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ASSESSMENT OF EXTREMES IN AIR TEMPERATURE OVER NORTH-EAST AND WEST COAST REGIONS OF INDIA

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ABSTRACT: The projected effect of climate change is the increase of both the frequency and intensity of extreme weather events. An attempt has been made to study the extremes in temperature over two regions of India i.e. North-East Region (NER) and West Coast Region (WCR). A detailed analysis indicated that in the NER, ten stations indicate increase in annual extreme minimum but significant at four stations. Post-monsoon season is very predominant where five stations show significant increase. In the WCR, all the stations indicate increasing trend in annual extreme maximum temperature significant at nine stations. Majority of the stations indicate significant increasing trend in all the seasons except monsoon season.

KEY WORDS: air temperature maximum, minimum, post-monsoon season, trends.

INTRODUCTION

The projected effect of climate change is the increase of both the frequency and intensity of extreme weather events. Occurrences of extreme events of severe highs and low temperatures claim hundred of lives as well as cause extensive damage to the economy. Therefore, possible long term changes in the intensity of such events are of great concern. Every region of the world experiences with record-breaking values in the weather parameter extremes from time to time. According to NOAA (2010), each of the last 13 years (1997–2009) was one of the 14 warmest years ever recorded since the year 1850.

Studies of trends in temperature extremes and intra-seasonal variability of daily temperatures over various regions of the globe are few. Klein Tank *et al.* (2006) have studied the changes in daily temperature and precipitation extremes in central and South Asia, and reported that 70% of the stations have significant increase in warm nights/days and thereby decrease in cold nights/days. Nicholls *et al*. (2005) found an association between increase in hot days and warm nights in East Asia–West Pacific Region and El Niño. The trends of extreme climate indices in over Asia Pacific region showed relationship between seasonal and diurnal extreme climate changes (Griffiths *et al*. 2005).

Looking at the extreme weather events, India has witnessed many such episodes whereby 70% of its population relying on agriculture, the impact of extreme weather event is critical. The summer of 1998 was very severe causing abnormal spells of high temperatures almost all over the country that resulted in more than 1 300 deaths (De and Mukhopadhyay 1998, De *et al.* (2005). Rao *et al.* (2005) examined trends in the frequency of extreme temperatures over India during winter and pre-monsoon seasons, they reported 80% of stations in Peninsular India showed increasing trend in the days with critical extreme maximum and minimum temperatures. About 80% of the stations showed increasing trend in the extreme minimum temperatures. Revadekar *et al*. (2009) concluded that El Niño and La Niña influence temperature extremes in India. Recently, Kothawale *et al.* (2010) reported that frequency of hot days and nights showed increasing trend while cold days and nights showed decreasing trends. The year 2009 was officially reported as the warmest year for India, by **I**ndia **M**eteorological **D**epartment (IMD).

It was observed that that very less literature was available on extreme temperature variations over NER. In this context, assessment of extreme weather helps in understanding the regional climate since the North-East and West Coast Regions are also prone to these variations. The present study tries to find whether there is any trend in extreme maximum or minimum over the study regions. Therefore, an attempt is made to study the extreme weather events on different temporal and spatial scales viz. annual, seasonal and monthly in view of projected impact of climatic change.

STUDY AREA

These two regions have some unique physical characteristics different from the rest of the country (Fig. 1). Both the regions have similarities in physiography that is rugged terrain. They receive heavy rainfall due to orographic effect. West coast, because of its proximity to the Arabian Sea experiences less seasonal contrast in temperature while a sharp changing relief of the north-east makes it difficult to generalize on temperature and precipitation. The foot hills, mountain tops and valleys generate wide contrast in temperature and precipitation. With this in view, an attempt is being made to investigate the changing patterns of extremes in temperature over these two regions.

MATERIAL AND METHODS

The data (1901–2006) for temperature extremes over 26 stations were prepared with the lowest minimum (TNN) and the highest maximum (TXX) in a month (Tab. 1). Accordingly the lowest/highest values were considered for each seasons used for this study. Using monthly temperatures, seasons pertaining to winter (January–February), pre-monsoon/summer (March–May), monsoon (June–September) and post-monsoon (October–December) and annual values were calculated over each station. In order to determine the significance of trend, Mann Kendall and linear regression coefficients were computed and tested at 0.05 and 0.01. Time series were plotted for the entire periods of record.

