CLIMATE CHANGE TRENDS IN BANGLADESH

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ABSTRACT

A summary of climate change trends in some hydrologic aspects that have manifested so far in Bangladesh is presented and compared with the forecasts, especially as reported in the Fourth Assessment Report of IPCC (2007). Changes in distribution pattern of temperature are analysed with quantile regression. Precipitation in Bangladesh is abundant compared to many other parts of the world, but it is the temporal distribution of rainfall that can have more significant impact if changes do occur. Changes in temporal distribution can be captured through PCI (Ceballos-Barbancho et al, 2008). There are certain aspects of climate change attributable to global warming which is occurring outside the territorial boundaries of Bangladesh but will affect the nation nevertheless. One such aspect is the decline of accumulated snow in the Himalayas, which is a major source of freshwater in Bangladesh. Another aspect is sea-level rise. Sea level will continue to rise in this century and beyond even with emission control and mitigation measures. Bangladesh being a deltaic region is very vulnerable to sea-level rise.

Keywords: *Climate change, IPCC projections, statistical analysis, water resources*

1. INTRODUCTION

Climate change may have profound ramifications in many parts of the world, and developing countries such as Bangladesh may not have the resources to deal with the adversities adequately. It is therefore merely not a rambling of a doomsayer to prepare and plan for counter measures, and action early rather than wait-and-see, to reduce spiralling remedial costs of the future. The effectiveness and ultimately the justification of any pre-emptive action would have to rely on the accuracy and confidence of the forecasts. In this paper an attempt is made to assess the current state of forecasts. As technology improves, the quality of forecasts would improve and therefore any mitigation strategy should be adaptive and should have provisions to incorporate the latest forecasts.

Bangladesh is one of the nations that would be hit the hardest with climate change. It is the most densely populated country excluding the city states in the world in a predominantly deltaic terrain that has about 5 percent of the land within 1 meter and 15 percent within 2 meters of the datum NAD83. The bulk of the population in Bangladesh live in the low lying areas and are engaged in agricultural activities, and agriculture as a sector is quite exposed to the effects of climate change.

The universal yardstick to gauge climate change is atmospheric temperature. Other aspects of climate change are usually regarded as spin-offs from changes in global temperature. Natural variability in atmospheric temperature includes many cycles, and from paleoclimatic observations, especially from polar ice cores and deep oceanic benthic fossils, many cycles have been detected in the earth's temperature. Notable among these cycles are the Milankovitch cycles of 100, 40 and 25 thousand years (Yang and Goodrich, 2008) caused by variations of eccentricity, axial tilt and precession of the earth's orbit around the sun. In the dominant 100 thousand year cycle, the earth takes about 90 thousand years to cool and another 10 thousand years to warm up. Unfortunately, we are now at the stage where it is warming up. These cycles are global, but cycles of smaller time scale are regional and vary from region to region. The proponents of the earth's ability to adjust to climate change often cite these cycles to argue their case, but these are cycles with periods of thousands of years, whereas the global warming we are experiencing today has a timescale of less than a century. Figure 1 shows the increase of global temperature of the recent past as published by IPCC (2007). It is somewhat alarming to note the rapid increase of slope as we approach the present.

