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Temperature patterns over Northeast and West Coast Regions of India

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Abstract. The study examines whether maximum/minimum temperature is responsible for a warming/cooling trend. In order to accomplish this, linear regression was used in temperature series such as mean (Tmean), maximum (Tmax), minimum (Tmin) and diurnal temperature range (DTR). A detailed analysis indicates that 11 out of 13 stations over the West Coast region (WCR) show a significant increase in annual Tmean as a result of an increase in annual Tmax. However, the Northeast region (NER) shows a mixed trend, with 6 stations displaying significant increases in annual Tmean and 2 showing significant decreases. Both these patterns can be ascribed to a decrease or increase either in Tmin or Tmax. In DTR, 85% of the stations over the WCR show a significant increasing trend, while 60% of stations in the NER display a significant decreasing trend. Analysis of meteorological parameters reveals that low/medium cloud, calm days, winds, forest cover and population growth influence Tmax/Tmin for the NER, whereas low cloud cover and wind direction have an influence over the WCR.

Key words:
trends,
diurnal range,
maximum,
minimum,
cloud cover

Introduction

Although global warming is perceived to be a universal phenomenon, many researchers have found contrasting results in urban climatic studies (Griffiths et al. 2005; Lim et al. 2005; Parker 2006; Ren et al. 2007; Fujibe 2009). Some studies indicate an increase in daily minimum temperatures (New et al. 2000; Jin and Dickinson 2002) while daily maximum temperatures have increased at a smaller rate, resulting in decreased diurnal temperature range. Mean temperatures (Tmean) have increased even in small towns in Japan (Schaefer and Domroes 2009) but Hansen et al. (2010) reported that urban influences are minute. It is believed that diurnal asymmetry in temperature trends has close links with changes in cloudiness, humidity, wind and soil moisture (IPCC 1990). Therefore, it is relevant to understand the changes in maximum temperature (Tmax) and minimum temperature (Tmin), as these would reflect in the diurnal temperature range (DTR) patterns. Makowski et al. (2008) reported that annual DTR reversed from a decrease to an increase during the 1970s in Western Europe and 1980s in Eastern Europe. They concluded that the DTR trend is due to changes in Greenhouse gas emission and incoming solar radiation. Zhou et al. (2010) analyse the trends and variability in Tmax, Tmin and DTR. The results show a reduction in DTR, suggesting the role of cloud cover, precipitation and soil moisture.

Indian researchers (Hingane et al. 1985; De and Prakasa Rao 2004; Kothawale and Rupa Kumar 2005) have studied temperature trends over the country and found that warming over India was solely related to maximum temperatures. Roy et al. (2007) found that surface temperatures over the Indian subcontinent were influenced by irrigation and agricultural activity. Dhorde et al. (2009) investigated land temperature trends in densely-populated cities in India, which show a positive change. Recently, Kothawale et al. (2010) examined annual Tmean, Tmax and Tmin, which showed significant increasing trends of 0.51°, 0.72° and 0.27°C, respectively, during the period 1901–2007. There is an increase in DTR during the period 1901–1987 as reported by Rupa Kumar et al. (1994), due to the increase in Tmax (0.6°C) and predominant during post-monsoon and winter seasons. However, Yadav et al. (2004) observed increase in DTR in the western Himalayas due to a decrease in Tmin and an increase in Tmax. Roy and Balling (2005) found an insignificant trend in DTR over the Deccan plateau in India. Rai et al. (2012) reported that in non-global (1901–1909 and 1946–1975) and global warming periods (1910–1945 and 1976 –2003), annual DTR increased in all seasons, with the largest increase in winter and the smallest in post-monsoon. Total cloud cover, along with precipitation and soil-moisture, are responsible for the increase in DTR.

In light of the above discussions, two vastly separated regions – the West Coast region (WCR) and the Northeast region (NER) of India (Figure 1) – have been selected to analyse aspects related to climate change in terms of global warming temperature patterns.

The two regions – the Northeast and the West Coast – both have rugged topography, and receive high rainfall (more than 250 cm) due to the orographic effect. However, there is also a dissimilarity; the WCR is influenced by the sea, while the NER is far away from oceanic influences. More than 80% of annual rainfall over the WCR is concentrated into the southwest monsoon, while, for the NER, 25% occurs during March to May and 65% during the southwest monsoon. The WCR, because of its proximity to the Arabian Sea, experiences less seasonal contrast in temperature, whereas, due to changes in relief, there is a variation in temperature and rainfall over the NER.

