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IMPACT OF CLIMATE CHANGE ON FLOODS OF BANGLADESH AND INTRODUCING FLOOD INTENSITY INDEX TO CHARACTERIZE THE FLOODING SCENARIO

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ABSTRACT

Bangladesh is a disaster prone country, and the effect of climate change magnifies the governing factors of the disasters. In this paper, firstly the temporal changes of pattern of different disasters in Bangladesh are discussed based on their occurrence rate, number of people killed, and exposure to human and economic loss. The paper is mainly concentrated on temporal variation of floods in Bangladesh. The decadal change in return period and probability of low, moderate and high flood events are presented. The term 'Flood Intensity Index (FII)' is introduced to characterize the flood, which is considered as a function of inundation depth and duration. FII is calculated for two mega floods of 1988 and 1998. It is observed that although the average depth of inundation among two mega floods does not differ too much, the FII in 1998 was much higher (about double) than 1988 flood, and that is why the economic loss in 1998 flood was much higher (about 2.33 times) than that of 1988 flood. Previous data and various future predictions showed that both the parameters in FII are in increasing trend due to climate change impact. The climate change induced increament in river discharge during monsoon will increase the inundation depth, and the increasing trend of Sea Level Rise will increase the duration of flood due to back water effect of sea. Therefore, the Flood Intensity Index will significantly be increased due to climate change. Since, the 'Flood Intensity Index (FII)' is a measurable index to characterize a flood accounting all the impacts of climate change, this index can be used in expressing the change in flooding scenario due to climate change.

Keywords: *Climate Change, Floods, Flood Intensity Index, Inundation, Sea Level Rise.*

1. INTRODUCTION

Bangladesh is one of the biggest deltas in the world and have an area of 1,44,000 sq. km. Geographically, it is situated at the tip of a funnel, through which huge amount of rain water discharged in monsoon to the ocean flushing over the country. Depression on the ocean, cyclones, tides and storm surges can easily affect the country through the unprotected shore. Therefore, Bangladesh is a disaster prone country. Effect of Climate Change magnifies the governing factors of disasters. The coastal belt of Bay of Bengal is in the south of Bangladesh. Among its 230 rivers, the Ganges, the Brahmaputra and the Meghna are the major rivers. They have vast catchment area (about 1.72 million km^2), whose only 7.5% lies within Bangladesh. Bangladesh experienced flood about every year. Generally 20% of the country is inundated in a normal flood, the highest flood inundates close to 100,000 km^2 in 1998 (Annual Flood Report, 2008). Since 1970, about 41 million people became homeless and it is estimated that it will be 68 million till 2020 (World Bank, 2000).

Previously, the area affected is used to be taken as the measure of intensity of floods (Miah, 1988; World Bank, 1989). Miah (1988) has catagorized the floods as normal, moderate, severe and catastrophic based on the flooding area as 21%, 21~26%, 26~34% and 34~38.5% of the country, respectively. Mirza (2002) reported the return period of those catagories of floods as 2.25, 4, 7 and 33 to 50 years, respectively. The World Bank (1989) also estimated the return periods of floods of different intensities with respect to the area covered (Table 1). It was suggested that a flood like that of 1988 would occur once in about 100 years while a flood like that of 1987 in about 20 years. However, the interval between major (catastrophic) floods has been declining in recent times and is likely to do so even more in future as a result of flood accentuating consequences of climate change and sea level rise . Note that floods inundating at least one-third of the country occurred on five occasions during the past half century: in 1955, 1974, 1987, 1988, and 1998, the interval having been 19 years, 13 years and 10 years successively.

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Table 1: Return period of flood characterized in relation to area covered (World Bank, 1989)

Return period Years	Affected area % of the country	Return period Years	Affected area % of the country
2	20	50	52
5	30	100	60
10	37	500	70
20	43	--	--

According to Table 1, the floods of 1988 and 1998 both have inundated about 60 per cent of the country, therefore both should have a return period of about 100 years. But in reality the 1998 flood event was far more destructive than the 1988 flood, as its duration (65 days) was several times of that (15-20 days) of the 1988 flood. Thus the destructive capacity of flood should be used to characterize the flood intensity. Obviously, when an area remains under flood water for a longer period, the greater the impact is likely to be. Therefore, In this study the term 'Flood Intensity Index (FII)' is introduced to characterize the flood, which is considered as a function of inundation depth and duration. A heuristic approach is described to explain how the climate change will magnify the flood intensity index of this country. In this paper, the temporal changes of pattern of different disasters in Bangladesh are also discussed based on their occurrence rate, number of people killed, and exposure to human and economic loss. The paper is mainly concentrated on temporal variation of floods in Bangladesh. The decadal change in return period and probability of low, moderate and high flood events are presented.

2. DATA

Three types of data is used in this study: i) the rainfall data, ii) the river discharge and flood hydrograph data and iii) time series of disasters in Bangladesh. For the first one monthly rainfall records of 17 stations (out of which, complete set of data was available in 12 stations) of Bangladesh for fifty years (1958–2007) are collected from Bangladesh Meteorological Department. For this data, homogeneity of rainfall records are analyzed by Shahid (2009), and reported that the data of all the stations are homogeneous. The data on time series of historical floods in Bangladesh with inundation area are collected from Bangladesh flood forcasting and warning center (FFWC). The disaster related data were collected from OFDA/CRED International Disaster Database EM-DAT (2011), Université Catholique de Louvain, Brussels, Belgium .

