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Climate change over India as revealed by critical extreme temperature analysis*

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सार – बहुत अधिक और बहुत कम तापमान तथा भारी वर्षा आदि जैसी विकट मौसम घटनाओं से हजारों की संख्या में जानें जाती हैं और प्रकृति तथा क्षेत्रीय अर्थव्यवस्था को भारी क्षति पहुँचती है। ब्यूरो ऑफ कनाडा (अंगर 1999) की रिपोर्ट के अनुसार 1987 से पूर्व में ऐसी कोई भी प्राकृतिक आपदा नहीं आई जिसके लिए एक बिलियन अमरीकी डॉलर से अधिक का बीमा का हर्जाना देना पड़ा हो। पिछले दशक के दौरान ऐसी 18 आपदाएँ आई हैं। इस अध्ययन से यह तथ्य ज्ञात हुआ है कि इन विकट घटनाओं के दुष्प्रभाव के कारण आर्थिक क्षति में वृद्धि हो रही है।

इस शोध पत्र में, 1971–2000 तक की 30 वर्षों की अवधि के आँकड़ों के आधार पर देश में फेले हुए 103 केंन्द्रों के अत्यधिक अधिक/अत्यधिक न्यून तापमानों का विवेचनात्मक अध्ययन किया गया है। लीस्ट स्कवेयर पद्धति का उपयोग करके 20° उ. के दक्षिण, 20° उ. के उत्तर तटीय केन्द्रों तथा पूर्वोत्तर भारतीय केंन्द्रों के लिए इन प्रवृत्तियों का अलग अलग अध्ययन किया गया तथा टी–स्टैटिस्टिक के उपयोग से इसकी सार्थकता का परीक्षण किया गया है। इस शोध–पत्र में इससे प्राप्त हुए परिणामों को प्रस्तुत किया गया है।

ABSTRACT. Extreme weather events such as high and low temperatures, heavy rainfall etc. claim thousands of lives and cause extensive damage to natural and regional economy. According to a report of the Bureau of Canada (Ungar 1999) there were no natural disasters before 1987 which caused insured losses of more than US $ 1 billion. During the past decade there have been 18 such disasters. The finding supports the fact that the impacts of these extreme events in terms of economic losses are increasing.

The paper presents a study of critical extreme maximum/minimum temperature days for 103 well distributed stations over the country for a data period of 30 years from 1971-2000. The trends are studied separately for stations south of 20° N, north of 20° N, coastal stations and NE Indian stations by using least square method and the significance is tested using t-statistic. The results are presented.

Key words – Critical extreme temperatures, Trends, Percentage frequencies and no. of days, Global warming, Climate change.

1. Introduction

Global warming, climate change and their impact have been receiving wider attention in the recent years among meteorologists and allied scientific fraternity. Many studies are available on the analysis of the earth's surface air temperature *vis-à-vis* climate change over India. Studies about the trends in the extreme temperature events over the Indian region are rare in the literature. In this work the extreme temperature analysis over the Indian region has been carried out to study the climate change over the region. Detailed analysis of the results are presented in this paper.

1.1. *Climate change*

1.1.1. *International scenario (Mean temperature)*

Karl *et al.* (1993) examined monthly mean maximum and minimum temperature for over 50% and 10% of north

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and southern hemisphere land mass stations respectively. Their results showed that the rise in minimum temperature has occurred at a rate of three times than that of maximum temperatures during the period 1951-90 (0.84° C *versus* 0.28° C). The decrease of diurnal temperature range is approximately equal to the increase of mean temperature. The decrease in the daily temperature is partially related to the increases in the cloud cover. Easterling *et al*. (1997) examined maximum and minimum temperature trends over the globe and concluded that diurnal temperature range (DTR) is continuing to decrease over the globe. This is due to daily minimum temperature increasing at a faster rate or decreasing at a slower rate than the daily maximum. In parts of New Zealand (Salinger 1995) and Alpine regions of Central Europe (Weber *et al*. 1994) maximum and minimum temperatures have increased at similar rate.

