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Changing Climatic Hazards in the Coast: Risks and Impacts on Satkhira, One of the Most Vulnerable Districts in Bangladesh

Md. Golam Rabbani, Md. Nasir Uddin and Sirazoom Munira

Abstract

Changes in the climate due to anthropogenic and natural variation are indicated by parameters including temperature and rainfall. Climate change variability with changing trends of the two have been unpredictable and unprecedented globally leading to changing weather patterns, natural disasters, leading to sectoral impacts on food and water security, livelihood, human health among others. This research analyses the changing patterns of these parameters over the last 35/37 years of Satkhira district of Bangladesh to assess the state and trend across spatial and temporal dimensions. Such, the study validates to rationalize the observed seasonal changes that persist in Satkhira of Bangladesh. Both in terms of intensity and frequency of the occurrences of natural disasters, the series of natural events have been triangulated, with impacts and vulnerability being assessed from temperature variations, erratic rainfall, cyclone, flood and water logging etc. The study's prime contribution remains in attribution of climate change in relation contextual circumstances in the region including sea level rise, salinity intrusion. Therefore, the risk and climatic hazards and its resulting impacts over time has been assessed to draw deeper connection between theoretical and practical values. The series of analyses also draw conclusion that assets are at risk from changing climatic condition.

Keywords: temperature, rainfall, climate risk, impact, Satkhira

1. Introduction

Bangladesh has long been recognized as being very vulnerable to both environmental degradation and climate change impacts [1, 2]. Increasing changes in climate variability and extreme events have pushed the country towards greater vulnerability. This vulnerability is compounded by low economic progress of the country, inadequate infrastructure, lack of institutional capacity, improper management practices, and increased dependency on the natural resource base which makes coping strategies difficult to implement.

It has been predicted that “climate change impacts will be differently distributed among different regions, generations, age classes, income groups, occupations and genders” [3]. The IPCC also notes: “the impacts of climate change will

fall disproportionately upon developing countries and the poor persons within all countries, and thereby exacerbate inequities in health status and access to adequate food, clean water, and other resources". It became an unkind or terrible reality for the communities of Bangladesh to face extreme climatic events e.g. recent prolonged and devastating floods (1998, 2004, 2007) and cyclonic events in last decades. IPCC Fifth Assessment Report (AR5) shows that the global average mean sea level rose by 1.7 mm per year during 1900–2010 and it further increased to 3.2 mm per year during 1993–2010 [4]. The most recent IPCC (2018) special report states that the global mean sea level rise is expected to be around 0.1 meter less with global temperature of 1.5°C compared to 2°C [5]. It is predicted that the sea level is likely to rise 30 and 50 cm by 2030 and 2050 respectively (World Bank, 2000). A recent report states that the range of sea level rise in the coast of Bangladesh is 6 mm to 21 mm/year during 1980–2010 [6]. This may have adverse impacts on natural resources in different degrees in different ecosystems (terrestrial and aquatic). IPCC Fifth Assessment Report (AR5) indicates that sea level rise and wave action are causing decline of vegetated coastal habitats across the world (Wong, 2014). Some other reports also state that the coastal communities of Bangladesh are exposed to risks of weather and climate related extreme events [7].

Variation in temperature, erratic behavior of rainfall, cyclonic events [Cyclone Sidr (2007), Cyclone Bijli, Cyclone Aila (2009), Cyclone Mahasen (2013), Cyclone Roanu (2016), Cyclone Fani and Cyclone Bulbul (2019) and Cyclone Amphan (2020)], salinity intrusion, droughts, extreme heat waves, cold wave etc. made their life and livelihoods miserable in the coast of Bangladesh in last decade.

Changes of climate may directly and indirectly affect freshwater resources (water availability and deteriorate water quality), fisheries biology and aquatic ecosystem, human health (increase incidences of water borne diseases e.g. diarrhea, cholera, dysentery etc.) and agriculture crops. These would result increase demand and consumption of water due to increase of temperature, increased pressure on groundwater, shortage of food due to decreased agriculture production and finally increase of morbidity and mortality of the communities with low resilience in the coast especially in Satkhira.