Table 2: Different types of disasters and the world ranking of Bangladesh (UN, 2009)

(a) Human exposure

Disaster Type	Population exposed	World ranking
Flood	19,279,660	1st out of 162 countries
Cyclone	4,641,060	6th out of 89 countries
Drought	642227	63rd out of 184 countries

(b) Economic exposure

Disaster Type	GDP exposed	World ranking
Flood	9.74 billion USD	3rd out of 162 countries
Cyclone	2.36 billion USD	12th out of 89 countries

3. ANALYSIS AND DISCUSSION

3.1 Disaster Profile of Bangladesh

Flood, cyclone and drought are the pivotal three disasters of Bangladesh. Based on the Global Assessment Report on Disaster Risk Reduction of United Nations in 2009, the world ranking of Bangladesh according to the total affected people and economic loss in different disasters is shown in Table 2. It is observed that the Flood is the mostly devastating disaster in Bangladesh compared to other disasters as it ranked 1st for the case of population exposed and 3rd in the case of economic exposure.

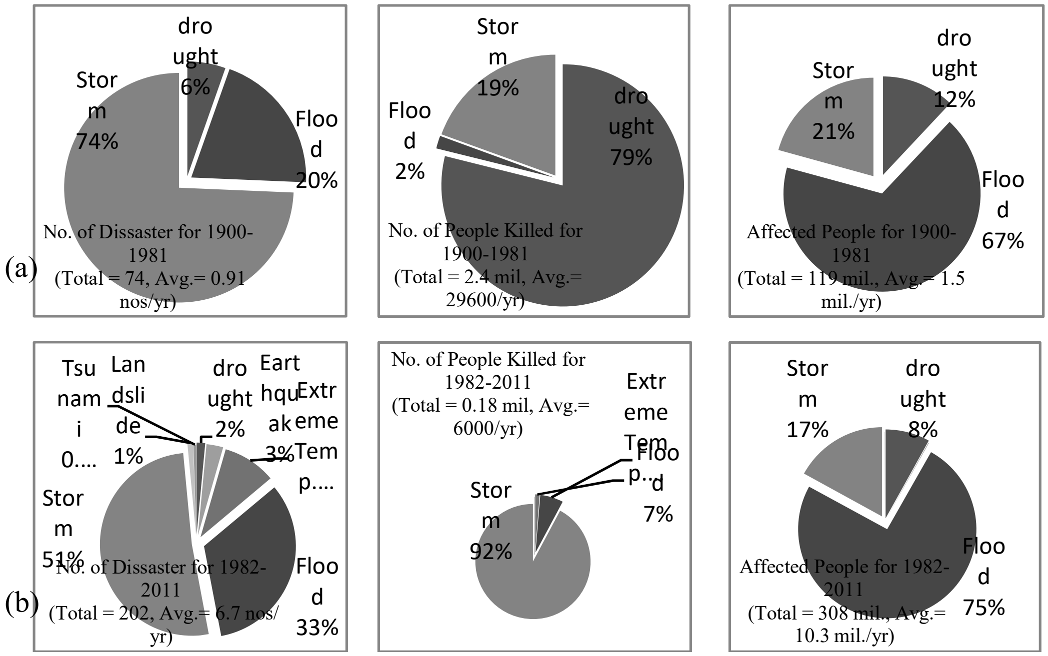
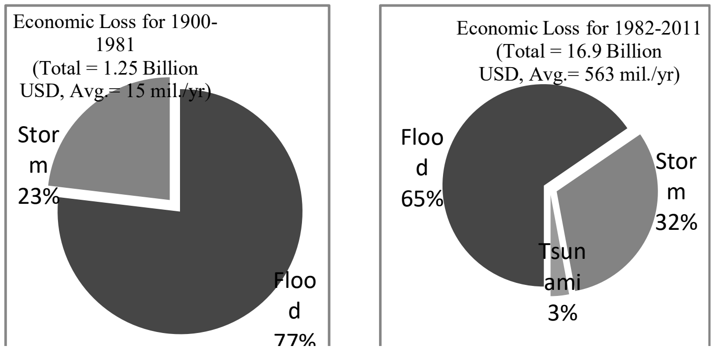


Figure 1: Comparison of affected people in different disasters between disaster year (a) 1900-1981 and (b) 1982-2011 (EM-DAT, 2011)

Considering the pattern of temporal variations, available disaster data from 1900 to 2011 was devided into two time spans: 1900-1981 (1st span) and 1982-2011 (2nd span). Their comparative nature is shown in Fig. 1. It is observed that the number and pattern of disasters in the two time spans are varied significantly. In earlier time span, the number of disaster was about 1 per year, and that number increased to about 6.7 in recent time span. In addition to that, new variety of disasters have been occured in recent past decades compared to that of before 1981. Although cyclone is the dominating disaster according to its number of yearly occurances with respect to others, its percent in 2nd span of time is reduced compared to 1st span of time. However, the percent of flood increased in recent years (1982-2011) compared to past decades. The yearly number of people killed by natural disasters is reduced by about 5 times in recent decades compared to 1st time span. That may be due to the improvement of management and communication facility of the country. In time span 1900-1981, the main cause of people killed was drought whereas killed due to cyclone and flood was very little compared to drought. But in the time span 1982-2011, the dominating disaster for people killed was storm (about 92%). Affected people per year was about 7 times higher in 1982-2011 than 1900-1981 span, and people mostly affected by flood in both spans, though the percentage is increasing day by day. Yearly affected people due to storm and drought is slightly decreasing during both cases.

