data of temperature and rainfall from 1981 to 2010 (June to September).

Raghavan (1966 and 1967), Rai Sircar and Datar (1963), Natarajan (1964), Bedi and Parthasarthy (1967), Bedekar et al. (1974) and Subbaramayya and Surya Rao (1976) studied the heat and cold waves over India. De et al. (2005) studied extreme weather events that occurred in India during the 1991-2004. De and Sinha Ray (2000) showed the impact of extreme events in the cold weather season during 1978-1999. They reported the number of deaths from extreme events in the cold weather season were 957 and 2307 during 1978-1999 over the state of Uttar Pradesh and Bihar respectively. It is due to poor level of development and lack of shelters for the outdoor workers and farmers. Raghavan (1967) showed that during the period 1911-1961 most severe cold wave events occur in Dras in March 1911. West Madhya Pradesh experienced most frequent cold wave/severe cold wave and highest number of cold wave/severe cold wave days during the decade 1971-80 (Pai et al., 2004). Rupa Kumar et al. (2002) reported rising of minimum temperature during winter season in India. According to Vinnikov et al. (1990) and Thapliyal and Kulshrestha (1991), air temperature plays an important role and is recognized as the state of climate. It has the ability to prevent the energy exchange process over the surface of the earth with reasonable accuracy. Vyver (2012) used a variety of efficient trend estimation methods to estimate regional changing process of temperature extremes. He also examined temporal patterns of climate stations located in Belgium and their associations with the changes of climate means during the period of 1952-1953.

In the present study, the frequency of cold wave/severe cold wave days has been analysed for the post-monsoon and winter season and their each month from October to February over Allahabad, Varanasi, Gorakhpur, Lucknow, Baharaich and Khiri of Eastern Uttar Pradesh, India during 1971-2010 and also for the four decades.

Data and Methodology

The daily mean minimum temperature data used over Allahabad, Varanasi, Gorakhpur, Lucknow, Baharaich, Khiri and Eastern U.P. during the post-monsoon season (October to December), winter season (January

to February) and their each month from October to February was provided by India Meteorological Department (IMD) for the period 1971-2010. Frequency of cold and severe cold wave days has been calculated as per IMD criteria (<http://www.imd.gov.in/doc/termglossary.pdf>) for 1971-2010 and its four decades viz. 1971-1980, 1981-1990, 1991-2000 and 2001-2010 denoted as D1, D2, D3 and D4 respectively and also for the whole period 1971-2010. It may be noted that some stations have no record for some days for which it is considered while calculation.

Results and Analysis

Variation of Cold Wave Events during October-December and Post-monsoon Season

Figure 1 shows the variation of cold wave events for the four different decades during the month of October. It shows that Allahabad, Varanasi and Lucknow follow the same pattern during first two decades namely D1 and D2 in which cold wave events have increased and then further have decreased in last two decades (D3 and D4). It also shows that Varanasi experienced highest cold wave events (18) during D2, which decreases to 12 in D3 and also is the highest one in this decade among all six stations. Gorakhpur shows a gradual decrease of cold wave events from first to last decade. While, in Bahraich continuous increasing pattern of cold wave events have been noted except last decade D4. In Kheri, an abrupt increase in a number of cold wave events is observed in the recent decade D4 as compared to other decades where its frequency is zero. Figure 2 reveals the comparison of cold wave events among four decades over six stations. Allahabad shows highest cold wave event in D1 and lowest in recent one i.e. D4 during November, whereas, Lucknow and Bahraich depict significant decrease of cold wave events from first to last decades. It is observed that Gorakhpur recorded maximum numbers of cold wave events during D2. While in Kheri there is a sudden decrease of cold wave events found in first two decades i.e. D1 and D2 and then a gradual increase of events is to be noted. However, Varanasi has shown an abrupt increase in cold wave events (10) in D3 i.e. highest no. of cold wave events among all six stations for the month of November.