2. Materials and methods

The research delved into the state and trend of some key climate related primary and secondary hazards including variation in temperature and rainfall, cyclonic events, salinity intrusion and sea level rise that are affecting the Southwest coast, especially Satkhira district of Bangladesh. Cyclone and storm surge, salinity intrusion and SLR are the key climate induced secondary hazards or disaster that are affecting the coastal communities. It is expected that the vulnerability may be enhanced in the future because of increased frequency and intensity of such events.

The key primary elements including temperature and rainfall of the research district (Satkhira) were collected from the Bangladesh Meteorological Department (BMD) and analyzed to see the trend of temperature over the 35 years long-period (1981–2015) and rainfall over 38 years long period (1981–2018). The research mainly considered at annual and seasonal trend of temperature and rainfall. The secondary literatures collected from different sources were used to analyze the state and trend of other secondary climatic hazards in the southwest coast of Bangladesh. The following sections provide the details of the trend of temperature and rainfall pattern in the study location (Map in **Figure 1**).

Figure 1.
Study area (Satkhira) map.

3. Results and discussions

3.1 Temperature

Bangladesh Meteorological Department (BMD) provided the climatic data for Satkhira district over the period 1981–2015. The climatic data comprised monthly, seasonal and annual average maximum and minimum temperature for the above-mentioned district. The following figure (**Figure 1**) shows that the 35 years annual mean maximum temperature follows a decreasing trend over the period of 1981–2015 while the annual mean minimum temperature go along with an increasing trend for the same period. Over the period, the highest annual mean minimum temperature (22.44°C) was observed in 2010 while the lowest (20.53°C) was in 1999 (**Figure 2**). The highest annual mean maximum temperature (32.51°C) was in 1987 while the lowest (30.08°C) was in 1981. It was also observed that both maximum and minimum (annual mean) temperature were on increasing trend for last ten years (2006–2015).

As mentioned above that the liner trend analysis shows the decreasing trend ($0.008^{\circ}\text{C}/\text{yr}$) of mean maximum temperature during 1981–2015 in Satkhira, which is statistically non-significant trend. The Mann-Kendal (MK) test also shows insignificant decreasing trend of annual mean maximum temperature in Satkhira during the same period. In terms of five-year moving average, the annual mean maximum temperature shows an increasing trend until mid-1980s and then suddenly drops in 1987. From 1990 onwards, no trend is observed; rather the temperature shows regular fluctuations.

The annual mean minimum temperature shows an increasing trend ($0.02^{\circ}\text{C}/\text{yr}$) during 1981–2015, which is highly statistically significant ($p = 0.002$). In non-linear trend, the MK test also found an increasing trend with statistical significance.

Figure 2.
Annual mean maximum temperature (1981–2015).

Figure 3.
Annual mean minimum temperature (1981–2015).

On seasonal analysis, average maximum temperature for the period of 1981–2015 was on decreasing trend in pre-monsoon, post-monsoon and winter while it was on increase (**Figure 3**) in monsoon. With the application of MK test, the mean maximum temperature in early winter (December, January) and late post monsoon (November) depicted statistically significant decreasing trend over the period of 1981–2015 in Satkhira. The mean minimum temperature was on increasing trend in all the seasons between 1981 and 2015 (**Figure 4**). The linear trend of annual mean minimum temperature in monsoon ($p = 0.009$) and post monsoon ($p = 0.002$) was found statistically highly significant increasing trend. Over the period of 1981–2015, the MK test also shows statistically significant increasing trend of mean minimum temperature in each of the months from June to December, except October. But again, both mean maximum and mean minimum temperature in monsoon was on increasing trend over the last 35 years (1981–2015).

Figure 4.
Seasonal mean maximum temperature (1981–2015).

3.2 Rainfall pattern

Annual and seasonal total rainfall of the study area was observed. During 1981–2015, the trend of total rainfall in Satkhira was on decreasing trend (Figure 5) (Rabbani et al., 2018). This linear trend of total rainfall over the period of 1981–2015 was found statistically non-significant decreasing trend. MK test also depicts that this rainfall trend is on decreasing trend without any statistical significance. In terms of five-year moving average, fluctuation was observed from mid 1980s to late 1990s. From 1999, it shows an upward trend but again it repeatedly dropped from 2007 to 2014.