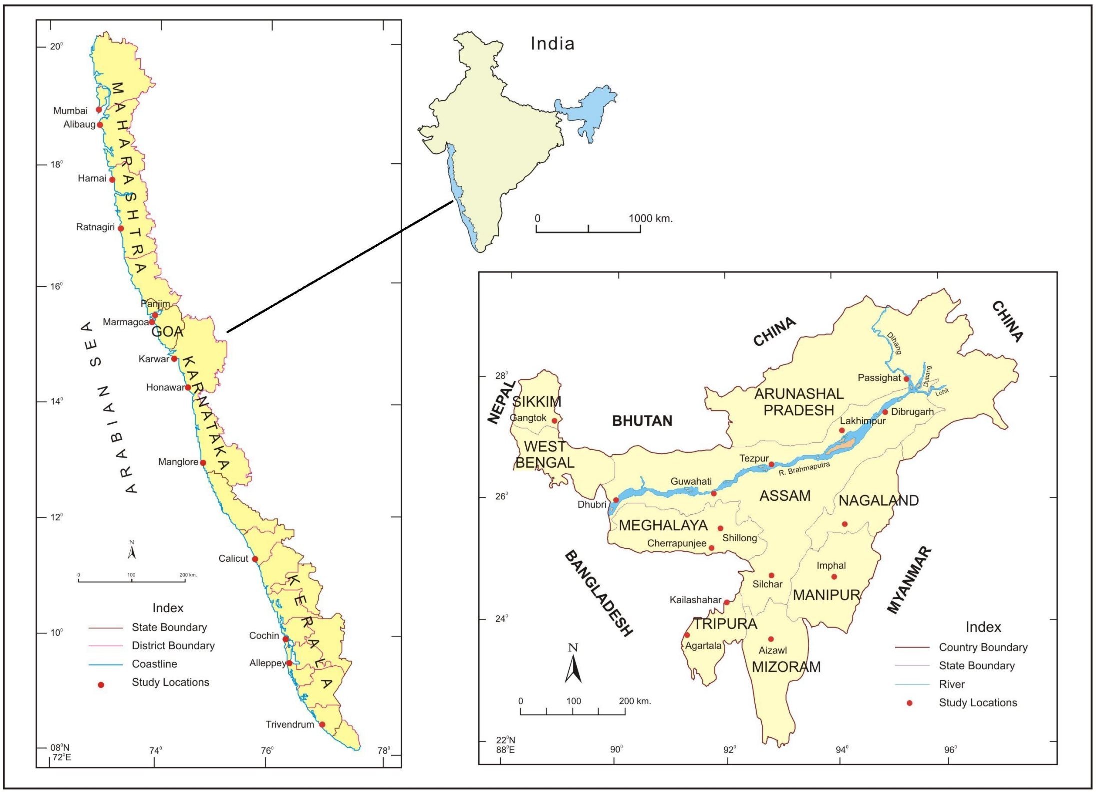

Fig.1. Study areas

Many researchers in India have investigated air temperature trends on spatial (country, homogenous region, regional, state or station) and temporal scales (century, 50 years, annual, seasonal, monthly and daily). However, this study is carried out based on political boundary and homogeneity in climatic phenomena. It analyses intra- and inter-regional differences in climate parameters.

Data and methods

Temperature variables, such as Tmean, Tmax, Tmin and DTR for 26 stations (Table 1) for the period 1901–2010 have been analysed in this study. It was not possible to obtain the meteorological data for other stations for the same period, because of data inadequacy.

Annual and seasonal time series were prepared from the monthly values. Low cloud (LC) and medium cloud (MC) amount in oktas, and wind data (viz., number of days with the wind coming from different directions) recorded at 0300 UTC and 1200 UTC during the period ranging from 1951 to 2006 were used for this study. The meteorological data was obtained from National Data Centre (NDC), India Meteorological Department (IMD) Pune, India. Apart from meteorological data, population data (1901–2011) published by the government of India (Census 2001 and 2011) was used for comparison and referencing purposes.

The month-wise temperature values pertaining to winter (January–February), pre-monsoon/summer (March–May), monsoon (June–September), post-monsoon (October–December) and annual values were calculated for each station. The seasons were based on the IMD classification. To determine the significance of trend, linear regression was used and time series graphs were plotted for the entire period. The trends are tested at 0.05 and 0.01 level of confidence.

Results

Annual and seasonal temperature trends

The trends for annual and seasonal temperatures were worked out and indicated in Table 2 below.

The results reveal that, in the NER, 70% of the stations (10 out of 13) show an increase in annual Tmean. The increase is significant at 9 stations (Pasighat, Dibrugarh, Lakhimpur, Guwahati, Shillong, Cherrapunjee, Imphal, Kailashahar and Agartala) with one station showing a significant decrease (Silchar). The decrease in annual Tmean in Silchar can also be attributed to the shortest data range. As far as seasons are concerned, Dibrugarh, Lakhimpur, Guwahati and Imphal show an increasing trend in Tmean in all the seasons, while Pasighat, Shillong, Cherrapunjee, Kailashahar and Agartala show a significant increasing trend in most of the seasons.

Table 1. Meteorological stations, with data period

NER	Data period	Elevation (m a.s.l.)	WCR	Data period	Elevation (m a.s.l.)
Pasighat	1957-2010	157	Mumbai	1901-2009	11
Dibrugarh	1970-2010	111	Alibag	1939-2008	7
Lakhimpur	1954-2010	102	Harnai	1970-2008	20
Tezpur	1940-2010	79	Ratnagiri	1901-2008	67
Guwahati	1903-2010	54	Panjim	1964-2010	60
Dhubri	1946-2010	35	Marmagoa	1970-2010	62
Silchar	1951-1993	29	Karwar	1915-2010	4
Gangtok	1970-2009	1812	Honavar	1939-2001	26
Shillong	1903-2010	1500	Mangalore	1901-2010	22
Cherrapunjee	1903-2010	1313	Calicut	1901-2010	5
Imphal	1954-2010	781	Cochin	1970-2010	3
Kailashahar	1959-2008	29	Alleppey	1944-2010	4
Agartala	1953-2007	16	Trivandrum	1901-2010	64

Source: Climatological Tables 1951–80, IMD, Pune

However, Agartala shows a significantly decreasing trend during the winter season.

