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Extreme Temperature Climatology and Evaluation of Heat Index in Bangladesh During 1981-2010

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ABSTRACT

In the advent of global warming, there are increased concerns regarding extreme weather events. Temperature variability appears to be the dominant aspect having a consequence on extreme climatic events and climate change. As elsewhere across the globe, South Asian countries have been witnessing an increase in occurrence of extreme climate events in recent decades. This paper demonstrates the temporal variation patterns of extreme temperature conditions in a climate-vulnerable country Bangladesh, based on some simulated temperature-related Climate Change Indices. The indices include Average Seasonal Maximum and Minimum Temperature (Tmax and Tmin) and Heat Index (HI). In the analysis of the paper the daily maximum, minimum and mean temperature and relative humidity records from 18 meteorological stations in Bangladesh were applied in calculating the indices, within a 30 year study period of 1981 to 2010. Comparison of the calculated values of these indices also shows significant enhancement in temperature extremes in the past decades. Averaged over all stations, the indices of temperature extremes indicate warming of both daily minimum and maximum temperature in the monsoon and pre-monsoon season, which influences the most in overall temperature rise in Bangladesh in the past reference period 1981-2010. This increase has been found more in eastern and south-western region than the other parts. Minimum temperature of the coastal and central areas of Bangladesh has shown a significant increase. The level of discomfort has also shown an upward shift.

Index Terms— anomaly, Bangladesh, climate change, Heat Index, temperature.

INTRODUCTION

In light of recent climate trends and current predictions for the twenty-first century, climatic change is becoming a major concern for scientists and society in general. There is an increasing interest in different parts of the world in research on extreme temperatures and their variation.Temperature extremes are an important aspect of any climate change because ecosystems and societal responses are most sensitive to them. Mearns et al. (1984) and Hansen et al. (1988) concluded that relatively small changes in the mean temperature could produce substantial changes in the frequency of temperature extremes.The last decade of the twentieth century was globally the hottest since the beginning of worldwide temperature measurement during the nineteenth century. Alexander et al. (2006) showed that annual trends in the lowest and highest daily minimum and maximum temperatures in the latter half of the twentieth century increased at many locations throughout the world. Further global warming ranging between 1.4^{o}C and 5.8^{o}C is expected by the end of the twenty-first century (IPCC 2007), which could also lead to an increase in temperature extremes.

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Global pictures of changes in climate extremes (Frich et al. 2002) typically show large areas with sparse data coverage or none at all. One such area includes parts of central and south Asia. Only a few national studies on extremes were made. Yan et al. (Yan et al. 2002) found that the number of cold days in China is gradually reducing over the 20^{th} century and the number of warm days is increasing only since 1961. Plummer et al. (1999) reported the same for Australia for the period of 1961-1995. Jones et al. 1999 concluded, the rise of temperature is associated with the reduction of cold days and it is also accompanied by reduction of the areas of extreme cool temperatures and increase of the areas of extreme warm temperature. In India, the frequency of occurrence of hot days and hot nights showed extensive increasing pattern while that of cold days and cold nights has shown widespread decreasing trend.

Heat Index combines air temperature and relative humidity to determine how hot it actually feels. It is also known as apparent temperature. The human body normally cools itself by perspiration, or sweating, in which the water in the sweat evaporates and carries heat away from the body. However, when the relative humidity is high, the evaporation rate of water is reduced. This means heat is removed from the body at a lower rate, causing it to retain more heat than it would in dry air (Ogunsote 2002). While there appears to be no official definition, a heat-wave may be considered as a prolonged period of excessively hot conditions that usually lasts more than three consecutive days. This definition, which includes the combined effect of high temperatures and humidity is based on Stedman's (1979) approach and allows us to compute the relevant heat wave index to assess the severity of heat-related events (Steadman 1979).

