THE DYNAMIC CHANGES OF CLIMATE IN BANGLADESH AND THE ADJACENT REGIONS IN ASSOCIATION WITH GLOBAL WARMING.

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Abstract The Global temperature has risen by about 0.6 ^{o} C over the past century and the trend of increase has been found to occur in an accelerated rate in the recent decades. This increase of the global temperature is attributed mostly to the enhanced Green House Gases in the atmosphere. The various climate models have predicted a rise of globally averaged surface air temperature between the range 1.4 - 5.8^{o} C by 2001 relative to 1990 due to the green house effect. The warming is supposed to modify the global circulation pattern and would change the regional climate. In the present paper, we investigate the dynamic changes of climate that took place in the recent decades over Bangladesh and the adjacent areas. Some aspects of inter-annual fluctuations have also been investigated. The time series data of temperature and rainfall of Bangladesh and the surrounding regions have mainly been used. The climatic parameters of other parts of the region or the world affecting the monsoon have also been used to investigate the influence of the distant events on the variation of climate over this part of the world. The analysis shows that the temperature and rainfall over Bangladesh and the adjacent areas are increasing annually, but there are dominant spatial and seasonal variations.

Keywords: Global Warming, Climate change, Bangladesh, Trend of Temperature

INTRODUCTION

Bangladesh is an agricultural country. Being situated in the monsoon region its economy is dependent on the activities of monsoon. IPCC (2001a,b) reported that the global surface temperature has increased by 0.6 ^{o}C in the past century. This warming trend has been accelerated during the last 3 decades and has been found to be 0.16 per decade. This warming has been attributed mainly due to the enhanced greenhouse gases. The projection made by various models depicts that the global temperature will increase by 1.4-5.8 ^{o}C by the end of this century with 1990 as the base year. This warming would be different for different regions and resulting climate at various parts of the world would also vary. The rainfall is expected to increase at some areas and decrease in others. Any major variations in the climatic pattern in or around Bangladesh especially in the catchment areas of the rivers Ganges, Brahmaputra and Meghna (GBM) system and their tributaries and distributors would affect on the hydrological system, environment, ecology and socio-economy of Bangladesh. Some studies have reported that the temperature and rainfall of Bangladesh have been increasing during the recent decades (Choudhury et al. 1997 and Karmaker et al. (2000). The annual and inter annual variation of rainfall have been studied by Nehrin et al. (1998) and the temporal oscillations of the scale of 2-3 years, 4-7 years, 9-11 years and around 20 years were found to exist in the annual rainfall of Bangladesh. However, these studies are not detail and up-to-date. Bangladesh has experienced three unprecedented floods in the recent decades in 1997, 1988 and 1998. The global sea levels have also been reported to rise due to warming of the seawater and melting of the glaciers (IPCC 2001a,b). Some studies have shown that the sea level is rising in the Bangladesh coast at an alarming rate (4.0-7.8 mm/year) of which around 2.0mm/year is due to warming of the sea and the rest might be due to geological subsidence (Khan et al. 1999, 2000 and 2001). However these aspects are subject to confirmation through more detail study.

From the above consideration, in the present paper, the study has been carried out on the recent climate variability and its trends using the data of temperature and rainfall in and around Bangladesh.

DATA USED AND METHODOLOGY

The temperature and rainfall data of 11 stations in Bangladesh, 8 stations in the northeastern India and 3 stations in Nepal for the period 1961 to 1999 or as available within this period have been used. The stations are listed in table-1. The mean temperature and rainfall

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for the individual years and also for the individual seasons (Winter: December, January and February; Pre-monsoon: March-May; Monsoon: June-September and Post-monsoon: October-November) have been estimated from the monthly data. The inter-annual variability and linear trends have been analyzed using the temporal plots of these parameters and least square regression analysis. The confidence levels of the slopes of the linear trends have been estimated using the F-test. For rainfall, analysis is still underway and the results for 17 stations have been now provided.

