Journal of Engineering Science 10(2), 2019, 33-48

JES

an international Journal

PATTERNS OF CLIMATE CHANGE AND ITS IMPACTS IN NORTHWESTERN BANGLADESH

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Received: 17 September 2019 Accepted: 27 October 2019

ABSTRACT

Climatological data on different parameters like daily temperature, rainfall, maximum and minimum temperatures, relative humidity and pre-monsoon daily thunderstorm frequency over Rajshahi, Rangpur and Dinajpur for the period 1981-2016 have been used to study their temporal variations on monthly, seasonal and annual basis. Rainfall data is also used to compute the non-rainy days (dry days), and the relative humidity is used to compute heat stress over the places under study. The trends of dry days and heat stress are studied. Daily maximum and minimum temperatures are used to find out the frequencies of temperature >36℃ and temperature <10℃ for studying trends of heat waves and cold waves over the region. The temporal variations of all the parameters have increasing trends except for some parameters which have increasing trends from 2000. The study has revealed that the annual mean temperature has increasing trends in Rajshahi and Rangpur with increasing rates of +0.012 and +0.017℃/year respectively during 1981-2016. It has decreasing trend in Dinajpur at -0.017℃/ year during 1981-2016. But annual mean temperature at Dinajpur has increasing trend at a rate of +0.014℃/year from 1990. Annual rainfall has decreasing trends at all stations under study. The rates of decreasing of annual rainfall are -8.946, -14.170 and -11.030 mm/year in Rajshahi, Rangpur and Dinajpur respectively. The study also reveals that the annual frequency of dry days has sharp increasing trends at the rates of +0.370, +0.096 and +0.205 day/year at Rajshahi, Rangpur and Dinajpur and the maximum increasing trend of annual dry days is at Rajshahi. The seasonal dry days have increasing trends from 2000 at all the places with much higher rates of increasing. This will enhance the drought conditions in northwest Bangladesh. The annual mean heat stress over northwest Bangladesh indicates significant increasing trends at Rajshahi and Rangpur and decreasing trend at Dinajpur during the period 1981-2016; whereas the annual heat stress at Dinajpur has increasing trends at +0.022/year since 1989. Rajshahi has the highest mean frequency of maximum temperature >36℃ in the month of May whereas Dinajpur and Rangpur have the maximum mean frequency of maximum temperature >36℃ in the month of April. Heat waves will be more long lasting in Rajshahi during April-July.

Keywords: *Climate change; heat waves; cold wave; heat stress; drought and flood*

1. INTRODUCTION

The peculiar geographical location with the Bay of Bengal (BoB) in the south and the Himalayan range in the north has made the deltaic Bangladesh most vulnerable in the world in respect of disasters of hydro-meteorological origin. The country has low flat terrain with large coastal region in the south, most part of which is normally inundated during high tide. Again, the country acts play-ground of different types of disasters like thunderstorms/tornado, drought, tropical cyclones and associated storm surges, floods, flash floods, cold waves and heat waves, heavy rainfall, erratic rainfall, etc. Since Bangladesh is a land of rivers across which three major rivers such as Ganga, Brahmaputra and Meghna (GBM) run to the BoB. These rivers with their tributaries become very lively during the monsoon season and cause river erosions in the country, displacing many vulnerable people almost every year. The coastal region is becoming more saline due to sea level rise and high tides. The global and local warming contributes to the increase in frequency and intensity of these disasters especially lightning associated with thunders. The adverse effects of climate change and increased frequency and intensity of different disasters have aggravated the overall economic development scenarios of the country as well as food security and livelihoods to a great extent. Though Bangladesh is a small country with high density of population, its different parts have different impacts of disasters and climate change. Northwestern Bangladesh is such a kind of region consisting of two administrative divisions: Rajshahi and Rangpur having the significant impacts of thunderstorms, floods, cold waves and heat waves, drought, heat stress, riverbank erosion, scarcity of water and reduced river flows in dry season, etc. As a result, their impacts on food security and livelihoods are immense in this region. It may be noted that drought is prominent in this region in pre-monsoon season. Sometimes, drought occurs in NW-Bangladesh during monsoon season too due to less rainfall activities. During southwest monsoon season, moderate to severe floods occur in this region as happened in August 2017.

Kulkarni *et al.* (2017) studied the impact of heat stress on animal health using Temperature Humidity Index (THI) over India. They have used the daily dry-bulb temperature and relative humidity data of 300 stations

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https://www2.kuet.ac.bd/JES/

ISSN 2075-4914 (print); ISSN 2706-6835 (online)

from 1980-2015 and THI was calculated. They prepared the monthly THI using GIS software. The criteria used for the study are given below:

No.	Category	THI values
1	No Stress	Below 70
2	Mild stress	70-75
3	Semi moderate stress	76-80
4	Moderate stress	81-85
5	Severe stress	85-90

They discussed the different heat stress conditions over India. In April, they found that the severe stress condition was located only over the Telangana, Rayalseema, southern Chhattisgarh and east coastal states of India. In May, severe stress condition was located over entire country. During June the Severe stress condition starts reducing over the country from the Western coastal states of India and completely removed in October. In the October, the No stress condition was moving from North (Jammu and Kashmir) to south and cover entire India during December except Kerala, Tamil Nadu, Rayalseema, Andhra Pradesh, middle Karnataka and Telangana. The severe stress condition over the Eastern coastal states was locating from the April to September while western coastal states except Gujarat were showing semi moderate stress condition. The oceanic features of BoB and topography of eastern coast play important role for the generation of severe stress condition during April to September.

Yousif and Tahir (2013) made a study on the application of Thom's Thermal Discomfort Index in Khartoum State, Sudan. This study found that less than 50% of the population experienced the sense of discomfort during November to April when the discomfort indices ranged from 22 to 24. But more than 50% of the population suffered from discomfort when the indices ranged from 24 to29 during April to October. The discomfort indices greater than 30 or 32 (indicating 100% of the population feeling discomfort or the condition of medical emergency, respectively) were not attained in Khartoum State.

Islam *et al*. (2014) studied the droughts of 1994, 2000 and 2006 in northern region of Rangpur division, Bangladesh. Regarding the people's perception about drought, 58, 55, 56, 57, 50, and 45% respondents believed drought was a curse of God, water shortage, dry weather condition, human intervention, dry red soil and outcome of sin respectively. In the drought prone area, livelihood pattern changes and migration of people takes place. The study revealed that about 84% drought victims migrated from drought prone area for better livelihoods and government assistance in 1994 severe drought while 65% of other households migrated for different incidents other than drought. In 2006, about 59% drought victims left the area whereas only 40% victims migrated in recent years. The study has revealed that the paddy faces the highest loss due to drought as production of paddy is very much dependent on the availability of water. About 53.33% production of paddy was reduced whereas the production of potato, jute, onion, and bean were decreased by 13.33, 26.66, 6.66 and 4% respectively due to drought in the area. Drought has adverse effect on ecology of the area. The study has revealed that a total 57% people responded that drought has an impact on cattle while 30% people strongly disagreed cattle was not in such danger during drought. About 65% people strongly agreed that goat dies during drought, which is even the cause of death of sheep and boar.

Rafiuddin *et al.* (2011) diagnosed drought in Bangladesh using Standardized Precipitation Index (SPI) using rainfall data of 27 stations during 1961-1990 and concluded that the exact drought month or year in a particular region is not easy to obtain from the SPI graphical patterns. SPI calculation over a region provides better consistency of drought situation instead of single station information. The study revealed that the frequency of moderate drought is higher for all over the country. The central, the northern and the southwestern regions are the most severe drought prone area in Bangladesh.

Murad and Islam (2011) made a drought assessment study in northwest region of Bangladesh. They used Surface Reflectance (SR) data of the Moderate Resolution Imaging Spectra Radio-meter Satellite (MODIS) with TERRA sensor for the period 2000-2008. They prepared the agricultural drought risk and meteorological drought risk area as shown in Fig 1 (a, b). It is seen that Gaibandha, Thakurgaon and Panchagarh districts face high agricultural drought risk covering 15.68% of the total area while the districts Bogra, Dinajpur, Nilphamari, Joypurhat and Sirajganj face moderate risk covering 33.15% of the total area. Kurigram. Lalmanirhat, Nawabganj, Pabna, Rajshahi and Rangpur have slight agricultural drought risk covering 35.70% of the total area but Naogaon and Natore covering 15.47% are is free from agricultural drought risk. The meteorological drought risk map (Figure 1b) shows very severe meteorological drought risk in Dinajpur, Thakurgaon and Gaibandha districts, whereas slight meteorological drought risks exist in Naogaon and Sirajganj districts.