The rise in heat index results in higher heat related mortality rate during summer. The combination of heat and high humidity may cause discomfort, heat stroke or even death to humans and animals. This heat related incidences have been studied extensively by various authors (Keatinge et al., 2000, Guest et al., 1999, Kumar, 1998, Pan & Li, 1995, Donaldson et al., 2003, Cristo et al., 2003 &Piver et al., 1999). The heat related-illness and casualties are likely to increase with predicted incidence of global warming and increasing duration of heat waves. Asia is most vulnerable to heat waves. A heat wave left at least 26 people dead in 2007. Nearly 200 people, including several children, were admitted to hospitals with symptoms of heat strokes. The heat wave brought 192 deaths in Pakistan, 11 deaths Nepal and 923 deaths in Japan (Indian Health News 13 June 2007; Khaleej Times 14 June 2007; Daily Times 10 June 2007).

Few researches have been on Bangladesh climate condition by Mahtab (1989), Pramanik (1983), BCAS (1994), BUP (1994), Bangladesh Climate Change Country Study Program (1997) etc. and all have the same view that Bangladesh is one of the foremost countries extremely susceptible to the unpleasant effects of global warming. According to the collected data of Bangladesh Meteorological Department, the mean and maximum annual temperature is increasing exceedingly resulting in definite rise in Bay of Bengal. The average annual temperature of Bangladesh is expected to increase by 1.4 ± 0.6^{o}C by 2050 (IPCC 2007; MoEF 2008). The BUP-CEARS-CRU (1994) study reported 0.5^{o}C to 2.0^{o}C rise in temperature by the year 2030 under 'business as usual' scenario of IPCC. It was reported by ADB (1994) that, for 2010 the temperature would rise by 0.3^{o}C and for 2070, the corresponding rise would be 1.5^{o}C.

In the present study, the changes in temperature extremes over Bangladesh are analyzed for the period 1981–2010. This paper starts with a description of the data, including their source as well as the methods used in the study. The results of the analysis are presented, discussed and concluded in the following parts.

STUDY AREA AND METHODOLOGY

Study area and Data

Bangladesh is located between 20.57°N to 26.63°N latitude and from 88.01°E to 92.68°E longitude. Monsoon weather prevails throughout the year in most parts of the country. Bangladesh's high susceptibility to climate change is due to a number of hydro-geological and socio-economic factors that include: (a) its geographical location in south Asia; (b) its flat deltaic topography with very low elevation; (c) extreme climate variability that is governed by monsoon, resulting in acute water distribution over space and time; (d) its high population density and poverty incidence; and (e) majority of the population being dependent on crop agriculture which is highly influenced by climate variability and change (Rajib et al, 2011). Following three distinct seasons can be recognized in Bangladesh from the climatic point-of-view: a) the dry winter season from November to February, b)the pre-monsoon season from March to May, and c) the monsoon season from June to October (Shahid&Behrawan2008). In this present study Bangladesh has been divided in four regions: i) North West Region (NWR) ii) South West Region (SWR) iii) Central Region (CR) iv) East Region (ER) (see Figure 1) (Rajib et al, 2012). Maximum and minimum temperatures data are available in daily scale from the Bangladesh Meteorological Department (BMD) observatory stations (Figure 1). To maintain data quality, some criteria are applied to the climate change indices; this is in reference to those adopted in the Western Regional Climate Center (WRCC) and other researchers (Griffiths and Bradley 2007). These criteria include the following: i) A month is considered as having complete data if there is less than or equal to 5 missing days. ii) A year is considered complete if all months are complete according to item 1. iii) A station series is considered complete if it has equaled to or more than 65%complete years according to item 2 in different periods. Following these criteria, 18 stations out of 35 have been finally selected for inclusion in the analysis.

