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Changes in Historical Precipitation Extremes over Bangladesh

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Abstract: ***Bangladesh has a tropical monsoon climate characterized by wide seasonal variations in rainfall, high temperatures, and high humidity. The fourth report by the Intergovernmental Panel on Climate Change (IPCC) stated that Bangladesh would experience heavier monsoons and that the melting of Himalayan glaciers will cause higher river flows and severe floods. Heavy rainfall is characteristic of Bangladesh. With the exception of the relatively dry western region of Rajshahi, where the annual rainfall is about 1600 mm, most parts of the country receive at least 2300 mm of rainfall per year. Because of its location just south of the foothills of the Himalayas, the region of Sylhet in northeastern Bangladesh receives the greatest average precipitation. About 80 % of Bangladesh's rain falls during the monsoon season. Climate change is one of the biggest issues confronting humanity in the 21st century. This will give rise to changes in weather patterns, and an increase in the frequency and severity of extreme events. Climate change might shift extremes towards conditions that will stress vulnerable countries such as Bangladesh. Changes in mean temperature and precipitation values could lead to amplified responses to their extreme values. The objective of the present research includes the trend analysis of precipitation extreme indices for selected meteorological stations in Bangladesh. Precipitation data from 1961-1990 collected by Bangladesh Meteorological Department (BMD) are used in this analysis. BMD data from a total of 22 stations are considered in this research. 11 extreme indices related to precipitation are considered in the present study. The precipitation extreme indices are calculated using RClimDex, which is written in statistical software package R. The maximum 1-day precipitation (RX1day) and maximum 5-day precipitation (RX5day); simple daily intensity index (SDII); numbers of heavy (R10mm), very heavy (R20mm) and extremely heavy (R50mm) precipitation days; consecutive wet days (CWD); very wet days (R95p), extremely wet days (R99p) and annual total wet-day precipitation (PRCPTOT) have been increasing in most of the BMD stations. Only consecutive dry days (CDD) are found to be decreasing. The trends of the precipitation extreme indices indicate a higher precipitation in the future.***

Keywords: Precipitation extremes, precipitation, climate change

1. Introduction

Bangladesh is one of the world's most densely population countries and also one of the most susceptible to the impacts of climate change. People in Bangladesh live dangerously close to the risks of natural disasters, such as cyclones, floods and droughts. Two-thirds of the country is less than 5 meters above sea level and in an average year, a quarter of the country is inundated due to flood. Bangladesh has experienced severe floods in every 4 to 5 years that may cover more than half of the country, and also occasional cyclones, resulting in significant losses to life and property. Bangladesh has achieved recent gains in the areas of economic growth and population control that could be reversed by climate change. The fourth report by the Intergovernmental Panel on Climate Change (IPCC) stated that Bangladesh would experience heavier monsoons and that the melting of Himalayan glaciers will cause higher river flows and severe floods. Rainfall will become heavier and more erratic while droughts will increase in frequency.

Bangladesh has a tropical monsoon climate characterized by wide seasonal variations in rainfall, high temperatures, and high humidity. Regional climatic differences in this flat country are minor. Three seasons are generally recognized: a hot, muggy summer from March to June; a hot, humid and rainy monsoon season from June to November; and a warm-hot, dry winter from December to February. In general, maximum summer temperatures range between 38 and 44 °C. April is the hottest month in most parts of the country and January is the coolest month. Heavy rainfall is characteristic of Bangladesh. With the exception of the relatively dry western region of Rajshahi, where the annual rainfall is about 1600 mm, most parts of the country receive at least 2300 mm of rainfall per year. Because of its location just south of the foothills of the Himalayas, the region of Sylhet in northeastern Bangladesh receives the greatest average precipitation.