1.2. *Indian scenario*

Pramanik and Jagannathan (1954) examined the trends of maximum and minimum temperatures of 30 Indian stations and concluded that there was no general tendency for a systematic increase or decrease in maximum and minimum temperatures. Hingane et. al. (1985) reported with more data that the mean annual temperature increased by 0.4° C / 100 years in India during 20th century. Kothwale (1992) reported that the mean annual maximum temperature has increased by about 0.5°C/100 years during the past century, while there was systematic change in the minimum temperature. Srivastava *et al*. (1992) studied decadal trends in the climate over India and reported that the temperatures North of 23° N showed a general decreasing trend while the southern part of the country has been getting warmer from surface to middle troposphere. While studying the effects of urbanisation on meteorological parameters Rao *et al*. (2004) observed that total cloud amount trends are decreasing in respect of 11 out of 15 stations. In general, there are some differences in trends on smaller spatial or temporal scales, but increase of maximum temperature is dominant over major parts of India particularly during summer and winter seasons.

1.3. *Climate change as seen by extreme temperature analysis*

1.3.1. *Global scenario*

Karl *et al.* (1996) developed a climate extreme index (CLI) for Contiguous United States (US). Their results showed that the climate of US had become more extreme in recent decades, but the magnitude and persistence of changes were not large enough to conclude that the increase of extreme reflects a non-stationary climate. Arthur and Allen (2002) examined trends in the 20th century temperature extremes over US. They observed decreasing warm exceedence trends during 1930-96 period due to peak of drought in 1930s and 1950s. However, in recent years (1960-96) majority of stations show increase in warm extreme exceedences. Significant increase in minimum temperature exceedence are found at nearly one third of the stations. Hyun *et al*. (2002) examined extreme temperature trends over south Korea. They observed that the frequency of extreme maximum temperature events show an increasing trend with higher values in 1980s and 1990s. The frequencies of occurrence of extreme minimum events show the opposite with statistically significant decreasing trend. Jones and Lister (2002) examined daily temperature records of St. Petersberg. They noticed a clear trend of lower number of extremely cold days during 20th century. Warm day counts a much smaller change. Yan *et al*. (2002) examined the trends of extreme temperatures over Europe and China. They reported decreasing of warm extremes before late 19th century, decreasing of cold extremes since then and increasing of warm extreme since 1960s. The early decrease and recent increase of warm extreme dominate in summer, while decrease of cold extremes in winter persists throughout. The annual frequency of cold extreme has decreased by about 7% per century. Warm extremes increased by 10% per century.

1.4. *Analysis of extreme temperature over India*

Much research work is not seen in the literature which deals with the analysis of extreme temperatures for discussing the climate change over India. Rao *et al.* (2000) studied the extreme maximum/minimum temperatures during summer and winter seasons over 40 selected cities and concluded that (*i*) in summer months the extremes of maximum and minimum month show an increasing trend over the peninsula. Over parts of north India the extreme maximum temperatures show an increasing trend while extreme minimum temperatures are exhibiting a decreasing trend leading to the fact that temperature variations are more over north India compared to peninsula. (*ii*) The extreme maximum/ minimum temperatures during winter months show a general increasing trend over parts of peninsula. The extreme maximum temperatures show a decreasing trend over central and northern parts of India while reverse is true in case of extreme minimum temperatures there by causing less diurnal variation.

2. Data and analysis

In the present study the extreme maximum/ minimum temperature data of 103 well distributed stations in India for last 30 years (1971-2000) have been selected

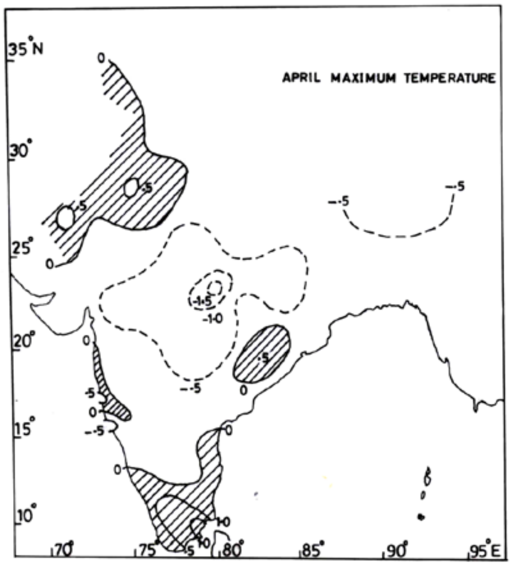

Fig. 1. Percentage frequency trend up to 5° C below April extreme maximum temperature. Shaded portions indicate positive trend

