Vol. 42: 185–193, 2010
doi: 10.3354/cr00889

CLIMATE RESEARCH
Clim Res

Published online July 20

Recent trends in the climate of Bangladesh

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ABSTRACT: Rainfall and temperature data recorded at 17 meteorological stations over the time period 1958–2007 were used to assess recent changes in the climate of Bangladesh. The results show increasing mean, mean maximum and mean minimum temperatures at a rate of 0.103, 0.091 and 0.097°C per decade, respectively. More warming was observed for winter compared to other seasons. Increases in annual and pre-monsoon rainfall were also observed at a rate of 5.53 and 2.47 mm yr^{-1}, respectively. The spatial pattern of rainfall trends shows an increase in annual, monsoon and pre-monsoon rainfall in the western part of Bangladesh. The findings of the present study are consistent with the results obtained in other parts of the Indian subcontinent.

KEY WORDS: Climate variability · Trend analysis · GIS · Bangladesh

1. INTRODUCTION

Climate is changing at both the global (Lambert et al. 2003, Dore 2005) and regional scales (Gemmer et al. 2004, Kayano & Sansígolo 2008) due to global warming. The implications of climate change are particularly significant for the regions already under stress, such as in Bangladesh, where hydrological disasters are common (Shahid & Behrawan 2008). The IPCC (2007) has named Bangladesh as one of the most vulnerable countries in the world due to climate change. It has been predicted that, due to climate change, there will be a steady increase of temperature and change in rainfall pattern, which might have a number of implications for agriculture (Karim et al. 1999), water resources (Fung et al. 2006) and public health (Shahid 2009).

Bangladesh belongs to the Asian monsoon regime which is characterized by a seasonal reversal of surface winds and a distinct seasonality of precipitation. During the boreal summer, winds blow from the Southern Hemisphere from mid-May to September, accumulating moisture and depositing copious amounts of precipitation over the South Asian continent. In the winter, dry winds blow from the cold land areas of Asia towards the warm Southern Ocean. The fundamental driving mechanisms of the monsoon cycle are the cross-equatorial pressure gradients established by thermal contrasts between the Asiatic land mass and the ocean, modified by the rotation of the earth, and the exchange of moisture between the ocean, atmosphere and land (Webster 1987). The interannual variability of the Asian monsoon is linked with the El Niño Southern Oscillation (ENSO). The general consensus is that during El Niño years anomalous subsidence suppresses convection over South Asia and results in a weaker monsoon. The tropospheric temperature gradient between the Tibetan Plateau (TP) and the Indian Ocean also plays a critical role in interannual variation of Asian summer precipitation (Immerzeel 2008). The snow depth on the TP affects the land surface thermodynamics and reduces this thermal gradient. Shaman et al. (2005) reported an inverse relationship between the spring snow depth on the TP and monsoon precipitation in Bangladesh.

Though literature is available on the rainfall patterns and climate of Bangladesh (Ahmed & Karmakar 1993, Ahmed et al. 1996, Hussain & Sultana 1996, Kripalani et al. 1996, Ahmed & Kim 2003, Islam & Uyeda 2008, Shahid 2008), studies on historical rainfall and temperature trends are very few (Jones 1995, Rahman et al. 1997, Singh 2001). Rahman et al. (1997) analyzed the trend of monsoon rainfall patterns and found that although the southeast part of the country shows a changing pattern of rainfall, the overall evidence does not suggest any changing pattern of monsoon rainfall. On the other hand, Singh (2001) reported that the monsoon rainfall over Bangladesh has increased dur-

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ing the period 1961–1991 with a maximum increase in September followed by that in July. The only work carried out so far on temperature trends in Bangladesh is by Jones (1995), who analyzed the monthly mean maximum and minimum temperatures over the period 1949–1989 and found no significant change in annual mean minimum and maximum temperatures. This contradicts the results obtained in the regions of India bordering Bangladesh (Pant & Rupa Kumar 1997). A large amount of scientific literature is available on the variability of rainfall and temperature of India (Mooley & Parthasarathy 1984, Rupa Kumar et al. 1992, Pant & Rupa Kumar 1997, Sinha Ray & De 2003, Arora et al. 2005, Guhathakurta & Rajeevan, 2008). These studies show an increase in the annual mean temperature over India in the last 100 yr, with a higher increase in winter temperature compared to pre-monsoon summer temperature. On the other hand, no statistically significant trend has been observed in monsoon rainfall over India as a whole (Thapliyal & Kulshrestha 1991, Pant & Rupa Kumar 1997). However, Rupa Kumar et al. (1992) reported that there are areas over India with decreasing rainfall, and other areas with increasing trends.