Table 1. Period of data and altitude for 26 Meteorological stations

NER	Data period	Altitude (m a.s.l.)	WCR	Data period	Altitude (m a.s.l.)
Pasighat	1957–1993	157	Mumbai	1901–2006	1
Dibrugarh	1970–2000	111	Alibag	1939–2002	7
Lakhimpur	1954–1993	102	Harnai	1970–2002	20
Tezpur	1939–1996	79	Ratnagiri	1901–2005	67
Guwahati	1903–2000	54	Panjim	1964–2003	60
Dhubri	1946–1993	35	Marmagoa	1970–2001	62
Silchar	1951–1993	29	Karwar	1915–2003	4
Gantok	1970–2000	1812	Honavar	1939–2002	26
Shillong	1903–2000	1500	Mangalore	1901–2001	22
Cherrapunjee	1903–2000	1313	Calicut	1901–2000	5
Imphal	1954–1998	781	Cochin	1970–2000	3
Kailashahar	1959–1996	29	Alleppey	1944–2000	4
Agartala	1970–2000	16	Trivandrum	1901–2004	64

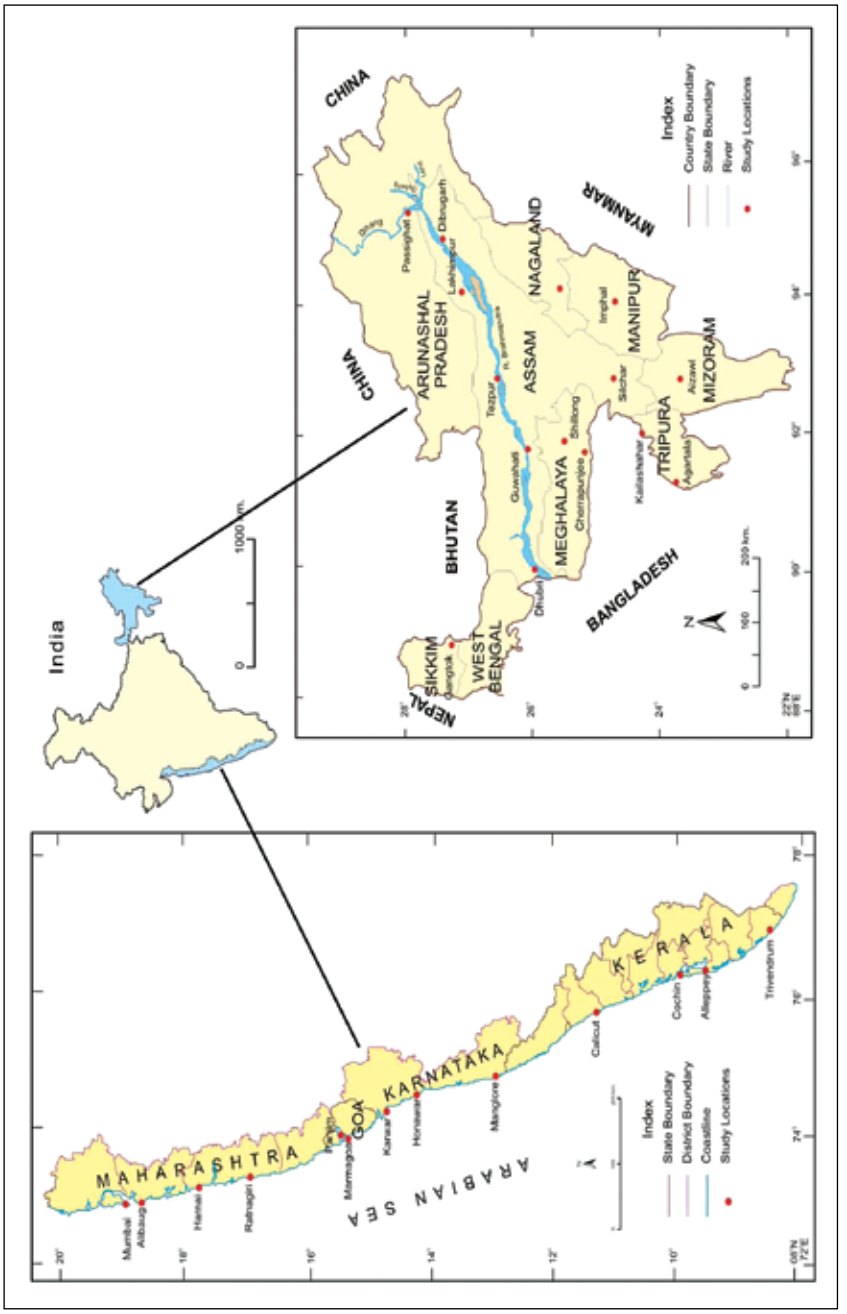

Figure 1. Study Area of North-East Region (NER) and West Coast Region (WCR)

RESULT AND DISCUSSIONS

TRENDS IN ANNUAL MAXIMUM EXTREMES

Extreme temperatures on annual and seasonal basis for the NER have been worked out. The results are reported in Table 2 and depicted in Figure 2. The table indicates that majority of the stations show increase in TXX on annual basis however none of them is significant. Out of four stations, three stations show significant trend at Gangtok, Imphal and Agartala (Fig. 3 a–c).