Figure 3 describes the comparison of cold wave events during December for six different stations during four different decades D1, D2, D3 and D4. It is observed that Allahabad shows a higher number of cold wave events in D1 and D3 and lower values in

D2 and D4. However, the maximum number of cold wave was observed in D2 and D3 as compared to other decades over Varanasi. In Gorakhpur cold wave events increased in recent decade. Lucknow follows the almost decreasing pattern of cold wave events in all four decades. Bahraich shows the occurrence of a maximum number of cold wave events during D1 decade and less number of cold wave events in D2 and D4. In Kheri station maximum number (five) of cold wave events were observed in recent decade while absent in another two decades namely D2 and D3. It is observed that an abrupt increase of cold wave events is noted in D1 over Lucknow and Allahabad. The variations of frequency of cold wave during post-monsoon season for all six stations are shown in Figure 4. During post-monsoon season (Figure 4), Allahabad shows decreasing pattern of cold wave events from first to last decade. It seems that over Allahabad D1 (30) is colder as compare to last decade (D4). In Varanasi recent decade has slightly more cold wave events than D1 (Figure 4). Whereas, during D2 (31) and D3 (33) higher number of cold wave events is noted. It has been observed that over Gorakhpur no change of cold wave events occurs in first two decades D1 and D2. Recent decade (D4) shows an increase of cold wave events as compared to previous decade (D3). Lucknow denotes consistent decrease of the cold wave from D1 to D4; Bahraich also shows lowest number of cold wave events in recent decade as compared to D1. In Kheri during recent decade, abrupt increase of cold wave events is observed as compared to other decades.

Decadal Variation of Cold Wave Events during January-February and Winter Season

Figure 5 represents the occurrence of cold wave events for the month of January. Figure 5 shows that D1 is the coldest decade in which maximum number of cold wave events were observed (29) and then it decreased in next two decades namely D2 and D3, again in recent decade (D4) it is slightly increasing (10) as compared to previous decade (D3) over Allahabad. Varanasi shows increasing pattern of cold wave events in first three decades and decrease in the recent decade while Gorakhpur shows the increased pattern of cold wave events (7) in recent decade as compared to the previous decade. Lucknow also follows the same pattern as Allahabad, where D1 is the most coldest decade in which maximum number of cold wave events is to be noted i.e. 27 then decreases in next two decades and again slightly increases in the recent one. However, over Bahraich and Kheri during D4 decade, maximum

number of cold wave events were found as compared to rest three decades i.e. D1, D2 and D3. Figure 6 represents the changes of cold wave events during the month of February for all four decades namely D1, D2, D3 and D4 over six different stations. Allahabad, Gorakhpur and Kheri depict consistent decreasing pattern of cold wave events from first to last decade. In these three stations, earlier decade (D1) is colder as compared to last three decades i.e. D2, D3 and D4. However, over Varanasi, Lucknow and Bahraich gradual decrease of cold wave events were found for first three decades and then it becomes slightly colder in last decade. It seems that first decade i.e. D1 has a significant number of cold wave events for all six stations.

Figure 7 shows cold wave events of winter season for D1, D2, D3 and D4 decades. In Varanasi continuous increasing pattern of cold wave occurs from D1 (5), D2 (26), D3 (29) and then slightly decreases in recent decade (18). Gorakhpur depicts a same number of events in D1 (13), D2 (13) and minimum in D3 (2). It also shows the cold wave events increased in recent decade (D4). Over Lucknow D1 (41) seems to be colder decade while, D3 experienced least cold wave events (5). However, during recent decade the cold wave events significantly increased. Bahraich shows gradual decreasing pattern of cold wave up to D3 and then slightly increases in D4. During recent decade significant increase of cold wave occurs over Kheri station.