About 80 % of Bangladesh's rain falls during the monsoon season. The monsoons result from the contrasts between low and high air pressure areas that result from differential heating of land and water. During the hot months of April and May, hot air rises over the Indian subcontinent, creating low-pressure areas into which rush cooler, moisture-bearing winds from the Indian Ocean. This is the southwest monsoon, commencing in June and usually lasting through September. Dividing against the Indian landmass, the monsoon flows in two branches, one of which strikes western India. The other travels up the Bay of Bengal and over eastern India and Bangladesh, crossing the plain to the north and northeast before being turned to the west and northwest by the foothills of the Himalayas. Although uncertainty exists about exactly how earth's climate responds to the greenhouse gases, global temperatures are rising (global warming). Some greenhouse gases, occur naturally in the atmosphere, while others result from human activities, and are mainly responsible for climate change. Climate change is one of the biggest issues confronting humanity in the 21st century. This will give rise to changes in weather patterns, and an increase in the frequency and severity of extreme events. The hypothesis is that warming ocean waters could feed more energy into high magnitude events, causing a significant increase in their frequency or intensity [1], [2]. However, climate change might shift extremes towards conditions that will stress vulnerable countries such as Bangladesh. There is growing evidence that the global changes in extremes that have been observed in recent decades [3] can only be explained if natural and anthropogenic factors are considered. [4] stated that changes in mean temperature and precipitation values could lead to amplified responses to their extreme values. [5] analyzed the trends in Turkey climate extreme indices from 1971 to 2004. The concluded that there are large coherent patterns of warming across in the country affecting both maximum and minimum temperatures but there is a much more mixed pattern of change in precipitation. [6] compared the climate means and extremes of Australia. They concluded that there is also some evidence that the trends of the most extreme events of both temperature and precipitation are changing more rapidly in relation to corresponding mean trends.

The objective of the present research includes the trend analysis of precipitation extreme indices for selected meteorological stations in Bangladesh.

2. Methodology

2.1 Data Collection

Precipitation data from 1961-1990 collected by Bangladesh Meteorological Department (BMD) are used in this analysis. BMD data from a total of 22 stations are considered in this research (Figure 1).

Figure 1: Bangladesh Meteorological Department (BMD) Stations

2.2 Extreme Indices

A joint WMO CCl/CLIVAR Expert Team (ET) on Climate Change Detection, Monitoring and Indices (ETCCDMI) has defined 27 extreme climate indices mainly focusing on extreme events (Table 1). Of those 27 extreme climate indices, 11 indices related to precipitation are considered in the present study, namely RX1day, RX5day, SDII, R10mm, R20mm, R50mm, CDD, CWD, R95p, R99p and PRCPTOT.

2.3 Extreme Indices Calculation

The precipitation extreme indices are calculated using RClimDex [7], which is written in statistical software package R. Kendall's tau based slope estimator has been used to compute the trends in the analysis. If the slope error is greater than the slope estimate, the slope estimate (i.e. trend) cannot be relied upon for a particular index if the probability value (i.e. P Value) is less than 0.05, the corresponding trend is significant at 95% level of confidence (Figure 2). The indices plot shows that R10mm will be increasing 0.519 day/year in Barisal and this trend is statistically significant at 95% level of confidence because of p value which is less than 0.05 (i.e. 0.03). To provide an overall picture of climate variation in Bangladesh, average trends are calculated for every precipitation extreme index, relative to the period 1961-1990.

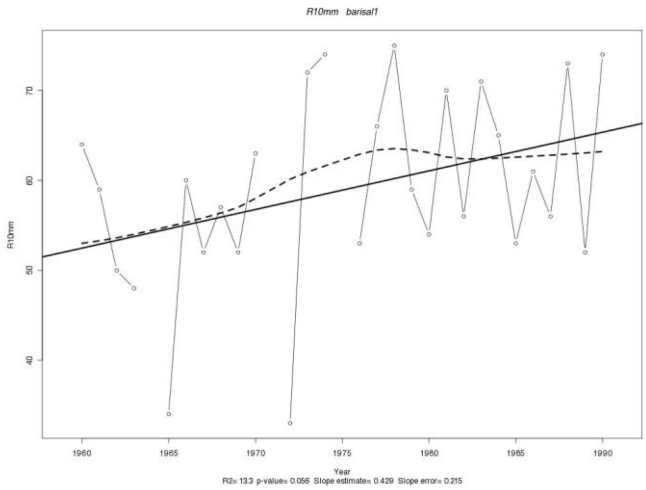

Figure 2: Trends in Number of heavy precipitation days in Barishal

2.4 Quality Control of Data

The quality control of data involves the careful evaluation of daily precipitation data to detect evidence of possible quality issues. The quality control procedure involves the following adjustment; if the precipitation value in negative, it is assumed to be a missing value (i.e. -99.9 in RClimDex input).