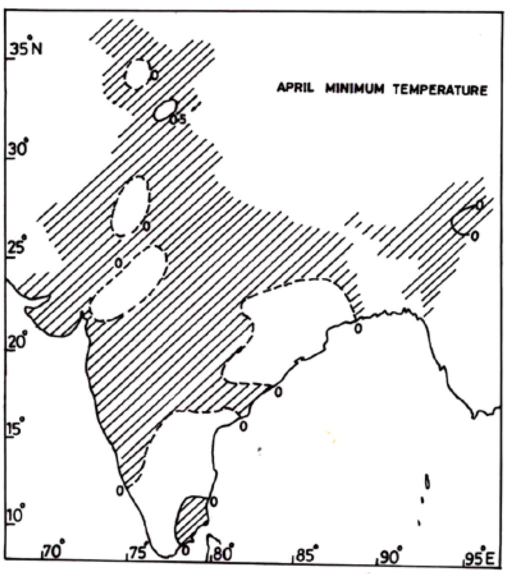

Fig. 2. Percentage frequency trend up to 5° C above April extreme minimum temperature. Shaded portions indicate positive trend

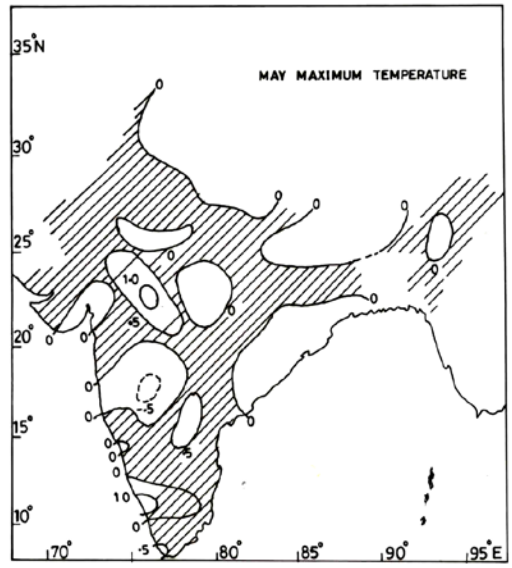

Fig. 3. Percentage frequency trend up to 5° C below May extreme maximum temperature. Shaded portions indicate positive trend

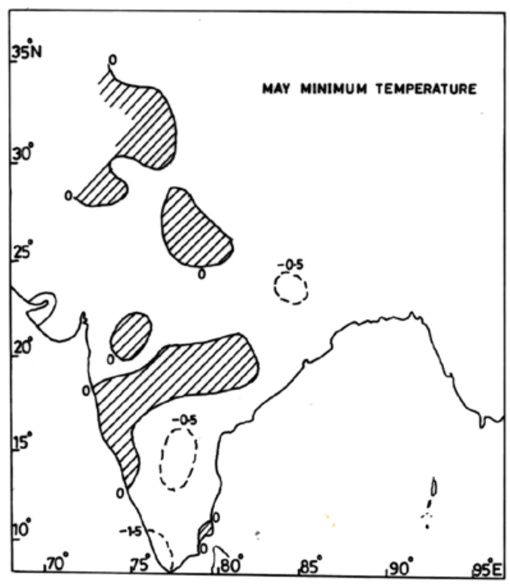

Fig. 4. Percentage frequency trend up to 5° C above May extreme minimum temperature. Shaded portions indicate positive trend

for March – May and November – January. The authors have considered the ever recorded highest maximum and lowest minimum temperatures (month wise) for these stations to define the critical extreme temperature (highest /lowest) days. A day is termed as critical extreme maximum temperature day if its maximum temperature is greater than (ever recorded extreme maximum temperature – 5° C). Similarly, the day is termed as critical extreme minimum temperature day if its minimum temperature is less than (ever recorded extreme minimum temperature + 5° C). For example, in the month of January of a particular year, number of critical extreme maximum temperature days has been obtained when the maximum temperature was higher than the (ever recorded extreme maximum –5° C). Following the above procedure, monthly frequencies of these critical extreme high and low temperature days have been computed for six months (March to May and November to January) for the past 30 years (1971-2000). Similarly, number of critical extreme minimum temperature days has been