The significant increase in Tmean is due to the effect of the increase in Tmin at Pasighat, Dibrugarh, Lakhimpur, Guwahati, Imphal, Gangtok, Shillong and Kailashahar across all the seasons. Agartala shows a significant increase in Tmin in all seasons except summer. However, Tmean values in Guwahati, Cherrapunjee and Imphal are also influenced by a significant increase in Tmax across all seasons. Stations like Dibrugarh and Lakhimpur show a significant increase in Tmax too, but not in all seasons. The significant decrease of Tmean in Silchar is due to a significant decrease in Tmax during the winter and pre-monsoon seasons. It is observed that the significant decrease in annual Tmax in Gangtok can be attributed to all the seasons except winter, while a mixed trend is reported at Dhubri, Kailashahar and Agartala.

From analysis, the significant increase in Tmean at nine stations seems to be influenced by Tmin, and not by Tmax. The above findings show a similarity with Kothawale et al. (2010), which reported significant warming during the winter and post-monsoon seasons. It is interesting to note that, though Gangtok does not show any significant trend in annual Tmean, it shows significant decreases and increases in Tmax and Tmin, respectively, in all seasons. The significant trend in Tmax/Tmin in Gangtok is similar to that of Gupta and Das (2006).

In the WCR, all stations show a significant increase in the annual Tmean. The same pattern is observed in Tmax. The results are reported in Table 2. However, the annual Tmin portrays a different picture, wherein four and six stations indicate significant decreases and increases, respectively, which influence Tmean. The significant increase in Tmean can be attributed to a significant increase in Tmax. 80% of the stations show a significant increase in Tmax, while only 46% stations display a significant increase in Tmin. The Mumbai, Ratnagiri, Alleppey and Trivandrum stations show a significant decrease in annual Tmin. However, in spite of this decrease in Tmin, annual Tmean shows a significant increase. The significant increase in Tmax in the majority of stations concurs with the findings of Dash et al. 2007. It is observed that Panjim, Marmagoa, Karwar, Honavar, Calicut and Cochin show significant increases in Tmin.

The significant increase across all seasons in Tmean at Mumbai, Alibag, Karwar, Mangalore, Calicut and Trivandrum is due to the significant increase in Tmax. The remaining stations show a significant seasonal increase in Tmean, except pre-monsoon. This pattern is also reflected in Tmax, apart from at Marmagoa and Panjim. In Tmin, the stations at Mumbai, Ratnagiri, Alleppey and Cochin show decreases, while significant increases are reported at Panjim, Marmagoa, Karwar, Honavar, Calicut and Cochin, although, as far as season-wise significance is concerned, these stations show mixed results.

In conclusion, more than 80% of the stations show significant warming in the Tmean during winter, monsoon and post monsoon seasons due to significant increase in Tmax.

Annual and seasonal trends of nean nonthly DTR

The trend patterns of DTR and the rate of change per year in respect of these stations is shown in Table 3.

The annual DTR in the NER (Table 3) exhibits an increasing trend at four stations, but this is significant only at one station, i.e. Cherrapunjee. This can be attributed to a decrease in the annual Tmin and significant increase in annual Tmax. Of the remaining nine stations, a significant decrease is observed at eight stations, namely, Pasighat, Dibrugarh, Guwahati, Silchar, Gangtok, Shillong, Kailashahar and Agartala. It is observed that the decrease in DTR at Pasighat, Dibrugarh, Shillong, Kailashahar and Agartala is attributed to an increase in annual Tmin. For Silchar, it is due to a significant decrease in Tmax, while for Gangtok it is attributed to a significant decrease in Tmax and increase in Tmin.

As far as seasonal trends are concerned; Dibrugarh, Guwahati, Shillong and Kailashahar show a significant decrease in DTR during all seasons because of the significant increase in Tmin. There is a significant decrease in DTR at Pasighat and Agartala during all seasons except winter at Pasighat and monsoon at Agartala. For Pasighat and Agartala, the decrease is due to the increase in Tmin. At Silchar, there is a significant decrease in all the seasons due to the significant decrease in Tmax, except during the monsoon season. Furthermore, Gangtok shows a significant decrease in all seasons due to a significant decrease in Tmax and an increase in Tmin. For Cherrapunjee, the significant increase is due to a significant increase in Tmax during all seasons.

Thus, it can be said that stations experiencing a decrease in DTR, both on the annual and seasonal scale, outnumber those reporting an increase. Tmin is increasing at a faster rate than Tmax, leading to an decrease in the DTR for the NER. This is comparable with the findings of Jhajhariaa and Singh 2010 on the DTR trends in Assam.