Climate models have been used to predict the change in rainfall and temperature of Bangladesh and India (Manabe et al. 1991, Stephenson et al. 2001, Kripalani et al. 2003, 2007, Agrawala et al. 2003, May 2004, Dash et al. 2006, Immerzeel 2008). However, consensus has not yet been reached on the projected strength of monsoon circulation and the quantum of rainfall. May (2004) used a climate model to study the rainfall pattern over the tropical Indian Ocean and predicted an increase in intensity of heavy rainfall events in Bangladesh. Immerzeel (2008) predicted seasonal increases in precipitation from 2000 to 2100, with more increases in the monsoon season compared to other seasons for the Brahmaputra basin. Rupa Kumar et al. (2006) projected a marked increase in both rainfall and temperature in India towards the end of the 21st century under scenarios of increasing greenhouse gas concentrations. Kripalani et al. (2007) reported that although the projected summer monsoon circulation appears to weaken, the projected anomalous flow over the Bay of Bengal and the Arabian Sea will support oceanic moisture convergence and more rainfall towards the southern parts of India. Stephenson et al. (2001) investigated possible trends in several large-scale indices that describe the Asian summer monsoon using results from recent atmospheric general circulation experiments and found a weakening of the monsoon circulation. Using the RegCM3 model, Dash et al. (2006) predicted weaker Indian summer monsoon and reduction of rainfall by about 30%. Pal et al. (2001) suggested that the total rainfall may not change significantly, but the temporal and spatial distribution of rainfall over India is likely to change. Finally, Kripalani et al. (2003) concluded that there seems to be no support for the intensification of the monsoon or the increased hydrological cycle as hypothesized by the greenhouse warming scenario in model simulations or in long-term historical observed data.

Several studies have shown that although atmosphere–ocean coupled models provide good representations of synoptic scale systems, direct use of the model scenarios on a regional scale suffers from errors, since general circulation models (GCMs) do not capture the finer details of the spatial variation in rainfall (De 2001, Rupa Kumar & Ashrit 2001, Kripalani et al. 2003). Sperber & Palmer (1996) evaluated the performance of 32 models for the prediction of interannual variability of rainfall over the Indian subcontinent for the period 1979–1988 and found that the precipitation variations over India are less well simulated. However, the models show better skill in reproducing the interannual variability of circulation indices over the Indian summer monsoon region, indicating that the models exhibit greater fidelity in capturing the synoptic dynamic fluctuations than the regional scale rainfall variations (Gadgil & Sajani 1998). Therefore, investigation through observational data is required to seek independent confirmation of the findings obtained through model simulations. Detailed study of annual and seasonal variation in the climate of Bangladesh with long-term observational data can be helpful to understand both regional climate changes as well as the broad features of the Asian coupled land–atmospheric system.

Though the trends of monsoon rainfall and temperature have already been carried out for 30 to 40 yr time series data for a number of stations in Bangladesh, those analyses were performed mostly on data before 1990 (Jones 1995, Rahman et al. 1997). Therefore, recent changes in the climate might not be apparent in those analyses. In the present study, trends in the annual and seasonal rainfall and temperature of Bangladesh in last 50 yr (1958–2007) were assessed and their spatial patterns are presented. Monthly mean rainfall and temperature data from 17 stations distributed throughout Bangladesh were used for this purpose. Annual time series of mean temperature, mean maximum temperature and mean minimum temperature were prepared and their trends were assessed. Average temperature series of each month were also prepared to decipher the seasonal change in temperature. Rainfall trends were computed for both annual and seasonal rainfall time series. For seasonal analysis of rainfall, each year was divided into 4 seasons depending upon the climatic conditions prevailing over the country. The Mann-Kendall test (Mann 1945, Kendall 1975) was used to detect the trend and Sen's slope method (Sen 1968) was used to determine the magnitude of change in the climate time series. The

Mann-Kendall test is an excellent tool for trend detection in water resource time series (Helsel & Hirsch 1992). Sen's slope method is insensitive to outliers and can give a robust estimation of trend (Yue et al. 2002).