On seasonal mean rainfall pattern, Pre-monsoon, monsoon and winter rainfall followed a decreasing pattern from 1981 to 2015 while post monsoon shows an increasing trend for the same period (Figure 6). On the other hand, the difference between the trend of total rainfall of monsoon and the rest three seasons is much closer in latter half of last 35 years (1981–2015) period.

In terms of five-year moving average, pre-monsoon mean rainfall did not show any notable trend between mid-1980s and mid-1990s. From 1995 it was on upward trend till 2001 but then it constantly dropped till 2012. Monsoon mean rainfall pattern shows irregular pattern from 1985 to 2005. From 2005 it was on decreasing trend. Similar pattern was observed for post-monsoon rainfall from 1985 to 2005

Figure 5.
Seasonal mean minimum temperature in Satkhira (1981–2015).

Figure 6.
Annual (total) rainfall in Satkhira during 1981–2015.

Figure 7.
Trend of seasonal rainfall (total) in Satkhira during 1981–2015, modified from [8].

but from 2007 it showed sharp downward trend till 2015. Five year moving average does not show any remarkable upward or downward trend over the 35 years period.

The study observed that the no of days without rainfall was on the increasing trend over 1981–2017, which is highly statistically significant ($p = 0.0001$) (Figure 7). The trend of days with over 100 mm and 150 mm rainfall were found to be on the decrease, which did not show any statistical significance (Rabbani et al., 2018). Five-year moving average of the trend of no of days without rainfall shows an upward trend from early 2000s. While five year moving average of the trend of days with above 100 and 150 mm rainfall during 1981–2017 in Satkhira shows a downward trend since 2006/2007.

3.3 Cyclone and storm surges in the southwest coast including Satkhira

On the number of cyclonic events that hit Bangladesh varies in different studies. [9] indicates that the coast of Bangladesh experienced 154 cyclonic events of different classes¹ between 1877 and 1995 while [10] refer 117 cyclonic events from

¹ The classes of cyclonic events include: Super Cyclonic Storm (greater than 220 km/hour), very severe cyclonic storm (119–220 km /hour), severe cyclonic storms (90–119 km/hour), cyclonic storms (60–90 km/hour), Deep depression (51–59 km/hour), Depression (32–50 km/hour) (Dasgupta et al., 2010).

1877 to 2003. Another study indicates that 149 cyclones hit Bangladesh between 1891 and 1998 [11]. This difference in number of cyclonic reference probably occurred because of the scope of different studies. However, it appears that 38 cyclonic events affected South-West coast (including Satkhira) between 1877 and 2010 [10]. Between 1970 and 2010, seven severe cyclone (>90 km/hour wind speed) devastated south-west coast (including current Satkhira District) and the local communities. Some studies clearly point that the storm surge accompanying with cyclone cause huge damage of the infrastructure and the wetlands resources. When it coincides with high tide, it becomes almost catastrophic with above 5-meter depth of inundation along the coast [12].

The following **Table 1** indicates that 40 cyclonic events affected South-West coastal region (Greater Khulna) including Satkhira during 1877–2010. Four severe cyclonic storms and one super cyclonic storm affected this region since 1973. Cyclone Sidr and Cyclone Aila devastatingly affected the study region. Increased intensity of the cyclonic events may increase risks of life and livelihoods of the local communities. Moreover, the compound effects of different climatic hazards/disasters may alter existing livelihoods opportunities. The poor households will have limited options for water supply, sanitation and farming practices if the ecosystems are more severely affected in future.

On Cyclonic events, IPCC Fourth Assessment Report predicts about the intensification of the extreme weather events such as cyclones and associated storm surges especially along the Bay of Bengal. There are evidences of decreasing frequency of monsoon depression and formation of cyclone but increase of intensity in the Bay of Bengal since 1970 [13, 14]. This prediction of decreasing frequency of cyclone is in line with earlier findings of Ali in 2000 although it partially differs with SMRC findings [15] which reveals that frequency of intense cyclone during post-monsoon (November) has been increasing. But many studies were conducted to understand the role of SST in formation and intensity of cyclonic events [e.g. 17, 18]. It is reported that increase of 2°C and 4.5°C of SST would cause increase of 10% and 25% wind speed of the cyclone respectively [11]. This generally means that the intensity of cyclone will be increased with increase of temperature.