Mirza (2005) made a study on the implications of climate change on river discharge in Bangladesh. According to him, there is a high seasonal difference in the availability of water. For the Ganges River, the ratio of dry and monsoon runoff is 1:6. This illustrates that Bangladesh has an abundance of water in the monsoon while the country still faces surface water scarcity in the dry season. Irrigated agriculture is highly dependent on dry season surface water availability.

On average, annually floods engulf roughly 20% of the area of the country, or about 3.03 mha (Mirza, 2003). In extreme cases, floods may inundate about 70% of Bangladesh, as it occurred during the floods of 1988 and 1998 (Ahmed and Mirza, 2000). Northwestern regions are particularly vulnerable to droughts. A severe drought can cause more than 40 percent damage to broadcast aus. Each year, during the kharif season, drought causes significant damage to the t. aman crop in about 2.32 million ha. In the rabi season, 1.2 million ha of cropland face droughts of various magnitudes. Apart from loss to agriculture, droughts have significant effect on land degradation, livestock population, employment and health (Ramamasy and Baas, 2007). Karmakar and Hassan (2018) in a study mentioned that rise in temperature at Rajshahi will have profound effect on agriculture. Due to less availability of water, the climate is changing at Rajshahi. Temperature is increasing and rainfall is decreasing. Frequency of heat waves in summer and cold waves in winter are increasing. Islam and Parveen (2004) made a study on the food security in the face of climate change, population growth, and resource constraints in Bangladesh perspectives. According to them, the overall impact of climate change on the production of food grains in Bangladesh would probably be small in 2030. This is due to the strong positive impact of CO_2 fertilization that would compensate for the negative impacts of higher temperature and sea level rise. In 2050, the negative impacts of climate change might become noticeable: production of rice and wheat might drop by 8% and 32%, respectively. According to Intergovernmental Panel on Climate Change (IPCC, 2001), discernable changes are about to take place in the climate system of the globe. South Asian region is likely to be one of the worst hit regions around the world due to its high susceptibility to extreme weather events as a consequence of high temporal, spatial, and inter-annual climate variability. It is prognosticated that the western Himalayan region will face increased vulnerability to drought, while the eastern Himalayan parts will experience increased floods in terms of both extent and frequency.

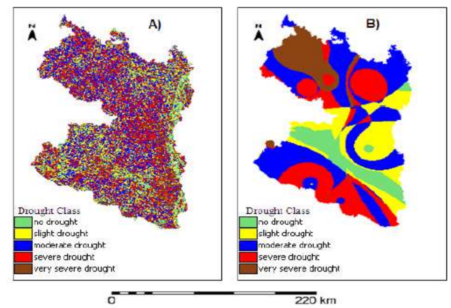

Figure 1: (a) Agricultural drought risk and (b) Meteorological drought risk area (Murad and Islam, 2011)

Karmakar and Shrestha (2000) made a study on the recent climatic changes in Bangladesh by using the temperature and rainfall for the period 1961-1990. The study reveals that the annual mean maximum temperature over Bangladesh has significant decreasing trend up to 1975 and very significant increasing trend after 1975. The annual mean minimum temperature over Bangladesh has an increasing trend up to 1978, which is statistically significant and after 1978 it has a slight decreasing trend which is not significant. The overall annual mean minimum temperature over Bangladesh for the period 1961-1990 has a slight decreasing trend. The overall trend of annual mean maximum temperature for the period 1961-1990 is of increasing order, which is statistically significant. The study also reveals that the annual mean temperature over Bangladesh has a slight increasing trend during the whole period 1961-1990. The seasonal rainfall over Bangladesh has increasing trends during all the seasons except the post-monsoon season when it shows a decreasing trend.

Ahmed and Alam (1999) made a study on the development of climate change scenarios in Bangladesh with General Circulation Models. According to them, the average increase in temperature would be 1.3°C and 2.6°C for the years 2030 and 2070, respectively. It was found that there would be a seasonal variation in changed temperature: 1.4°C change in the winter and 0.7°C in the monsoon months in 2030. For 2070 the variation would be 2.1°C and 1.7°C for winter and monsoon, respectively. For precipitation it was found that the winter precipitation would decrease at a negligible rate in 2030, while in 2075 there would not be any appreciable rainfall in winter. On the other hand, monsoon precipitation would increase at a rate of 12 per cent and 27 per cent for the two projection years, respectively.

The main objective of the present study is to investigate the trends of heat waves, cold waves, non-rainy days, humidity, thermal heat stress, thunderstorm frequency, some extreme events and their impacts in the northwestern Bangladesh

2. DATA USED AND METHODOLOGY

Daily data on dry-bulb temperature, rainfall, humidity, minimum temperature and maximum temperature along with the frequency of thunderstorms at Rajshahi, Rangpur and Dinajpur for the period 1981-2016 are collected from Bangladesh Meteorological Department (BMD) and used in the study. From the daily data, monthly, seasonal and annual mean temperatures, humidity, frequency of non-rainy days, and total rainfall are computed. The daily highest values of maximum temperature and humidity in each month are computed for period under study to find out the extreme cases of heat stress.

For spatial distributions of rainfall and temperature over northwest Bangladesh, the data of BMD for the period 1981-2016 at Rajshahi, Rangpur, Dinajpur, Ishurdi, Bogra, Mymensingh, Dhaka and Faridpur are used. The temporal variations of seasonal and annual temperatures, rainfall, non-rainy days and humidity are graphically prepared and the trends are computed. The annual mean temperature and rainfall are spatially distributed over northwest Bangladesh, and the spatial distributions of maximum and minimum temperatures during cold and heat waves are made. The monthly mean temperature and humidity along with the highest values of maximum temperature and humidity are used to compute the Thom's Temperature and Humidity Index (THI) for Rajshahi, Rangpur and Dinajpur stations according to the following the same formula (Thom, 1959):

$$THI = 0.8 \times T + \frac{RH}{100} \times (T - 14.4) + 46.4$$

Where, T is the dry-bulb or ambient temperature in °C and RH is the humidity (%).

3 RESULTS AND DISCUSSION

3.1 Spatial distribution of rainfall in northwest Bangladesh

The distribution of average annual rainfall for the period 1981-2016 reveals that 1500-2300 mm rainfall occurs annually in northwestern part of the country, having relatively less rainfall in the west and higher rainfall in the northeast. From the spatial distribution of seasonal rainfall, it has been found that the seasonal rainfall ranges are 26-28, 230-417, 1049-1666 and 125-177 mm in winter, pre-monsoon, monsoon and post-monsoon seasons respectively (Table 1). The distribution patterns of annual and monsoon rainfall are shown in Figure 2(a-b), showing the minimum rainfall near Rajshahi.

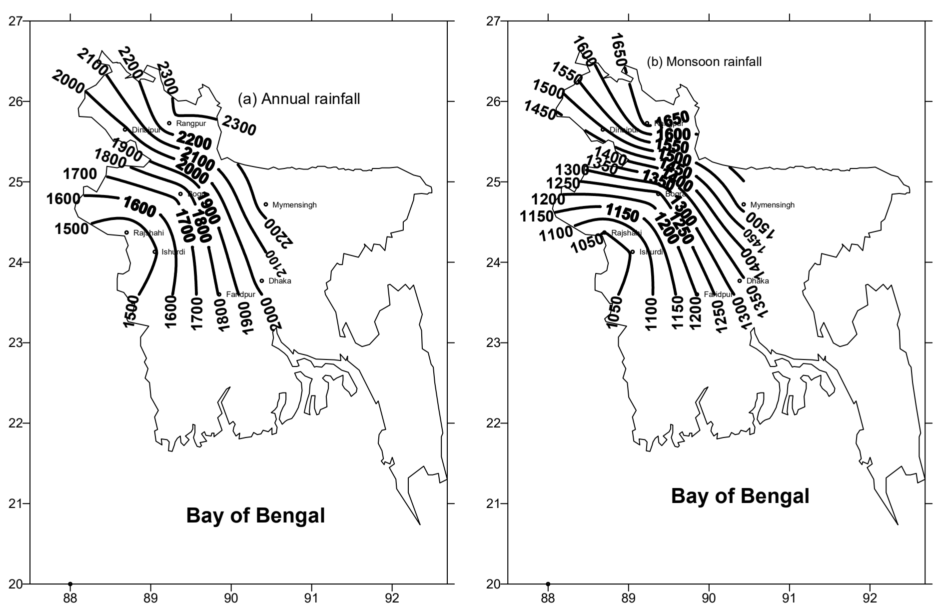

Figure 2: Spatial distribution of average (a) annual rainfall (mm) and (b) monsoon total rainfall (mm) over northwestern Bangladesh during 1981-2016.