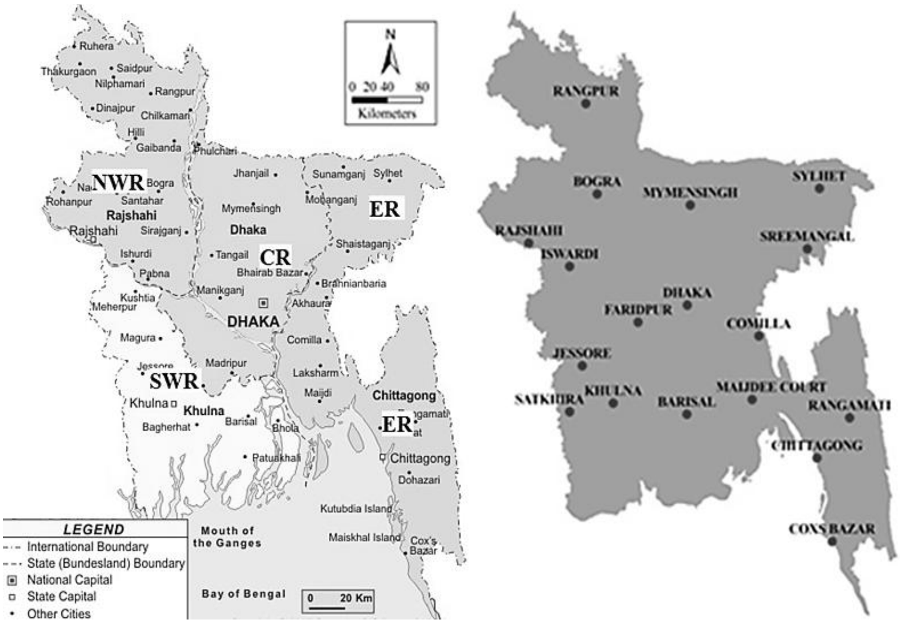

Figure 1.Location of BMD stations (right) and different regions considered (left) in Bangladesh.

Methodology

In order to have a basis for assessing future impacts of climate change, it is necessary to obtain a quantitative description of the changes in climate to be expected (climate scenarios). According to IPCC-TGICA (2007), a popular climatological baseline period is the non-overlapping 30-year "normal" period as defined by the World Meteorological Organization (WMO). In the present study, 1981–2010 have been considered as the study period.

The joint World Meteorological Organization Commission for Climatology (CCl)/World Climate Research Program (WCRP) project on climate variability and predictability (CLIVAR) Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI) have made an effort to develop a suite of core climate extreme indices (Islam et al 2009). Some of these ETCCDMI indices, being compiled in Table I, have been applied in this research.

Anomaly has been used in order to observe the trend of extreme events. Temperature anomaly is defined as the deviation from the average over the 30-yr base period between 1981 and 2010. The normalized anomalies of each station have been calculated by subtracting the mean temperature of a station for 1981–2010 from annual temperature of that station and dividing it by the standard deviation. The method of moving average, also known as running mean, was used to smooth the temperature series. This method helped to highlight the periodic variations in the series.

Increase in humidity and temperature causes increase in apparent temperature. Steadman (1979) developed Heat index based on this relationship. In order to arrive at this equation, a multiple regression analysis was performed on the data from Steadman's table (Rothfusz, 1990). The resulting equation could be considered a Heat Index equation, although it is obtained in a "round-about" way (Rothfusz 1990).

$$HI = -42.379 + 2.04901523\,T + 10.14333127\,R - 0.22475541\,TR - 6.83783\times10^{-3}T^2 - 5.481717\times10^{-2}R^2 + 1.22874\times10^{-3}T^2R + 8.5282\times10^{-4}TR^2 - 1.99\times10^{-6}T^2R^2$$

Where, T = ambient dry bulb temperature (°F), R = relative humidity. Because this equation is obtained by multiple regression analysis (Steadman 1979), the heat index value (HI) has an error of ±1.3°F. The formula is valid only when air temperature and relative humidity are higher than 27°C (80°F) and 40%, respectively.