In the WCR, twelve stations show an increasing trend in annual DTR, significant at Mumbai, Alibag, Harnai, Ratnagiri, Panjim, Karwar, Honavar, Mangalore, Calicut, Alleppey and Trivandrum (Table 3). This can be ascribed to the significant increase in annual Tmax. At Mumbai, Ratnagiri, Alleppey and Trivandrum, in addition to the increase in Tmax, Tmin also decreases significantly, thereby resulting in an increase in DTR.

As far as seasonal trends in DTR are concerned, there is a significant increase in all seasons at Mumbai, Alibag, Harnai, Ratnagiri, Karwar, Honavar, Mangalore, Calicut, Alleppey and Trivandrum, due to a significant increase in Tmax. However for Mumbai, Ratnagiri, Alleppey and Trivandrum it is also attributed to a significant decrease in Tmin in most seasons. On the other hand, for Panjim, Karwar and Calicut, it is also attributed to a significant increase in Tmax.

In the WCR, the majority of stations reveal a significant increasing trend in DTR due to the faster rate of increase of the Tmax trend. The trend in DTR behaves in accordance with that of all India (Kothawale and Rupa Kumar 2005). This is one of the most important changes in climatic parameters over the WCR.

Temperatures in relation with other meteorological parameters

Temperatures are generally considered to be influenced by other parameters such as cloud cover, rainfall and wind, of which cloud cover is the major concern. Therefore, in the following paragraphs, apart from the analysis of cloud, difference in wind direction, rainfall, population data, forest cover, wetlands and topography have all been dealt with to support the temperature trends. Observations show that, over many continental regions, there was a general increase in cloud cover between the 1950s and 1990 (IPCC 2001), while geographic distribution shows a decrease in the amount of optically thick cloud occurring in the extratropics (Marchand 2013). Groisman et al. (2004) and Dai et al. (2006) reported an increase in total cloud amounts over the United States. Endo and Yasunari (2006) found a decreasing frequency in cumulus clouds over eastern China in spring, summer and autumn. In fact, Qian et al. (2006) reported that long-term reductions in total and low-level cloud cover accompanied a long-term decline in solar flux over China. Time series of total cloud cover show a large decrease for South America, small decreases for Eurasia and Africa, and no trend for North America (Warren and Eastman 2007). From 1981 to 2006, the rate of dimming is twice as large during cloudy conditions as compared during clear sky conditions (Padma Kumari and Goswami 2010).

Bearing this in mind, it is pertinent to analyse and understand how the above parameters affect the Tmin/Tmax using 13 stations each from NER and WCR. The trends in Tmin/Tmax and low/medium cloud (LC/MC) amount are reported in Table 4 in respect of all the stations. They are discussed below.

In the NER, Tmin shows a significant increasing trend at Pasighat, Dibrugarh, Lakhimpur, Guwahati, Gangtok, Shillong, Imphal, Kailashahar and Agartala. However, the significant rise is not supported by the Low or Medium Cloud (LC/MC) amount, except at Pasighat, Guwahati, Shillong and Agartala (from 1970 onwards). Furthermore, the significant increase in Tmax at Pasighat, Dibrugarh, Lakhimpur, Guwahati, Cherrapunjee and Imphal is due to the decrease in cloud amount at Pasighat, Lakhimpur, Guwahati, Cherrapunjee and Imphal. In Tmin, the rate of change per year varies from 0.001 to 0.011 oktas/year while in Tmax it varies from -0.001 to -0.014 oktas/year.

During all seasons, the significant rise in Tmin is supported by the increase in Low or Medium Cloud (LC/MC) amount, where the rate of change varies from 0.001 to 0.018 oktas/year. In Tmax, the significant increase is attributed to the decrease in LC/

MC amount, which varies from -0.001 to -0.024 oktas/year. It is observed that, during all seasons, Tmax is supported by the trend in cloud amount in the majority of stations. However, the significant rise in Tmin is not supported by the trend in cloud amount. So, population data was used to infer the changes in Tmin as it plays an important role in influencing the trend. In the NER, the analysis of population data (1901–2011) indicates exponential growth at Dibrugarh $y=7526e^{0.275x}$, Lakhimpur $y=913.3e^{0.355x}$, Kailashahar $y=6886e^{0.214x}$, Guwahati $y=4349.e^{0.470x}$, Shillong $y=6861e^{0.349x}$, Agartala $y=3251e^{0.382x}$, Imphal $y=55409e^{0.122x}$. The fact is that, even though smaller in population than the cities in the WCR, the towns in the NER have an influence on Tmin.

It is a well-known fact that topography plays an important role in influencing Tmin, for which reason it was assessed. The Guwahati, Shillong and Imphal stations are either surrounded by – or located on the leeward side of – mountain ranges. The mountains block the flow of wind and lead to a rise in Tmin. To support the change in minimum temperature, the percentage numbers of calm days (mean value) published by IMD were used. Thus, in the morning hours the percentages of calm days (absence of wind) (38%, 64% and 55%, respectively) are higher at those stations, leading to the rise in Tmin. The same pattern is also observed at Pasighat (33%), Dibrugarh (40%), Lakhimpur (29%), Gangtok (72%), Kailashahar (34%) and Agartala (26%).