Table 1: Mean rainfall during 1981-2016 in northwest Bangladesh

Stations	Pre-monsoon	Monsoon	Post-monsoon	Winter	Annual
Rajshahi	230.92	1048.67	125.22	28.48	1435.778
Rangpur	416.89	1665.83	177.19	28.34	2288.417
Dinajpur	303.42	1492.72	158.94	26.95	1983.556

3.2 Distribution of temperature over northwest Bangladesh

The distribution of mean annual temperature for the period 1981-2016 reveals that the annual mean temperature ranges from about 24.5 °C in the north and 25.2 °C in the south over northwest Bangladesh. From the spatial distribution of seasonal mean temperature, it has been found that the seasonal mean temperature ranges are 19.9-20.8, 25.5-27.6, 28.5-28.8 and 24.2-24.5°C in winter, pre-monsoon, monsoon and post-monsoon seasons respectively. The spatial distribution patterns of annual and pre-monsoon mean temperature are shown in Figure 3 (a-b). It may be mentioned that the monsoon mean temperature is higher than that of the pre-monsoon temperature. This may be attributed to the fact that the difference between day temperature and night temperature is less in the monsoon season than that in the pre-monsoon, though the maximum temperature in the pre-monsoon temperature is much higher than that in the monsoon season.

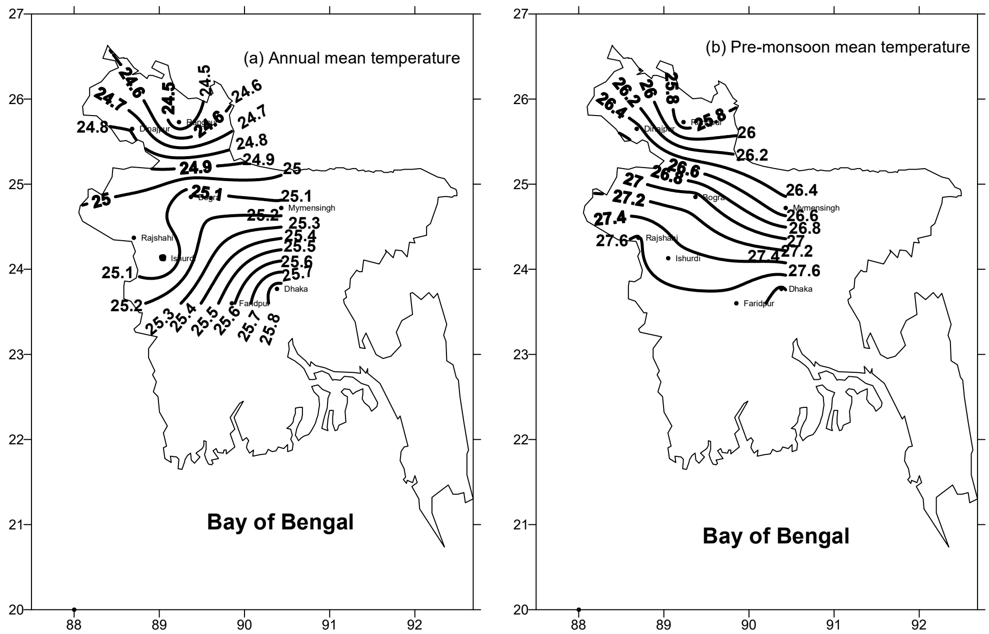

Figure 3: Spatial distribution of (a) annual mean temperature (°C) and (b) pre-monsoon mean temperature (°C) over northwestern Bangladesh during 1981-2016

3.3 Trend in annual and seasonal temperature in northwest Bangladesh

The trends in annual and seasonal mean temperature are computed for the three stations in northwest Bangladesh. There is inter-annual variability in both annual and season temperatures as can be seen from Figure 4(a-c) for annual mean temperature for example. The trends in annual and seasonal mean temperature are given in Table 2. It is seen that the annual mean temperature has increasing trends at Rajshahi and Rangpur with increasing rates of +0.012 and +0.017°C/ year respectively whereas it has decreasing trend at Dinajpur with -0.017°C/year. The seasonal mean temperature at Rajshahi and Rangpur has increasing trends, except in winter when it has decreasing trend at Rajshahi. The rate of increase in monsoon mean temperature is +0.024°C/year at Rajshahi. The seasonal temperature at Dinajpur has decreasing trends except the monsoon season when it has increasing trend. The maximum decreasing trend in mean temperature is -0.052°C/year during winter season at Dinajpur.

Table 2: Trends of temperature (°C/year) and rainfall (mm/ year) during 1981-2016 in northwest Bangladesh

Stations	Trends of temperature (°C/year)					Trends of rainfall (mm/ year)				
	Annual	Pre-monsoon	Monsoon	Post-monsoon	Winter	Annual	Pre-monsoon	Monsoon	Post-monsoon	Winter
Rajshahi	+0.012	**+0.020**	**+0.024**	+0.003	-0.008	-8.946	+0.029	-6.788	-1.115	-0.993
Rangpur	+0.017	+0.018	+0.019	**+0.021**	+0.004	-14.170	-0.342	-13.800	+0.667	-0.660
Dinajpur	-0.017	-0.015	+0.016	**-0.030**	**-0.052**	-11.030	-1.302	-9.870	+0.944	-0.249

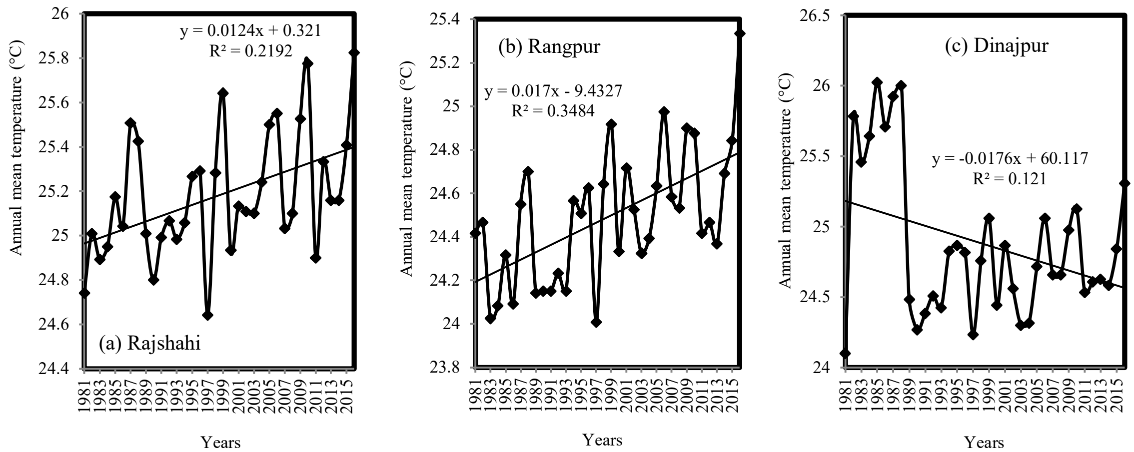

Figure 4: Trend in annual mean temperature (°C) at (a) Rajshahi, (b) Rangpur and (c) Dinajpur during 1981-2016

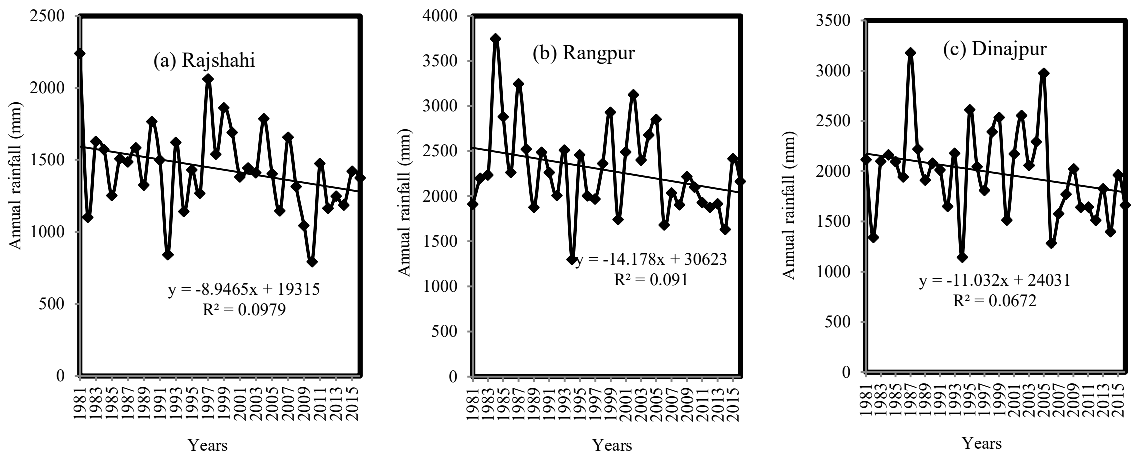

Figure 5: Trend in annual rainfall (mm) at (a) Rajshahi, (b) Rangpur and (c) Dinajpur during 1981-2016