Variation of Cold Wave Events during October to February for 1971-2010

The comparison of cold wave events over six different stations of eastern Uttar Pradesh for each month of October to February during 1971-2010 is shown in Figure 8. It shows that cold wave events from October to February were found to be 9, 7, 34, 53 and 32 respectively over Allahabad. It is also observed that a maximum number of cold wave events occurred during the month of January and minimum in November. While in Varanasi occurrence of cold wave events were 33, 16, 33, 62 and 16 from October to February respectively showing January has maximum number of events and November and February have minimum. Gorakhpur shows slight increase of cold wave events in February than January i.e. 18 and 17 respectively. However, Lucknow shows January as coldest month as compared to all other months considered. Bahraich follows the same pattern as Gorakhpur in which occurrence of cold wave event in February is slightly more than January

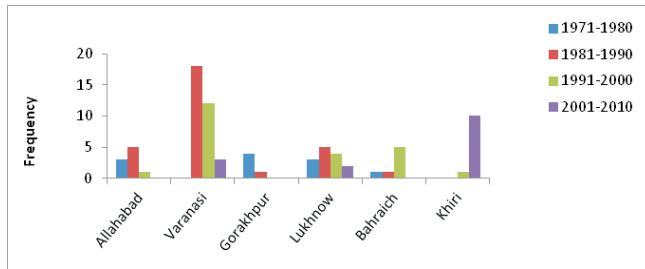


Figure 1: Frequency of cold wave days over six different stations for D1, D2, D3 and D4 for the month of October.

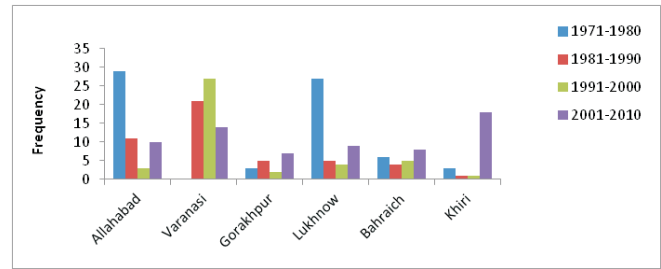


Figure 5: Frequency of cold wave days over six different stations for D1, D2, D3 and D4 for the month of January.

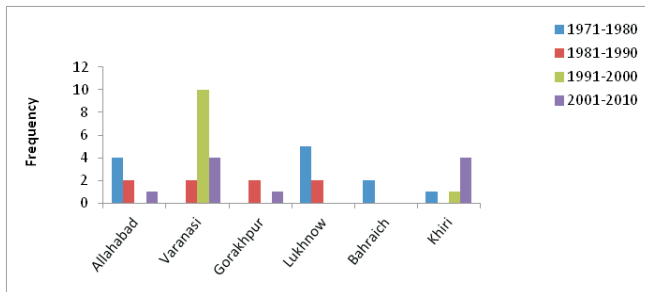


Figure 2: Frequency of cold wave days over six different stations for D1, D2, D3 and D4 for the month of November.

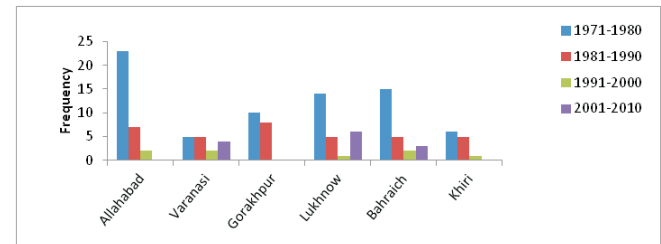


Figure 6: Frequency of cold wave days over six different stations for D1, D2, D3 and D4 for the month of February.

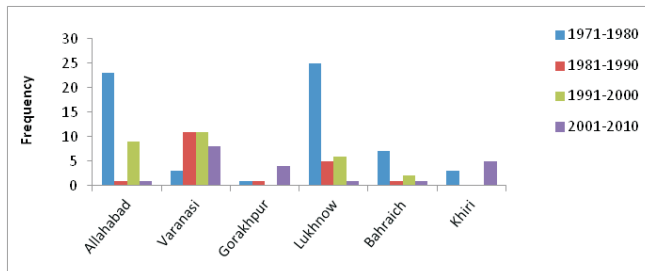


Figure 3: Frequency of cold wave days over six different stations for D1, D2, D3 and D4 for the month of December.