Table-1: List of the stations used for the study

Sl. No.	Station Name	Lat (°)	Long (°)	Elevation (m)	Period of Data
1	Pusma Camp	28.88	81.25	950	1965-96
2	Kathmandu	27.70	85.37	1337	1968-96
3	Dibragarh	27.47	94.92	106	1961-90
4	Tarahara	26.70	87.27	200	1970-96
5	Gauhati	26.10	91.58	54	1961-90
6	Rangpur	25.73	89.23	32.6	1961-99
7	Dinajpur	25.65	88.68	36	1961-99
8	Patna	25.62	85.17	53	1961-90
9	Allahabad	25.45	81.73	98	1961-90
10	Cherrapunji	25.25	91.73	1313	1961-90
11	Sylhet	24.90	91.88	33.5	1961-99
12	Bogra	24.85	89.37	18	1961-99
13	Rajshahi	24.37	88.70	16.8	1961-99
14	Daltonganj	24.05	84.07	221	1961-90
15	Dhaka	23.77	90.38	8	1961-99
16	Jessore	23.18	89.17	6.1	1961-99
17	Satkhira	22.72	89.08	4	1961-99
18	Kolkata	22.65	88.45	10	1961-90
19	Rangamati	22.53	92.20	62.5	1961-99
20	Chittagong	22.27	91.82	4.0	1961-99
21	Cox's Bazar	21.43	91.93	2.1	1961-99
22	Cuttack	20.80	85.93	27	1961-90

RESULTS AND DISCUSSIONS

The maximum of mean monthly temperature in Bangladesh is attained in April and this warm period continues up to September. The minimum temperature is obtained in January. In the central and southern part of Bangladesh the annual profile of temperature has bimodal nature with a secondary minimum in July-August due to slight decrease of temperature during this period. The monsoon usually sets on during the first week of June. About 75% of the rainfall in Bangladesh occurs during the monsoon period, which lasts up to the first week of October. Significant amount of rainfall (10-15 %) is obtained during the pre-monsoon period. Thus, the rainfall of monsoon and pre-monsoon is very important for recharging of the surface and ground water. On the other hand, the access rainfall causes floods and deficit rainfall causes droughts. The variation of temperature and rainfall and their trends are described below.

Variation of temperature

The temporal plots of the time series of annual temperature of the selected stations (not shown here) show that the temperature has the dominant increasing trends over Bangladesh. The slopes of the linear trends of the regression analysis of the annual and the seasonal mean temperature have been shown in table 2.

From the temporal plots it can be seen that the annual and seasonal mean temperature exhibits variation of time scale of 2-3 years, and 4-7 years of which 4-7 years mode of variation is dominant. The variations with T> 7 years are also present at some stations, but are not prominent.

The El Niňo/Southern Oscillation (ENSO) phenomena is characterized with similar scales of variations which is known to have influences on the climatic fluctuation of other regions including monsoon (Walker and Bliss, 1932; Bjerknes, 1963 and Webster, 1981). The existence of this ENSO scale of variation in the annual and seasonal temperature indicates the existence of possible links of variation of monsoon with the ENSO phenomena.

The least square regression analysis shows that the annual temperature has warming trends in Bangladesh and the adjacent territories of India and Nepal with a few exceptions (Table-2). The trends of annual and seasonal mean temperature are discussed below.

TRENDS OF ANNUAL MEAN TEMPERATURE

The annual temperature shows warming trends in all the stations in Bangladesh and in the adjacent territories except Tarahara, Allahabad, Cherrapunji and Rangamati where cooling trends are observed (table 2). Strong warming is observed at Pusma Camp and Kathmandu in Nepal at the rate of 0.035ºC/year and 0.045ºC/year respectively. Analyzing the maximum temperature over Nepal, Shrestha et al. (1999) have found strong increase of the maximum temperature. Such warming over the Himalayas might affect the mountain ecology and accelerate the melting of icecaps and glaciers.

As it can further be seen in table 2 that the stations over the northeastern Bangladesh and the adjacent stations of northeastern India, the increasing trend of annual temperature is rather week. Surprisingly Cherrapunji shows cooling trend at the rate of -0.018ºC/year, while nearby station Gauhati to the north and Sylhet (Bangladesh) to the south show increasing trends of 0.008 ºC/year and 0.02ºC/year respectively. The central and southern Bangladesh including Calcutta and Daltongonj of India have shown warming trends with high warming rate at Dhaka (0.031ºC/year) and Cox's Bazar (0.036ºC/year). Unlike these stations, Rangamati, which is located in the southeastern hilly region of Bangladesh, exhibits strong cooling trend (-0.032ºC/year). The station average temperature over Bangladesh shows an increasing trend of annual temperature at the rate of around 0.014 ºC/year which is a bit lower than the warming trend of the global average surface air temperature (0.016 ºC/year).