3.4 Trend in annual and seasonal rainfall in northwest Bangladesh

Figure 5(a-c) shows the temporal variation of annual rainfall in Rajshahi, Rangpur and Dinajpur respectively. The annual rainfall has inter-annual variability but has significant decreasing trends in all the stations, having the rates of decreasing of -8.946, -14.170 and -11.030 mm/year in Rajshahi, Rangpur and Dinajpur respectively as given in Table 2. These decreasing rates are very high and alarming for the occurrence of drought in northwestern part of Bangladesh. The seasonal rainfall has also decreasing trends in northwest Bangladesh except the pre-monsoon season when it has increasing trend in Rajshahi and the post-monsoon season when there is increasing trends in Rangpur and Dinajpur. The decreasing trends in monsoon season are very high and significant with rates of decrease of -6.788, -13.800 and -9.870 mm/year in Rajshahi, Rangpur and Dinajpur during the period 1981-2016 (Table 2). On the average, northwest Bangladesh is likely to have more drought conditions, even in monsoon season if the present rate continues.

3.4 Heat Waves and Cold Waves over Bangladesh

Bangladesh experiences moderate to severe cold waves and heat waves frequently almost in every year during the winter season and the pre-monsoon seasons respectively. These cold waves and heat waves affect the health and livelihoods of the people, especially the children, women and elderly people. The cold waves and heat waves enter Bangladesh through west-northwest region of the country mainly; cold wave is also found to enter through the Srimangal-Sylhet region (Figure 6).

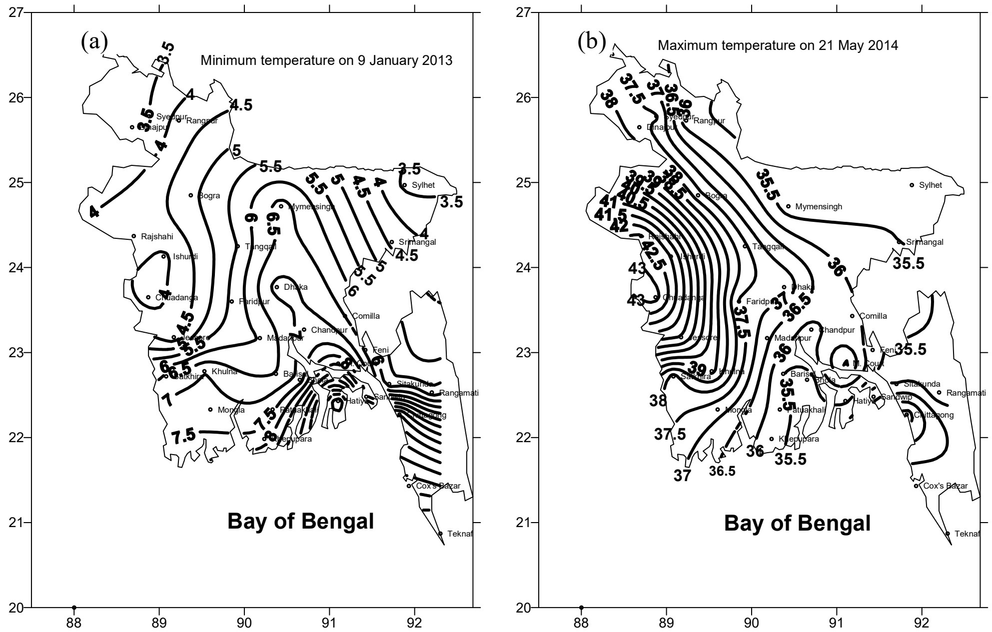

Figure 6: Distribution of (a) minimum temperature (ºC) causing Cold Wave in Bangladesh on 19 January 2013 and (b) maximum temperature (ºC) causing Heat Wave on 21 May 2014 in Bangladesh

During the winter season, cold wave occurs frequently in the northwest affecting the people of area and the night temperature sometime goes down to about 3°C or even below causing severe cold wave there. In 2013, the minimum temperature came down to 3.2°C at Dinajpur on 9 January (Figure 6a). In the pre-monsoon especially in the month of April or May, the day maximum temperature goes beyond 40°C frequently; on 21 May 2014 the maximum temperature rose to 43.2°C at Chuadanga and 42.6°C at Rajshahi (Figure 6b) and 41.0°C at Jashore on 21 May 2014.

Table 3: The classifications of cold and heat waves are as follows as per BMD

Types	Cold Waves	Heat Waves
	Minimum temperature (ºC)	Maximum temperature (ºC)
Mild	8-10	36-38
Moderate	6-8	38-40
Severe	4-6	40-42
Extreme	4	>42

3.4.1 Frequency of minimum temperature <10°C

The frequencies of minimum temperature (T_{min}) <10°C (cold waves) over Rajshahi, Rangpur and Dinajpur during 1981-2016 have been computed from the daily minimum temperature data obtained from BMD using excel program. The monthly mean days with T_{min} < 10°C i.e. the frequency of T_{min} < 10°C are given in Table 4. It is seen that mild to severe cold waves (here not separated in classes) occur over northwest Bangladesh in December, January and February mainly, though there are records of cold waves in March and November but very less. Average maximum frequency of cold waves is 10-13 days in January, but cold waves of 2-5 days are also found to occur in December. The mean frequency of cold wave days is slightly less in Rangpur as compared to that in Rajshahi and Dinajpur.

The temporal variations of the annual frequency of days with T_{min} <10°C are given in Figure 7(a-c) for Rajshahi, Rangpur and Dinajpur respectively. Figure 7a shows that the frequency of days with T_{min} <10°C may vary from 7 to 39 days in a year at Rajshahi and it has increasing trend at a rate of +0.035 days/year, which means that the duration of cold waves may increase in future at Rajshahi if this trend continues. At Rangpur, the annual frequency of T_{min} <10°C varies from 2 to 31 days and has decreasing trend at a rate of -0.123 days/year, which means that the duration of cold waves may decrease in future if this trend continues and the persistence of cold waves is less at Rangpur as compared to that at Rajshahi (Figure 7b). At Dinajpur, the annual frequency of T_{min} <10°C varies from 3 to 42 days (Figure 7c) and has decreasing trend at a rate of -0.119 days/year, which means that the duration of cold waves may also decrease in future if this trend continues and the persistence of cold waves is less at Dinajpur as compared to that at Rajshahi.

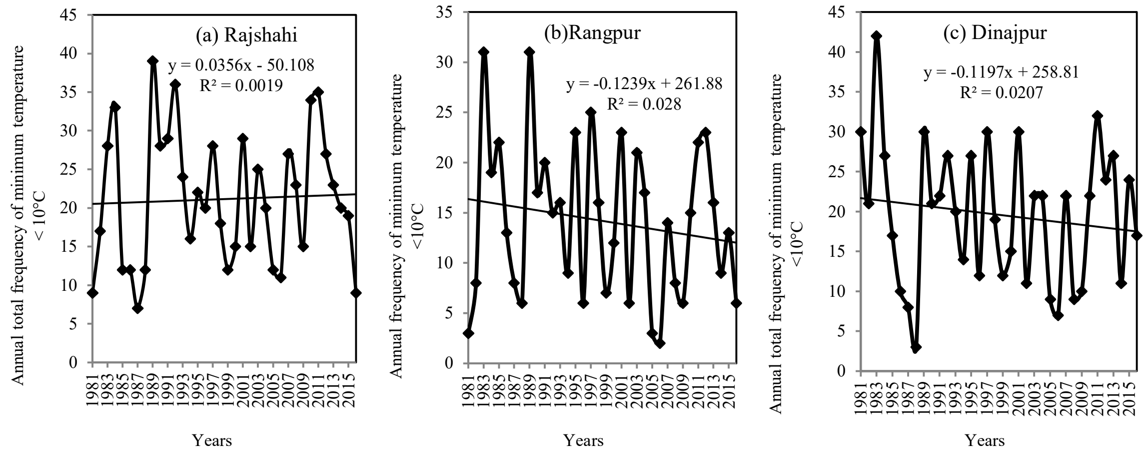

Figure 7: Trend in annual frequency of Tmin < 10°C at (a) Rajshahi, (b) Rangpur and (c) Dinajpur during 1981-2016