The pie charts in Fig. 2 shows that in the recent time span 1982-2011, total economic loss was 16.9 billion USD where average economic loss was 563 million USD/yr which was 38% higher than the past decades, though the liable disasters for economic loss was almost same. As the number of disasters has been increased in recent decades, the affected people and economic loss have also increased. In this case also, the dominating disaster is mostly flood and next is storm. The summary of disaster parameters for two time spans is shown in Table 3. It revealed that the disaster numbers, number of affected people and economic loss are increased with time in an alarming rate.



(a) Disaster Year 1900-1981 (b) Disaster Year 1982-2011

Figure 2: Comparison of economic loss in disasters between year 1900-1981 and 1982-2011

Table 3: Summary of the comparison of disaster parameters

Disaster Parameters	1900-1981	1982-2011
Events/Year	0.91	6.7
No. of people killed/Year	29,600	6,000
Affected people/Year	1.5 Million	10.3 Million
Economic loss/year	15 Million USD	563 Million USD

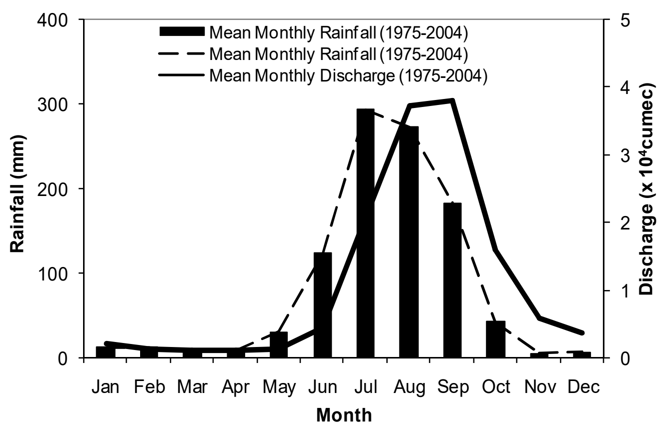


Figure 3: Ganges basin mean monthly rainfall and mean monthly discharge at Hardinge bridge point of Ganges river (Jian *et al*., 2009)

3.2 Contribution of Territorial Rainfall and River Discharge on Floods of Bangladesh

Bangladesh has a tropical climate, which is dominated primarily by monsoon and partly by pre-monsoon and post-monsoon circulations. The annual average precipitation is about 2,300 mm, varying from as little as 1,200 mm in the west to over 5,000 mm in the east. It acclaims four different seasons namely: pre-monsoon (March to May), monsoon (June to September), post-monsoon (October to November) and winter (December to February). Figure 3 shows that the seasonal variation of rainfall is very high. The scenario in the variation of river discharge is much more severe. The discharge curve is found to be lagged by months to the rainfall curve. Since the discharge in the river is highly influenced by the huge upstream flow outside the country, it is not expected to show a definite relationship between rainfall and river discharge pattern. But the figure that prepared averaging 20 years data, show similar pattern in curve between rainfall and discharge for Ganges Basin.

Figure 4 shows the comparison of monsoon rainfall anomaly with that of flooding area. The anomaly is defined as the percent deviation of a parameter from its yearly/seasonal mean value. It is observed that for more than 85% cases, the flood anomaly is in phase with that of territorial rainfall. Although it is expected that the huge upstream flow has a high impact on floods of Bangladesh, such scenario is observed only for 15% cases. In the Fig. 4, 1998 flood is observed to be such a case.