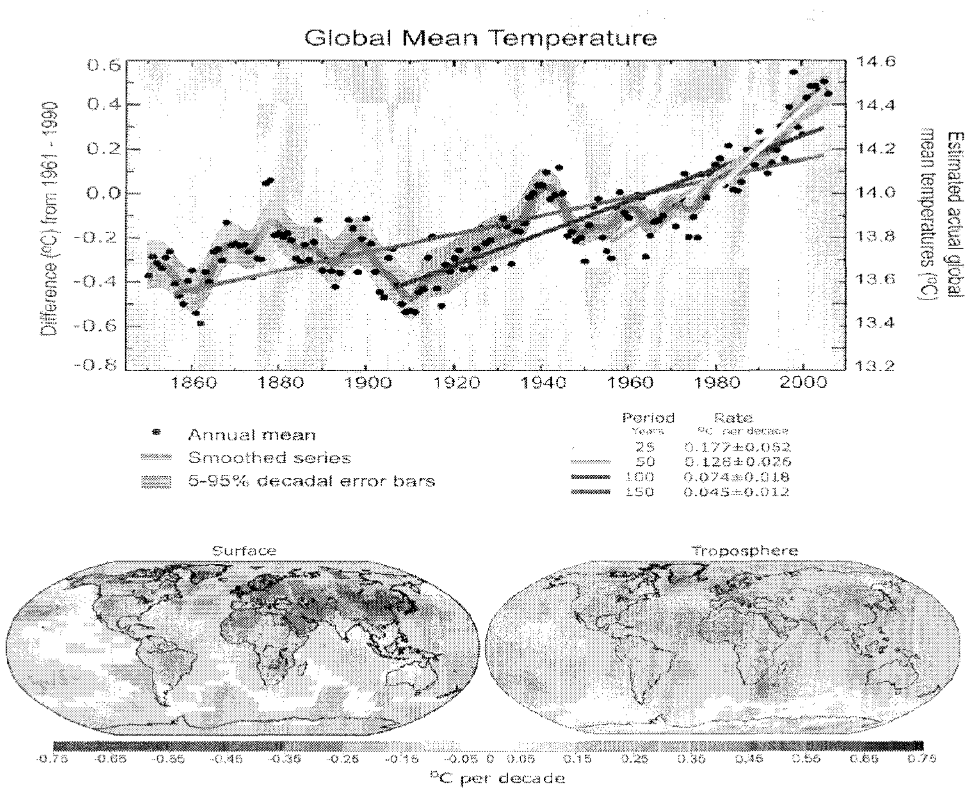

Figure 1: Trends in global temperature in recent past.

The global warming phenomenon of the recent times is mostly attributable to anthropogenic activities, specifically to the industrial revolution which actually started in the 1850s. However, from climatic records it has been found that the effects started manifesting after 1950 (Ammann et al., 2007). It is therefore pertinent to analyse temperature data of stations where records are available since 1950. Surprisingly, many parts of the world have recorded a decline in temperature during the period 1950-80, which again is attributed to anthropogenic contributions of sulphate aerosols into the atmosphere (Emanuel, 2008). The dominant effects of anthropogenic contributions of greenhouse gases into the atmosphere truly began to be felt after 1980.

2. OBSERVED TRENDS

To analyse trends in atmospheric temperature in Bangladesh, the country has been divided into four hydrological regions which are: northwest, southwest, northeast and southeast – these are the traditional hydrologic units. In the northwest region temperature data of Rangpur, Dinajpur, Bogra, Rajshahi and Pabna have been analysed. This region is now showing a slight rising trend in average temperature of 0.01^0C per year. The rise appears fairly uniform because the slope calculated for the period 1950-80 is similar to the slope for the period 1981-2008. In the southwest region temperature data of Barisal, Faridpur, Jessore, Khulna and Satkhira were analysed. Over the long period of record there were no significant trends with any station. However, after 1980 a flat gradient in minimum temperature and a rising trend in maximum temperatures can be observed – the gradient increases as we move from inland towards the coast and from east to west. Satkhira had the highest gradient of 0.02^0C/year and Faridpur and Jessore had the lowest gradient being less than 0.01^0C/year. Barisal data is suspect because there is discontinuity and sudden jumps in the data, which puts in doubt if there is a gradient as we move along the coast from east to west. In the northeast region, temperature data of Dhaka, Mymensingh, Sylhet, Srimangal, Brahmanbaria, and Comilla were analysed. Dhaka shows a flat gradient in annual mean temperature during the period 1950-80 and then a rising gradient of 0.05^0C/year. Mymensingh shows a flat trend during the period 1950-80 similar to Dhaka and then a rising trend of 0.02^0C/year. Dhaka is a much bigger metropolitan area with much higher growth rate compared to Mymensingh. Sylhet showed a falling trend during the period 1950-1980 of -0.01^0C/year and a rising trend of 0.03^0C/year after 1980. Observation in Brahmanbaria and Comilla shows a flat gradient during the period 1950-1980 and sufficient records after that period are not available to make any inferences about the trend. In the southeast region data of Maijdi Court, Chittagong, Rangamati and Cox's Bazar were analysed. Except Rangamati all the stations are in the coastal area. All three coastal stations showed similar falling trend during 1950-80 period of -0.02^0C/year and then a rising trend of 0.06^0C/year. Rangamati showed a rising trend during 1950-65 and then a falling trend of -