Table 4: Mean frequency of days with Tmin <10°C

Stations	Monthly mean days with Tmin <10°C				
	January	February	March	November	December
Rajshahi	13	3	0.14	0.06	4.75
Rangpur	10	3	0.03	0.00	2
Dinajpur	13	3	0.03	0.06	4

3.4.2 Frequency of maximum temperature >36°C

The monthly variation of mean frequency of maximum temperature (T_{max})>36°C for Rajshahi, Rangpur and Dinajpur is shown in Figure 8. The figure shows that Rajshahi has the highest mean frequency of T_{max} >36°C and is 13 days in the month of May during 1981-2016 whereas Dinajpur and Rangpur have the maximum mean frequency in the month of April, having 5.72 days and 2 days in Dinajpur and Rangpur respectively. The figure also indicates that the heat waves are more frequent in Rajshahi during April-July. The temporal variation of the annual frequency of days T_{max} >36°C at Rajshahi, Rangpur and Dinajpur during 1981-2016 are shown in Figure 9(a-c) respectively, showing inter-annual variation in the frequency of days with T_{max} >36°C. Figure 9a shows that the annual frequency of days with T_{max} >36°C has increasing tendency at Rajshahi at the rate of 0.655 days/year, whereas the same has no trend at Rangpur and decreasing trend at Dinajpur at the rate of -0.091 days/year during 1981-2016 as shown in Figure 9(b-c). But these figures show that the annual frequency of days with T_{max}>36°C at Rangpur and Dinajpur has sharp increasing trends from 1999 and 2002 respectively. If the current rates of increase in the annual frequency of days with T_{max} >36°C would continue in future, the heat waves would have tremendous impacts on the food security (crops, animals, etc.) in future and the situation would be more aggravated in Rajshahi.

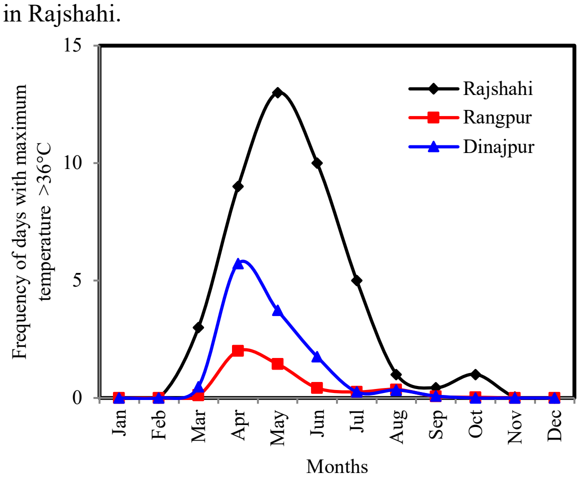

Figure 8: Monthly variation of the mean frequency of days with maximum temperature>36°C at Rajshahi, Rangpur and Dinajpur during 1981-2016

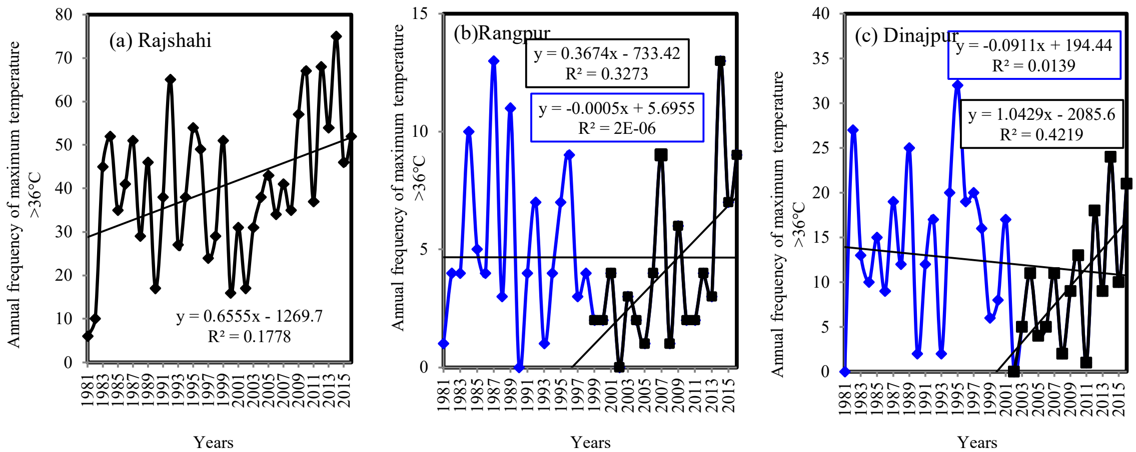

Figure 9: Trend in annual frequency of T_{max}>36°C at (a) Rajshahi, (b) Rangpur and (c) Dinajpur during 1981-2016

3.5 Non-rainy days and drought condition in northwest Bangladesh

The monthly, seasonal and annual frequencies of non-rainy days i.e. dry days have been computed through excel program for Rajshahi, Rangpur and Dinajpur during the period 1981-2016. Table 5 represents the monthly mean frequency of dry days in northwest Bangladesh. Non-rainy days are maximum in January and December with frequency of 30 days. It is minimum during the monsoon months with lowest minimum frequency of 10-11 days in July and then it increases slowly up to December. The temporal variations in annual non-rainy days during 1981-2016 are shown in Figure 10(a-c) for Rajshahi, Rangpur and Dinajpur respectively. All the figures show inter-annual variability in non-rainy days and sharp increasing trends in dry days at the rates of +0.037, +0.096 and +0.205 day/year at Rajshahi, Rangpur and Dinajpur respectively. The maximum increasing trend of dry days is at Rajshahi and indicates more drought conditions likely and is alarming for food security.

Table 5: Monthly mean frequency of dry days in northwest Bangladesh during 1981-2016

Station	Monthly mean frequency of dry days											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rajshahi	30	26	28	25	22	16	11	13	15	24	29	30
Rangpur	30	27	28	22	16	12	11	15	14	24	29	30
Dinajpur	30	27	29	24	19	14	10	14	14	25	29	30

The seasonal trends in non-rainy days are also computed and are given in Table 6, which shows that the dry days are increasing during 1981-2016 in the three places of northwest Bangladesh in all the seasons except the pre-monsoon season at Rangpur and Dinajpur and post-monsoon season at Rajshahi when dry days are seen to decrease during 1981-2016. But the seasonal trends in non-rainy days are all positive in all the seasons from the year 2000 with much higher increasing rates at all the stations. The increasing trend of dry days is maximum at Rajshahi during the monsoon season when the rate is +0.184 day/year during 1981-2016. The increasing trend of dry days is likely to increase drought condition in northwest part of the country with increasing adverse impact on food security in future if the present trends continue.

3.6 Trend in relative humidity in northwest Bangladesh

Monthly mean relative humidity (%) during 1981-2016 in northwest Bangladesh is given in Table 7, which shows that the monthly mean RH ranges from 61.81to 86.67%, having minimum RH in March and higher RH during the monsoon season. During the period 1981-2016, the annual mean RH has increasing trends at Rajshahi and Dinajpur at the rates of +0.99% and +0.253% per year whereas annual RH has decreasing trend of -0.096% per year at Rangpur. Figure 11(a-c) shows the temporal variation of annual mean RH at Rajshahi, Rangpur and Dinajpur respectively. All the figures show inter-annual variability with definite decreasing trends since 1998 in the northwest part of the country. These decreasing trends in RH indicate drying conditions over the area agree with the increasing dry days, which may increase drought situation there in future if the situations continue.