Winter

The winter temperature has strong increasing trend over Nepal and extreme northeastern India. The increasing trend at Kathmandu is 0.063ºC/year. Except Dinajpur, Rajshahi and Rangamati, all the stations in Bangladesh show warming trend with relatively high values in Dhaka (0.03ºC/year) and Cox's Bazar (0.041ºC/year). Dinajpur and Rajshahi representing the northwestern Bangladesh show the decreasing trends of –0.013ºC/year and 0.014 ºC/year, while Rangamati in the southeast has a very strong cooling trend (-0.06 ºC/year) in the winter. The above results show that the winter is growing milder over most of the area except the northwestern Bangladesh and southeastern hilly region of the country, where winter is expected to be cooler.

Pre-monsoon

Nepal has shown pre-monsoon warming trends at Pusma Camp and Kathmandu with slope values of 0.029ºC/year and 0.034ºC/year. The northeastern India, and extreme northern part of Bangladesh show very week cooling or warming trends with some exceptions. The exceptions are Allahabad, Patna and Cherrapunji, which have cooling trends at the rate around –0.02 to –0.025 ºC/year. Dinajpur, Bogra and Rajshahi in the northwestern Bangladesh show a negative trends of –0.011 to –0.015 ºC/year. Daltonganj, Dhaka and Cox's Bazar have shown warming trends at the rate of 0.023ºC/year, 0.021ºC/year and 0.030ºC/year respectively. Rangamati shows strong cooling at the rate of -0.041ºC/year. From the above discussions, it is seen that the changing pattern of temperature over this area has an extremely heterogeneous character. The cooling is more prevalent over the northern Bangladesh and the adjacent areas in India in the pre-monsoon season while the Himalayan region shows strong warming. The latter is expected to enhance the melting of the Himalayan snow and ice.

Monsoon

Strong warming trend is observed in the monsoon season in the Himalayan stations of Pusma Camp (0.048ºC/year), Kathmandu (0.037ºC/year), Tarahara (0.009ºC/year) and Dibrugarh (0.015ºC/year). At all other stations to the south up to Dinajur the trends are negligible. Patna, Allahabad and Cherrapunji exhibit some cooling at the rate of –0.005ºC/year, -0.027ºC/year and -0.023ºC/year respectively. Other stations in Bangladesh show the warming trends during monsoon with high values at Dhaka (0.031ºC/year) and Cox's Bazar (0.033ºC/year). Rangmati as usual shows a deceasing trend of temperature but with a weaker rate (-0.012 ºC/year). This shows that warming is more dominant over Bangladesh and Himalayan region. The increasing temperature in the Himalayan region would favour the melting of snow and ice in the mountains. These trends are mostly within the range 0.030-0.047ºC/year. However, Rangamati showed the decreasing trend. From the above discussions, it appears that the more rapid warming occurs over Bangladesh and the upstream areas in the territories of Nepal and northeastern extreme corner of India.

Post-monsoon

The northern region (northeastern India and Nepal) show strong warming trends during the post-monsoon season with maximum at Kathmandu (0.051ºC/year). Gauhati and Patna in India and Rangpur and Dinajpur in northern Bangladesh show moderate warming trends of 0.018ºC/year, 0.023ºC/year, 0.148ºC/year and 0.007ºC/year respectively. Rest of the areas of the territories in Bangladesh experienced very strong warming trends compared to other seasons.

Interannual variation of rainfall

The interannual variation of rainfall has been studied using the yearly time series of annual and seasonal total rainfall. From the temporal plots (are not shown here). The temporal plots of annual and seasonal rainfall show the presence of ENSO scale of variations with time period of 2-3 years and 4-7 years the latter mode is dominant. The existence of ENSO modes in the rainfall variations indicates the possible impact of ENSO phenomena on the rainfall of this region.

The linear trends have been studied by least square regression analysis individually for annual and seasonal time series data. The results have been presented in table 3. The characteristics of trends of rainfall are described below.