Table I. Definitions of Temperature Extremes Indices

Index	Indicator's Name	Description	Unit	Reference
HI	Heat Index	An index that combines air temperature and relative humidity to determine the human-perceived equivalent temperature	ºC/ºF	Steadman RG (1979)
Tmax	Maximum Temperature	Maximum daily temperature	ºC	EMULATE and ETCCDMI
Tmin	Minimum Temperature	Minimum daily temperature	ºC	EMULATE and ETCCDMI

http://cccma.seos.uvic.ca/ETCCDMI/list_27_indices.html

Table II. Effects of Heat Index (Source: Wikipedia)

Heat Index		Classification	Notes
27–32°C	80–90 °F	Very Warm	Caution — fatigue is possible with prolonged exposure and activity. Continuing activity could result in heat cramps
32–41°C	90–105 °F	Hot	Extreme caution — heat cramps and heat exhaustion are possible. Continuing activity could result in heat stroke
41–54°C	105–130 °F	Very Hot	Danger — heat cramps and heat exhaustion are likely; heat stroke is probable with continued activity
over 54°C	over 130 °F	Extremely Hot	Extreme danger — heat stroke is imminent

RESULT & DISCUSSION

Annual-MonthlyVariation of HI

For understanding the pattern of extreme heat index value events, the mean annual cycle of HI values have been accounted in Figure 2. These annual cycles are characterized by mean of monthly HI values over the period 1981-2010. An upward shift in the HI values is noticeable throughout our study period. For the period 1981-1990, HI values were within comfortable limit. But the situation continues to worsen with time. March- April and November-December can be acknowledged as 'very warm' while May-October is 'hot' according to the HI chart for the period 1991-2010.Higher temperature value from April to November is responsible for increased HI index values.

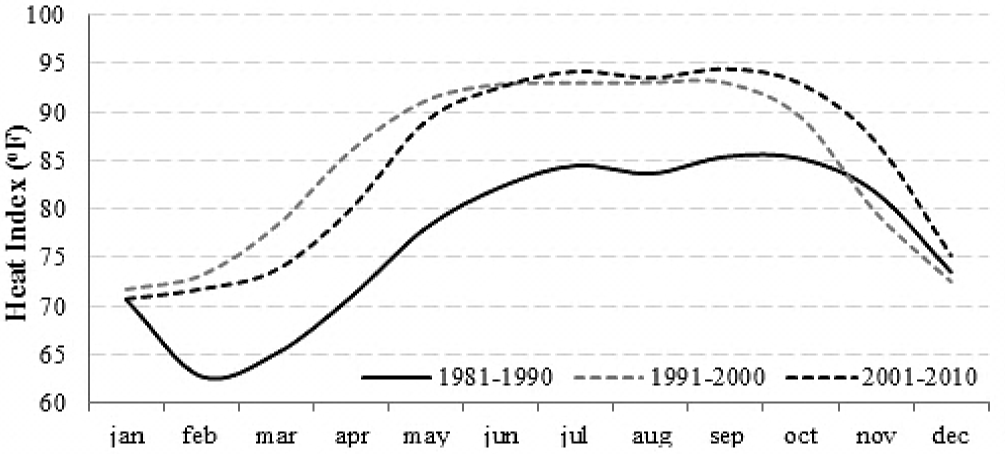

Figure 2. Monthly variation of Heat Index during recent decades

Seasonal Variation of Heat Index

Figure 3 shows that North-western region experienced decrease in HI value in the dry season from 1981-1995, then started increasing from 1995. The HI values of the monsoon season over the country can be recognized as 'hot'. South-western region was most uncomfortable whereas North-western region was comparatively comfortable. Eastern region displayed comparatively lower HI values, although it had regular fluctuations. In pre-monsoon the situation of the country was 'very warm'.

Seasonal Variation of Tmax and Tmin

Seasonal Variation of Tmax and Tmin has been presented in Figure 4a and 4b respectively in the form of temperature anomaly. Temperature anomaly is defined as the deviation from the average over the 30-yr base period between 1981 and 2010.The normalized anomalies of each region have been calculated by subtracting the mean temperature of a year (in 1981-2010 period) from annual temperature of that region and dividing it by the standard deviation. Central region shows high increase in Tmax with regular peaks during pre-monsoon and monsoon. Tmax shows increasing trend in eastern region for all seasons. High fluctuations can be observed in Tmax of north western region in pre-monsoon. South-western region can be identified as a vulnerable region. The increase in Tmin over the country is responsible for the overall increase in average temperature of the country.