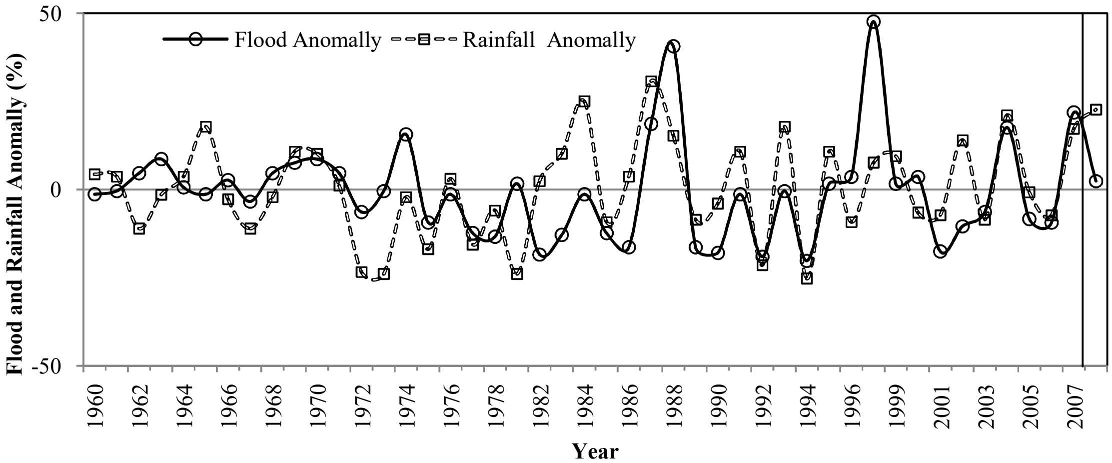


Figure 4: Corellation between Rainfall and Flood in the country

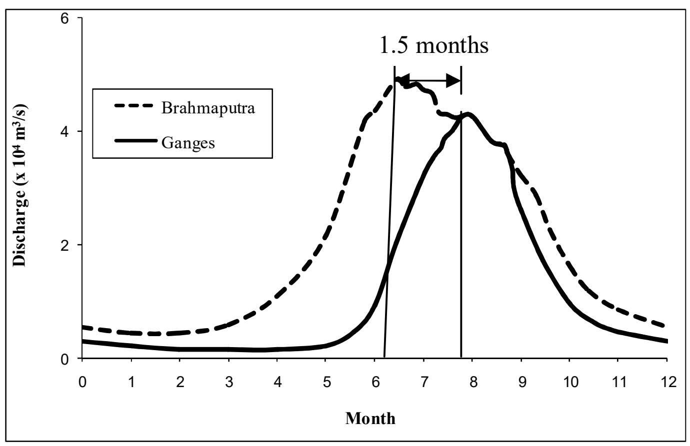


Figure 5: Time lag between Peak Discharges in Ganges and Brahmaputra River Hydrograph

Figure 5 compares the mean monthly discharge at Hardinge Bridge Point of Ganges river and that of Bahadurabad point of Brahmaputra river. It shows that it has very high discharge in monsoon, mainly July to September. It is important to mention that the annual cycles of discharge in Brahmaputra river indicates significant phase differences with Ganges. The Brahmaputra flow increases rapidly in late spring and peak at mid of July, ahead of the Ganges by about two months, probably for two reasons: firstly, due to extreme human activity in Ganges basin, plus the different basin time-scales; Second, rains generally occur in Assam (to the northeast of Bangladesh) some weeks earlier than over the Ganges catchment (Lawrence and Webster, 2002). The phase difference in the rising limb of their hydrograph is 1.5 months. Probably, this is the reason for which most of the annual flood hydrographs show double peaks: in July and end of Aug. If the Brahmaputra does not discharge out its peak flow rapidly, its peak will coincide with the peak of Ganges and it will cause an extreme high flood.

3.3 Visible Impact of Climate Change on Floods

3.3.1 Increase of Brahmaputra River Discharge

Figure 6 shows the temporal variation of mean seasonal discharge at Bahadurabad point of Brahmaputra river for wet (June to October) and dry seasons (November to May) seperately. It is found that in both the seasons, the discharge is increasing with time. In wet season, the yearly increasing rate of Brahmaputra river discharge is about 54 cumec and that of dry season is about 114 cumec. The discharge has been increased about 7.5% in last 50 years (1956~2006). The fluctuation in the variation of monsoon discharge is also increased. The variation of averaged monthly discharge for two averaging time spans 1956-1980 and 1981-2005 is compared in Fig. 7. The averaged monthly Brahmaputra discharge in Bangladesh in recent time span (1981-2005) is found to be increased by about 8% compared to ancient span (1956-1980).

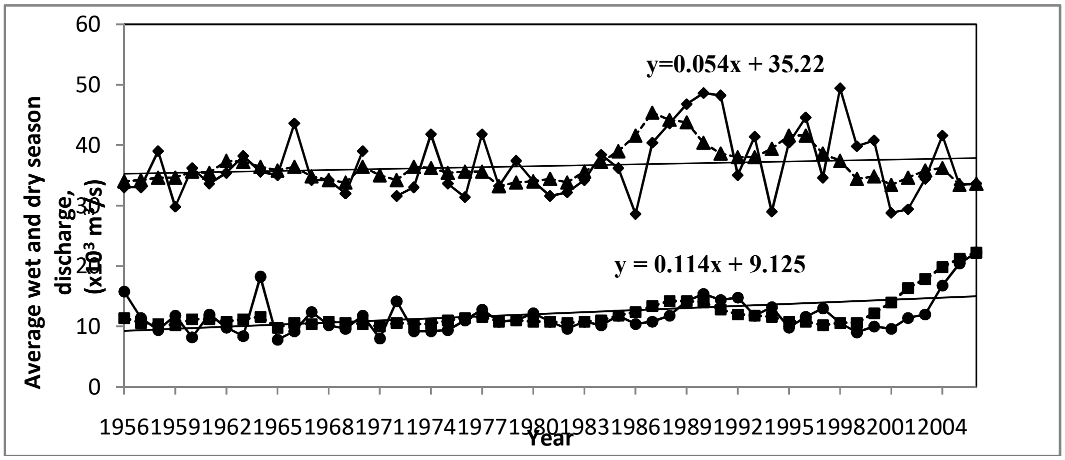


Figure 6: Temporal change of discharge in Brahmaputra River for wet and dry seasons