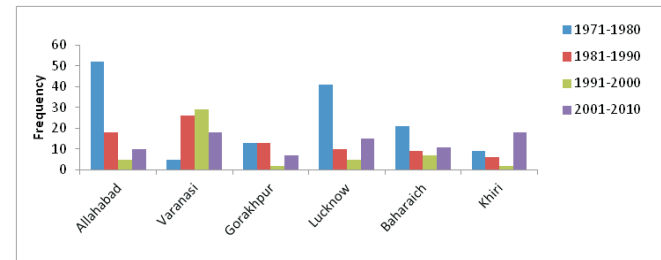


Figure 7: Frequency of cold wave days over six different stations during D1, D2, D3 and D4 for the winter season.

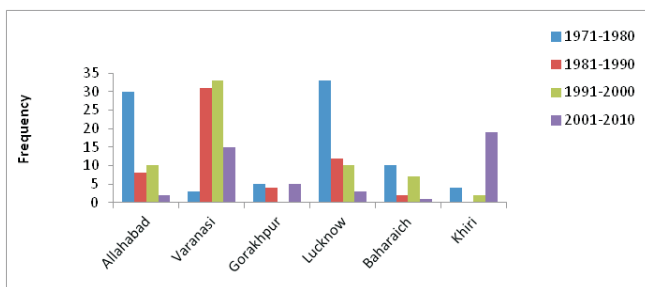


Figure 4: Frequency of cold wave days over six different stations for D1, D2, D3 and D4 for the post-monsoon season.

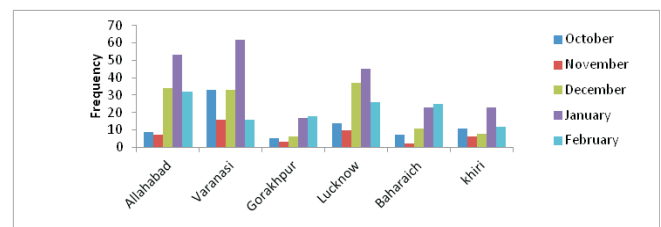


Figure 8: Comparison of cold wave events during October-February for 1971-2010 over six different stations.

and least number of cold wave occur in November i.e. 2. Kheri also shows a maximum number of cold wave in January and least in November. From these above descriptions it has been observed that for all six stations

during 1971-2010 January was the coldest months over all stations except Gorakhpur and Bahraich where February was slightly colder as compared to January, whereas, November shows minimum number of cold wave events for all six stations.

Variation of Cold Wave Events during Post-monsoon and Winter Season for 1971-2010

Figure 9 represents cold wave events during the post-monsoon season from 1971-2010 over six different stations. The occurrence of cold wave events for Varanasi, Lucknow, Allahabad, Khiri, Bahraich and Gorakhpur were found to be 82, 58, 50, 25, 20 and 14 respectively. It has been observed that during post-monsoon season maximum number of cold wave events occur over Varanasi. While, minimum cold wave days are found in Gorakhpur. Figure 10 illustrates the cold wave event of winter season from 1971 to 2010 over six different stations. This figure depicts that during winter season maximum number of cold wave events occur in Allahabad station and are more colder as compared to other five. While Varanasi and Lucknow show slightly less number of cold wave events, minimum and equal number of cold wave events occur in Gorakhpur (35) and Kheri (35) stations.

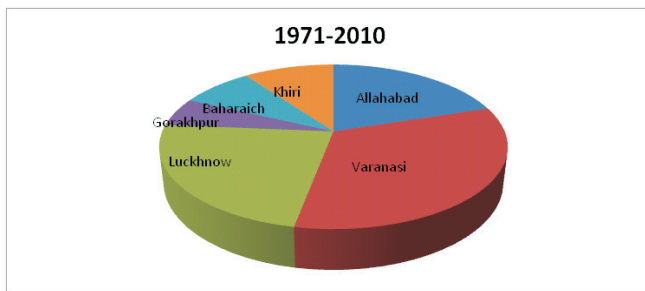


Figure 9: Comparison of cold wave events for post-monsoon season during 1971-2010 over six different stations.