2. CLIMATE OF BANGLADESH

Bangladesh is primarily a low-lying plain of about 144 000 km^2, situated on deltas of large rivers flowing from the Himalayas. Geographically, it extends from 20° 34′ to 26° 38′ N latitude and from 88° 01′ to 92° 41′ E longitude. Bangladesh has a sub-tropical humid climate characterized by wide seasonal variations in rainfall, moderately warm temperatures and high humidity (Rashid 1991). Four distinct seasons can be recognized from a climatic point of view: (1) the dry winter season from December to February, (2) the pre-monsoon hot summer season from March to May, (3) the rainy monsoon season from June to September, and (4) the post-monsoon autumn season from October to November. Rainfall varies from 1400 mm in the west to more than 4400 mm in the east, with a west–east gradient of almost 7 mm km^{-1}. Higher rainfall in the northeast is caused by the additional uplifting effect of the Meghalaya Plateau. More than 75 % of the rainfall in Bangladesh occurs during the monsoon season, caused by weak tropical depressions that are brought from the Bay of Bengal into Bangladesh by the wet monsoon winds. The average temperature ranges from 7.2 to 12.8°C during winter and 23.9 to 31.1°C during summer, and January is the coldest month and May is the hottest month. The mean temperature gradient in the pre-monsoon season is oriented southwest to northeast, with the warmer zone in the southwest and the cooler zone in the northeast. In winter, the mean temperature gradient is oriented south to north; the southern region is 5°C warmer than the northern region (Agrawala et al. 2003). It has been projected by climate models that the temperature would rise 2.4°C and the rainfall by 9.7 % at the end of the present century (Agrawala et al. 2003). The impacts of intense precipitation and extreme weather events are already felt in Bangladesh. Floods in 1988, 1998, 2004 and 2007, and cyclones and tidal surges in 1991, 1998, 2000, 2004 and 2007 record the increase of extreme events in both frequency and severity (Mallick 2008).

3. DATA AND METHODS

The Bangladesh Meteorological Department (BMD) has 27 stations for measuring daily rainfall and other weather parameters. Long-term (>50 yr) daily temperature and rainfall records are available only from 17 of these stations; 50 years (1958–2007) of rainfall records from those 17 stations were used in the present study to assess the recent change in the climate of Bangladesh. The 17 stations are distributed throughout the country (Fig. 1).

The Mann-Kendall test (Mann 1945, Kendall 1975) was applied to detect the trend in rainfall time series, and Sen's (1968) slope method was used to determine the magnitude of change. Confidence levels of 90, 95 and 99 % ($p < 0.10$, $p < 0.05$ and $p < 0.01$, respectively) were taken as thresholds to classify the significance of positive and negative precipitation trends. However, to detect temperature trends, confidence levels of 95 and 99 % ($p < 0.05$ and $p < 0.01$, respectively) were taken as thresholds, as the change in temperature is more prominent compared to rainfall.

To map the spatial pattern of trends from point data, we used the kriging interpolation method of the geostatistical analysis tool in ArcMap 9.1 (ESRI 2004).

4. RESULTS AND DISCUSSION

4.1. Temperature

A significant increase of mean temperature was noted at 10 stations, and mean minimum and mean maximum temperatures at 9 stations (Table 1).

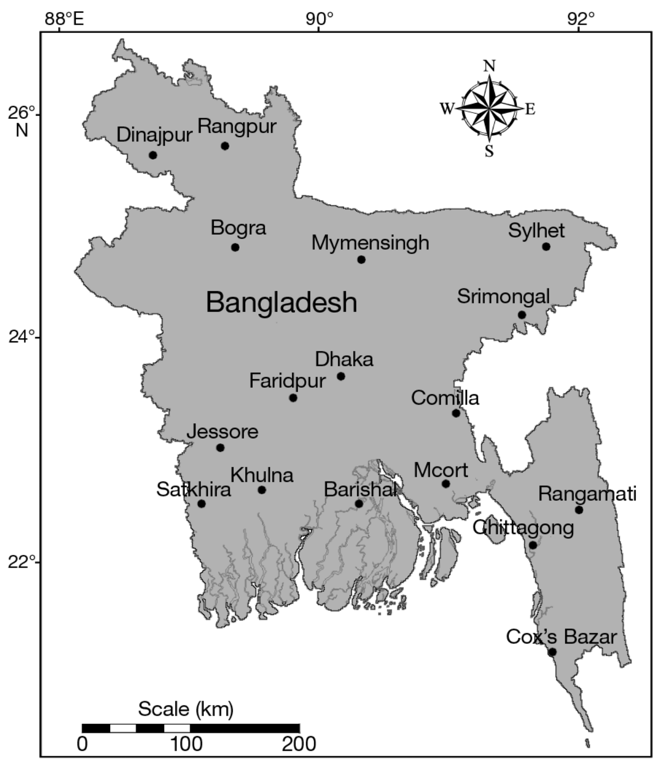

Fig. 1. Bangladesh, showing meteorological stations used in the present study

Table 1. Trends in mean minimum, mean maximum and mean temperatures (°C decade^{-1}) in Bangladesh. *p < 0.05; **p < 0.01