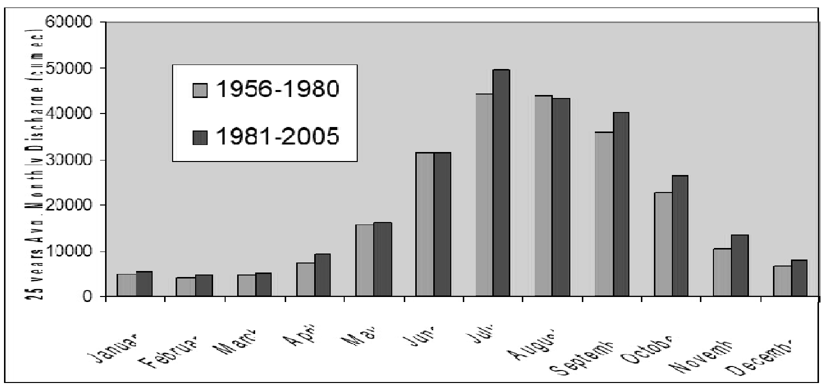


Figure 7: Monthly variation of Brahmaputra River Discharge in two time span

3.3.2 Change in the trend of historical floods and rainfalls in Bangladesh

The historical time series of floods in Bangladesh shows that the top 5 floods in terms of inundated area are occurred in last 20 years in 55 years of history (Fig. 8). 1998 Flood is the most devastating flood, inundation was close to 67% that displaced more than 30 million people with 20 million homeless; estimated damage was 2.8 billion USD. On the other hand, the second ranked flood was in1988, where 61% of the area was inundated; estimated damage was 1.2 billion USD. Although the inundation area in 1998 flood is about 6% higher than 1988, the estimated damage is 2.33 times higher. The cause behind this is explained under next subheadings in detail.

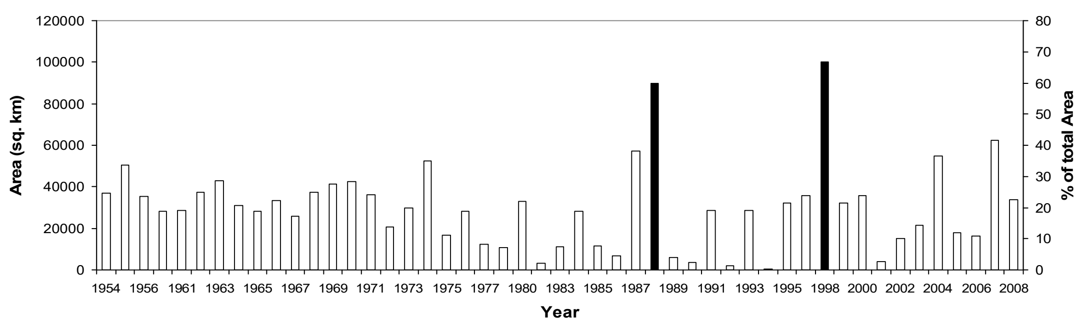


Figure 8: Time series of historical floods in Bangladesh with inundation area

Inundation to the extent of 20% area of the country is beneficial for crops and ecological balance (Annual Flood Report, 2008). But the flood more than 20% cause direct and indirect damages and considerable inconveniences to the people. From Fig. 8, it is also evident that the extreme flood events in terms of inundation area are also increased in recent years. During 1954~1972, the yearly flooding area was quite uniform, after that year to year fluctuation in flooding area is very high. It is observed that the number of moderate floods are decreased highly and they are converted to either extreme high floods or the extreme low floods. Evidence of such extreme events and rapid change of flood intensity indicates the effect of climate change.

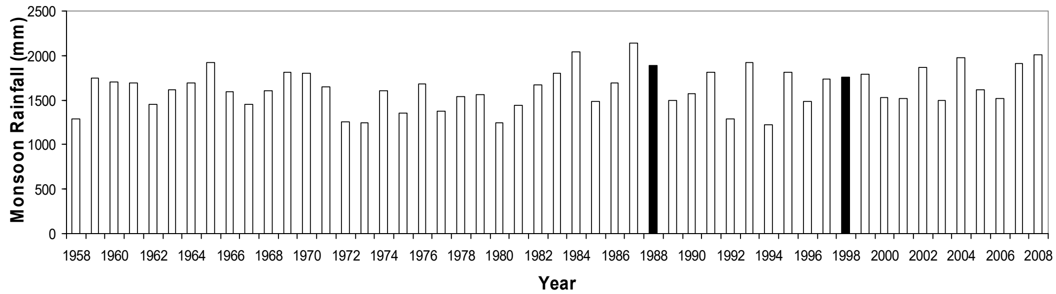


Figure 9: Time series of Monsoon rainfall in Bangladesh

Figure 9 shows the time series of monsoon rainfall over Bangladesh for a period of 1958 to 2008. If we draw a trend line for these 50 years of rainfall data, it can be found that the monsoon rainfall increases very gently as 2.65 mm/year. Many researchers explain it as the probable impact of climate change, which is also match with the prediction of 4th IPCC report (IPCC, 2007). From the figure it is also observed that the rainfall over Bangladesh in 1998 is about 6% lower than that of 1988, although in 1998 the flooding area was 6% higher than 1988. Reasonably, the rainfall at upstream also plays a role in inundating the country.

3.3.3 Impact of climate change on the return period and frequency of floods

To analyze the temporal change of return period and probability of floods, the floods were classified into three catagories: low, moderate and high flood events. Actually this classification is simplar than that of reported by Miah (1988). This simple classification is used to avoid the complexity in understanding the climate change impacts on temporal variation of flood frequency. In this study the moderate flood events were defined as the mean flooding area of a period ± 5%. Considering time series of flooding area from 1954 to 2008, the moderate flood events were found as 19% to 29% area flooding of the country. Therefore, the low flood means <19% and high flood means >29% area flooding events. To show the temporal change, the data set was divided into two equal time spans: 1954-1981 and 1982-2008. The return period and probability of occurance were calculated for this two sets of data and presented Fig. 10. It is observed that, in high flood events (Inundation > 29% area), the return period decreased and the probability increased by about 3 times in recent decades. In low flood events (Inundation <19% area), the return period decreased in recent decades and the probability increased by about 1.4 times. In Moderate Flood events (Inundation =19 - 29% area), the return period increased and the probability is reduced to about half (1/2).