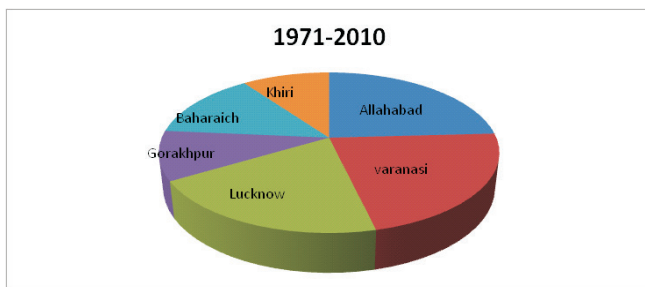


Figure 10: Comparison of cold wave events for winter season during 1971-2010 over six different stations.

Decadal Variation of Severe Cold Wave Events over Six Different Stations

The severe cold wave events over Allahabad are presented in Table 1. It is observed that for the months of October-February, post-monsoon and winter season experienced significant numbers of severe cold wave events during the first decade. During D2 severe cold

wave events only occurred for the month of November (1), February (3), post-monsoon (1) and winter season (3). D3 depicts complete absence of severe cold wave in all months and season. The recent decade also shows the absence of severe cold wave except for January and winter season (8). The study further revealed that in Allahabad maximum number of severe cold wave events i.e. 26 were observed during winter season. It is also observed that during D1, January (12) and February (14) months are more susceptible to severe cold wave conditions. The occurrence of severe cold wave events over Varanasi for different months and seasons during the period of D1, D2, D3 and D4 were presented in Table 2. The severe cold wave of different frequency shows that Varanasi experienced maximum severe cold wave during D2, in which January (12) and February (7) represent more susceptible months while in post-monsoon severe cold wave (3) were observed. D1 shows the absence of severe cold wave while in D3 severe cold wave condition occurs only in October and January months. D4 also shows a complete absence of severe cold wave except in January (4). It is observed from Table 3 that severe cold wave were absent during D1 and D3 decades over Gorakhpur, D2 shows the presence of severe cold wave for the months of January (1), February (2) and also in winter season (3). During recent decade severe cold wave events were only observed in January and winter season. It is apparent from Table 4 that during D1 each month (October-February), post-monsoon and winter season is more susceptible to severe cold wave condition as compared to other decades over Lucknow. In D2 decade severe cold wave days were absent for October-December and post-monsoon season, while present in January (1) and February (3) months. D3 shows complete absence of severe cold wave condition except for October (1). Recent decade shows complete absence of severe cold wave over Lucknow.

It is observed from Table 5 that during all four decades severe cold wave events were absent for the month of October, so the frequency of severe cold wave for November-February months and post-monsoon, winter season were discussed for Bahraich. It further revealed that during D1 and D3 decades, post-monsoon season experienced 3 and 1 number of severe cold wave events respectively. During D2, highest numbers of severe cold wave occur for winter season (8). During recent decade complete absence of severe cold wave was observed over Bahraich. Table 6 shows that during D1 severe cold wave occurs with same frequency in December (1), January (1) and February (1) months.

Table 1: Frequency of severe cold wave days during D1, D2, D3 and D4 over Allahabad

<i>Period</i>	<i>Month</i>					<i>Season</i>	
	<i>October</i>	<i>November</i>	<i>December</i>	<i>January</i>	<i>February</i>	<i>Post-monsoon</i>	<i>Winter season</i>
D1	1	2	1	12	14	4	26
D2	0	1	0	0	3	1	3
D3	0	0	0	0	0	0	0
D4	0	0	0	8	0	0	8

Table 2: Frequency of severe cold wave days during D1, D2, D3 and D4 over Varanasi

<i>Period</i>	<i>Month</i>					<i>Season</i>	
	<i>October</i>	<i>November</i>	<i>December</i>	<i>January</i>	<i>February</i>	<i>Post-monsoon</i>	<i>Winter season</i>
D1	0	0	0	0	0	0	0
D2	1	1	1	12	7	3	19
D3	2	0	0	10	0	2	10
D4	0	0	0	4	0	0	4

Table 3: Frequency of severe cold wave days during D1, D2, D3 and D4 over Gorakhpur