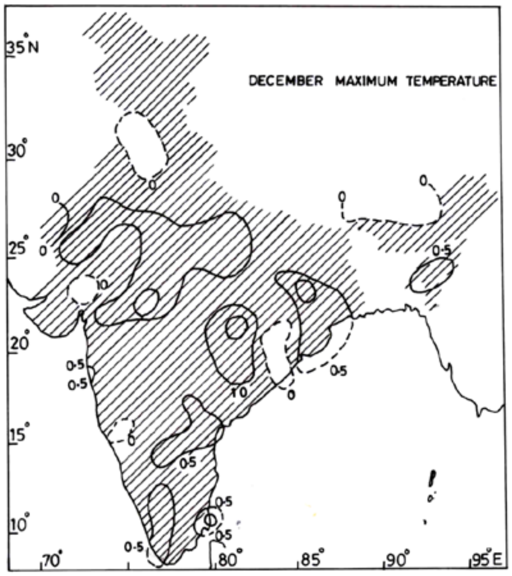

Fig. 5. Percentage frequency trend up to 5° C below December extreme maximum temperature. Shaded portions indicate positive trend

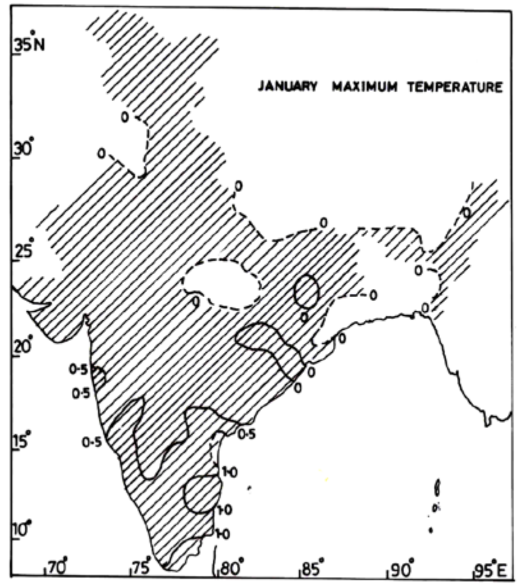

Fig. 7. Percentage frequency trend up to 5° C below January extreme maximum temperature. Shaded portions indicate positive trend

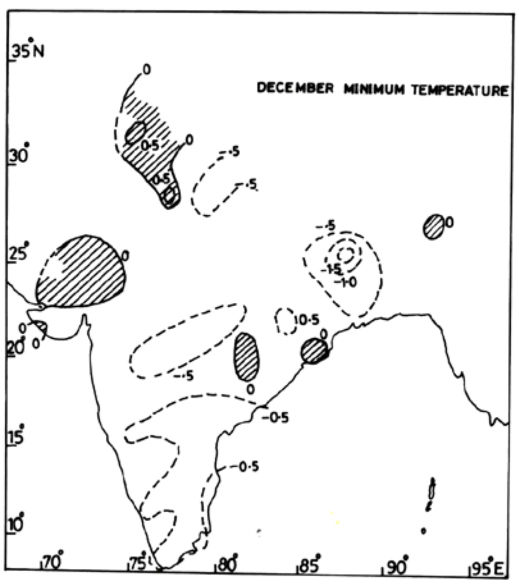

Fig. 6. Percentage frequency trend up to 5° C above December extreme minimum temperature. Shaded portions indicate positive trend

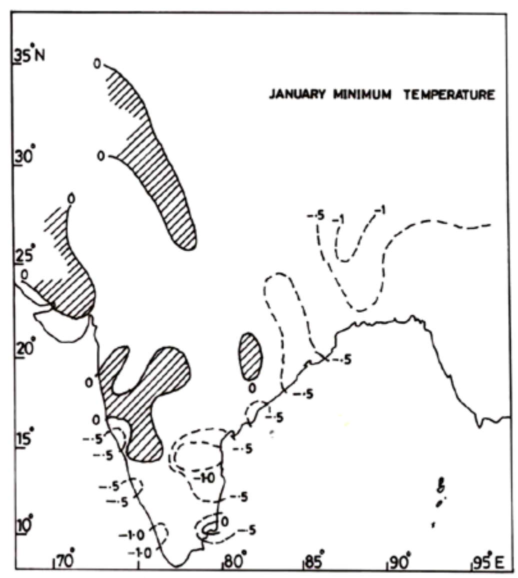

Fig. 8. Percentage frequency trend up to 5° C above January extreme minimum temperature. Shaded portions indicate positive trend