Annual rainfall

From the table-3 it can be seen that very high trend of rainfall is observed over the northern Bangladesh and adjacent areas of India and Nepal to the north with maximum at Cherrapunji (99 mm/year). The secondary maxima are located at Rangpur (19 mm/year), Tarahara (16 mm/year), Patna (13 mm/year) and Sylhet (10 mm/year). Kolkata also shows considerable increasing trend of rainfall (14 mm/year)

Winter rainfall

The winter over Bangladesh and the surrounding areas are relatively dry. However, the trend analysis shows the increasing trend of rainfall all most all over the study area. Sylhet shows a negative trend.

Table-2: Trends of annual and seasonal mean temperature (^oC/year)

Sl. No.	WMO No.	Station Name	Period	Winter	Pre-monsoon	Monsoon	Post-mon	Annual
1		Pusma Camp	1965-96	0.0214	0.0294	0.0484	0.0345	0.0350
2	44454	Kathmandu	1968-96	0.0626	0.0343	0.0368	0.0511	0.0452
3	42312	Dibrugarh	1961-90	0.0203	0.0037	0.0153	0.0303	0.0171
4		Tarahara	1970-96	0.0110	-0.0031	0.0091	0.0098	0.0065
5	42410	Gauhati	1961-90	0.0159	-0.0073	0.0018	0.0181	0.0077
6	41859	Rangpur	1961-99	0.0028	0.0001	0.0036	0.0148	0.0051
7	41863	Dinajpur	1961-99	-0.0127	-0.0024	0.0057	0.0069	-0.0004
8	42491	Patna	1961-90	0.0265	-0.0259	-0.0053	0.0234	0.0031
9	42475	Allahabad	1961-90	0.0070	-0.0218	-0.0272	-0.0218	-0.0179
10	42515	Cherrapunji	1961-90	-0.0078	-0.0249	-0.0234	-0.0106	-0.0175
11	41891	Sylhet	1961-99	0.0294	0.0059	0.0195	0.0365	0.0206
12	41883	Bogra	1961-99	0.0121	-0.0106	0.0172	0.0402	0.0138
13	41895	Rajshahi	1961-99	-0.0142	-0.0154	0.0082	0.0120	-0.0014
14	42587	Daltonganj	1961-90	0.0453	0.0230	-0.0029	0.0273	0.0233
15	41923	Dhaka	1961-99	0.0303	0.0210	0.0312	0.0463	0.0306
16	41936	Jessore	1961-99	0.0077	0.0098	0.0163	0.0261	0.0147
17	41946	Satkhira	1961-99	0.0122	0.0066	0.0143	0.0177	0.0124
18	42809	Kolkata	1961-90	0.0314	-0.0026	0.0165	0.0362	0.0189
19	41966	Rangamati	1961-99	-0.0604	-0.0406	-0.0119	-0.0279	-0.0319
20	41978	Chittagong	1961-99	0.0181	0.0038	0.0247	0.0306	0.0188
21	41992	Cox's Bazar	1961-99	0.0405	0.0301	0.0332	0.0467	0.0363
22	42970	Cuttack	1961-90	-0.0124	-0.0569	-0.0261	-0.0102	-0.0272

Table-3: Trends of seasonal and annual rainfall (mm/year)

Sl. No.	WMO No.	Station Name	Period	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual
1		Pusma Camp	1965-96	1.2229	0.7962	-5.4107	-0.62	-4.23
2	44454	Kathmandu	1968-96	1.9323	1.3708	-0.7473	-0.4063	1.8583
3	42312	Dibrugarh	1961-90	-0.0416	-1.2454	7.2625	1.1662	7.3861
4		Tarahara	1970-96	1.2171	2.8612	12.416	-0.0965	16.285
5	42410	Gauhati	1961-90	0.8790	1.7519	3.6841	2.2934	8.5730
6	41859	Rangpur	1961-99	0.7249	0.8642	15.8900	1.5236	18.8740
7	42491	Patna	1961-90	0.3656	0.5652	13.786	-1.7892	12.800
8	42475	Allahabad	1961-90	0.7719	0.2981	-2.5343	-0.0453	-1.590
9	42515	Cherrapunji	1961-90	4.1988	51.475	34.345	10.227	99.031
10	41891	Sylhet	1961-99	-1.2648	8.1210	2.8991	0.0688	10.1110
11	42587	Daltonganj	1961-90	1.0892	1.6983	1.6334	0.1830	4.1437
12	41923	Dhaka	1961-99	0.8163	3.3378	-1.7721	1.4073	3.7066
13	41936	Jessore	1961-99	0.9525	3.3861	0.5949	-0.9568	3.6221
14	42809	Kolkata	1961-90	0.5713	3.3974	10.046	0.3551	14.191
15	41966	Rangamati	1961-99	0.7281	7.5666	-3.5520	-0.3121	4.8600
16	41992	Cox's Bazar	1961-99	0.5502	3.5598	-8.7410	-0.9074	-5.0657
17	42970	Cuttack	1961-90	0.1832	1.1717	-0.7942	0.4097	4.6754