On seasonal basis, six out of thirteen stations indicate increasing trend during the winter season, but none of them is significant while three stations (Silchar, Gangtok and Agartala) show significant decreasing trend in TXX. During summer season, six stations indicate increase in TXX but none of them is significant while seven stations depict decrease in TXX of which significant trend is observed at Silchar, Imphal and Agartala only. In the monsoon season, majority of the stations except Gangtok show increasing trend in TXX which is significant only at Dhubri. While Gangtok reports significant decrease in TXX. During the post-monsoon season again, mixed trends are observed with eight stations showing increasing trend and only significant at Dhubri, Cherrapunjee and Imphal. It is noted that Gangtok indicates significant decrease at 99% in TXX during all the seasons except summer. Though increase in annual TXX is observed at several stations it is not significant however decrease is observed at few stations seasonally. The monthly trends in TXX are reported in Table 3.

Table 2. Trends in NER TXX (* Indicate ά=0.05% and ** ά=0.01% level)

Stations	Annual	Seasons			
		Winter	Summer	Monsoon	Post monsoon
Pasighat	+	+	+	+	+
Dibrugarh	+	+	+	+	+
Lakhimpur	+	+	+	+	+
Tezpur	+	–	+	+	–
Guwahati	+	+	+	+	–
Dhubri	+	–	+	+**	+**
Silchar	+	–*	–*	+	–
Gantok	–**	–**	–	–**	–**
Shillong	+	–	–	+	–
Cherrapunjee	+	+	–	+	+*
Imphal	–*	+	–*	+	+*
Kailashahar	–	–	–	+	+
Agartala	–*	–*	–*	+	+

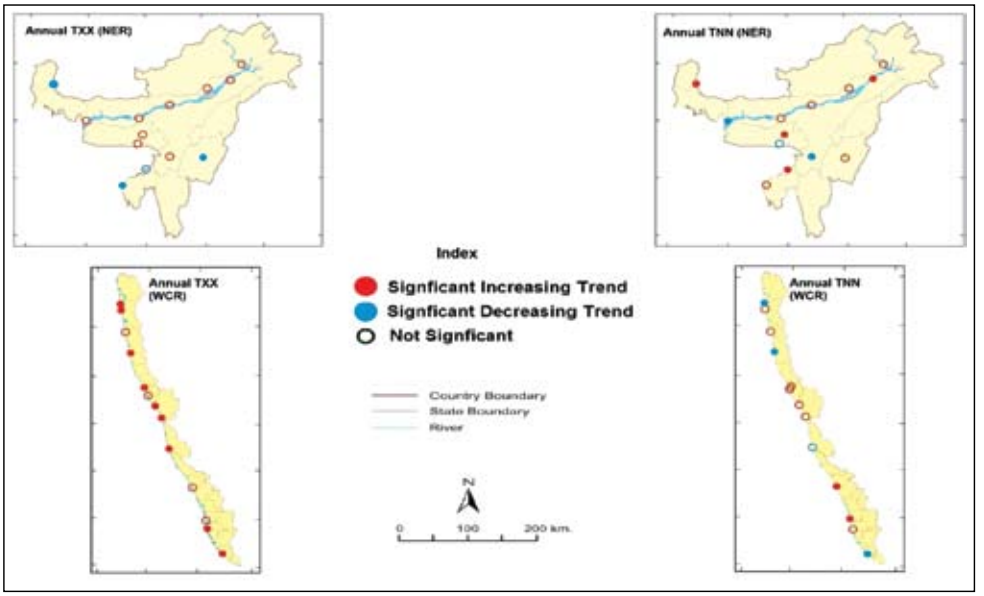

Figure 2. Annual maximum (TXX) and minimum temperature extremes (TNN) in NER and WCR

Table 3. Monthly trends in NER TXX (* Indicate ά=0.05% and ** ά=0.01% level)

Stations	Months												
	J	F	M	A	M	J	JY	A	S	O	N	D	AN
Pasighat	+*	+	–	–	+	+	+	+	+	–	+*	+	+
Dibrugarh	+**	+	–	+	+	+	+	–	+	+	+**	+	+
Lakhimpur	+**	–	–	–*	+	+	–	+	+*	+*	+*	+	+
Tezpur	+	–	+	–	–	+*	+	+	+	–	+	–	+
Guwahati	+	+	+	+	+	+	+	+	+	–	+	+	+
Dhubri	+	–	+*	–	–	+*	+**	+**	+*	+**	+	+	+
Silchar	–*	–*	–	–*	–	+	–	–	+	–	–	–*	+
Gantok	–*	–**	–**	–	–	–*	–**	–**	–**	–**	–**	–**	–**
Shillong	–**	–	–	–	+	+*	–*	+	–*	–	+	–	+
Cherrapunjee	–	+	+	–	+	+	–	+	+	+	+**	+	+
Imphal	+*	+	–	–*	–	+	+	+	+*	+*	+**	+	–*
Kailashahar	+	–	+	–	–	+	–	+	+	+	+**	+	–
Agartala	+	–*	–**	–*	+	+*	–	+*	–	+	+	+	–*