Table 1: List of Precipitation Extreme Climate Indices

ID	*Indicator name*	*Definitions*	*Units*
RX1day	Max 1-day precipitation	Monthly maximum 1-day precipitation	mm
RX5day	Max 5-day precipitation	Monthly maximum consecutive 5-day precipitation	mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as PR >=1.0mm) in the year	mm/day
R10mm	Number of heavy precipitation days	Annual count of days when PR >= 10mm	Day
R20mm	Number of very heavy precipitation days	Annual count of days when PR >= 20mm	Day
Rnnmm	Number of days above nn mm	Annual count of days when PR >= nn mm, nn is user defined threshold	Day
CDD	Consecutive dry days	Maximum number of consecutive days with RR<1mm	Day
CWD	Consecutive wet days	Maximum number of consecutive days with RR>=1mm	Day
R95p	Very wet days	Annual total PRCP when PR>95th percentile	mm
R99p	Extremely wet days	Annual total PRCP when PR>99th percentile	mm
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (PR>=1mm)	mm

2.5 Missing Data Handling

Missing precipitation data are accounted for using the ETCCDMI standard criteria (ETCCDMI, 2010). Briefly, monthly indices are not computed if more than three days are missing in the month. The annual values are computed if no more than 15 days are missing in the year. However, an annual value will also not be computed if data for any month are missing.

3. Results and Discussion

The trends of the precipitation extreme indices are shown in the following table (Table 2 a & b). The positive value signifies the increasing trend and the negative value indicates decreasing trend of an index per year. Kendall's tau based slope estimator has been used to compute the trends in the analysis. If the slope error is greater than the slope estimate, the slope estimate (i.e. trend) cannot be relied upon for a particular index if the probability value (i.e. P Value) is less than 0.05, the corresponding trend is significant at 95% level of confidence. According to [8] the trends of precipitation extreme indices are significantly changing which could be a living proof of global warming for the Bangladeshis. With a flat terrain and high population density this can mean higher occurrences of catastrophic events. And eventually greater damages to the vulnerable societies as a whole.

Table 2(a): The Trends of Precipitation Extreme Indices/yr

Station	*RX1day*	*RX5day*	*SDII*	*R10mm*	*R20mm*	*R50mm*
	Mm	Mm	mm/day	day	day	day
Barisal	-1.33	-2.07	-0.05	0.52	0.23	-0.08
Bogra	1.13	3.52	0.11	0.32	0.26	0.17
Chandpur	-1.43	-0.95	-0.03	0.84	0.32	0.08
Chittagong	3.10	6.08	0.10	0.11	0.06	0.01
Comilla	-2.40	-4.58	-0.33	-0.03	-0.15	-0.19
Cox's Bazar	-1.70	-3.71	-0.15	0.13	-0.02	0.07
Dhaka	-1.26	-1.46	0.02	0.25	0.26	0.09
Dinajpur	1.54	2.80	0.02	0.56	0.34	0.15
Faridpur	1.03	4.55	0.05	0.31	0.17	0.05
Hatiya	-1.89	-6.32	-0.11	0.24	0.23	-0.02
Jessore	0.62	1.19	0.13	0.26	0.23	0.11
Maijdicourt	1.67	0.62	0.04	0.06	0.00	0.09
Mymensing	1.10	0.77	0.03	0.23	0.20	0.22
Patuakhali	2.72	-1.96	-0.92	1.00	-0.15	-0.54
Rajshahi	-0.29	-0.09	-0.19	0.17	0.03	-0.02
Rangamati	1.42	-0.47	0.09	-0.01	-0.06	0.02
Rangpur	1.13	4.06	0.28	0.62	0.63	0.29
Sandwip	-2.07	-3.28	-0.55	0.43	-0.02	-0.15
Sitakunda	13.69	35.35	0.67	2.57	1.92	0.87
Srimangal	0.90	0.98	-0.06	0.12	-0.12	-0.02
Sylhet	0.47	0.65	0.09	0.42	0.38	0.24
Teknaf	3.27	20.06	0.89	0.60	1.49	0.89
Average	0.97	2.53	0.01	0.44	0.28	0.11