Table III gives a combative study percentage change in annual average values of the indicators during different seasons. It demonstrates the degree of changes that occurs during the monsoon and pre-monsoon in relation with the dry season. In both cases, very high increase in percentage change is observed for T min. Monsoon season reveals high degree of disparity in terms of HI.

Table III. Percentage Change in Annual Average Values of Selected Indices

INDICATORS	DRY	MONSOON	% of change	DRY	PRE-MONSOON	% of change
T max(°C)	27.44	31.66	15.38	27.44	32.64	18.94
T min(°C)	15.27	25.24	65.26	15.27	20.87	36.61
HI(°F)	76.50	93.06	21.65	76.50	80.55	5.29

Table IV illustrates the comparison of the various chosen indicators for the 3 decades from 1981-2010. Maximum temperature is seen to increase markedly during monsoon and pre-monsoon seasons. So is the case with minimum temperature. HI values are found within comfortable limit during the dry season. But it increases rapidly during monsoon season and then again decreases during pre-monsoon.

Table IV. Annual Average Values of Selected Indices

SEASON	INDICATOR	NORTH WESTERN			SOUTH WESTERN			CENTRAL			EASTERN		
		1981-1990	1990-2000	2001-2010	1981-1990	1991-2000	2001-2010	1981-1990	1991-2000	2001-2010	1981-1990	1991-2000	2001-2010
DRY	Tmax(°C)	26.5	26.4	26.4	27.6	27.5	27.9	27.8	27.8	27.6	27.5	28.0	28.4
	Tmin(°C)	13.4	13.6	14.0	15.5	15.6	15.7	15.4	15.1	15.5	16.6	16.3	16.4
	HI(°F)	76.0	74.8	75.3	77.4	76.7	76.1	77.7	76.7	76.4	77.7	76.9	76.4
MONSOON	Tmax(°C)	31.8	32.1	32.4	31.4	31.5	32.1	31.4	31.7	31.9	30.7	31.2	31.5
	Tmin(°C)	24.9	25.3	25.4	25.3	25.5	25.7	25.3	25.4	25.6	24.8	24.9	25.1
	HI(°F)	92.7	93.5	94.2	94.1	94.5	95.2	93.4	93.2	93.4	90.6	90.9	90.9
PRE-MONSOON	Tmax(°C)	32.7	33.0	32.8	32.9	33.1	33.7	32.3	32.5	32.8	32.0	31.7	32.2
	Tmin(°C)	20.8	21.2	22.7	23.1	23.3	23.6	22.4	22.5	23.0	22.5	22.6	22.9
	HI(°F)	79.2	78.9	78.5	82.2	81.8	82.5	80.9	80.1	80.4	80.7	80.3	81.0