determined for which the minimum temperature was lower than (the ever recorded lowest minimum + 5° C). Subsequently, monthly frequencies of these critical extreme high and low temperature days have been obtained for the past 30 years (1971-2000). The percentage monthly frequencies of critical extreme maximum and minimum temperature days are calculated and have been subjected to trend analysis by using the least square method. The significance is tested at 95% level using *t* - test and the results are reported.

The trends of percentage frequency of number of days of critical maximum and minimum temperatures are plotted on the charts and analysed. The monthly results are discussed. The percentage frequency trend of extreme critical maximum / minimum temperatures for April, May, December and January are shown in Figs. 1 to 8 respectively.

TABLE 1

Stations South of 20° N

No. of stations with event type	Mar	Apr	May	Nov	Dec	Jan
1. Number of stations with increasing critical extreme maximum temperature days	25 (62) 12 *	22 (55) 5*	25 (62) 10*	32 (80) 12*	33 (82) 14*	35 (88) 13*
2. Number of stations with maximum temperature decreasing (cool days)	15 (38) 2*	18 (45) 5*	15 (38) 2*	8 (20) 1*	7 (18) -	5 (12) -
3. Number of stations with minimum temperature increasing (warm nights)	24 (60) 8*	16 (40) 1*	25 (62) 10*	35 (88) 19*	32 (80) 12*	32 (80) 19*
4. Number of stations with increasing critical extreme minimum temperature days	16 (40) 2*	24 (60) 7*	15 (38) 4*	5 (12) -	8 (20) -	8 (20) 1*

- Figures in brackets indicate percentage number of stations
- Number with star indicates that trend is significant at 95% level of confidence

TABLE 2

Stations North of 20° N

No. of stations with event type	Mar	Apr	May	Nov	Dec	Jan
1. Number of stations with increasing critical extreme maximum temperature days	15 (24) 1*	20 (32) 2*	35 (56) 5*	44 (70) 4*	54 (86) 25*	48 (76) 14*
2. Number of stations with maximum temperature decreasing (cool days)	48 (76) 21*	43 (68) 8*	28 (44) 3*	19 (30) 3*	9 (14) 2*	15 (24) 2*
3. Number of stations with minimum temperature increasing (warm nights)	57 (90) 14*	24 (38) 1*	44 (70) 7*	57 (90) 29*	46 (73) 15*	47 (75) 13*
4. Number of stations with increasing critical extreme minimum temperature days	6 (10) 2*	39 (62) 11*	19 (30) -	6 (10) -	17 (27) 2*	16 (25) -

- Figures in brackets indicate percentage number of stations
- Number with star indicates that trend is significant at 95% level of confidence

3. Results and discussion

Monthly results are summarized below :

March – Maximum temperatures

The days are becoming extremely warmer over major parts of south peninsula consisting the areas of Tamil Nadu, Kerala, coastal and south interior Karnataka, south coastal A. P., Rayalaseema, south Telengana, Saurashtra & Kutch, Orissa and extreme north coastal A. P. Over the remaining parts of the country the days are becoming cooler.

March – Minimum temperatures

Nights are becoming cooler over areas of Konkan and Goa, parts of south Maharashtra parts of Rayalaseema, coastal and north Interior Karnataka and over a small part of central Tamil Nadu. Nights are becoming warmer over the remaining parts of the country.

April – Maximum temperatures

Days are becoming warmer over south coastal A. P., Tamil Nadu, Kerala, coastal Karnataka, parts of south Interior Karnataka, Konkan, Goa, interior Orissa, Rajasthan, Punjab, Haryana and Delhi. Over remaining parts of the country days are becoming cooler.

April – Minimum temperatures

Nights are becoming cooler over southeast Tamil Nadu, parts of Rajasthan, Gangetic West Bengal, Jharkhand, parts of Chattisgarh, Madhya Pradesh, Maharashtra, Uttaranchal and U. P. Over the remaining areas of the country nights are becoming warmer.