In addition, increase in SLR will bring the water line further inwards. Consequently, the effect of storm surge will penetrate deeper into the landmass. These are going to largely affect agricultural production, health, loss of livelihoods and increase in poverty of this Southwest coastal region including Satkhira. The recent Cyclone Amphan of 2020 killed 31 people and affected over 10 million people altogether in Bangladesh². Total damage from cyclone Amphan worth BDT 1100 crore or Taka 11 Billion (USD 130 Million).

3.4 Salinity intrusion and sea level rise (SLR)

Sea level rise and salinity intrusion are already affecting the coastal communities in Bangladesh. It is projected that the possible SLR may severely affect the coast of the country. It has been reported that a vast and diverse coral reef of South Asia were lost in 1998 due to coral bleaching induced by the 1997/98 El Niño event [16–18]. A study report shows that Bangladesh would face the largest impacts due to SLR [19]. The possible SLR may affect Bangladesh by inundating coastal areas. As mentioned above it has been predicted that by 2030 and 2050 at least 30 and 50 cm sea level will rise respectively. Another report shows that if 25 cm sea level rises then 40 percent of Sundarban will be submerged, and in case of rising sea level by above 60 cm, the whole Sundarban will disappear [20]. A recent report

² The Dhaka Tribune, 22 May 2020.

SL	Year	Month of occurrence	Type of Cyclonic event
1	1877	6–8 August	Tropical Depression
2	1877	18–20 August	Tropical Depression
3	1881	26–28 May	Tropical Depression
4	1885	16–19 June	Tropical Storm
5	1890	22–24 June	Tropical Depression
6	1895	30-Sep	Not Available
7	1899	13–16 July	Tropical Depression
8	1904	10–12 June	Tropical Depression
9	1906	25–27 July	Tropical Storm
10	1907	23–26 June	Tropical Storm
11	1908	16–22 June	Tropical Storm
12	1916	4–6 June	Tropical Storm
13	1919	5–10 August	Tropical Depression
14	1919	23–25 September	Not Available
15	1928	1–2 August	Tropical Depression
16	1932	7–10 June	Tropical Depression
17	1932	11–15 November	Tropical Depression
18	1937	11–14 October	Tropical Storm
19	1938	25–28 May	Tropical Depression
20	1939	30-Sep	Tropical Depression
21	1944	24–31 August	Tropical Depression
22	1959	9–18 July	Tropical Depression
23	1963	October	Tropical Depression
24	1965	9–12 May	Tropical storm
25	1966	September	Severe Cyclonic Storm
26	1968	June	Tropical Depression
27	1969	October	Tropical Storm
28	1970	October	Tropical Storm
29	1973	December	Very Severe Cyclonic Storm
30	1986	November	Severe Cyclonic Storm
31	1988	October	Tropical Storm
32	1988	November	Very Severe Cyclonic Storm
33	1996	October	Tropical Storm
34	1998	November	Very Severe Cyclonic Storm
35	2000	October	Tropical Storm
36	2002		Tropical Storm
37	2007	15-Nov	Super Cyclonic Storm
38	2009	24–25 May	Very Severe Cyclonic Storm
39	2019	9–11 November	Cyclone Bulbul (Very Severe Cyclonic Storm)
40	2020	16–21 May	Cyclone Amphan (Super Cyclonic Storm)

Source: [10, 11].

Table 1.
Cyclonic events that affected south-west coast (greater Khulna) since 1877.

Figure 8.
Trend of “no of days without rainfall” during 1981–2017 in Satkhira, modified from [8].

Figure 9.
Trend of days with above 100 and 150 mm rainfall during 1981–2017 in Satkhira, modified from [8].

shows that there is a trend of increasing SLR at different points by 6–20 mm/year during 1983 to 2012 [21] (**Figures 8–10**).