Station	Minimum	Maximum	Mean
Sylhet	0.19**	0.26**	0.21**
Srimongal	0.30**	0.01	0.17*
Comilla	–0.03	–0.03	–0.08
Rangamati	–0.46**	–0.14	–0.36**
Chittagong	0.15*	0.21**	0.16**
Cox' Bazar	0.24**	0.48**	0.36**
MCort	0.37**	0.20**	0.27**
Faridpur	0.31**	0.18**	0.27**
Dhaka	0.29**	0.32**	0.30**
Mymensingh	0.05	0.00	0.05
Khulna	–0.27**	0.06	–0.09
Barishal	0.00	0.21**	0.12**
Satkhira	0.10	0.16*	0.11
Jessore	0.10	0.22**	0.15**
Bogra	0.13**	0.11	0.13**
Dinajpur	0.00	0.00	0.00
Rangpur	0.25**	–0.15	0.01
Overall mean	0.103*	0.091*	0.097*

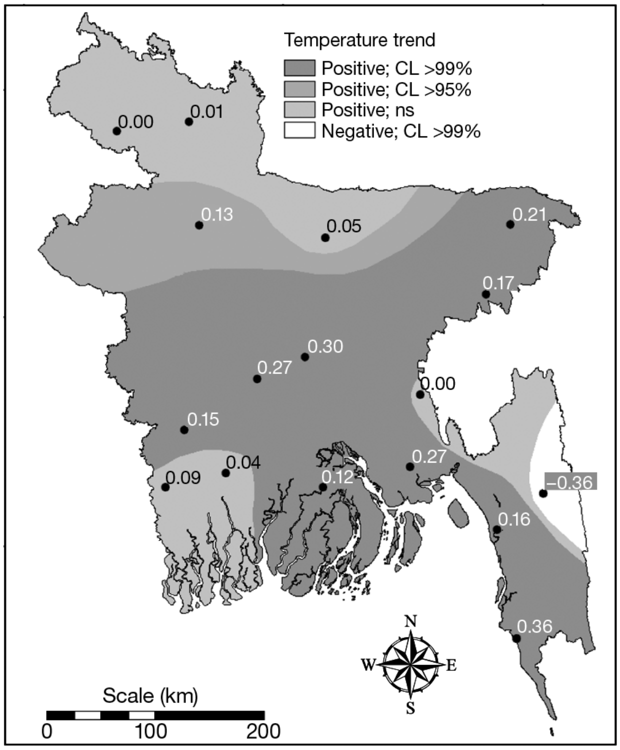

Fig. 3. Trends in mean temperature in Bangladesh, 1958–2007. Numbers are change in temperature (°C decade^{-1}). White numbers: significant (see legend for level of significance). CL: confidence level; ns: not significant

Temperatures across stations were averaged to get the time series (Fig. 2). The Mann-Kendall trend test shows a significant increase of mean temperature. The magnitude of change assessed by Sen's slope method shows that mean temperature has increased by 0.097°C decade^{-1} in last 50 yr. Significant increases in mean maximum and mean minimum temperatures of 0.102 and 0.091°C decade^{-1}, respectively, were also observed. These results differ from those obtained by Jones (1995), who found no significant change in annual mean minimum and mean maximum temperatures in Bangladesh. However, our results corroborate the trends in average mean minimum and mean maximum temperature of the Indian subcontinent (Arora et al. 2005)

There is a significant increase in mean temperature in most of Bangladesh, except in northern Bangladesh, in the foothills of the Himalayas (Fig. 3). A maximum increase of 0.36°C decade^{-1} ($p < 0.01$) was found at Cox's Bazar, in the southeastern coastal zone of Bangladesh. The maximum decrease in mean temperature (–0.36°C decade^{-1}, $p < 0.01$) was observed at Rangamati, located in the southeastern hill region of Bangladesh. The cause of this decreasing trend of temperature is not known.