0.04^0C/year which continued beyond 1980. In general, it appears that all along the coast the temperature is rising faster than inland over the years after 1980. If we look at a very long record of data that is available for Calcutta, we can see a rising trend of 2^0C per century until 1950, a fall of 0.5^0C from 1950 to 1980 and then a rise of 0.04^0C/ year. It should be noted that Bangladesh faces the opposing effects of global warming and global dimming quite noticeably – the mostly alluvial terrain puts in lot of dust in the atmosphere which contributes significantly to dimming.

To determine trends in distribution pattern of temperature, quantile regression (Chamaille-Jammes et al., 2007) of monthly temperature data of a few stations for the period 1950-2007 have been done. For Dhaka the trends in various quantiles are given in Figure 2. It can be seen from the figure that increase in minimum temperatures has been steeper than the maximum temperatures, and the median temperatures have the steepest gradient. For Jessore in the southwest region, the maximum temperatures have been static, the minimum temperatures show a slight rising trend but the steepest gradient is with the median temperatures somewhat similar to Dhaka. For Bogra in northwest region, the maximum temperature has remained steady over the period, but for shorter periods a decline can be observed during 1950-80 and increase during 1980-2007. There is a rising trend in the minimum temperatures but the steepest gradient is in the median temperatures similar to Dhaka. For the southeast region temperature data of Rangamati has been analysed. It has been chosen because the station is different from others in that it is a hill station and in a rainforest. The maximum temperature in Rangamati actually shows a decline. The minimum and median temperatures follow the same trend as in Dhaka. From quantile regression of temperatures of different hydrological regions it appears in general that the maximum temperatures have not changed much, the minimum temperatures show a slight rising trend, but the number of warmer days in a year have increased significantly.

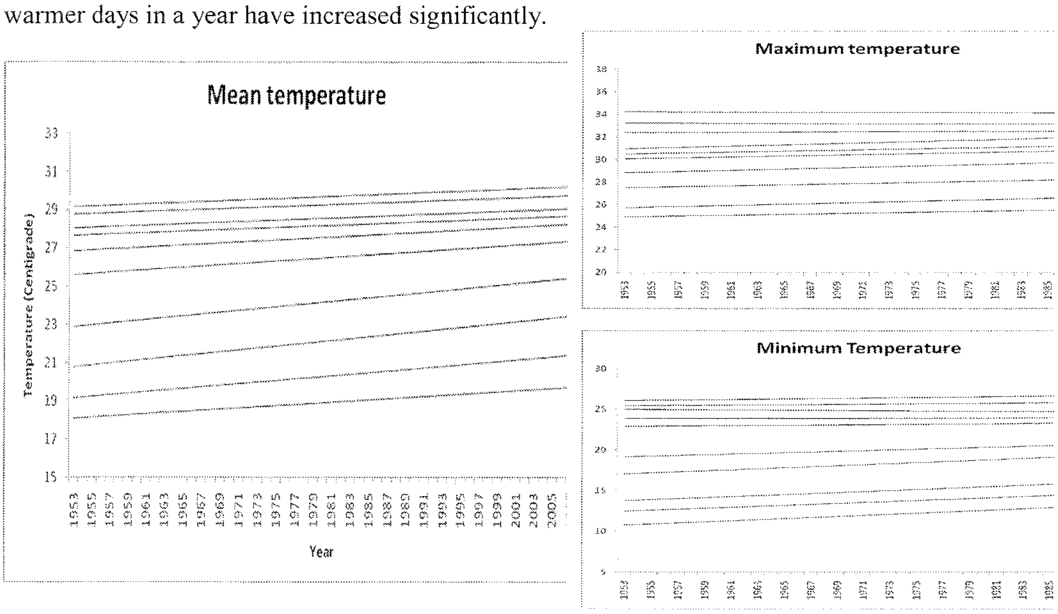

Figure 2: Trends in quantile values of monthly mean, maximum and minimum temperatures in Dhaka.