TABLE 3

Stations in NE India

	No. of stations with event type	Mar	Apr	May	Nov	Dec	Jan
1.	Number of stations with increasing critical extreme maximum temperature days	0 (0) -	4 (36) -	3 (27) 1*	8 (72) 1*	8 (72) 1*	6 (55) 1*
2.	Number of stations with maximum temperature decreasing (cool days)	11 (100) 6*	7 (64) 1*	8 (72) 1*	3 (27) 1*	3 (27) 1*	5 (45) 1*
3.	Number of stations with minimum temperature increasing (warm nights)	9 (82) 2*	7 (64) -	9 (82) 1*	8 (72) 2*	8 (72) 3*	9 (82) 2*
4.	Number of stations with increasing critical extreme minimum temperature days	2 (18) 1*	4 (36) -	2 (18) -	3 (27) -	3 (27) 1*	2 (18) -

- Figures in brackets indicate percentage number of stations
- Number with star indicates that trend is significant at 95% level of confidence

TABLE 4

Coastal stations

	No. of stations with event type	March	April	May	Nov	Dec	Jan
1.	Number of stations with increasing critical extreme maximum temperature days	21 (70) 11*	18 (60) 5*	20 (67) 9*	24 (80) 9*	27 (90) 12*	27 (90) 12*
2.	Number of stations with maximum temperature decreasing (cool days)	9 (30) 1*	12 (40) 3*	10 (33) 2*	6 (20) -	3 (10) -	3 (10) -
3.	Number of stations with minimum temperature increasing (warm nights)	21 (70) 7*	15 (50) 1*	19 (63) 5*	26 (87) 15*	23 (77) 7*	2 (83) 15*
4.	Number of stations with increasing critical extreme minimum temperature days	9 (30) 2*	15 (50) 4*	11 (37) 2*	4 (13) -	7 (23) -	5 (16) -

- Figures in brackets indicate percentage number of stations
- Number with star indicates that trend is significant at 95% level of confidence

May – Maximum temperatures

Days are becoming cooler over Gangetic West Bengal, Orissa, Jharkhand, north coastal Andhra Pradesh, central parts of Madhya Pradesh, parts of NE India, Uttaranchal, Punjab, extreme NW UP., north Madhya Maharashtra, north interior Karnataka. Over the remaining parts of India, they are becoming warmer.

May – Minimum temperatures

Nights are becoming cooler over J. & K., parts of Punjab, north Rajasthan, parts of west U. P., Chattisgarh, Vidharbha, north Madhya Maharashtra and Konkan. Over remaining parts of India, they are becoming warmer.

November – Maximum temperatures

Days are becoming cooler in parts of Punjab, Chandigarh, Haryana and Delhi, north and western parts of M. P., north Gujarat, Vidarbha, parts of north interior Karnataka. Over the remaining parts of India days are becoming warmer.

November – Minimum temperatures

Nights are becoming cooler over a small pocket of extreme north interior Karnataka and adjoining Madhya Maharashtra. Over the remaining parts of India they are becoming warmer.

December – Maximum temperatures

Days are becoming cooler over extreme NW Rajasthan, parts of Punjab, Haryana, parts of north Gujarat, parts of north interior Karnataka, Orissa and Arunachal Pradesh. Over the remaining parts of India, days are becoming warmer.

December – Minimum temperatures

Nights are becoming cooler over parts of J. & K., Punjab, Haryana, Delhi, parts of west Rajasthan, Chattisgarh and coastal Orissa. Over the remaining parts of the country nights are becoming warmer.

January – Maximum temperatures

Days are becoming cooler over parts of Punjab, Gangetic West Bengal, parts of NE India and central parts of Madhya Pradesh. Over the remaining parts of the country days are becoming warmer.

January – Minimum temperatures

The nights are becoming cooler over J. & K., Punjab, Haryana, Chandigarh, Delhi and over the parts of Vidarbha, Konkan and Madhya Maharashtra, north interior Karnataka and over a small area in Chattisgarh. Over the remaining parts of India, nights are becoming warmer.

At this stage, it is difficult to attribute a particular cause or reason for the trends in critical extreme temperatures. These trends can be attributed to urbanization, industrialization, deforestation, heat island or to the global warming or to their combined effect. A further detailed study in this direction examining each factor is required which is beyond the scope of this paper.