For Shillong, the significant increase in annual Tmin is supported by an increase in the LC amount

Table 2. Temperature trends in NER and WCR (R^2 linear trend coefficients)

Stations	**Annual**		
Parameter	**Tmean**	**Tmax**	**Tmin**
	NER		
Pasighat	0.21**	0.06*	0.24**
Dibrugarh	0.46**	0.14**	0.66**
Lakhimpur	0.43**	0.40**	0.20**
Tezpur	no trend	no trend	no trend
Guwahati	0.21**	0.08**	0.21**
Dhubri	no trend	0.01	**0.02**
Silchar	**0.20****	**0.12****	no trend
Gangtok	0.06	**0.19****	0.28**
Shillong	0.28**	no trend	0.50**
Cherrapunjee	0.05**	0.37**	**0.02**
Imphal	0.49**	0.50**	0.25**
Kailashahar	0.30**	0.01	0.46**
Agartala	0.10**	no trend	0.17**
	WCR		
Mumbai	0.36**	0.71**	**0.02***
Alibag	0.47**	0.76**	0.01
Harnai	0.19**	0.51**	no trend
Ratnagiri	0.22**	0.56**	**0.03***
Panjim	0.31**	0.44**	0.09*
Marmagoa	0.22**	0.27**	0.11*
Karwar	0.64**	0.70**	0.27**
Honavar	0.29**	0.37**	0.08**
Mangalore	0.34**	0.49**	no trend
Calicut	0.54**	0.45**	0.46**
Cochin	0.20**	0.13**	0.21**
Alleppey	0.04*	0.33**	**0.09****
Trivandrum	0.69**	0.83**	**0.11****

Table 2. cont.

Stations	Winter			Summer		
Parameter	Tmean	Tmax	Tmin	Tmean	Tmax	Tmin
			NER			
Pasighat	0.14**	0.08*	0.15**	0.03	no trend	0.15**
Dibrugarh	0.39**	0.11*	0.49**	0.13**	no trend	0.55**
Lakhimpur	0.30**	0.19**	0.11**	0.13**	0.05*	0.13**
Tezpur	no trend	no trend	no trend	no trend	no trend	no trend
Guwahati	0.10**	0.04*	0.08**	0.09**	0.03*	0.14**
Dhubri	**0.10****	**0.09****	**0.02**	no trend	no trend	**0.01**
Silchar	**0.18****	**0.16****	no trend	**0.18****	**0.18****	no trend
Gangtok	0.07*	**0.01**	0.29**	0.01	**0.20****	0.23**
Shillong	0.15**	**0.01**	0.33**	0.03*	no trend	0.08**
Cherrapunjee	no trend	0.12**	**0.04***	0.03*	0.17**	no trend
Imphal	0.48**	0.32**	0.24**	0.17**	0.02	0.20**
Kailashahar	0.15**	no trend	0.38**	0.02	**0.02**	0.18**
Agartala	0.01	**0.05***	0.12**	**0.08***	**0.22****	no trend
			WCR			
Mumbai	0.12**	0.41**	**0.03***	0.11**	0.32**	no trend
Alibag	0.06*	0.25**	no trend	0.21**	0.51**	no trend
Harnai	0.09*	0.17**	0.01	no trend	0.09*	0.007
Ratnagiri	0.12**	0.41**	**0.08****	0.07**	0.35**	**0.03***
Panjim	0.35**	0.36**	0.11**	0.05	0.18**	no trend
Marmagoa	0.23**	0.22**	0.15**	0.02	0.08*	no trend
Karwar	0.43**	0.54**	0.02*	0.33**	0.43**	0.08**
Honavar	0.10**	0.26**	no trend	0.02	0.13**	0.02
Mangalore	0.38**	0.47**	no trend	0.09**	0.27**	**0.07****
Calicut	0.46**	0.45**	0.31**	0.33**	0.29**	0.27**
Cochin	0.17**	0.05	0.22**	0.04	0.04	0.03
Alleppey	0.05*	0.25**	**0.01**	no trend	0.16**	**0.11****
Trivandrum	0.36**	0.72**	0.11**	0.43**	0.75**	**0.13****
	Monsoon			Post-monsoon		
			NER			
Pasighat	0.08*	no trend	0.20**	0.12**	0.04	0.15**
Dibrugarh	0.18**	0.01	0.53**	0.37**	0.23**	0.33**
Lakhimpur	0.30**	0.31	0.08*	0.37**	0.27	0.21**
Tezpur	no trend	no trend	no trend	no trend	no trend	no trend
Guwahati	0.08**	0.03*	0.08**	0.23**	0.06**	0.25**
Dhubri	0.21**	0.36**	no trend	**0.07***	no trend	**0.04**
Silchar	**0.06**	no trend	**0.02**	**0.08**	0.10*	no trend
Gangtok	0.10*	**0.16****	0.24**	0.03	**0.12***	0.25**
Shillong	no trend	no trend	no trend	0.40**	no trend	0.55**
Cherrapunjee	0.01	0.16**	**0.01**	0.09**	0.40**	**0.02**
Imphal	0.38**	0.58**	0.11**	0.41**	0.47**	0.17**
Kailashahar	0.27**	0.14**	0.24**	0.40**	0.13**	0.41**
Agartala	0.28**	0.34**	0.13**	0.31**	0.15**	0.26**

Table 2. cont.