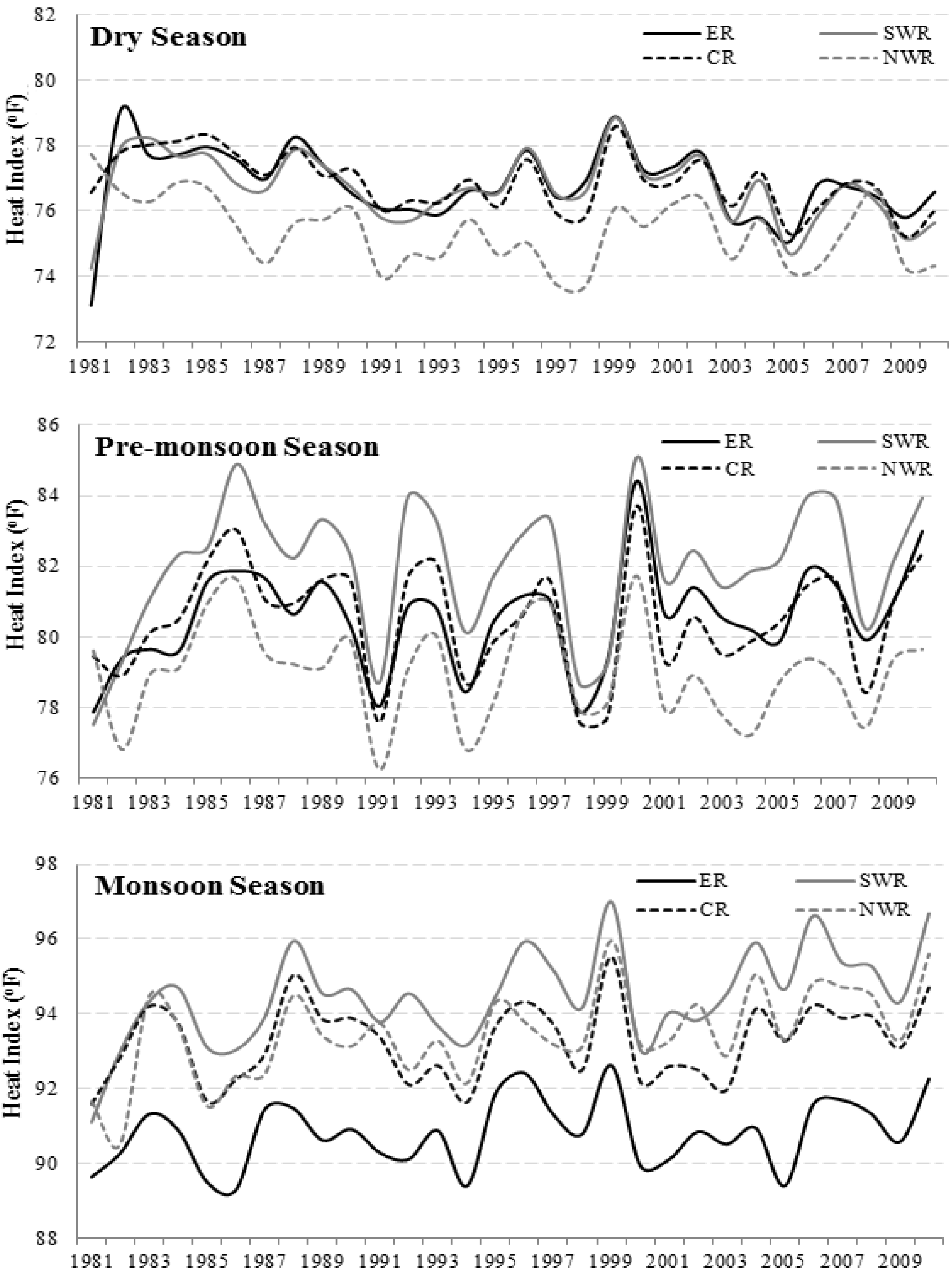

Figure 3. Seasonal variation of Heat Index in different regions

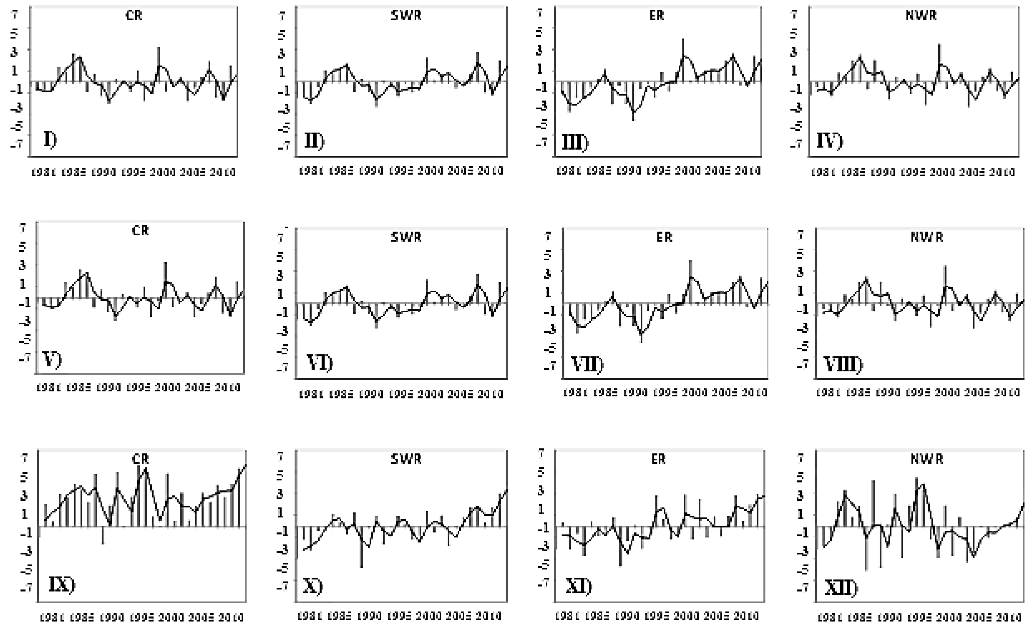

Figure 4a.Tmax anomalies for dry (i to iv), monsoon (v to viii) and pre-monsoon (ix to xii) [x axis represents year, and y axis represents anomaly (^{o}C)]

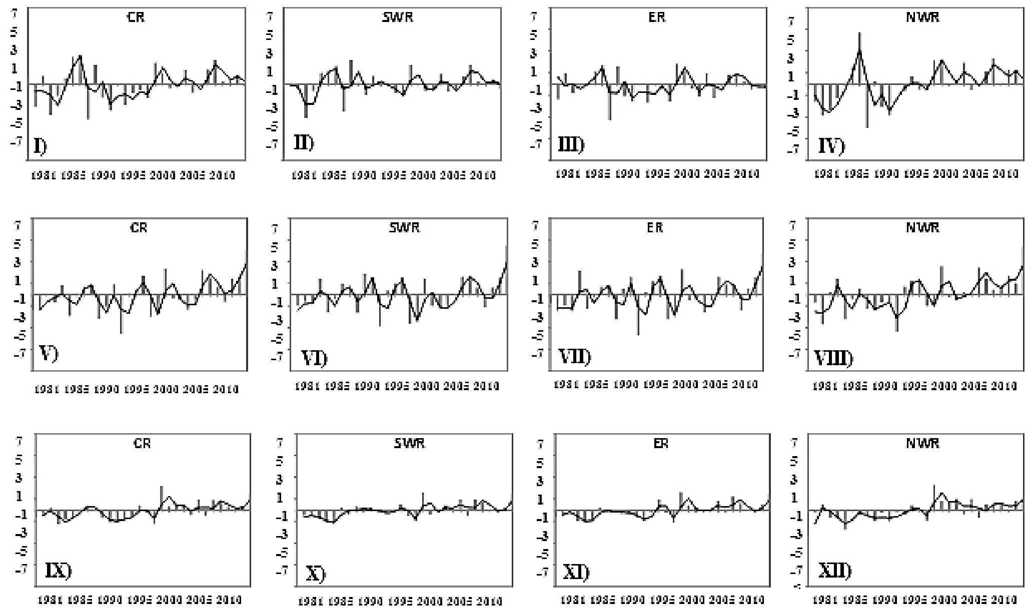

Figure 4b. Tmin anomalies for dry (i to iv), monsoon (v to viii) and pre-monsoon (ix to xii) [x axis represents year, and y axis represents anomaly (^{o}C)]

CONCLUSION

This paper stands for an outline of temperature trends in Bangladesh. Bangladesh has warmed up during the last 18 years; annual temperature has increased by 0.4-0.6°C during the period 1981-2010. Annual average warming was mainly the result of monsoon and pre-monsoon warming. Averaged over all stations, the indices of temperature extremes indicate warming of both the cold tail and the warm tail of the distributions of daily minimum and maximum temperature in the monsoon and pre-monsoon season, which influences the most in overall temperature rise in Bangladesh in the past reference period 1981-2010. This increase has been found more in eastern and south-western region than the other parts. Minimum temperature of the coastal and central areas of Bangladesh hasalso shown a significant increase.The analysis represents that the number of cold days has been reducing drastically in those regions. Minimum temperature of the coastal and central areas of Bangladesh has shown a significant increase. Also, the level of discomfort, in terms of Heat Index, has also shown an upward shift through time.The discomfort level has increased in the recent two decades markedly.

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