To analyse trends in precipitation, data is obtained from several sources. To get overall regional pictures data from NOAA NCEP CPC PRECL datasets are analysed. These data are collated from precipitation observations of many stations. The grid point (88.75E, 23.75N) is used for western part of the country and (91.25E, 23.75N) is used for eastern part of the country. To test trends and changes in trends in precipitation data, the World Meteorological Organization (WMO)'s recommended method is the Mann-Kendall (M-K) test (Liu, 2008). The test statistic for the M-K test for a time series x_i of length n is given as follows:

$$S = \sum_{i=2}^{n}\sum_{j=1}^{i-1} sign(x_i - x_j), \quad \text{where } sign(x_i - x_j) = \begin{cases} -1, & \text{when } x_i - x_j < 0 \\ 0, & \text{when } x_i - x_j = 0 \\ 1, & \text{when } x_i - x_j > 0 \end{cases}$$

The variance of S is given by, $\mathrm{Var}[S] = n(n-1)(2n+5)/18$ and for hypothesis testing for the significance of the trend, the computed Z-statistic is given as: $Z = S/\sqrt{\mathrm{Var}[S]}$.

For progressive M-K test to detect any significant changes in trend, m_i is computed for each term in the time series and represents the number of later terms that exceed the term under consideration x_i.

$$d_k = \sum_{i=1}^{k} m_i, \quad 2 \le k \le n$$

Presuming that the series is random and independent, the expected values and variances of d_k are given by:

$$E[d_k] = k(k-1)/4\ , \quad \mathrm{Var}[d_k] = \frac{k(k-1)(2k+5)}{72}, \quad 2 \le k \le n$$

We define $u(d_k) = (d_k - E[d_k])/\sqrt{\mathrm{Var}[d_k]}$, which when plotted against time constitute the curve C_1. Applying the same method to the inverse series, we can obtain the curve C_2. If the two curves intersect, the intersection point marks the time when a significant change in the trend has occurred. $u(d_k)$ is normalized, and therefore, standard normal distribution can be used to construct confidence intervals.

For the western region linear regression of annual precipitation yields a slope of 0.62, but S from M-K test is 109, standard deviation of S is 149, Z is 0.73, and therefore, the slope is not significant. Linear regression on individual months showed a falling trend in the rainy season months and a rising trend in the non-rainy season months, but the variability was higher than the annual values. For the eastern region linear regression of annual precipitation yields a slope of -1.98 , but S from M-K test is -119, standard deviation of S is 149, Z is -0.80, and therefore, the slope is not significant. Similar to western region, the falling trends in rainy reason months appeared much sharper than the non-rainy season months. To test changes in distribution pattern of rainfall, Precipitation Concentration Index (PCI) was calculated. PCI is given as follows: $PCI = [(\sum_{i=1}^{12} p_i^2)/(\sum_{i=1}^{12} p_i)^2]\times 100$. A PCI value of less than 10 indicates a reasonable distribution of rainfall across several months, whereas a PCI value of over 20 indicates most rain fall in one or two months. For the western region the PCIs varied between 14 and 18 with a slope of -0.03 indicating lessening in skewness of distribution. For the eastern region the PCIs varied between 13 and 18 with a slope of -0.015.

Pluviometric station observations albeit with significant number of missing values show consistent trends. Dhaka for the period 1953-99 has a mean precipitation of 2072mm with a slope of 9mm/yr and mean PCI of 17 with a slope of -0.08. The corresponding mean precipitation; slope; mean PCI and slope of PCI values for Rangpur, Jessore, Sylhet and Chittagong are 2116mm, 1613mm, 4080mm, 2888mm; 21mm/yr, 7mm/yr, 43mm/yr, 5mm/yr; 20, 18, 17, 20 and -0.12, -0.02, -0.09, and 0.10, respectively.