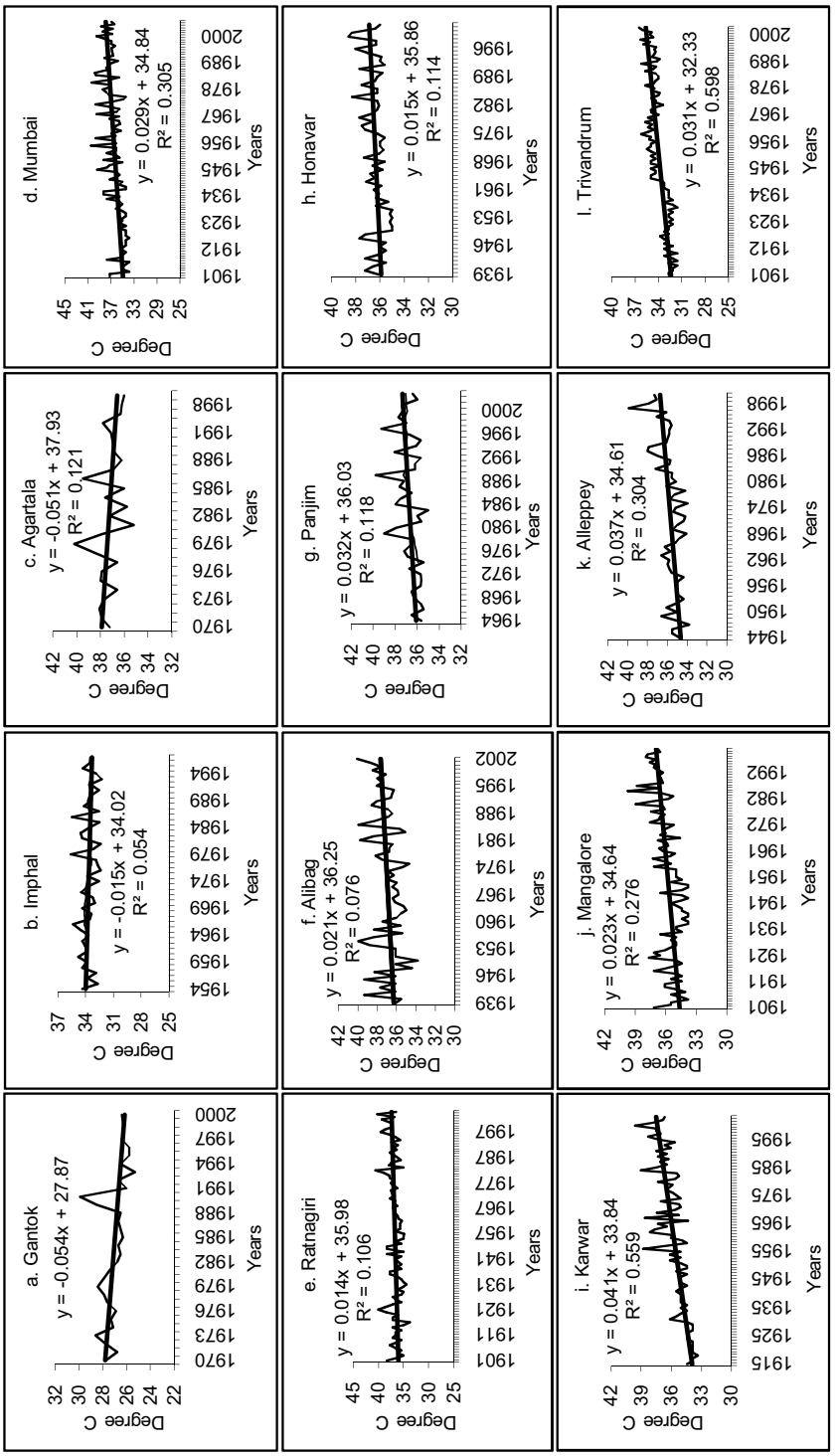

Figure 3. Annual maximum air temperature extremes (TXX) in NER and WCR

Table 4. Trends in WCR TXX (* Indicate ά=0.05% and ** ά=0.01% level)