Table 2(b): The Trends of Precipitation Extreme Indices/yr

Station	*CDD*	*CWD*	*R95p*	*R99p*	*PRCPTOT*
	day	day	mm	mm	mm
Barisal	-1.19	0.34	-4.87	-0.12	8.55
Bogra	-0.42	0.04	9.62	5.26	19.99
Chandpur	-0.92	0.21	2.43	3.57	24.37
Chittagong	-0.16	-0.04	5.95	2.13	6.07
Comilla	0.59	0.07	-18.78	-14.58	-20.50
Cox's Bazar	-1.06	0.31	-12.40	-10.11	-6.74
Dhaka	-0.55	0.08	-4.02	-0.23	9.01
Dinajpur	-0.86	0.32	11.71	5.09	26.35
Faridpur	-0.12	-0.02	6.99	3.33	12.79
Hatiya	-0.78	0.15	-15.51	-7.54	-4.54
Jessore	-0.06	-0.14	6.08	2.82	13.21
Maijdicourt	0.53	0.18	13.52	6.09	12.22
Mymensing	-0.74	0.29	9.30	4.17	19.48
Patuakhali	-1.72	1.41	-43.96	8.86	-18.87
Rajshahi	-1.22	0.11	-3.21	-3.50	2.70
Rangamati	0.22	0.13	4.74	4.16	-0.53
Rangpur	-0.37	-0.03	18.64	6.37	34.05
Sandwip	-0.02	0.40	-15.90	-13.72	-5.53
Sitakunda	-3.56	0.87	49.76	21.95	133.50
Srimangal	-0.49	0.15	-0.91	2.81	0.44
Sylhet	-0.83	0.26	16.83	5.92	27.92
Teknaf	1.65	0.79	36.95	17.89	87.63
Average	-0.55	0.27	3.32	2.30	17.34

3.1 RX1day and RX5day

The maximum 1-day precipitation (RX1day) has been increasing in most of the stations (Figure 3a). The estimated average increase is 0.97 mm per year. Sitakunda (13.69 mm/year) showed the highest increasing trend and Comilla (-2.40 mm/year) showed the highest decreasing trend. The maximum 5-day precipitation (RX5day) has been increasing in most of the stations (Figure 3b). The estimated average increase is 2.53 mm per year. Sitakunda (35.35 mm/year) showed the highest increasing trend and Hatiya (-6.32 mm/year) showed the highest decreasing trend.

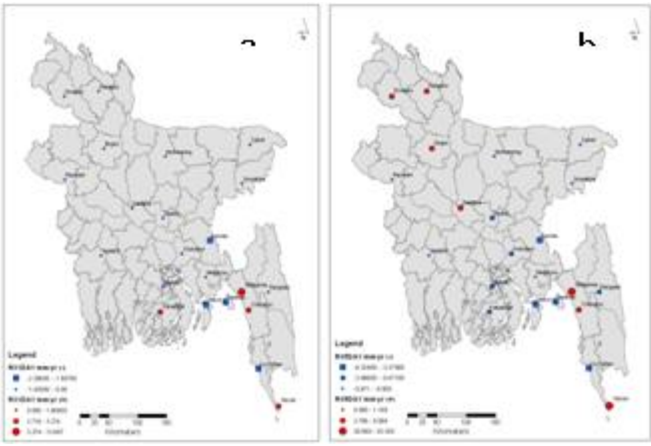

Figure 3: (a) The maximum 1-day precipitation, (b) The maximum 5-day precipitation

3.2 SDII

The simple daily intensity index (SDII) is found to be increasing in most of the locations (Figure 4). The computed average increase is 0.01 mm/day per year, which can be translated into an increase of 1 mm/day in 100 years. The maximum increasing trend was observed in Teknaf (0.89 mm/day per year) and the maximum decreasing trend was observed in Patuakhali (-0.92 mm/day per year).