3. PREDICTIONS

General circulation models (GCMs) are the primary tools available today for climate projections. These are numerical representation of the dynamics of the earth's atmosphere, ocean, cryosphere and land. Many different GCMs are in operation with different assumptions and parameterizations of the physical processes – modelling the entire world in grid-points with typical grid sizes of 150-300km. Sub-grid scale processes such as cloud formation and precipitation are difficult to be included. Therefore, no two GCMs yield the same result. Despite widely varying outputs, they are found useful because certain GCMs simulate well certain areas and others simulate well other areas.

Regarding temperature and rainfall, IPCC collated the findings from 21 GCMs, to estimate the change from the base year 1980-99 to 2080-99 with the A1B scenario, which basically assumes full technological developments with no mitigation measures adopted. IPCC's (Regional Climate Projections, Chapter 11, Working Group 1, Fourth Assessment Report) future projections for temperature change (^{0}C) are given in Table 1 and for precipitation change (%) are given in Table 2.

The values given in Table 1 fits generally with historical hydrological trends we have determined from available data for lower quartiles, but not for upper quartiles. None of the precipitation projections of Table 2 are supported by the historical data. Minimum rainfall values appear to be rising and maximum rainfall values appear to be falling rather than the reverse. These errors in GCMs appear perhaps because precipitation is dominated by much smaller processes than what a coarse grid of a GCM can capture. This deficiency is sometimes addressed by dynamical downscaling into a Regional Climate Model (RCM), which is basically a nested modelling approach. However, Somot et al. (2008) have demonstrated that dynamical downscaling may not be capable of providing adequate feedback loop to the parent model and therefore may not improve the accuracy. It is therefore perhaps logical to infer that the precipitation forecasts made by the GCMs and as presented by IPCC for Bangladesh are unreliable.

Table 1 IPCC projected temperature change from 1980-99 level to 2080-99.

	Temperature change (^{0}C)				
Season	Minimum	First Quartile	Median	Third Quartile	Maximum
DJF	2.7	3.2	3.6	3.9	4.8
MAM	2.1	3.0	3.5	3.8	5.3
JJA	1.2	2.2	2.7	3.2	4.4
SON	2.0	2.5	3.1	3.5	4.4
Annual	2.0	2.7	3.3	3.6	4.7

Table 2 IPCC projected precipitation change in percent from 1980-99 to 2080-99.

	Precipitation change (%)				
Season	Minimum	First Quartile	Median	Third Quartile	Maximum
DJF	-35	-9	-5	1	15
MAM	-30	-2	9	18	26
JJA	-3	4	11	16	23
SON	-12	8	15	20	26
Annual	-15	4	11	15	20

There are certain aspects of climate change attributable to global warming which is occurring outside the territorial boundaries of Bangladesh but will affect the nation nevertheless. One such aspect is the sea-level rise. Sea level will rise due mainly to thermal expansion of the oceans and melting of the land ice. Although this rise is not going to be spatially uniform because of ongoing geoid change, it will affect the coastal areas all over the world. In the 20th century, the sea level rose by 0.8 to 3.3mm/year with an average of 1.8mm/year. Since 1993 satellite altimetry records a rising rate of 2.8mm/year, however, it is unclear whether the record is actual variability or there have been problems with satellite calibration. The fourth assessment report of IPCC (2007), summarises from many GCM outputs the possible sea level rises from 1980-99 values to 2090-99 values. They are provided under different SRES (Special Report on Emissions Scenarios) described in the third assessment report of IPCC, which capture possible future developments under four narrative storylines – A1 (world markets), A2 (state enterprise), B1 (global sustainability), and B2 (local stewardship) – no scenario is more likely than the other. A1 storyline with rapid economic growth has three technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T) or balanced energy (A1B). Table 3 presents the projections. However, some analysts consider these projections as conservative and suggest that the actual sea level rise that would occur at the end of this century is 1.4 metres if the current trend continues (Rahmstorf, 2007).