Pre-monsoon Rainfall

Pre monsoon rainfall shows increasing trend all over the study area except Dibrugarh. The pre-monsoon generally gets 10-15% of the total rainfall. But corresponding to the trend of annual rainfall the pre-monsoon trends are much rapid in terms of percentage. The increasing trend at Cherrapunji is 51.5 mm/year, that at Sylhet is 14.1 mm/year and in the eastern and southeastern Bangladesh, the trends are in the range of 6-7 mm/year. Such increasing trend of pre-monsoon rainfall increases the risk of flash floods in the northeastern, eastern and southeastern Bangladesh.

Monsoon

The monsoon rainfall shows the increasing trend all over the study area except the northern Nepal (Kathmandu and Pusma camp) and the southeastern Bangladesh. The latter areas have decreasing trends of rainfall.

Cherrapunji has the maximum increasing trend (34 mm/year). Rangpur, Patna and Tarahara have the increasing trends of 16 mm/year, 14 mm/year and 12 mm/year respectively. The axis of the maxima of the increasing trends passes over the northern part of Bangladesh and adjacent areas of India, which elongates from east to west over the upper catchments of the GBM river system. Such increasing trends of rainfall increase the risks of severe floods in Bangladesh. The recent floods of 1987, 1988 and 1998, which exceeded the records until those years, may be cited as the evidence of the impact of increasing rainfall trends. All these three floods were caused by excess rainfall over the same areas where the increasing trends of monsoon rainfall are also high. The rainfall that caused these floods were obtained from frequent and long lasting land depressions in the foot hill of Himalayas and in the areas over the northern Bangladesh and adjacent territories of India.

Post monsoon rainfall

Bangladesh and the rest of the study area get very small rainfall in the post-monsoon season compared to monsoon and pre-monsoon. Dibrugarh, Gauhati, Rangpur, Cherrapunji and Dhaka exhibit increasing trends of rainfall at the rate of 1.2 mm/year, 2.3 mm/year, 1.5 mm/year, 10.2 mm/year and 1.4 mm/year during the post-monsoon. Jessore exhibits decreasing trends of –1.0 mm/year. Quadir (2001) has shown that Barisal has also decreasing trend of rainfall of rainfall (-1.2 mm/year).

CONCLUSION

The analysis of temperature and rainfall shows that these parameters undergo the interannual variations of ENSO scales of which 4-7 years mode is prominent.

The annual temperature shows strong increasing trend over Nepal and central and southern Bangladesh. The trends of temperature vary along the seasons. Strong increasing trends of temperature is observed in all the seasons except the pre-monsoon when the increasing trend is very week and decreasing trend is also observed at some places.

From the rainfall data analysis, it has been found that the rainfall increases in all most all the places in all the seasons with a few exceptions. The trends show seasonal variations. Rainfall over northern Bangladesh and the adjacent territories over India have strong increasing trends in the pre-monsoon and monsoon seasons, which indicates increasing risks of pre-monsoon flash floods and more severe monsoon floods. The southeastern region of Bangladesh shows a decreasing trend of rainfall during monsoon. Because of increased rainfall and temperature the weather would be more hot and humid in the future.

The study shows how the global warming as experienced in the recent years has influenced over the climate of Bangladesh and the adjacent areas. The possible impacts of the climate change on the regional levels are to be given more attention for assessment of impacts and vulnerability of such changes on the ecology, environment and socio-economy of the countries of the region.

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