To examine critically, the total number of stations are divided into two parts (*i*) stations (40) south of 20° N and (*ii*) stations (63) north of 20° N and the results are presented in Tables 1 & 2 respectively.

From Table 1 (stations south of 20° N), it is seen that during summer months (March to May) about 60% of the stations are exhibiting an increasing trend in the critical extreme maximum temperature days and nights are also becoming warmer. For about 40% of stations the days are becoming cooler and the critical minimum extreme temperature nights are increasing for about 40% to 60% of stations. During November – January the critical extreme maximum temperature days and warm nights are increasing in about 80% to 88% cases. The day temperatures are decreasing and increase in critical extreme minimum temperature nights are observed in about 12% to 20% of the stations. The number of stations with * indicate that trends are significant at 95% level of confidence.

From Table 2 (stations north of 20° N) it is seen that during summer months, the number of stations with increasing critical extreme maximum temperature days are varying between 24% & 56%, with a maximum percentage (56%) of stations in May. The nights are becoming warmer for 70% to 90% of the stations in the months of May and March with lower number of stations (38%) in April. The days are becoming cool with maximum number of stations (68% to 76% in April and March) and decreasing to 44% in the month of May. The number of stations with critical extreme minimum temperature days are 10% (March) to 30% (May) and having a maximum of 62% in the month of April.

During November - January, the critical extreme maximum temperature days are increasing in 70% to 86% of the stations and warm nights are increasing for 73% to 90% of stations. The days are becoming cooler for 14% to 30% of the stations and critical extreme minimum temperature nights are between 10% & 27% of the stations.

To examine the effect in the hilly regions of NE India & coastal stations authors have also studied (*i*) coastal stations (30) and (*ii*) stations (11) in NE India and the results are presented in Tables 3 & 4 respectively.

From Table 3 (NE India) it is noticed that during summer there is increase in critical extreme maximum temperature days for 27% to 36% of the stations in the months of May and April with no station showing increasing trend in March. The nights are warmer in 64% to 82% of the stations. The days are cool in 64% to 100% stations and critical extreme minimum temperature days are increasing for 18% to 36% of the stations. During November – January the critical maximum temperature days are increasing for 55% to 72% of the stations and nights are also warmer for 72% to 82% of the stations. The days are cool for 27% to 45% stations and critical minimum extreme temperature days are increasing for 18% to 27% of the stations.

From Table 4 (coastal stations), it is seen that during summer months about 60% to 70% of the coastal stations are showing an increasing trend in the critical extreme maximum temperature days with an equal number showing an increase in the minimum temperatures. For about 30% to 40% of the stations the days are becoming cooler and cooler nights are experienced in 30% to 50% of the stations. During November – January the critical extreme maximum temperature days are increasing in 80% to 90% of the stations with an almost equal number of stations showing increase in minimum temperatures. The day temperatures are decreasing and the nights are becoming cooler in about 10% to 23% of the stations.

Decadal mean temperature trends

Decadal trends of mean air temperatures (maximum + minimum / 2) for the same number of stations are analysed and shown in Fig. 9. The trends are negative over parts of Rajasthan, J. & K., Himachal Pradesh parts of southwest U.P., northern parts of M.P., Jharkhand and NE India. Over the remaining parts of the country the trends are increasing.

4. Conclusions

(*i*) The trends are not uniform for all the Indian stations during March – May and November – January.

(*ii*) In peninsular India (*i.e*., south of 20° N) during March – May / November – January, sixty / eighty percent of stations are having an increasing trend in critical maximum temperature days coupled with increasing night temperatures.

(*iii*) During summer months about 40 % stations north of 20° N are showing increasing critical extreme maximum temperature days while night temperatures are increasing for about 80% of the stations. During November – January, the critical extreme maximum temperature days and warm nights are increasing in 79% of the stations.

(*iv*) About 30% of the stations in NE India (during April and May) are showing increasing trend in critical maximum temperature days, while night temperatures are increasing from about 70% of stations. During November – January, the critical maximum days are increasing for about 63% of stations and minimum temperatures are increasing for about 77%.

(*v*) During summer 60% to 70% of the coastal stations are showing an increasing trend in critical extreme maximum days and increase in night temperatures. The number of stations increased to 80% to 90% during November – January.

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