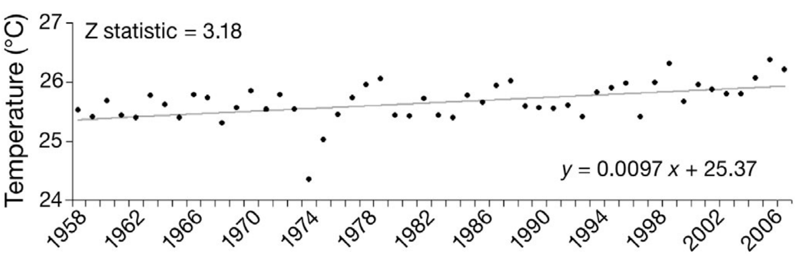

Fig. 2. Trend in mean temperature in Bangladesh over the period 1958–2007

Table 2 shows a significant increase in monthly mean temperatures in the months of January and February at more than one-third of the stations. A significant increase in temperature was also observed in monsoon months at more than one-third of the stations. By contrast, a significant decrease in temperature during pre-monsoon hot summer months (March–May) was observed at only a few stations. The trend analysis of monthly mean temperature averaged over the country shows an increase in temperature for the months of August, November and December. The highest increase was observed in November at a rate of 0.3°C decade^{-1}. Seasonal analysis of temperature shows that the temperature is increasing significantly, but only in winter.

Changes in areal averaged temperature over Bangladesh assessed by Agrawala et al. (2003) based upon over a dozen GCMs reveals an average temperature rise of 1.3°C by 2030 with more warming in winter (1.1°C) than in summer (0.8°C). A transient model by the Geophysical Fluid Dynamics Laboratory also estimated a greater warming in winter compared to summer (Manabe et al. 1991).

Table 2. Monthly mean temperature change (°C decade^{-1}) in Bangladesh. *p < 0.05; **p < 0.01

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sylhet	0.39**	0.33*	0.03	0.11	0.17	0.19*	0.21*	0.26**	0.08	0.24*	0.45**	0.39**
Srimongal	0.29*	0.46**	–0.08	–0.11	–0.03	0.11	0.00	0.04	–0.02	0.12	0.44**	0.56**
Comilla	–0.08	–0.05	–0.33*	–0.37*	–0.30*	0.13	0.15	0.23**	0.00	–0.06	–0.28*	0.10
Rangamati	–0.48**	–0.39**	–0.52**	–0.35*	–0.33*	0.02	0.07	0.13	–0.13	–0.17*	–0.20*	–0.40**
Chittagong	0.14	0.36**	0.20	0.16	0.04	0.25**	0.19**	0.25**	0.18**	0.27**	0.29**	0.42**
Cox's Bazar	0.43**	0.57**	0.42**	0.27*	0.18	0.31**	0.33**	0.39**	0.30**	0.42**	0.50**	0.53**
MCort	0.25*	0.35**	0.19	0.14	0.11	0.15	0.26**	0.35**	0.20*	0.33**	0.46**	0.55**
Faridpur	0.25*	0.43**	–0.03	0.10	0.09	0.21**	0.19**	0.19*	0.03	0.21*	0.67**	0.61**
Dhaka	0.30*	0.42**	0.11	–0.08	–0.04	0.19*	0.17**	0.21**	0.10	0.21**	0.48**	0.48**
Mymensingh	0.00	0.16	–0.19	–0.23	–0.11	0.09	0.00	0.06	–0.06	0.03	0.21*	0.19
Khulna	–0.34	0.00	–0.29	0.03	–0.15	0.06	0.10	0.10	0.08	0.00	0.17	–0.02
Barishal	0.13	0.24	–0.02	–0.03	–0.08	0.08	0.08	0.16**	–0.04	0.09	0.26*	0.43**
Satkhira	0.07	0.07	–0.23	–0.03	0.00	0.09	0.21**	0.12	0.12*	0.08	0.26*	0.22*
Jessore	0.04	0.29	–0.07	0.06	0.02	0.12	0.21**	0.23**	0.05	0.18*	0.36**	0.40**
Bogra	0.08	0.17	–0.20*	–0.38**	–0.30	0.14	0.16*	0.22**	0.03	0.20*	0.45**	0.37**
Dinajpur	–0.10	0.06	–0.05	–0.37*	–0.08	–0.01	0.00	0.11	–0.09	–0.06	0.21*	0.21
Rangpur	0.08	0.25	0.08	–0.17	–0.03	0.04	0.00	–0.05	–0.25**	–0.03	0.24*	0.42**
Overall mean	0.05	0.22	–0.06	–0.13	–0.14	0.09	0.07	0.15*	–0.01	0.12	0.30**	0.23*

4.2. Rainfall

Significant increases in annual and pre-monsoon rainfall were observed at more than one-third of stations (Table 3). The changes in rainfall during monsoon, post-monsoon and winter were significant only at a few stations, mostly situated in the western part of the country.

The mean annual rainfall was 2488 mm. The deviation of annual precipitation from mean precipitation varied from +408 mm to –586 mm (Fig. 4). The trend analysis over the annual rainfall time series revealed the presence of a positive trend (Mann-Kendall test, Z = 1.957, $p < 0.10$). The magnitude of change of annual rainfall estimated by Sen's slope estimator shows that the annual rainfall of Bangladesh increased at a rate of +5.53 mm yr^{-1}.