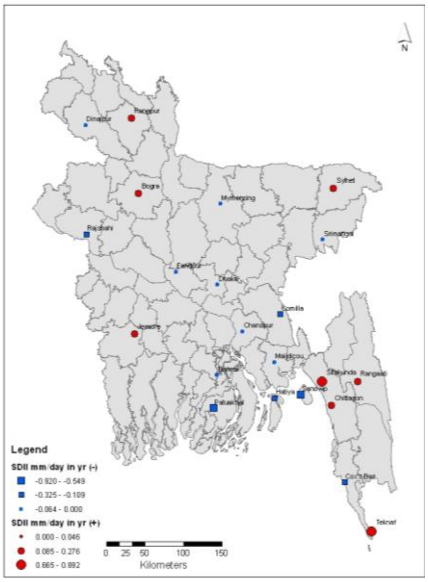

Figure 4: Trends in Simple Daily Intensity Index (SDII)

3.3 R10mm, R20mm and R50mm

Numbers of heavy (R10mm), very heavy (R20mm) and extremely heavy (R50mm) precipitation days have been increasing in most of the stations (Figures 5a, 5b and 5c). Estimated average increase for R10mm is 0.44 day, for R20mm is 0.28 day and for R50mm is 0.11 day. The maximum increase in R10mm (2.57 days/year) and R20mm (1.92 days/year) was observed in Sitakunda; and the maximum decrease in R10mm (-0.03 days/year) and R20mm (-0.15 days/year) was observed in Comilla.The maximum increase in R50mm was observed in Teknaf (0.89 day/year) and the maximum decrease was observed in Patuakhali (-0.54 day/year).

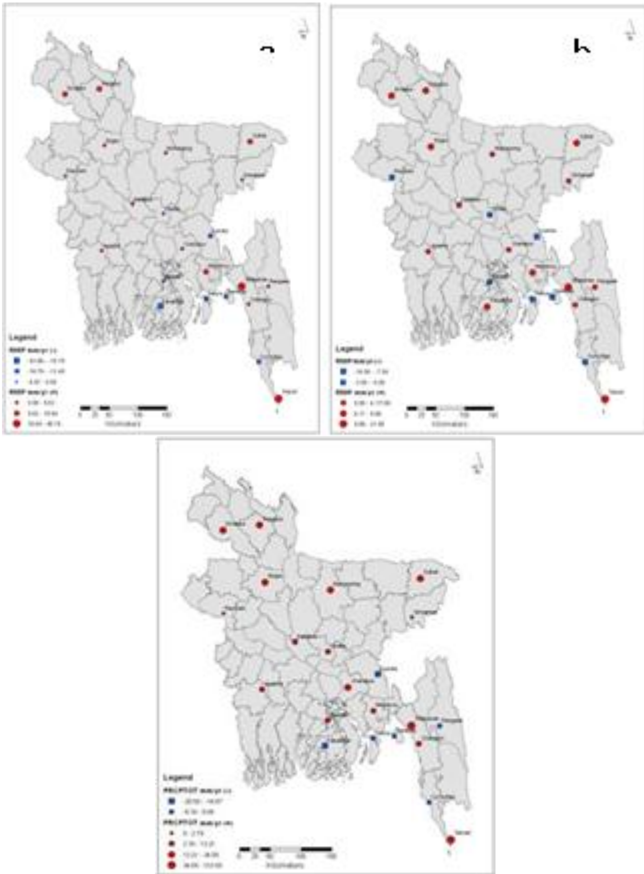

Figure 5: Trends in (a) Very wet days, (b) Extremely wet days, (c) Annual Total wet-day ppt.