Stations	Annual	Seasons			
		Winter	Summer	Monsoon	Post monsoon
Mumbai	+**	+**	+**	+	+**
Alibag	+*	+	+*	+**	+**
Harnai	+	+*	+	+*	+**
Ratnagiri	+**	+**	+**	+	+
Panjim	+*	+	+	+	+
Marmagoa	+	+**	–	+	+
Karwar	+**	+**	+**	+**	+**
Honavar	+*	+**	+**	+	+
Mangalore	+*	+**	+**	+	+**
Calicut	+	+**	+	+	+**
Cochin	+	+	+*	+	+
Alleppey	+**	+**	+**	+**	+**
Trivandrum	+**	+**	+**	+**	+**

The table indicates that Gangtok shows significant decrease in majority of the months except for April and May. Silchar also indicates decrease in TXX during ten months of the year which is significant in the months of January, February, April and December. Dhubri experiences significant increase in the TXX for six months of the year namely March, June to October. It is observed that six out of 11 stations reported significant increase in the month of November.

In summary, on annual basis none of the stations indicate significant increase in TXX but three stations show significant decrease. Post-monsoon season is very predominant when two stations each show significant increase/decrease. Gangtok reports significant decrease in TXX in majority of the months.

The results for the WCR are shown in Table 4 and illustrated in Figures 2 and 3 (d–l), which is self explanatory and indicates that significant increase in TXX at majority of the stations.

The seasonal trends (Tab. 4) indicates that significant increase in TXX is more pronounced during winter season where ten cities out of thirteen depict significant increase while during the monsoon season only five cities indicate significant increase. During summer and post monsoon seasons, again majority of the stations indicate significant increase in TXX. It is observed that almost all the stations with the exception of Marmagoa during summer show increase in TXX.

The monthly trends for TXX were analysed and the results are reported in Table 5.

The table indicates that Panjim, Karwar, Alleppey and Trivandrum showed increase in TXX significant at 99% level during all the months while Mumbai, Alibag and

Table 5. Monthly trends in WCR TXX (* Indicate ά=0.05% and ** ά=0.01% level)

Stations	Months												
	J	F	M	A	M	J	JY	A	S	O	N	D	AN
Mumbai	+**	+**	+**	+**	+**	+	+**	+**	+**	+**	+**	+**	+**
Alibag	+*	+	+	+**	+**	+**	+**	+**	+**	+**	+**	+**	+*
Harnai	+*	+	+	+	+	+*	+	+	+	+*	+*	+	+
Ratnagiri	+	+**	+**	+**	+**	+	+	+*	+**	+	+	+*	+**
Panjim	+**	+**	+**	+**	+**	+**	+**	+**	+**	+**	+**	+**	+*
Marmagoa	+	+*	–	+	+	–	+	+	+	–	+	+	+
Karwar	+**	+**	+**	+**	+**	+**	+**	+**	+**	+**	+**	+**	+**
Honavar	+*	+	+**	+**	+**	+	+	+	+**	+	+	+**	+*
Mangalore	+**	+**	+**	+**	+**	+**	+	+**	+**	+**	+**	+**	+*
Calicut	+**	+**	+**	+	+	+	+	+	+**	+*	+**	+**	+
Cochin	+	+	+	+	+	+*	+	+	+	+	+	+	+
Alleppey	+*	+**	+**	+**	+**	+**	+**	+**	+**	+**	+**	+**	+**
Trivandrum	+**	+**	+**	+**	+**	+**	+**	+**	+**	+**	+**	+**	+**

Mangalore indicate increase in TXX in majority of the months except June, February and March, and July, respectively. Marmagoa on the other hand report significant increase only in the month of February while the months March, June and October show decrease in TXX but not significant. Similar pattern is observed for Cochin where the increase in TXX is significant only in the month of June.

TRENDS IN ANNUAL MINIMUM EXTREMES

The result obtained for the trends in extreme minimum air temperature for the NER are reported in Table 6 and depicted in Figures 2 and 4.

When examined on the annual scale, 10 stations out of 13 indicate increase in TNN with significant trend only at four stations namely Dibrugarh, Gangtok, Shillong and Kailashahar. A significant decrease in this series is observed only at two stations namely Dhubri and Silchar. These significant trends are illustrated in Figure 4 (a–f).