A significant increase in rainfall occurred only in the pre-monsoon season at a rate of 2.47 mm yr^{-1} ($p < 0.01$). The rate of increase was approximately 5.5% per decade. No change in monsoon rainfall was observed over Bangladesh, much like other parts of the Indian subcontinent. Changes in post-monsoon and winter rainfalls were also not significant. A study by Agrawala et al. (2003) on changes in precipitation over Bangladesh using climate models projected increased precipitation in annual, pre-monsoon, monsoon and post-monsoon rainfall and no appreciable change in winter rainfall. A study using the Geophysical Fluid Dynamics Laboratory transient model (Manabe et al. 1991) also estimated little change in winter precipitation and an increase in precipitation in other seasons (Ahmed & Alam 1999).

Thunderstorms are the sources of pre-monsoon rainfall in Bangladesh (Sanderson & Ahmed 1979). The thunderstorm season begins in the northeastern and eastern parts of the country by the first week of March. Activity gradually moves westward, and becomes significant in the western part of the country only before the advent of the summer monsoon in late May or early June. During the early part of the

Table 3. Annual and seasonal rainfall change (mm yr^{-1}) in Bangladesh. *p < 0.10; **p < 0.05; ***p < 0.01

Station	Annual	Monsoon	Pre-monsoon	Post-monsoon	Winter
Sylhet	8.11	2.00	2.20	0.22	0.45
Srimongal	–0.29	–2.24	–0.20	0.14	–0.34
Comilla	–2.97	–4.34	1.78	–0.60	0.01
Rangamati	11.38**	5.61	8.18**	0.00	0.07
Chittagong	7.68	0.74	7.63***	0.53	0.13
Cox' Bazar	4.82	3.18	8.14*	0.32	0.09
MCort	0.00	–2.88	2.90	0.15	–0.08
Faridpur	0.84	–0.91	0.07	0.72	0.41
Dhaka	4.33	1.12	1.05	1.55	0.29
Mymensingh	7.86	0.20	2.69	2.73*	0.25
Khulna	7.79**	2.83	–1.15	1.80**	0.45*
Barishal	0.89	0.89	1.23	–0.45	0.04
Satkhira	6.97**	2.93	1.93	0.18	0.43
Jessore	7.62**	4.70*	2.76*	1.50	0.01
Bogra	6.47	2.50	4.18**	1.00	0.14
Dinajpur	14.39***	11.08***	7.44***	1.23	0.50***
Rangpur	16.45***	11.15***	5.75**	2.65**	0.28
Overall mean	5.53*	2.24	2.47***	1.03	0.18

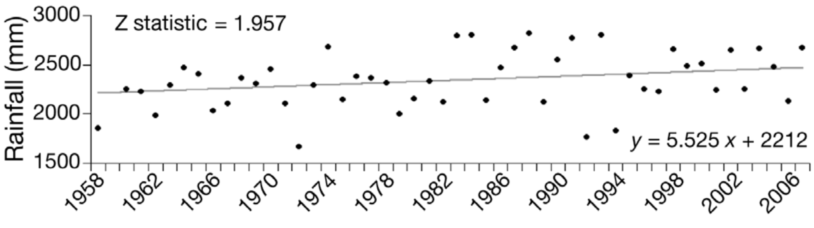

Fig. 4. Trend in annual rainfall in Bangladesh over the period 1958–2007

thunderstorm season, a zone of discontinuity crosses the country from southwest to northeast, separating the hot dry air from the dry interior of India, and the warm moist air from the Bay of Bengal (Sanderson & Ahmed 1979). The activity of the thunderstorms during the pre-monsoon season depends upon the supply of moist air from the Bay of Bengal. Stronger and more continuous winds from the Bay of Bengal during pre-monsoon months in the recent years, due to the increase of sea surface temperature (Khan et al. 2000), might be the cause of increased pre-monsoon rainfall in Bangladesh.

Fig. 5 shows a significant increase of annual rainfall in the western part. The maximum increase was recorded in north Bangladesh at a rate of 16.45 mm yr^{-1} ($p < 0.01$). Rainfall was also found to increase significantly ($p < 0.05$) at Rangamati, situated in the southeastern hill region.