In fact, the SLR is likely to inundate the coastal wetlands, lowlands, accentuate coastal erosion, increase frequent and severe floods, create drainage and irrigation problems and finally dislocate millions of people from their homes and occupation [22]. This may catalyze the increasing rate of rural –urban migration within the country. An estimation based on a coarse digital terrain model and global population distribution data, shows that SLR will directly affect more than 1 million people in 2050 in each of the Ganges- Brahmaputra-Meghna delta in Bangladesh [23]. On the other hand, salinity became one of the major problems for the coastal zones of Bangladesh. This is happening may be due to low flow of fresh water from the Ganges and ingress of salt water from Bay of Bengal. So the compound effect of SLR and salinity may disrupt agriculture (e.g. reduction of rice), mangroves including the Sunderbans and coastal ecosystem including ponds and create additional health problems in the local communities. The recent reports state that the coastal community may suffer more with water borne diseases and other physical problems (e.g. menstruation problems of the women from drinking of saline water) due to SLR and salinity intrusion [24]. However, the poor and marginal groups would be critically affected by the possible SLR and salinity intrusion in coastal zone of Bangladesh.

Figure 10.
Water level trends for the Ganges, Meghna and Chittagong coastal sub zone of Bangladesh based on the data of last 30 years. Source: [21].

3.5 Synthesis of climate hazards, risk and impacts in Satkhira

Analysis shows that the trend of mean maximum temperature in monsoon over a 35-year period (1981–2015) is on increasing trend while it is on decrease in all other seasons in the study area of Satkhira. According to Mann Kendall test, the trend of mean maximum temperature of November, December and January is on decrease significantly over the period of 1981–2015. It was also observed that the average minimum temperature was increasing trend for the last 35 years period (1981–2015) with statistical significance. Both maximum and minimum temperature trend is also on increase in monsoon for the same period. It indicates that monsoon was warmer in last 35 years. Early winter days were also on cooling trend. Nights are on warming trend in every season over the 35 years period in Satkhira. Rainfall patterns are changing in the study district. Pre-monsoon rainfall is also decreasing over the above-mentioned period. Likewise, the number of days without rainfall has increased with statistical significance over the same period. It specifies that the study communities are losing the rainy days even in monsoon. It may be argued that a longer span of rainless days, over extraction of water during warmer seasons and high rates of evaporation, especially during pre-monsoon periods, may present possible reasons for depleting water levels. Existing literature demonstrates that changes of temperature and rainfall pattern have an impact on wetlands [25–27]. [28] mention that climate change and water-related infectious diseases are also intertwined.

The literatures on major secondary elements of climate change including cyclone and storm surges, salinity intrusion and sea level rise (SLR) were collected and reviewed to see the changes over the decades. As the study area is close to the Bay of Bengal, the risks related to cyclonic events and storms surges, salinity intrusion in water and soil and potential sea level rise is high for the natural resources and local communities. The following sections provide details on the changes of key secondary events of climate change in the study location. The research

summarizes the details on key secondary events of climate change in the study location, Satkhira. Existing literature encompasses key major secondary elements including cyclones, sea level rise and salinity intrusion, all of which are detrimental events in the face of climate change. Since 1970s the frequency of monsoon depression and cyclone formation in the Bay of Bengal has reduced whereas the intensity has increased [29]. Rabbani et al., [30] posits that the acceleration in the wind speed may as well bring unprecedented casualties in the coastal ecosystems, pushing the vulnerable communities towards greater risks of losing lives.

This research also speculates deeper practical connections between theory and practice. It comes to the conclusion that the compound effects of different climatic disasters may alter existing livelihoods opportunities. The poor households will have limited options for water supply, sanitation and farming practices if this area is more severely affected in future. It may be inferred that Cyclone Sidr (2007), Cyclone Aila (2009) and Cyclone Amphan (2020) largely impacted on the study region while it occurred causing increased intensity of the cyclonic events to the risks of many. The research therefore posits connection between life and livelihood of the communities susceptible to the impacts of climate change and overall resilience it is failing to build. Literature shows the various times of the year when cyclonic events have been in effect from 1877 to 2020. It can be indicated that cyclone usually hit the Southwest coast between May and December, whereas