Bangladesh being primarily a deltaic country has been identified as one of the most vulnerable to sea-level rise. Areas where land accretion cannot keep pace with rising sea level will experience inundation, higher flood risk, water logging, salinity intrusion into estuaries and groundwater, and different water infrastructure needs.

Table 3 Possible sea level rise from 1980-99 level to 2090-99 level under different SRES as reported by IPCC. GHG represents expected stabilization level of the concentration of greenhouse gases.

Scenarios	B1	A1T	B2	A1B	A2	A1FI
GHG (ppm)	600	700	800	850	1250	1550
Sea level rise (metres)	0.18-0.38	0.20-0.45	0.20-0.43	0.21-0.48	0.23-0.51	0.26-0.59

Another important aspect of climate change is the shrinking cryosphere of the Himalayan region. The Himalayas have the highest volume of ice outside the polar region and it is a primary source of freshwater for Bangladesh. In 2005 WWF released a report warning that Himalayan glaciers are currently receding at a rate of 10 to 15 meters per year, which is also supported by other studies such as by Hasnain (2007). In India, Gangotri Glacier is retreating at the rate of 23 meters annually. If this continues, within the next 50 years July-through-September river flow of the Ganges will decrease by two-thirds. This will adversely affect the agricultural activities of over 50 percent of the nation.

4. DISCUSSION

The rising temperature in Bangladesh appears to be the direct consequence of climate change. Climate change may also affect rainfall though it has not been found to be statistically significant yet. Perhaps the most important impacts of climate change in the context of Bangladesh is sea-level rise and reduced availability of freshwater. Sea level will continue to rise in this century and beyond even with emission control and mitigation measures. Bangladesh being a deltaic region is very vulnerable to sea-level rise. Combating sea-level rise will perhaps be the greatest challenge that Bangladesh would face in not so distant future. Unfortunately, the options are limited due to high population density, thick alluvial deposits, gentle terrain and lack of resources. If population migration is an unavoidable alternative, it is perhaps high time that the planning process is started in right earnest.

There are reasons to believe from evidences elsewhere in the world that global warming is contributing to more frequent occurrences of extreme climatic events. Figure 3 shows the number of disaster scale floods and the number of destructive tropical storms that occurred in Bangladesh over the years. Data for these two figures are obtained from EM-DAT (The OFCA/CRED International Disaster Database, Brussels, Belgium). Both figures show a rising trend.

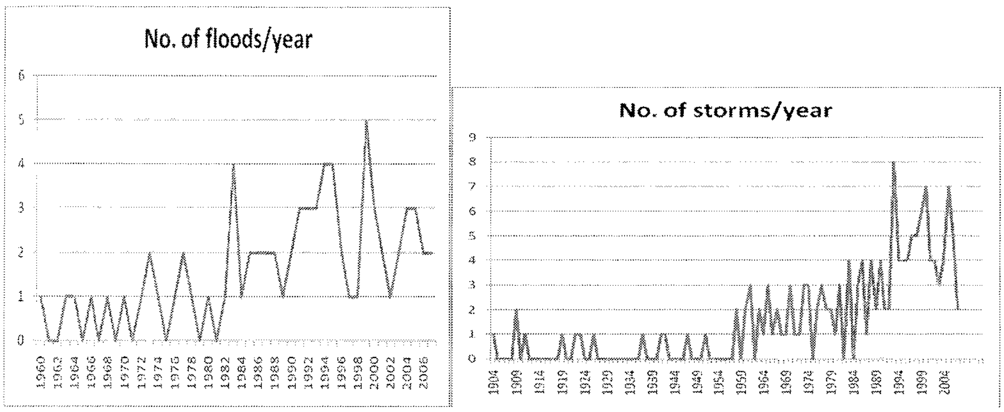

Figure 3: Number of flood disasters and destructive storms in Bangladesh occurring annully.

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