Fig. 6a shows significant increase of monsoon rainfall only in the western part. The maximum increase of rainfall was observed in northern Bangladesh at a rate of 11.15 mm yr^{-1} ($p < 0.01$). Though the findings of present study agree with the result obtained by Rahman et al. (1997), i.e. no change in monsoon rainfall over Bangladesh, they are not in agreement with the spatial pattern of monsoon rainfall trends in Bangladesh. Rahman et al. (1997) found a changing pattern of monsoon rainfall at the stations located in the southeast hill region; this is in contrast to the findings of the present study, where changes were mostly observed in the stations located in northwest Bangladesh near the foothills of the Himalayas. However, the results of the present study are consistent with the findings of Krishna Kumar et al. (2003). They found a statistically significant decreasing trend in monsoon rainfall in northeast India (east of Bangladesh) at a rate of 6 to 8 % 100 yr^{-1} below normal, and a statistically significant increasing trend over central India (west of Bangladesh) at a rate of 10 to 12 % per 100 yr above normal.

Fig. 6b shows a significant increase of pre-monsoon rainfall in the northwestern and southeastern parts of Bangladesh. The maximum increase was observed in the north at a rate of 7.44 mm yr^{-1} ($p < 0.01$).

There exists a positive correlation between the sea surface temperature in the Bay of Bengal and the rainfall in Bangladesh (Salahuddin et al. 2006). The monsoon flows in 2 branches, one strikes western India and the other travels up the Bay of Bengal and over eastern India and Bangladesh. The monsoon from the Bay of Bengal crosses the plain to the north and northeast before being turned to the west and northwest by the foothills of the Himalayas. Simulated increases in sea surface temperature in GCMs show that it alters wind patterns to the west of Bangladesh, leading to an accumulation of moisture in the region and greater rainfall during the summer monsoon season (Cash et al. 2007). Khan et al. (2000) found that sea surface temperature of the Bay of Bengal has increased during the 14 yr period from 1985 to 1998. This increase in sea surface temperature causes an increase in precipitation due to the increase in convection (Alapaty et al. 1995). Therefore, an increase in sea surface temperature of the Bay of Bengal might be the cause of increased precipitation in Bangladesh.

Due to its geographical position, Bangladesh is one of the most disaster-prone countries in the world. Small changes in the mean and standard deviation of temperature and rainfall can produce relatively large changes in the probability of extreme events (Rodrigo

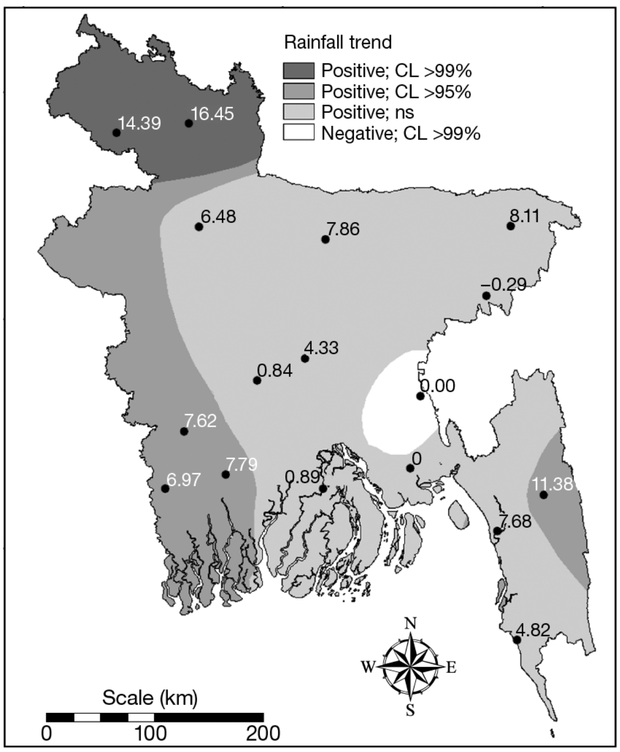

Fig. 5. Annual rainfall trends in Bangladesh, 1958–2007. Numbers are change in rainfall (mm yr^{-1}). White numbers: significant (see legend for level of significance). CL: confidence level; ns: not significant