SL	Climate Change Related Key Hazards	Key Impacts and vulnerability
1	Temperature variations	<ul style="list-style-type: none">• Challenges in domestic and irrigation water supply• Surface water quality deteriorates• Inadequate safe drinking water• Sanitation problems increase
2	Erratic behavior of rainfall	<ul style="list-style-type: none">• Affects agricultural yields• Increases incidences of water borne diseases and associated cost• Loss of working days especially in monsoon
3	Cyclone and storm surge	<ul style="list-style-type: none">• Damage of infrastructure (roads, culverts, embankments and so on)• Lack of water for domestic purposes including drinking, sanitation and hygiene practices• Loss and damage of fisheries and dependent livestock• Increased water borne diseases• Forced migration
4	Salinity and potential Sea level Rise	<ul style="list-style-type: none">• Salinity affects water and soil/lands• lack of freshwater supply including drinking water• Loss of crops/lands• Forced migration
5	Flood/water logging	<ul style="list-style-type: none">• Affects standing crops, fisheries and livestock• WASH challenges• Increases incidences of water borne diseases and associated cost• Increases incidences of water borne diseases and associated cost• Damage housing and infrastructure• Enhance river bank erosion

Table 2.
Climate change related hazards and associated impacts in the study location, Satkhira.

Monsoon and Post-Monsoon are the main seasons for cyclonic events in greater Khulna region including Satkhira. In the cyclone history, the highest occurring month was found June (8 times) followed by October (7 times). On the other hand, sea level rise and salinity intrusion are already affecting the coastal communities in Bangladesh. It is projected that the possible SLR may severely affect the coast of the country. The research delves into all these aspect through the lens of livelihood options which needs to be ensured against the devastating climate hazards within the coastal zones of Bangladesh.

This research shows the results of the district Satkhira but the most marginalized and poor populations situated in disaster prone areas of Bangladesh are often victims of extreme climatic conditions. **Table 2** shows impacts on the life and livelihoods is also jeopardized through these uncertain series of hazards and vulnerabilities, environmental migration from riverbank erosion, inundation, sea level rise etc. along with the impact on agriculture, a number of other sectors are impacted which includes water resources, forestry, food security, human health, infrastructure, settlements including displacement of inhabitants and loss of livelihood, coastal management and even sustainable disaster response and recovery plans. Therefore, resulting adaptation need of the vulnerable communities remain wide-ranging. Needs and demands of the vulnerable poor range from financial, technological needs to capacity building, administration, research and development, health, infrastructure etc. There is a dire requirement for serious intervention in the areas of food security, water security and related aspects to build a resilient community of poor and marginalized communities. Additionally, effort is also needed in comprehensive disaster management, flood control, enhanced rural and urban resilience of vulnerable groups, migration and other critical issues. Innovative, well-communicable, transparent and climate-smart solutions are needed to combat these challenges for the poor.

4. Conclusions

The currently existing challenges of climate change has been unanimously recognized by the international community, as a result of which Bangladesh, small country in terms of territory, ranks high in the list of most vulnerable countries on earth- as stated. The geographical characteristics of Bangladesh are heavily dependent on local and regional hydrological characteristics, which rely on climatic processes incusing dimensions of seasonality. Despite being a nano-emitter of the harmful greenhouse gases that contribute to increase the global average temperature, Bangladesh is the hardest hit as a result of climate change impacts. Larger and more integrated and innovative solutions are required to truly tackle the problem. Being one of the most climate vulnerable countries in the world, Bangladesh is at risk of natural disasters such as riverine and flash floods, tropical cyclones, storm surges, droughts, salinity intrusions, sea level rise and riverbank and coastal erosions. The trend analysis in this study shows that the changing patterns of temperature and rainfall of the country has a number of implications on agriculture and food security, water sector, health sector, livestock and fisheries and overall livelihood of the communities. Both the rural and the urban sectors are affected due to the unpredictable implications within these sectors. The effects of climate change are ubiquitous and all encompassing, causing the magnitude, frequency and duration of such natural disasters to increase, thus making marginalized communities extremely vulnerable. While the country has made a number of significant progress in reducing death burden from natural disasters, the remaining challenge is to protect the livelihoods which push people below the poverty line, force them to

migrate to the urban areas in search of work and also excludes them from a rightful participation in shaping the local level decision-making and service provisioning in favor of them. To that, this study concludes that further data science applications to socio-environmental studies like these should be in continuation for deeper assessment of vulnerability assessment to take right national and global policy uptakes.

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