	Tmean	Tmax	Tmin	Tmean	Tmax	Tmin
			WCR			
Mumbai	0.10**	0.35**	**0.01**	0.36**	0.68**	no trend
Alibag	0.42**	0.61**	0.05*	0.28**	0.52**	0.01
Harnai	0.10*	0.39**	no trend	0.22**	0.35**	0.02
Ratnagiri	0.02	0.12**	**0.01**	0.16**	0.39**	no trend
Panjim	0.22**	0.26**	0.09*	0.09*	0.13**	0.03
Marmagoa	0.22**	0.23**	0.17**	0.01	no trend	0.03
Karwar	0.55**	0.62**	0.25**	0.62**	0.71**	0.22**
Honavar	0.18**	0.15**	0.14**	0.29**	0.26**	0.16**
Mangalore	0.12**	0.29**	no trend	0.36**	0.51**	no trend
Calicut	0.34**	0.31**	0.19**	0.47**	0.40**	0.32**
Cochin	0.24**	0.24**	0.14**	0.05	0.01	0.10*
Alleppey	no trend	0.12**	**0.06***	0.12*	0.41**	**0.07***
Trivandrum	0.57**	0.76**	**0.03***	0.71**	0.80**	0.01

* 0.05; ** 0.01 - trends statistically significant, bold - downward trends

Table 3: DTR trends in NER and WCR (R^2 linear trend coefficients)

Stations	Annual	Winter	Summer	Monsoon	Post-monsoon
			NER		
Pasighat	**0.101***	0.002	**0.125****	**0.16****	**0.019**
Dibrugarh	**0.346****	**0.055**	**0.208****	**0.177****	**0.064***
Lakhimpur	0.018	0.029	**0.001**	0.08*	**0.001**
Tezpur	**0.002**	**0.004**	0.004	no trend	**0.023**
Guwahati	**0.032***	**0.005**	**0.004**	**0.011**	**0.069****
Dhubri	0.027	**0.001**	0.01	0.182**	0.015
Silchar	**0.092***	**0.179***	**0.133***	no trend	**0.099***
Gangtok	**0.515****	**0.357****	**0.56****	**0.359****	**0.47****
Shillong	**0.464****	**0.343****	**0.082****	no trend	**0.569****
Cherrapunjee	0.298**	0.323**	0.154**	0.15**	0.322**
Imphal	no trend	0.014	**0.06***	0.043	no trend
Kailashahar	**0.363****	**0.355****	**0.22****	**0.06***	**0.229****
Agartala	**0.18****	**0.214****	**0.147****	0.002	**0.086****
			WCR		
Mumbai	0.739**	0.6**	0.564**	0.48**	0.691**
Alibag	0.763**	0.373**	0.76**	0.721**	0.364**
Harnai	0.201**	0.05	0.128*	0.111*	0.201**
Ratnagiri	0.554**	0.485**	0.519**	0.279**	0.279**
Panjim	0.196**	0.06*	0.231	0.109*	0.012
Marmagoa	0.064	0.029	0.116*	0.138**	**0.036**
Karwar	0.528**	0.351**	0.321**	0.446**	0.304**
Honavar	0.174**	0.09*	0.306**	0.025	0.004
Mangalore	0.405**	0.317**	0.326**	0.245**	0.359**
Calicut	0.158**	0.061**	0.081**	0.189**	0.111**
Cochin	1.00E-05	**0.142****	0.009	0.104*	**0.016**
Alleppey	0.464**	0.292**	0.387**	0.219**	0.456**
Trivandrum	0.787**	0.74**	0.744**	0.73**	0.735**

* 0.05; ** 0.01 - trends statistically significant, bold - downward trends

Table 4: Trends in cloud amount in NER and WCR (Slope value)