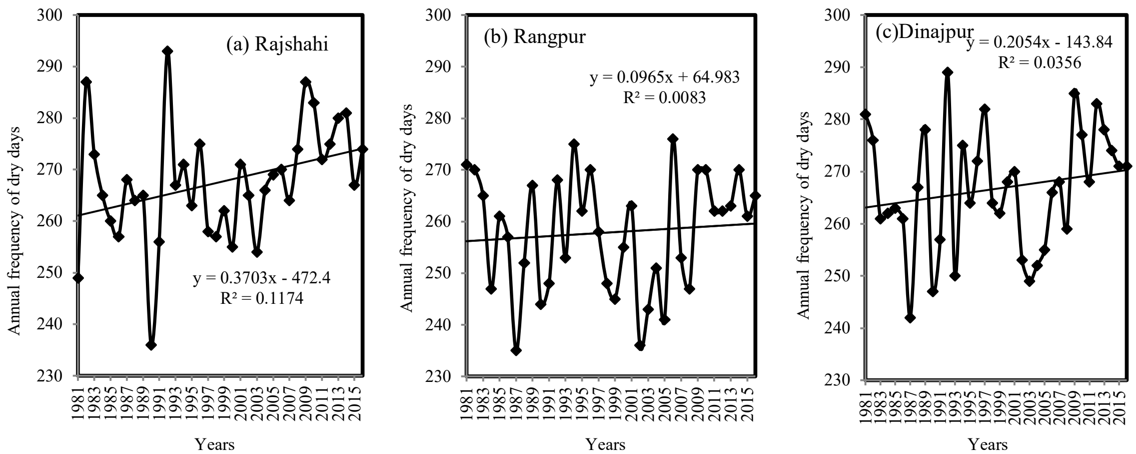

Figure 10: Trends in annual frequency of dry days (day/year) at (a) Rajshahi, (b) Rangpur and (c) Dinajpur during 1981-2016

Table 6: Trends in annual and seasonal frequency of dry days (day/year) in northwest Bangladesh during 1981-2016

Stations	Trends in frequency of dry days (day/year)				
	Pre-monsoon	Monsoon	Post-monsoon	Winter	Annual
Rajshahi	+0.126	+0.184	-0.019 (+0.110 from 2000)	+0.057	+0.037
Rangpur	-0.087 (+0.392 from 2000)	+0.096	+0.059	+0.029	+0.096
Dinajpur	-0.049 (+0.399 from 2000)	+0.162	+0.052	+0.054	+0.205

Table 7: Monthly mean RH (%) during 1981-2016 in northwest Bangladesh

Station	Monthly mean RH (%)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rajshahi	77.75	71.14	62.47	65.56	75.08	82.64	86.67	86.08	85.58	82.44	78.17	78.69
Rangpur	81.53	74.08	67.33	72.97	79.78	84.25	85.14	84.57	86.04	83.42	79.42	80.83
Dinajpur	77.86	69.14	61.81	66.64	75.42	81.03	83.53	83.5	84.64	80.83	76.39	78.08

Table 8: Trends in annual and seasonal mean RH (%/year) in northwest Bangladesh during 1981-2016

Stations	Trends in RH (%/year)				
	Pre-monsoon	Monsoon	Post-monsoon	Winter	Annual
Rajshahi	+0.158	-0.020	+0.110	+0.168	+0.099
Rangpur	+0.091	-0.085	-0.064	+0.048	-0.096
Dinajpur	+0.402	+0.074	+0.220	+0.367	+0.253

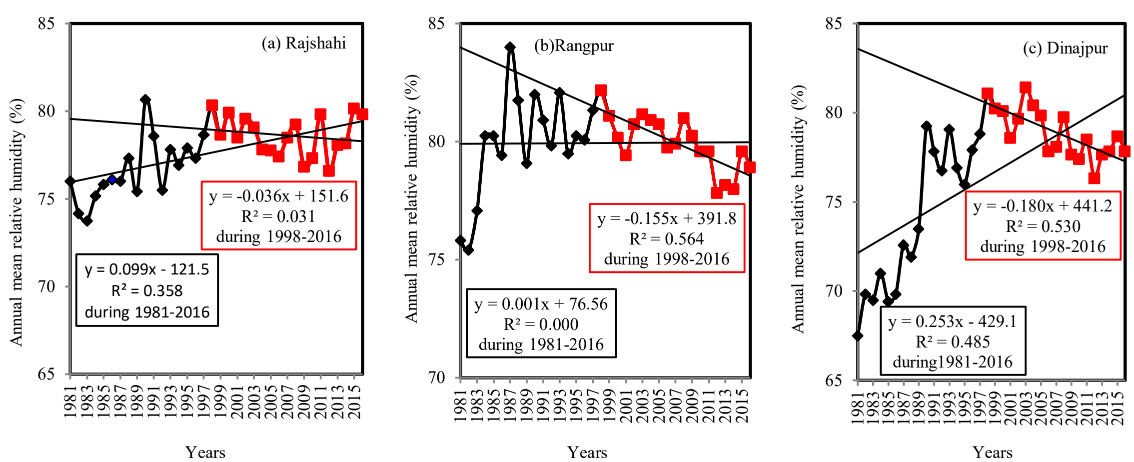

Figure 11: Trend in annual RH (%) at (a) Rajshahi, (b) Rangpur and (c) Dinajpur during 1981-2016

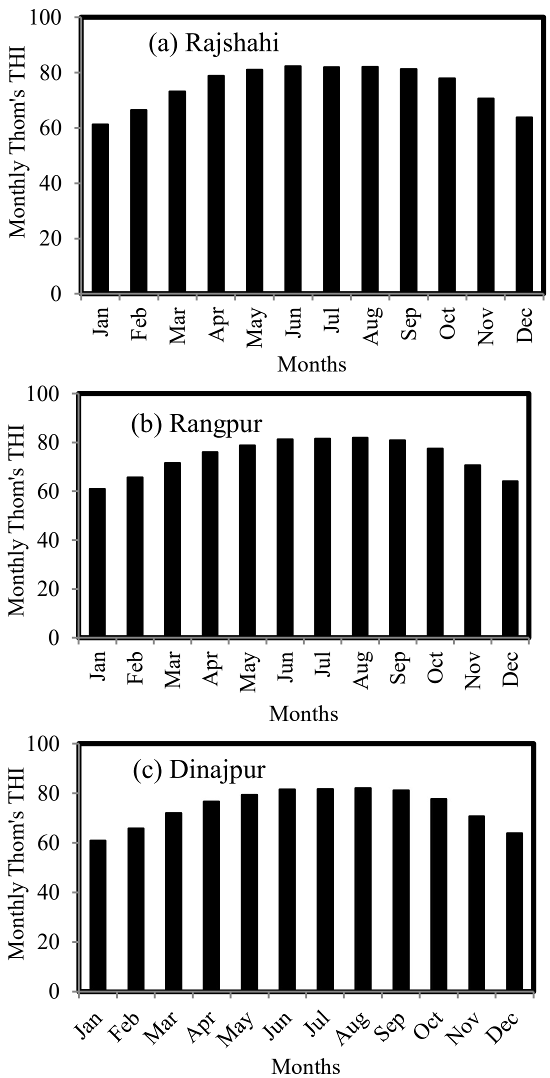

Figure 12: Monthly variation of Thom's THI at (a) Rajshahi, (b) Rangpur and (c) Dinajpur

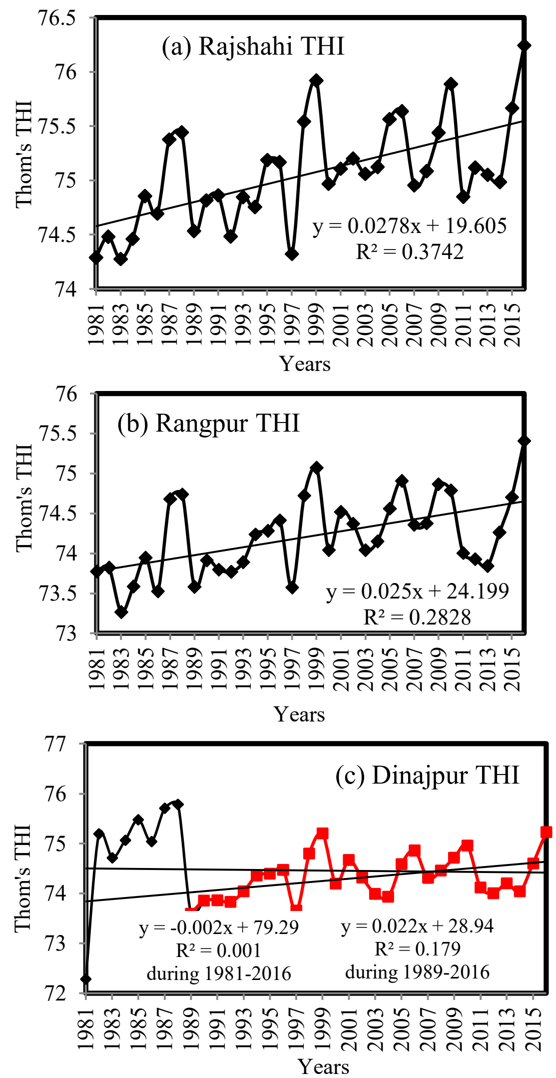

Figure 13: Trend in Thom's THI (a) Rajshahi, (b) Rangpur and (c) Dinajpur during 1981-2016

The trends in seasonal and annual mean RH during 1981-2016 are given in Table 8 for the three places under study. The table shows that the seasonal mean RH has increasing trends in all the seasons except at Rajshahi and Rangpur during the monsoon season and Rangpur in the post-monsoon season when RH has decreasing trends. The increasing trends are much higher at Dinajpur. From the analysis, it is also found that RH has decreasing trends since around 1998 at all the places in all the seasons.