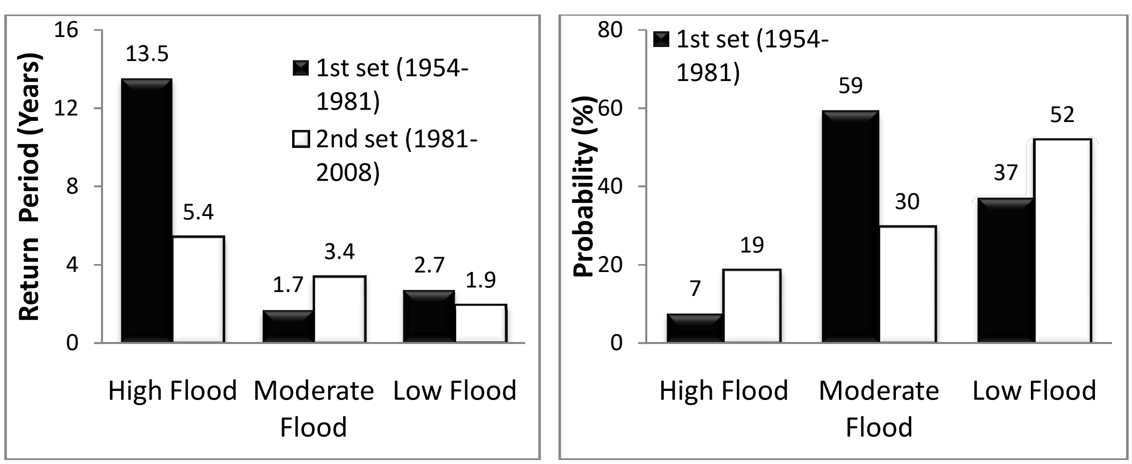


Figure 10: Temporal change in return period and probability of flood in Bangladesh

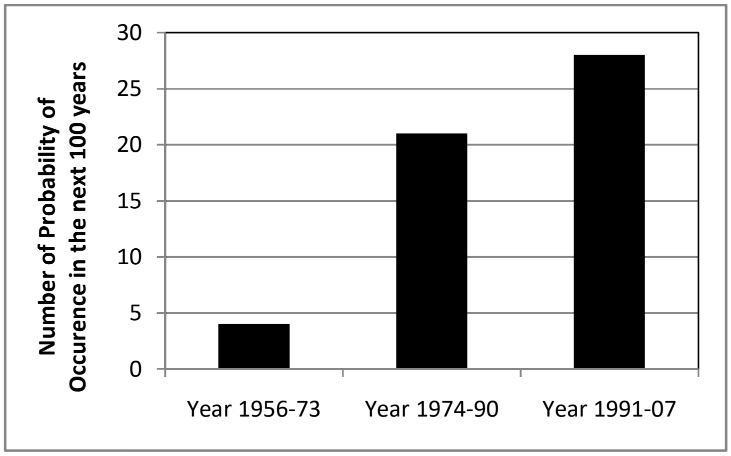


Figure 11: Increase in number of occurrence of characteristic flood over the historical years at Bahadurabad Point of Brahmaputra River

Considering a particular example of flood at Bahadurabad point of Brahmaputra river with discharge of 76,137 m^3/s, for a duration of 1956 to 2007, it is found that the probability of occurrence of the characteristic flood is increased from 4% to 28% over the last 52 years (1956~2007). Figure 11 shows the increase of number of occurrence of the characteristic flood over the three equal durations.

3.4 Impact of Climate Change on the Intensity of Flood

3.4.1 Conceptual Model to Explain the Climate Change Impact on Flood

We know the main causes of flood in Bangladesh are excessive precipitation, low topography and flat slope of the country. Among others, the frequent development of low pressure areas and storm surges in the Bay of Bengal can impede drainage, and the severity of flooding is greatest when the peak floods of the major rivers coincide with these effects.

Mohal *et al.* (2006) predicted that, by the year 2100, the temperature will be increased about 2.4^0C, the monsoon precipitation will be increased about 11.8% and the SLR will be 30cm ~ 1 m (9 cm ~ 88 cm by IPCC, 2007). They also predicted that, for 2^0C temperature rise and 10% increase in precipitation, the discharge in Ganges river will be increased about 19%, that of Brahmaputra will be increased about 13%, and about 11% discharge will be increased in Meghna river. That means, on an average, 10 to 20% discharge will be increased in all the three mighty rivers in Bangladesh by the year 2100 with a significant amount of SLR.