The seasonal trends (Tab. 6) reveals that during the winter season, majority of the stations show increasing tend in TNN and significant change has been observed at Dibrugarh, Shillong and Kailashahar. While for Dhubri and Cherrapunjee indicates significant decreasing trend. In summer season, increase in TNN is observed over majority of the stations however it is significant only at Shillong. Tezpur and Dhubri on the other hand, indicate significant decrease in TNN. During the monsoon season, a mixed trend has been observed with Gangtok and Kailashahar having significant increase while Dhubri and Cherrapunjee show significant decrease in TNN. In the post monsoon season, majority of the stations show increasing trend significant at

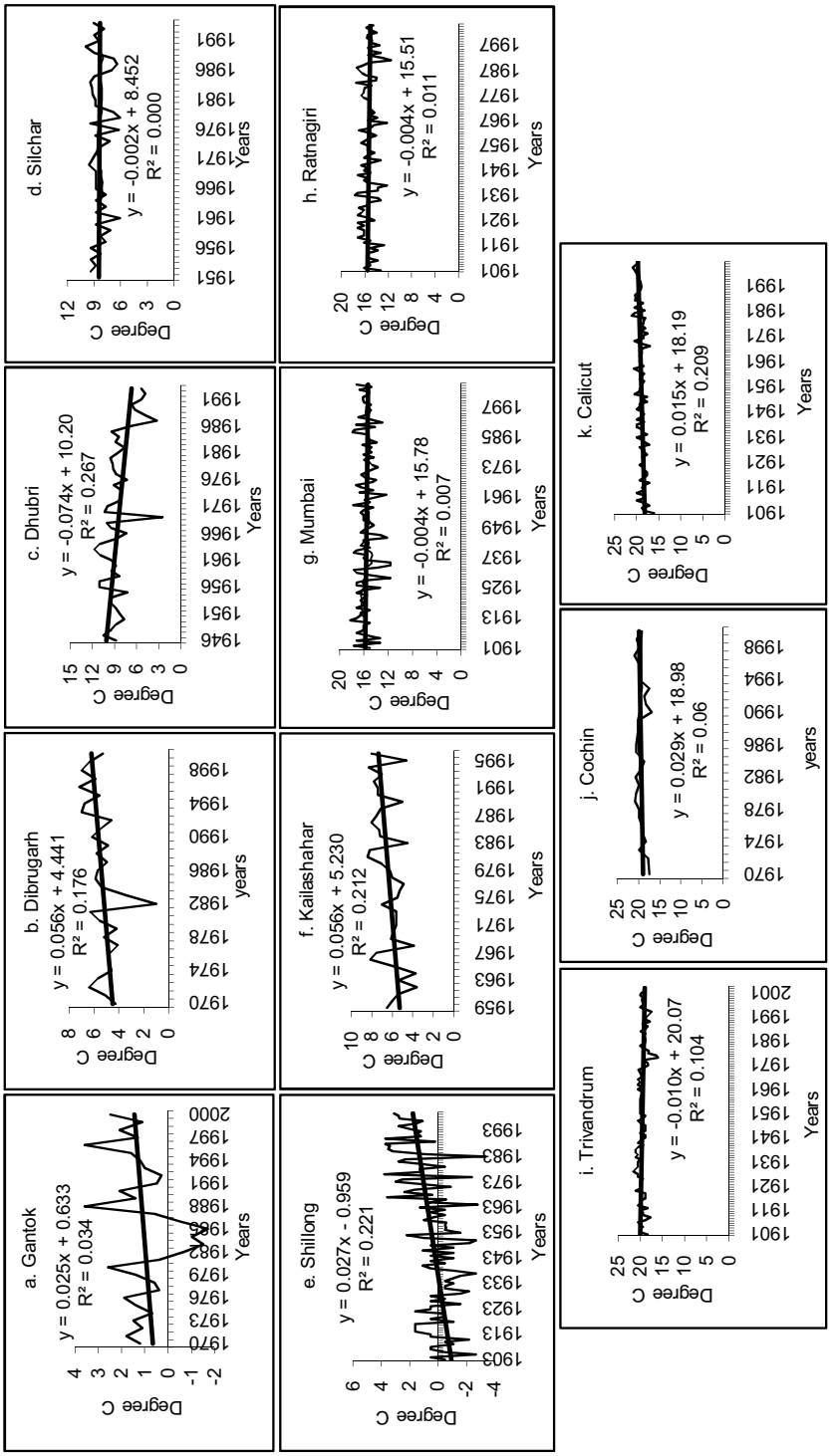

Figure 4. Annual minimum air temperature extremes (TNN) in NER and WCR

Table 6. Trends in NER TNN (* Indicate ά=0.05% and ** ά=0.01% level)

Stations	Annual	Seasons			
		Winter	Summer	Monsoon	Post monsoon
Pasighat	+	+	+	+	+
Dibrugarh	+**	+**	+	+	+**
Lakhimpur	+	+	+	–	+
Tezpur	+	+	–*	–	–
Guwahati	+	+	+	–	+**
Dhubri	–**	–**	–**	–**	–**
Silchar	–*	–	+	–	+
Gangtok	+*	+	+	+*	+*
Shillong	+**	+**	+**	–	+**
Cherrapunjee	–	–**	+	–*	–
Imphal	+	+	+	–	+
Kailashahar	+**	+**	+	+*	+*
Agartala	+	+	+	–	+