	03 UTC		12 UTC			03 UTC		12 UTC	
Annual	**Tmin**	**LC/MC**	**Tmax**	**LC/MC**	**Annual**	**Tmin**	**LC/MC**	**Tmax**	**LC/MC**
			NER				**WCR**		
Pasighat	+**	0.001	+*	-0.001	Mumbai	-*	-0.019	+**	-0.015
Dibrugarh	+**		+**		Alibag	+		+**	
Lakhimpur	+**		+**	-0.002	Harnai	+		+**	
Tezpur	+		-		Ratnagiri	-*	NA	+**	NA
Guwahati	+**	0.011	+**	-0.007	Panjim	+*		+**	-0.010
Dhubri	-		+		Marmagoa	+*		+**	-0.000
Silchar	-		-**		Karwar	+**	0.001	+**	-0.014
Gangtok	+**		-**		Honavar	+**	0.001	+**	-0.010
Shillong	+**	0.009	-		Mangalore	-		+**	-0.017
Cherrapunjee	-		+**	-0.014	Calicut	+**	0.000	+**	-0.032
Imphal	+**		+**	-0.001	Cochin	+**	0.001	+**	
Kailashahar	+**		+		Alleppey	-**	-0.03	+**	-0.036
Agartala	+**	0.003	no trend		Trivandrum	-**	no trend	+**	-0.001
					Winter				
Pasighat	+**		+*	-0.005	Mumbai	-*	-0.002	+**	-0.000
Dibrugarh	+**		+*		Alibag	-		+**	-0.008
Lakhimpur	+**	0.001	+**	-0.002	Harnai	+		+**	
Tezpur	-		-		Ratnagiri	-**	NA	+**	NA
Guwahati	+**	0.014	+*	-0.002	Panjim	+**		+**	-0.008
Dhubri	-		-**		Marmagoa	+**		+**	-0.001
Silchar	+		-**		Karwar	+*	0.001	+**	-0.019
Gangtok	+**		-		Honavar	+		+**	-0.011
Shillong	+**	0.004	-		Mangalore	-		+**	-0.004
Cherrapunjee	-*	-0.006	+**	-0.018	Calicut	+**	0.002	+**	-0.034
Imphal	+**		+**	-0.002	Cochin	+**	0.000	+	
Kailashahar	+**		-		Alleppey	-		+**	-0.039
Agartala	+**		-*	0.002	Trivandrum	-**	no trend	+**	no trend
					Summer				
Pasighat	+**	0.002	-		Mumbai	-		+**	-0.006
Dibrugarh	+**		+		Alibag	+		+**	-0.007
Lakhimpur	+**		+*	-0.001	Harnai	-		+*	
Tezpur	-		+		Ratnagiri	-*	NA	+**	NA
Guwahati	+**	0.012	+*	-0.003	Panjim	+		+**	-0.009
Dhubri	-		+		Marmagoa	-		+*	-0.000
Silchar	-		-**		Karwar	+**	0.004	+**	-0.015
Gangtok	+**		-**		Honavar	-		+**	-0.011
Shillong	+**	0.007	+		Mangalore	-**	-0.001	+**	-0.013
Cherrapunjee	-		+**	-0.014	Calicut	+**	0.000	+**	-0.035
Imphal	+**	0.001	+		Cochin	+		+	
Kailashahar	+**		-		Alleppey	-**	-0.034	+**	-0.036
Agartala	+		-**	0.002	Trivandrum	-**	no trend	+**	-0.009

Table 4. cont.

Monsoon									
Pasighat	+**	0.001	+		Mumbai	-		+**	-0.037
Dibrugarh	+**	2E-05	+		Alibag	+*	0.000	+**	-0.007
Lakhimpur	+*		+		Harnai	+		+**	
Tezpur	-		-		Ratnagiri	-	NA	+**	NA
Guwahati	+**	0.018	+*	-0.003	Panjim	+*		+**	-0.013
Dhubri	+		+**	-0.021	Marmagoa	+**	0.001	+**	-0.001
Silchar	-		-		Karwar	+**	0.001	+**	-0.013
Gangtok	+**		-**	NPLC	Honavar	+**	0.004	+**	-0.012
Shillong	+		+		Mangalore	no trend		+**	-0.028
Cherrapunjee	-		+**	-0.012	Calicut	+**	0.003	+**	-0.029
Imphal	+**		+**	-0.002	Cochin	+**		+**	
Kailashahar	+**		+**	-0.003	Alleppey	-*	-0.025	+**	-0.035
Agartala	+**	0.002	+**	-0.001	Trivandrum	-*	no trend	+**	-0.000
Post-monsoon									
Pasighat	+**	0.002	+		Mumbai	-		+**	-0.005
Dibrugarh	+**	0.002	+**	0.007	Alibag	+		+**	-0.007
Lakhimpur	+**		+		Harnai	+		+**	
Tezpur	+		-		Ratnagiri	+		+**	NA
Guwahati	+**	0.003	+**	0.010	Panjim	+		+**	-0.009
Dhubri	-		-		Marmagoa	+		+	
Silchar	-		-*		Karwar	+**	0.004	+**	-0.012
Gangtok	+**		-*		Honavar	+**	0.000	+**	-0.007
Shillong	+**	0.007	-		Mangalore	+		+**	-0.011
Cherrapunjee	-		+**	-0.024	Calicut	+**	0.000	+**	-0.032
Imphal	+**		+**	-0.003	Cochin	+*	0.000	+	
Kailashahar	+**	LCTC	+**		Alleppey	-*	-0.030	+**	-0.036
Agartala	+**	0.005	+**	-0.001	Trivandrum	-		+**	-0.000

Note: NA - not available, * 0.05; ** 0.01 - trends statistically significant, significant trend, NPLC - not possible to use, LC/MC - low clouds/medium clouds.