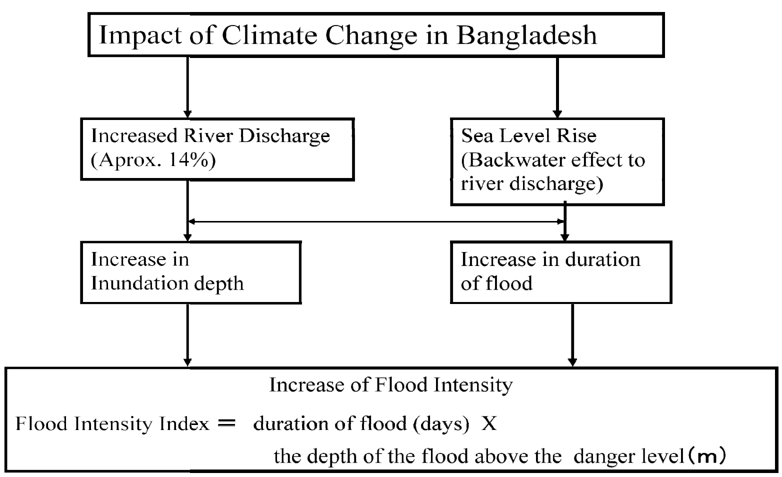


Figure 12: Impact of climate change over flood

To explain the long term effect of climate change on flooding scenario of Bangladesh, an index named *Flood Intensity Index* is introduced here to characterize the intensity of flood. Flood Intensity Index is defined as the product of the depth of flood above the danger level (m) and the duration of flood (days). A conceptual model to explain the impact of climate change on the flooding scenario of Bangladesh is presented in Fig. 12. It shows that due to increase of river discharge, the inundation depth will be increased; on the other hand, due to Sea Level Rise there will be drainage congestion to drain out the river water to the sea due to back water effect of higher elevated sea level. This will cause the slow down of rate of discharging river water to the Sea, which will actually influence to prolong the duration of flood. Since both the parameters of flood intensity index will be increased by the impact of climate change, the intensity of flood will also be increased significantly. An example of calculating Flood Intensity Index is given below.

3.4.2 Calculation of Flood Intensity Index

In this section, the flood intensity index is calculated for 1998 and 1988 floods and compared with a normal flooding year 2008. The water level above the danger level during flood is termed here as inundation depth. Figure 13 shows the comparison of inundation depths in 1998 and 1988 floods with normal flooding year 2008 for some locations in Brahmaputra basin. Figure 15 shows the same for some locations in Ganges basin. In a same flood, the depth of inundation shows different trend in different Basins. Comparing the trend of inundation depth between 1988 and 1998 flood in Ganges basin for some locations, it is found that the average flooding depth in 1998 flood is little bit higher than 1988 flood. On the other hand, in most of the locations of Brahmaputra basin, the inundation depth of 1998 flood is less than 1988 flood. On an average, it can be concluded that, the flooding depth between 1988 and 1998 flood did not differ much.

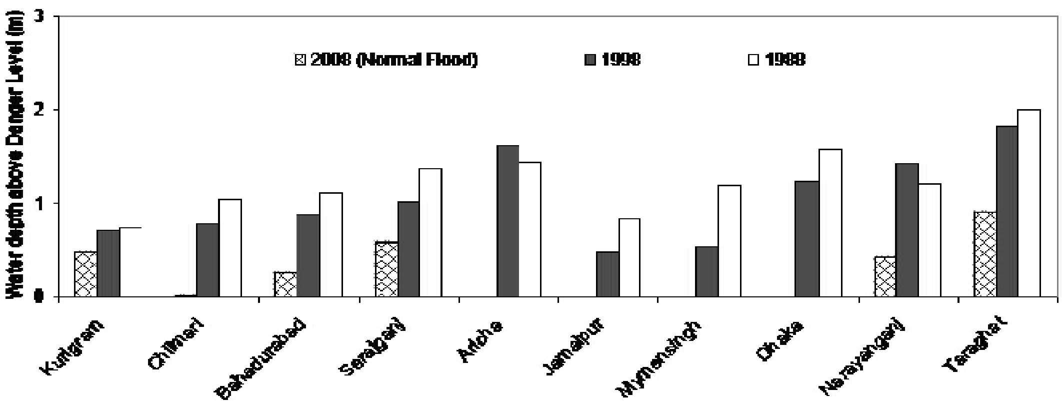


Figure 13: Comparison of inundation depth in 1998 and 1988 floods with normal flooding year 2008 for some locations in Brahmaputra basin

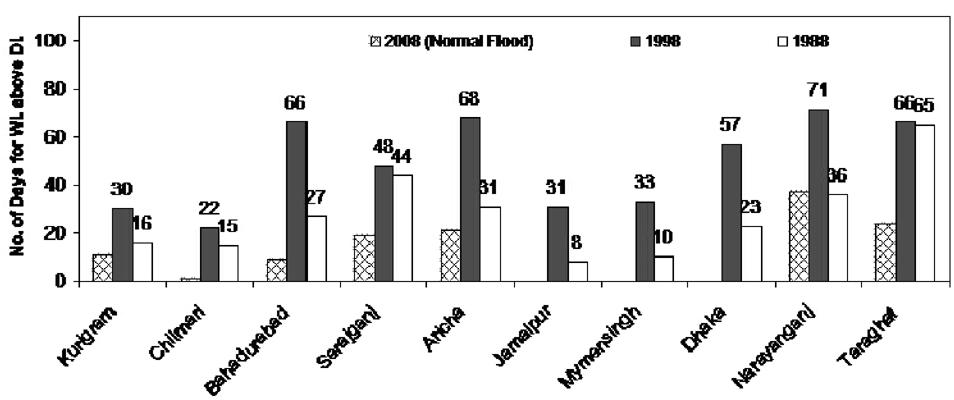


Figure 14: Comparison of durations of inundation in 1998 and 1988 floods with normal flood year 2008 for some locations in Brahmaputra basin