Dibrugarh, Guwahati, Gantok, Shillong and Kailashahar. On the other hand, a significant decreasing trend is observed at Dhubri. It is observed that closely spaced stations namely Kailashahar and Silchar show contrasting trends in annual TNN. Silchar show decrease in annual TNN due to decrease during winter and monsoon season while Kailashahar reported increase in annual TNN as a result of increase in all the seasons except monsoon season. Silchar is close to the southern tip of the Khasi-Jaintia hills and is flanked by Mizo and Manipur hills. This cold katabatic winds flowing in the night may cause lowering of the minimum temperature. Whereas, Kailashahar is on the south west of Silchar away from the Khasi-Jaintia hills and is on the plain of Indo-Bangladesh border and may not be influenced by the orography. The monthly trends are reported in Table 7.

The table indicates that the months January to June and November, December are marked by increase in the TNN for majority of the stations. Particularly, the stations Dibrugarh, Shillong, Imphal and Kailashahar indicate increase in TNN during the months January to March and from October to December. For Dibrugarh, the significant trends are observed during the months from October to December. At Shillong, it is from January to March and October to December, for Imphal; February and March while it is February, August and December for Kailashahar. During the months of July, August and September mixed trends are observed. Dhubri show decrease in TNN throughout all the months except June, this decrease is significant during February to April, July and October to December. Cherrapunjee and Silchar also indicate decrease in TNN in majority of the months except April and May for Cherrapunjee and February to May, November and December at Silchar.

Table 7. Monthly Trends in NER TNN (* Indicate ά=0.05% and ** ά=0.01% level)

Stations	Months												
	J	F	M	A	M	J	JY	A	S	O	N	D	AN
Pasighat	+	+	+	–	+	+	–	+	+	–	+	+	+
Dibrugarh	+	+**	+	+	+	+	+	+	+	+*	+**	+**	+**
Lakhimpur	+	+	+	+	–	+	+	+	–	+	+	+	+
Tezpur	+	+	–	–	–**	+	–	+	–*	–	+	–	+
Guwahati	+	+	+	+	+	+	–	–	–*	+	+*	+	+
Dhubri	–	–**	–**	–*	–	+	–**	–	–	–**	–**	–**	–**
Silchar	–	+	+	+	+	–*	–*	–	–	–	+	+	–*
Gantok	+	+	+	+	+	+	+	+*	+	+	+**	+	+*
Shillong	+**	+**	+**	+	+	+	+	+	+	+**	+**	+**	+**
Cherrapunjee	–**	–	–	+	+	–	–*	–**	–**	–	–	–	–
Imphal	+	+**	+**	+	–	+	–	–	–	–	+	+	+
Kailashahar	+*	+**	+	+	+	+	+	+*	+	+	+	+*	+**
Agartala	–	+*	+	–	–	+	+	–	–	–	+	+	+

Four stations show significant increase in annual TNN while two stations show significant decrease. Significant decrease in TNN is observed in all the seasons at Dhubri. Again post monsoon season stands out showing significant increase in five stations. Shillong and Gantok show increase in TNN during all the months.

The annual and seasonal trends in TNN for WCR are reported in Table 8 and only the significant trends are depicted in Figure 4 (g–k).

The table indicates that nine cities show increase in TNN however it is significantly only at Calicut and Cochin. Four cities on the other hand show decrease in TNN which is significant at Mumbai, Ratnagiri and Trivandrum.

The seasonal trends are indicated in Table 8, which indicates that in the winter season, significant increase is observed at Calicut and Cochin while Mumbai, Ratnagiri and Trivandrum reported significant decrease in TNN. During summer season, Mumbai, Ratnagiri and Trivandrum again depict significant decrease in TNN which is further continue during monsoon and post monsoon seasons while not a single station registers significant increase in TNN during summer season. Monsoon season is marked by significant increase in TNN for Harnai and Marmagoa. Whereas during post-monsoon season Karwar and Calicut show significant increase in TNN.

The monthly trends in respect of TNN extremes are reported in the following Table 9.

The above table revealed that Mumbai and Trivandrum indicate decrease in the TNN during majority of the months except February and November respectively. These trends are significant for all the months for Trivandrum and also for Mumbai except for the months of March and December. Ratnagiri and Mangalore show

decrease in TNN in majority of the months. However, significant decrease is observed during monsoon season at Ratnagiri. Calicut and Cochin on the other hand show increase in TNN in all the months except the months April and May for Calicut. Panjim also reported increase in TNN but not significant in any of the months.