3.4 CDD and CWD

Consecutive dry days (CDD) are decreasing in most of the stations and the average value being -0.55 day/year (Figure 6a). The maximum increase has been estimated in Sitakunda (1.65 day/year) and the maximum decrease has been estimated in Teknaf (-3.56 day/year). Consecutive wet days (CWD) are increasing in most of the stations and the average value being 0.27 day/year (Figure 6b). The maximum increase has been estimated in Patuakhali (1.41 day/year) and the maximum decrease has been estimated in Jessore (-0.14 day/year).

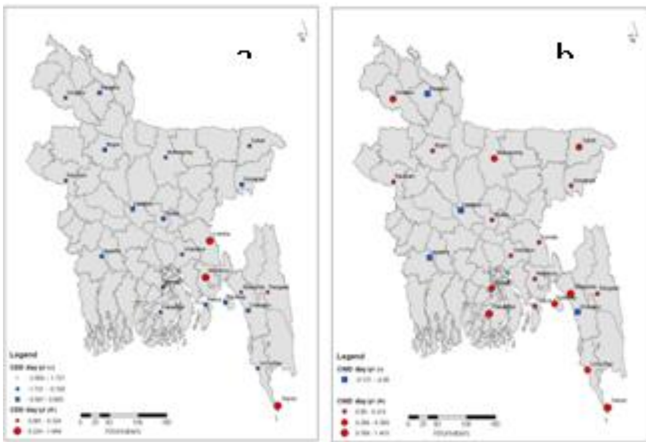

Figure 6: Trends in (a) Consecutive Dry Days, (b) Consecutive Wet Days.

3.5 R95p, R99p and PRCPTOT

Very wet days (R95p) and extremely wet days (R99p) are increasing in most of the stations with an average increase of 3.32 and 2.30 mm/year respectively. The maximum increase of R95p was observed in Sitakunda (49.76 mm/year) and the maximum decrease was observed in Patuakhali (-43.96 mm/year). The maximum increase of R99p was observed in Sitakunda (21.95 mm/year) and the maximum decrease was observed in Comilla (-14.58 mm/year). Annual total wet-day precipitation (PRCPTOT) is increasing at an average rate of 17.34 mm/year with a maximum increase observed in Sitakunda (133.50 mm/year) and a maximum decrease observed in Comilla (-20.50 mm/year).

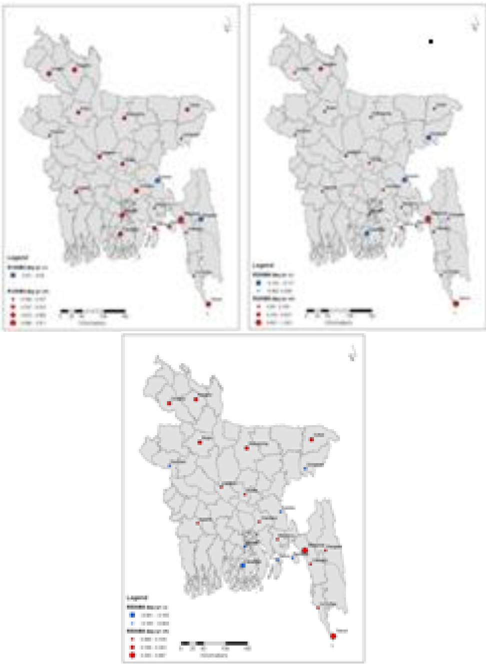

Figure 7: Trends in number of (a) Heavy precipitation days, (b) Very heavy precipitation days and (c) Extremely heavy precipitation days.

4. Conclusion

The results give us very important information about the following trends in precipitation extreme indices:

- The maximum 1-day precipitation (RX1day) and maximum 5-day precipitation (RX5day) have been increasing in most of the stations.
- The simple daily intensity index (SDII) is found to be increasing in most of the locations.
- Numbers of heavy (R10mm), very heavy (R20mm) and extremely heavy (R50mm) precipitation days have been increasing in most of the stations.
- Consecutive dry days (CDD) are decreasing and consecutive wet days (CWD) are increasing in most of the stations.
- Very wet days (R95p), extremely wet days (R99p) and annual total wet-day precipitation (PRCPTOT) are increasing in most of the stations.

5. Acknowledgement

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