3.7 Heat stress in northwest Bangladesh

Heat stress has been assessed in terms of Thermal heat Index (THI). Monthly mean THI has been computed from monthly mean temperature and RH data for the period 1981-2016 for Rajshahi, Rangpur and Dinajpur and the distributions of monthly THI are shown in Figure 12(a-c) respectively. The figures show that moderate heat stress, on the average, exists during the monsoon season and mild heat stress prevails during the pre-monsoon and post-monsoon seasons. December, January and February i.e. the winter season has no heat stress. It may be mentioned that heat waves prevail over Bangladesh during pre-monsoon season when the temperature rises to 38-42°C or more, which when combined with moderate humidity creates extreme heat stress as shown in Table 9, for example. Analysis of the annual mean heat stress over northwest Bangladesh indicates significant increasing trends at Rajshahi and Rangpur and decreasing trend at Dinajpur during 1981-2016. The trends are +0.027, +0.025 and -0.002 per year at Rajshahi, Rangpur and Dinajpur respectively as seen from Figure 13(a-c). But the Figure 13c also shows that the annual heat stress has increasing trend at Dinajpur at a rate of + 0.022

per year since 1989. This increasing tendency of heat stress in northwest Bangladesh would have impact on agricultural sector as well as the food security in future if trend continues.

Table 9: Extreme THI in northwest Bangladesh

Stations	Date	Tmax (°C)	RH (%)	THI
Rajshahi	19 May 1972	45.1	67	103.12
Rangpur	02 May 1966	42.8	46	93.75
Dinajpur	20 May 1961	43.3	35	91.19

3.8 Thunderstorms in northwest Bangladesh

Thunderstorms are severe weather phenomena, which occur in northwest Bangladesh especially in the pre-monsoon season and this region is entry point of these storms mostly. Though seasonally 40-70 thunderstorms occur here (Karmakar and Mannan, 2014) but the seasonal frequency sometimes exceeds 100 in a particular year. They are the most destructive disasters for damaging mango fruits, trees, paddy and other agricultural crops. These storms are associated with numerous hails of moderate to big sizes, and these hails and the gusty winds are detrimental to mango, paddy, etc. The trend analyses of monthly and seasonal thunderstorms are given in Figure 14 (a-c) for Rajshahi, Rangpur and Dinajpur respectively. All these figures indicate increasing trends in the monthly and seasonal frequencies of thunderstorms. If the present trends continue, there will be more thunderstorms and more thunderstorms would be associated with more gusty winds, more lightning, more thunder and more hails; these would result in more loss of lives and damage to natural and agricultural resources, having huge impact on food security.

3.9 Extreme events in northwest Bangladesh

3.9.1 Heavy rainfall

The northwestern part of Bangladesh is affected by severe floods during the monsoon season mainly and these floods occur due to heavy to very heavy rainfall over north-northwest region and the catchment areas north of Bangladesh. In August 2017, very heavy rainfall of 332 mm in 24 hours occurred at Tetulia on 11 August and the whole region had about 850 mm during 9-13 August as can be seen from Figure 15. As a result, severe floods occur in Gaibandha district (Figure 15).

3.9.2 Floods

Rangpur and Rajshahi divisions are susceptible to floods, sometimes severe floods occur in this region during the southwest monsoon season. In some years, the region is affected recurring floods in the same year. In 2017, severe floods occurred in three countries such as Bangladesh, Nepal and India. In Bangladesh Gaibandha was the worst hit district (Figure16). According to BWDB, the water level in the Brahmaputra rose by 49 cm during the period and it was flowing 78 cm above its danger level at Fulchharighat point of the district. The Ghagot which was flowing through the mainland of the district rose by 56 cm during the period and was flowing 64 cm over its danger mark at New Bridge Road point of the district town. The other major rivers such as the Teesta and the Karotoa were flowing 03 cm and 02 cm above their danger marks respectively. Due to the rise in water level in the Brahmaputra and the Teesta, the fresh areas of chars and the river basin of 26 unions of Sundarganj, Sadar Fulchhari and Saghata Upazila were submerged. According to the DRRO, a total of 139,000 people of 35,000 families of the Upazilas were marooned.

3.9.3 River erosion

Floods and river-bank erosion in the rainy season are common in northwest Bangladesh almost every year (Figure 17). The Jamuna, Teesta and Ghagot rivers become ferocious when heavy rainfall occurs in the north and in the catchment areas. Generally, riverbeds are filled up by siltation and accommodating capacity of the rivers have become less and as a result floods occur, causing significant impacts in different sectors such agriculture, social, economic, health, education, etc. The people become homeless due to land erosion. They suffer from loss of properties; belongings and their livelihoods are affected severely. The children cannot go to School and their education is hampered. The poor people change their livelihoods and are compelled to migrate to other areas. At some places, river water level crossed its previous recorded highest level as can be seen in Table 10.

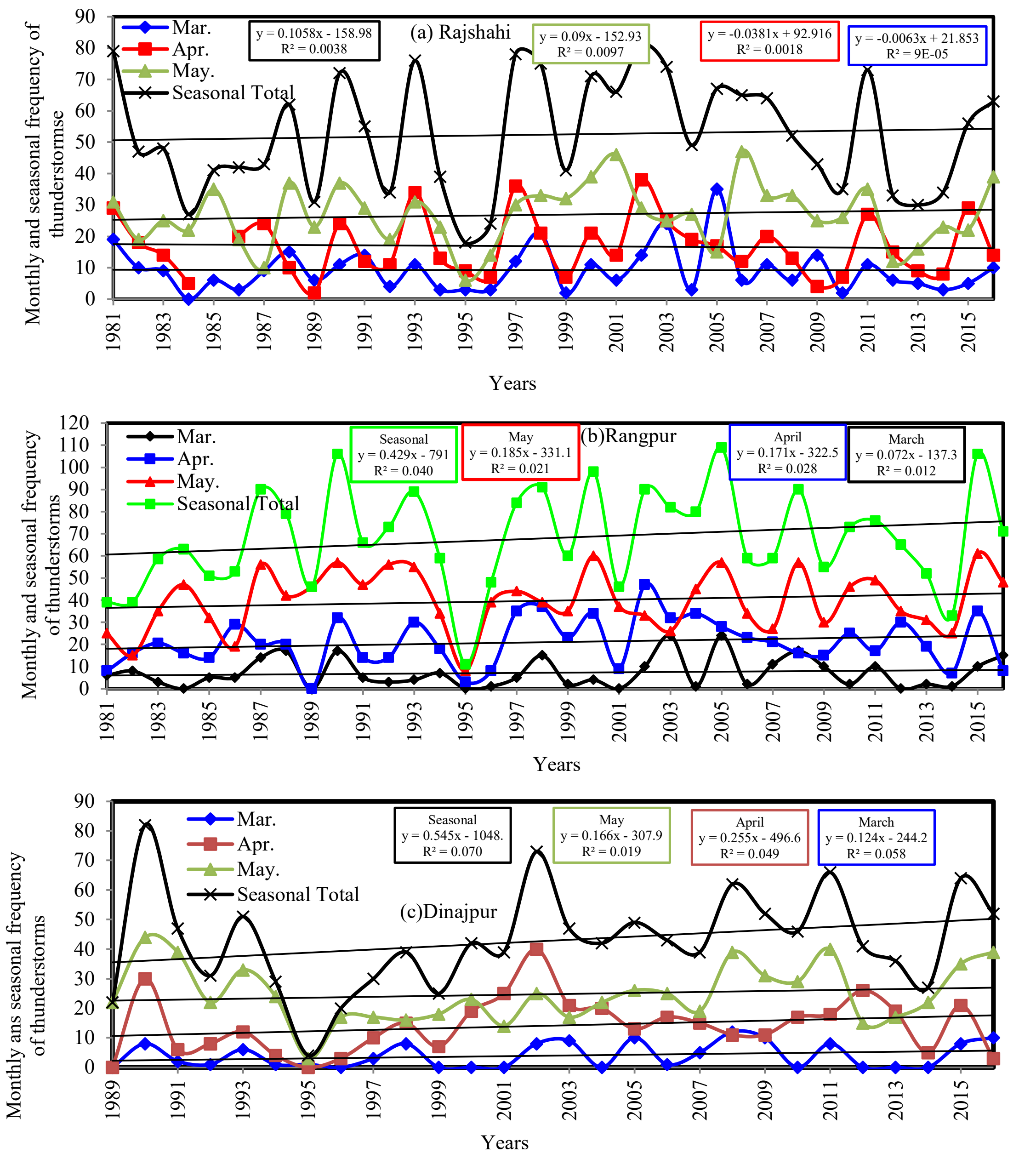

Figure 14: Trends in monthly and seasonal frequency of thunderstorms at (a) Rajshahi, (b) Rangpur and (c) Dinajpur during 1981-2016