(0.009 oktas/year). The same pattern is observed during all seasons (0.004 to 0.007 oktas/year) except monsoon. Silchar witnessed a significant decreasing trend in annual Tmax due to a decrease during the winter and summer seasons. The significant decrease in Tmax during the winter season is influenced by an increase in rainfall (y=0.973x + 41.19). The significant decrease in summer Tmax can be attributed to the presence of 340 wetlands (7,188 hectares) which helps in cooling (albedo effect). Apart from this, 59% (Forest Survey of India 2011) of the land is covered by forest. Thus, there is a significant decrease in Tmax. This further confirms the role of land-use patterns and changes in moderating the temperatures, as observed in an earlier study. Wetland and forest cover average data for Silchar was estimated by the Assam Remote Sensing Application Centre and the Forest Survey of India. Such a decrease is corroborated by the findings of Chhabra et al. (1997), wherein a significant fall in seasonal and annual Tmax is reported. Gangtok reported a significant increasing trend in annual Tmin due to increases during the summer, monsoon and post-monsoon seasons. The significant increase in Tmin in all seasons could be attributed to the increase ($y=2574e^{0.478x}$) in population during the period 1951–2001. However, the significant decrease in annual Tmax is due to the decrease across all seasons. This can be ascribed to the increase (y=25.86x + 2908) in forest cover (Forest Survey of India 2005). In the NER, warming is detected even in small towns. Thus, the patterns of temperature in the NER are influenced by clouds, calm days, rainfall, winds, forest cover, population and topography, etc.

In the WCR, four stations (Mumbai, Ratnagiri, Alleppey and Trivandrum) out of thirteen show a decrease in annual Tmin which is significant at 0.01 level. The significant decrease can be attributed to the decrease in the LC amount (0.000 to -0.019 oktas/year). The same trend is observed in Tmin during all seasons; the decrease in LC ranges from -0.001 to -0.034 oktas/year. There is also a significant increase in annual Tmax in all the thirteen stations, which can be attributed to a decrease in LC amount (0.000 to -0.036 oktas/year). It is also observed that in all seasons the majority of stations reported a significant increase in Tmax as a result of a significant decrease in LC amount (0.000 to -0.039 oktas/year). But for the Ratnagiri station the cloud data are not available, while for Alibag, Harnai and Cochin, the trend in Tmax is not supported by the cloud amount.

In their studies on total amount of cloud (Rao et al. 2004) reported a decreasing trend in 11 stations, of which 5 are significant, including Mumbai. However, for Trivandrum, though Tmin shows a significant decrease in all the seasons, it is not supported by the cloud amount.

In order to find the causative factor, wind frequencies were analysed and trend lines were drawn. The predominant direction for wind at Trivandrum during winter is northerly and northeasterly; during summer it is easterly and northerly, whereas in monsoon it is north-westerly and westerly. There is an increasing trend in frequency of wind direction during winter (y=0.074x + 3.744), summer (y=0.040x + 4.678) and monsoon (y=0.296x + 21.45), respectively, along with the mean wind speed (y=0.032x + 5.418). Therefore, the significant decrease in annual Tmin and all the seasons is supported by significant increases in frequency of wind and mean wind speed. Similarly, the significant increase in Tmax during winter at Trivandrum can also be supported by significant decrease in mean wind speed (y=-0.075x + 8.143) and frequencies of winds coming from westerly, south-westerly and southerly directions (y=-0.055x + 14.08).

Karwar, Honavar, Calicut and Cochin stations show a significant increase in annual Tmin; this is supported by the increase in LC amount (0.000 to 0.001 oktas/year). The same trend is reported in all seasons for these stations; there is an increase in LC amount (0.000 to 0.004 oktas/year) and this might have an influence on Tmin. For two stations, namely Panjim and Marmagoa, the significant increase in Tmin is not supported by the trend in cloud amount.

There is a significant increase in annual Tmin at Karwar, Calicut and Cochin; however, this is not supported by the LC amount during the study period. On the other hand, when data are analysed from 1970s onwards, there is an increase in LC amount and this could be comparable with the patterns of increase in the Tmin at these stations. The increased patterns of Tmin at these stations also show a similarity with Kothawale and Rupa Kumar (2005).

Conclusions

The comparative study on temperature trends on annual and seasonal bases in a tropical rainy climate was investigated for 26 stations for the period 1901–2010. The study revealed that both the regions have warmed, but significantly in Tmax for WCR, while for NER it is Tmin that has a significant bearing on the natural and human environment. The key findings are summarised below;

- The number of stations showing significant decreases in DTR is more than that showing increases in DTR, due to the faster rate of increase in Tmin. In the NER, apart from LC and MC amount, there are also other factors controlling the trends of Tmax and Tmin, viz., forest cover (cooling), topography (blocking the flow of wind) and population growth.
- The majority of stations in the WCR show a significant increasing trend in DTR as a result of a significant increase in Tmax. The trends in Tmax and Tmin are supported by decreasing trends in LC amount and wind patterns.

Overall, the results show the contrasting changes in temperature series in these two regions; the increase in Tmax in the WCR is consistent with global temperature changes due to greenhouse gas emissions in the atmosphere, while for NER, it is Tmin which can be attributed partly to regional and local factors. The inclusion of more stations with long-term data will quantify the changes in climatic parameters over a larger area, especially the hilly NER. Furthermore, to identify any weather changes, the installation of more weather stations (in rural areas and towns) based on different physio-climatic zones is essential. However, there is an inadequacy in climatic data and sparse distribution of meteorological stations in the NER, which precludes confirmation of temperature analysis and results.

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