<i>Period</i>	<i>Month</i>					<i>Season</i>	
	<i>October</i>	<i>November</i>	<i>December</i>	<i>January</i>	<i>February</i>	<i>Post-monsoon</i>	<i>Winter season</i>
D1	0	0	0	0	0	0	0
D2	0	0	0	1	2	0	3
D3	0	0	0	0	0	0	0
D4	0	0	0	1	0	0	1

Table 4: Frequency of severe cold wave days during D1, D2, D3 and D4 over Lucknow

<i>Period</i>	<i>Month</i>					<i>Season</i>	
	<i>October</i>	<i>November</i>	<i>December</i>	<i>January</i>	<i>February</i>	<i>Post-monsoon</i>	<i>Winter season</i>
D1	1	1	4	1	3	6	4
D2	0	0	0	1	3	0	4
D3	1	0	0	0	0	1	0
D4	0	0	0	0	0	0	0

Table 5: Frequency of severe cold wave days during D1, D2, D3 and D4 over Bahraich

<i>Year</i>	<i>Month</i>					<i>Season</i>	
	<i>October</i>	<i>November</i>	<i>December</i>	<i>January</i>	<i>February</i>	<i>Post-monsoon</i>	<i>Winter season</i>
D1	0	1	2	0	3	3	3
D2	0	0	0	3	5	0	8
D3	0	0	1	1	2	1	3
D4	0	0	0	0	0	0	0

Table 6: Frequency of severe cold wave days during D1, D2, D3 and D4 over Kheri

<i>Period</i>	<i>Month</i>					<i>Season</i>	
	<i>October</i>	<i>November</i>	<i>December</i>	<i>January</i>	<i>February</i>	<i>Post-monsoon</i>	<i>Winter season</i>
D1	0	0	1	1	1	1	2
D2	3	0	1	0	2	4	2
D3	3	4	3	1	0	10	1
D4	3	1	2	8	3	6	11

While in D2 maximum frequency of severe cold wave was present in October (3) and then in February (2), in D3 decade post-monsoon season experienced the highest frequency of severe cold wave events (10) as compared to winter season (1). Khiri shows a significant number of severe cold wave events during recent decade, in which January month is more susceptible to severe cold wave condition (8) than others. During D4 post-monsoon and winter season denotes 6 and 11 number of severe cold wave events respectively.

Conclusions

The variations of the frequency of cold wave/severe cold wave may be due to the variation in extreme temperature over the regions. The occurrence of cold wave/ severe cold wave over the hilly regions and the adjoining plains is mainly due to the mid-latitude westerlies which often have weak frontal characteristics (De et al., 2005). The following conclusions may be drawn from the study:

- No significant cold wave events observed over Gorakhpur, Allahabad and Bahraich during October and November. In Varanasi, a maximum number of cold wave days are found during D2 in October and December, whereas during D3 in November. The highest numbers of cold wave days are found in Kheri during recent decade i.e. D4 in the month of October.
- During post-monsoon season Varanasi experienced a significant number of cold wave days during D1 to D4. However, the cold wave event increases abruptly in recent decade over Kheri.
- The significant cold wave days over Varanasi is found during D2 to D4 in the month of January. The cold wave days are significantly observed during recent decade over all stations for the month of January.
- Kheri and Bahraich show increasing pattern of cold wave days from D1 to D4 in the month of February. However, during February, recent decade D4 shows increased cold wave days as compared to previous decade except Allahabad, Gorakhpur and Kheri.
- Cold wave days increased in recent decade D4 as compared to previous decade D3 over all stations except Varanasi during winter season.
- Varanasi shows the highest number of cold waves among all stations from October to February, post-monsoon season and Allahabad shows during winter season during 1971-2010.
- All stations except Lucknow and Bahraich experienced severe cold wave days in recent decade as compared to previous decades during January and winter season. However, the significant severe cold wave days were found in D3 and D4 for each month and season over Kheri.

The variations represent how local places contribute to global climate change. Therefore, along with large-scale circulation, regional and local changes might play a crucial role in influencing the observed climate in a given area. The sensitivity studies are also helpful in working out of a proper mitigation and sustainable development plan of a given place.

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