Table 8. Trends in WCR TNN (* Indicate ά=0.05% and ** ά=0.01% level)

Stations	Annual	Seasons			
		Winter	Summer	Monsoon	Post monsoon
Mumbai	–**	–*	–**	–**	–*
Alibag	+	+	–	+	+
Harnai	+	+	+	+**	+
Ratnagiri	–*	–*	–*	–**	–
Panjim	+	+	+	+	+
Marmagoa	+	+	+	+*	+
Karwar	+	–	+	+	+**
Honavar	+	–	–	+	+
Mangalore	–	–	–	–	+
Calicut	+**	+**	+	+	+**
Cochin	+**	+**	+	+	+
Alleppey	+	+	–	+	+
Trivandrum	–**	–**	–**	–**	–*

Table 9. Monthly trends in WCR TNN (* Indicate ά=0.05% and ** ά=0.01% level)

Stations	Months												
	J	F	M	A	M	J	JY	A	S	O	N	D	A
Mumbai	–**	+	–	–**	–**	–**	–**	–**	–**	–**	–**	–	–**
Alibag	–	+	–	–*	–	+	+	+	+	–	+	+	+
Harnai	–	+	+	–	+	+	+*	+	–	–*	+	+	+
Ratnagiri	–**	+	–	–	–**	–**	–*	–*	–	–	+	–	–*
Panjim	+	+	+	–	+	+	+	+	+	+	+	+	+
Marmagoa	+	+	+	–*	+	+	+	+	+	–	+	+	+
Karwar	–	+	+	–*	–**	+	+	–	+	+	+*	+	+
Honavar	–	–	–	+	–	+	+	+	+*	+	+	+	+
Mangalore	–	–	–	–	–	+	–	–	–	–	–	+	–
Calicut	+**	+*	+	–	–**	+	+**	+	+	+	+	+**	+**
Cochin	+	+**	+	+	+	+	+	+	+	+	+	+	+**
Alleppey	+	+	+	–	–*	–	+	+	+	–	+	+	+
Trivandrum	–**	–**	–**	–**	–**	–*	–**	–**	–**	–**	+	–**	–**

CONCLUSIONS

The study helps us to draw the following conclusions which are summarized below.

In the NER, nine out of thirteen stations show increase in TXX but not significant on annual basis whereas four stations indicates decrease in annual TXX significant at Gangtok, Imphal and Agartala.

It is also observed that during monsoon season twelve stations indicates increasing trend in TXX but significant only at one station-Dhubri.

Ten stations indicate increase in annual TNN but significant only at four stations i.e. (Dibrugarh, Gangtok, Shillong and Kailashahar), while three stations reported decrease which is significant at Dhubri and Silchar. As far as seasons are concerned, majority of the stations indicate increasing trend except during the monsoon season in TNN, where it is significant at a few stations only.

Post-monsoon season is very predominant when five stations show significant increase in TNN.

Findings are similar with those of Vincent *et al.* (2005) where they reported that percentage of cold nights is decreasing while the percentage of warm nights is increasing. These changes are more pronounced during the summer and autumn. Further, Kothawale *et al.* (2010) found that hot nights have increased over all the regions in India with significant increase over North-West, East Coast and West Coast whereas cold nights have decreased significantly over Western Himalaya and North-East.

In the WCR, 9 out of 13 stations indicate significant increasing trend in annual TXX. Majority of the stations indicate significant increasing trend in all the seasons except monsoon season. Nine stations show increase in annual TNN however it is significant only at Calicut and Cochin while four cities on the other hand show decrease in TNN which is significant at Mumbai, Ratnagiri and Trivandrum.

Majority of the stations indicate increase during monsoon and post monsoon seasons in TNN but these are significant at few stations while winter and summer season reported mixed trend of increase/decrease.

The increase in extreme maximum temperature in WCR behaves similar with the global trends. Changes in the extremes of temperature are also consistent with the warming of the climate and increase in the number of warm extremes and a reduction in the number of cold extremes (IPCC 2007). The increase in summer extreme temperature confirms with finding of Revadekar *et al.* (2009) where they found that ENSO is associated with increase (decrease) in temperature extremes over the country during summer monsoon (northeast monsoon). In their study on extremes in surface temperature over south China Gong *et al.* (2004) reported that extreme maximum temperature has increased significantly. They found that large scale north western Pacific subtropical high plays an important role in the jump-like changes of the temperature extremes.

This research study is a unique and a rare of its kind as these two different distinct regions showing different temperature characteristics. The findings are complex and difficult as to what causes the warming trend over WCR in extreme maximum while for NER it is extreme minimum. These changes in extreme temperatures can be attributed partly to regional and local factors which in addition to the overall effect of global warming.

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