Table 10: Severe flood at several places (BWDB, 2017)

River	Station	Previous WL	Level in 2017
Tangaon	Thakurgaon	51.26	51.30
Teesta	Dalia	52.95	53.05
Dharla	Kurigram	27.66	27.84
Jamuna	Bahadurabad	20.71 (2016), 20.62(1988)	20.84
Jumeswari	Badarganj	32.92	33.61

3.10 Impacts of climate change in NW-Bangladesh

During the study, field visits had been organized at different Upazilas of Nawgaon, Gaibandha, Kurigram, Rajshahi, Rangpur and Dinajpur to gather the data on the impacts of climate change and extreme disastrous climatic events. Besides, some seminars were organized with the local people, Upazila and districts officials and elite people to validate the information on the impacts of climate change obtained from the local people. The impacts of climate change, as obtained, are summarized below:

- ➢ The people, especially the children and elderly people, suffer from heat stroke; domestic animals are affected by diarrheas and other diseases during heat waves. Rearing of livestock is hampered due to increase in temperature and heat. Flowering of crops is affected more due to more increasing trends in monsoon temperature.
- ➢ The increasing trend in pre-monsoon temperature has intensified the intensity of heat waves, drought conditions and thunderstorms in Rajshahi and Rangpur.

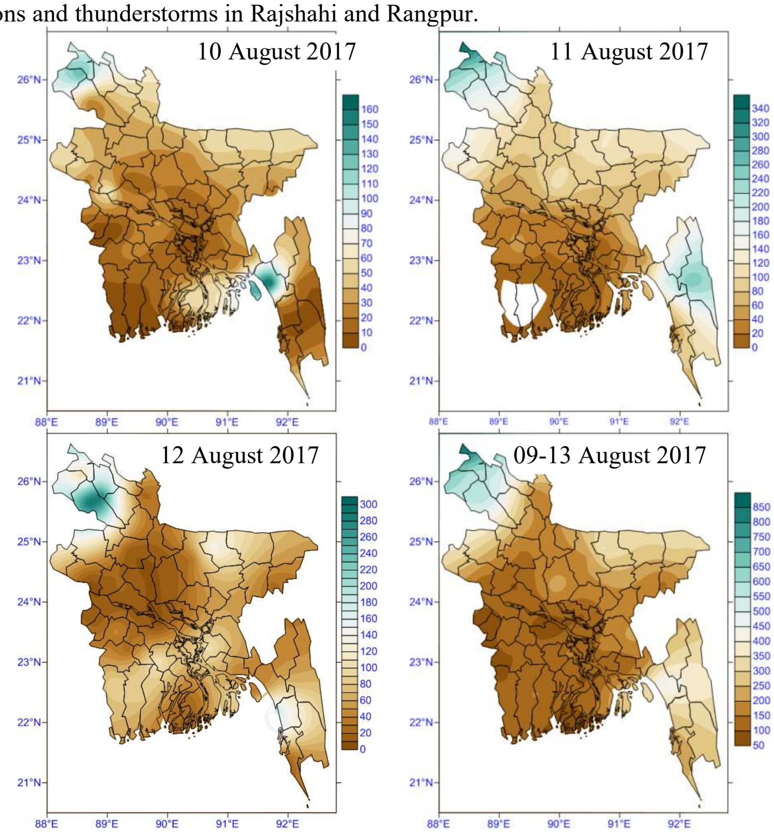

Figure 15: Recorded rainfall during flood of 9-13 August 2017 (Mannan, 2017)

Figure 16: Overall flood situation in chars and river basin areas of the Brahmaputra River in the district of Gaibandha (Reports BSS: Daily sun, 2017).

Figure 17: Riverbank erosion at Kurigram (Green Watch, 2016)

- ➢ While the decreasing trend in winter temperature in Dinajpur has intensified cold waves, more thick fogs occur, which have great impacts on agriculture, livestock rearing, controlling of insects and food security as a whole.
- ➢ Northwest Bangladesh has more drought conditions during the pre-monsoon season; even sometimes in monsoon season. Agriculture sector and food security are affected due to the decrease in rainfall.

- Lightning and thunder kill more people now-a-days due increase in their frequencies.
- The extremes events which affect the region, the poor community, agriculture and livelihoods are heavy rainfall, floods, riverbank erosion, drought, heat waves, cold waves, heat stress, Kalbaishakhi/ thunderstorms, lightning and thunder, decreasing of ground water level, etc.

4 CONCLUSIONS

On the basis of the present study, the following conclusions can be drawn:

i. The annual mean temperature ranges from about 24.4°C in the north and 25.2°C in the south over northwest Bangladesh. From the spatial distribution of seasonal mean temperature, it has been found that the seasonal mean temperature ranges are 18.0-18.2° 25.6-27.8 28.2-28.8 and 24.2-24.6°C in winter, pre-monsoon, monsoon and post-monsoon seasons respectively. The monsoon mean temperature is higher than that of the pre-monsoon temperature.

ii. Annual mean temperature has increasing trends in Rajshahi and Rangpur with increasing rates of +0.012 and +0.017°C/ year respectively. It has decreasing trend in Dinajpur at -0.017°C/ year. The seasonal mean temperature at Rajshahi and Rangpur has increasing trends in all the seasons, except the winter season when the temperature has decreasing trend at Rajshahi. The maximum rate of increase in monsoon mean temperature is +0.024°C/year in Rajshahi. The seasonal mean temperature in Dinajpur has decreasing trends except the monsoon season when it has increasing trend. The maximum decreasing trend in mean temperature is -0.052°C/ year during winter season in Dinajpur.

iii. Annual rainfall has decreasing trends at Rajshahi, Rangpur and Dinajpur. The rates of decreasing of annual rainfall are -8.946, -14.170 and -11.030 mm/year in Rajshahi, Rangpur and Dinajpur respectively. The seasonal rainfall has also decreasing trends in northwest Bangladesh except the pre-monsoon season when it has increasing trend in Rajshahi and the post-monsoon season when there is increasing trends in Rangpur and Dinajpur. The decreasing trends in monsoon season are very high and significant with rates of decrease of -6.788, -13.800 and -9.870 mm/year in Rajshahi, Rangpur and Dinajpur respectively.

iv. Annual frequency of days with minimum temperature <10°C has increasing trend (+0.035 days/year) at Rajshahi and decreasing trends at Rangpur (-0.123 days/year) and Dinajpur (-0.119 days/year). The duration of cold waves may increase in future at Rajshahi and decrease at Rangpur and Dinajpur.

v. Rajshahi has the highest mean frequency of maximum temperature >36°C in the month of May whereas Dinajpur and Rangpur have the maximum mean frequency of maximum temperature >36°C in the month of April. Heat waves will be more long lasting in Rajshahi during April-July. The annual frequency of heat wave days with T_{max} >36°C has increasing tendency in northwest Bangladesh.

vi. Non-rainy days (dry days) are maximum in January and December with frequency of 30 days. It is minimum during the monsoon months with lowest minimum frequency of 10-11 days in July and then it increases slowly up to December. The annual frequency of dry days has sharp increasing trends at the rates of +0.037, +0.096 and +0.205 day/year at Rajshahi, Rangpur and Dinajpur and the maximum increasing trend of annual dry days is at Rajshahi. The seasonal dry days have increasing trends from the year 2000 at all the places with much higher rates of increasing.

vii. During the period 1981-2016, the annual mean RH has increasing trends at Rajshahi and Dinajpur at the rates of +0.99% and +0.253% whereas decreasing trend of -0.096% per year at Rangpur. The annual and seasonal mean relative humidity have definite decreasing trends since 1998 in the northwestern part of the country.

viii. The annual mean heat stress over northwest Bangladesh indicates significant increasing trends at Rajshahi and Rangpur and decreasing trend at Dinajpur during the period 1981-2016. But the annual heat stress at Dinajpur has increasing trends at +0.022/year since 1989.

ix. The monthly and seasonal frequencies of thunderstorms during the pre-monsoon season have increasing trends over northwest Bangladesh.

ACKNOWLEDGEMENT

The author is thankful to Dr. Atiq Rahman, Executive Director of Bangladesh Centre for Advanced Studies (BCAS) and Dr. Dwijen Mallick, Team Leader of NETZ Project for their suggestions and inspiration to carry out this study. Special thanks go to Mr. Shamsuddin Ahmed, Director of Bangladesh Meteorological Department (BMD) and Dr. Md. Abdul Mannan, Meteorologist of BMD for supplying relevant climate data for carrying out the present study.

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