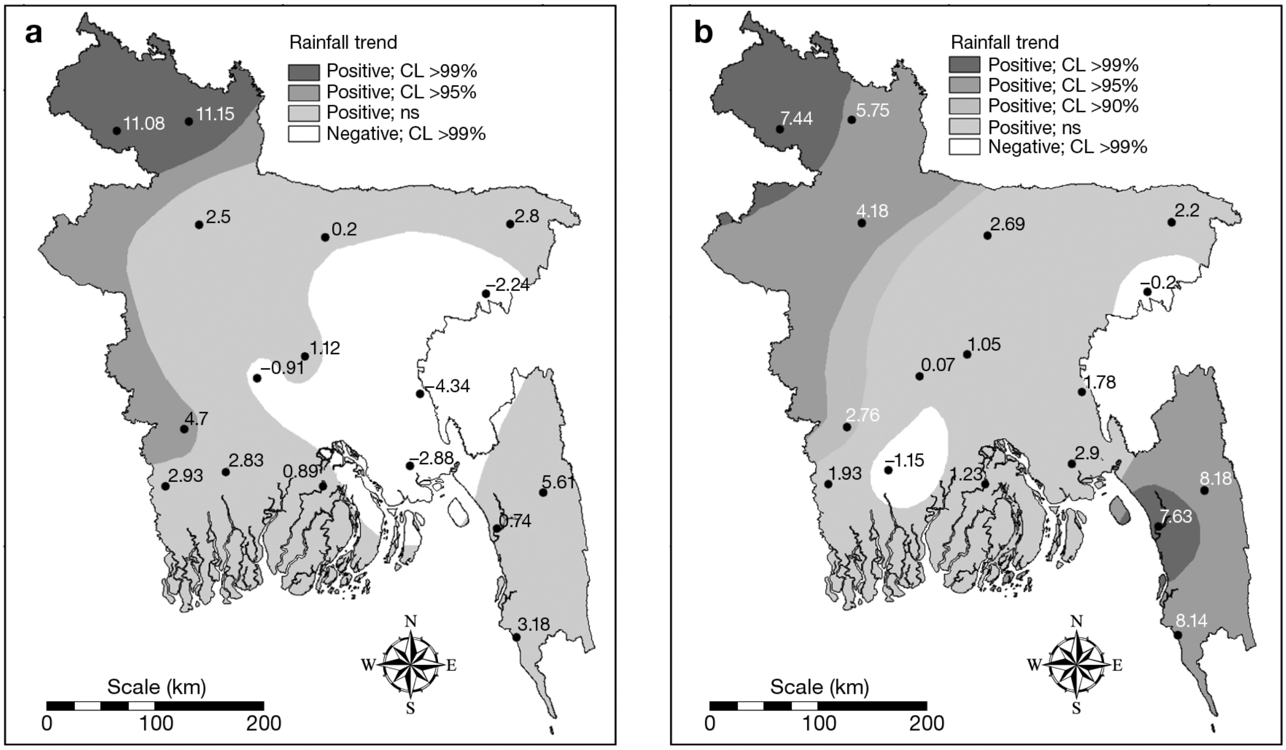

Fig. 6. Trends in (a) monsoon and (b) pre-monsoon rainfall of Bangladesh, 1958–2007. Numbers are change in rainfall (mm yr^{-1}). White numbers: significant change (see legend for level of significance). CL: confidence level; ns: not significant

2002, Su et al. 2006). Therefore, Bangladesh may face more extreme weather events and related disasters in the future due to the increase in the mean values of temperature and rainfall. Rainfall intensity and temperature are positively correlated with the occurrence of cholera and diarrheal diseases (Rowland 1986, Hashizume et al. 2007). On the other hand, increased pre-monsoon precipitation can reduce the groundwater demand for irrigation and may help to decrease the pressure on groundwater resources. Increased precipitation can also boost groundwater recharge; the low groundwater level is a major problem due to the over-exploitation of groundwater for irrigation in some areas of Bangladesh.

As the assessment of climate change is one of the main aspects of adaptation and planning, it is hoped that the present study will assist in guiding interventions aimed at agriculture, water resources and disaster management in Bangladesh.

5. CONCLUSIONS

A significant increase in mean temperature and average areal rainfall over Bangladesh has been observed during the last 50 yr. The spatial pattern shows that monsoon rainfall has increased in the western part of Bangladesh. Increased sea surface temperature might have altered the wind patterns in this area, leading to an accumulation of moisture. However, the data and analysis in the present study are insufficient to draw conclusions about the impact of global climate change on Bangladesh. A more detailed study through observational data and climate models is required to establish the link, if it exists. Increased temperature and monsoon precipitation might cause outbreaks of tropical diseases and increased severity and frequency of hydrological disasters. On the other hand, increased rainfall can help to keep the groundwater levels in balance. It is expected that the climate trend maps and the results of the present study will help to delineate climate change policy planning in Bangladesh, as well as to understand the regional climate changes in order to better understand the broad features of the Asian coupled land–atmospheric system.

Acknowledgements. This study was supported by a Return Fellowship of the Alexander von Humboldt Foundation, Germany

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Editorial responsibility: Mauricio Lima, Santiago, Chile

Submitted: March 26, 2009; Accepted: June 4, 2010
Proofs received from author(s): July 17, 2010