Figures 14 and 16 show the comparison of durations of inundation in 1998 and 1988 floods for several locations in Brahmaputra basin and Ganges basin, respectively. From the figures it is found that the durations of flood at most of the locations in both Brahmaputra and Ganges rivers are much higher in 1998 than 1988 flood. The durations of flood in 1998 were 3.88 times higher in Jamalpur (Old Brahmaputra), 3.3 times higher in Mymensingh (Old Brahmaputra), 2.5 times higher in Dhaka (Buriganga), 2.4 times higher in Bahadurabad (Brahmaputra) and 1.7 times higher in Goalanda (Ganges) than that of 1988 flood. If we compare Figs. 13 and 14, most of the places the inundation depth in 1998 is seen less than 1988 but the duration of flood in 1998 is found much higher than 1988. Therefore it can be concluded that, although the depth of inundation among two floods does not differ too much, the duration of flood in 1998 was much (up to 4 times) higher than 1988 flood.

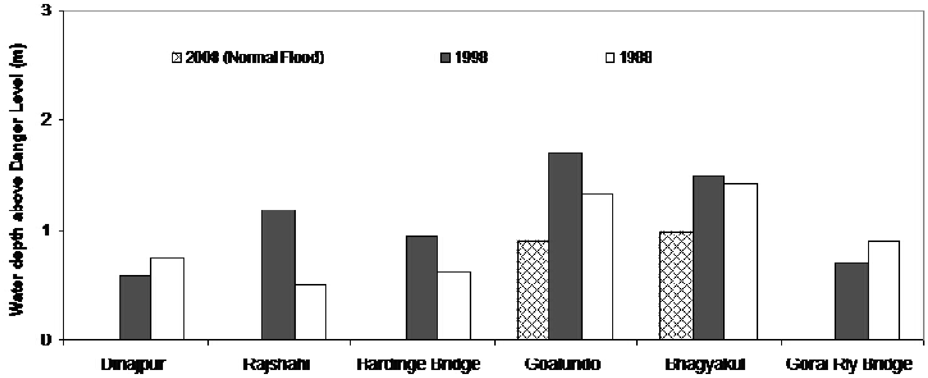


Figure 15: Comparison of inundation depth in 1998 and 1988 floods with normal flooding year 2008 for some locations in Ganges basin

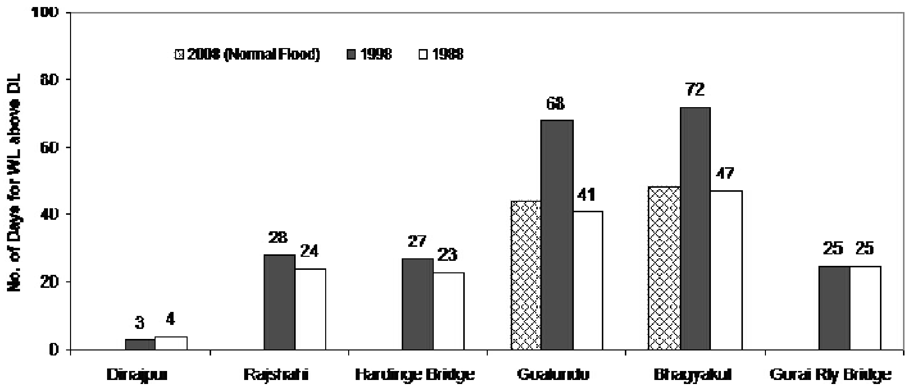


Figure 16: Comparison of durations of inundation in 1998 and 1988 floods with normal flooding year 2008 for some locations in Ganges basin.

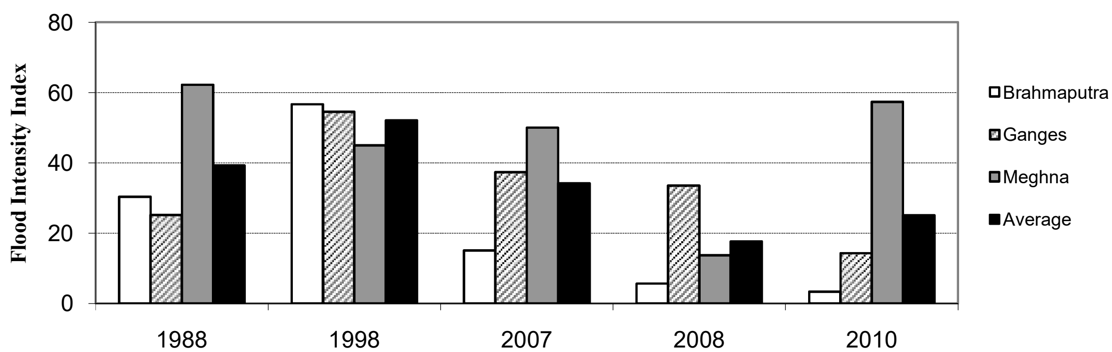


Figure 17: Comparison of Flood Intensity Index of 1998 and 1988 floods with normal flooding years for Ganges, Brahmaputra and Meghna basin.

Figure 17 shows the calculated Flood Intensity Index for different basins and their averages for years 1988, 1998, 2007, 2008 and 2010. It shows that although the depth of inundation among 1988 and 1998 floods does not differ too much, the Flood Intensity Index in 1998 was much higher than 1988 flood, that is due to the prolong duration of flood in 1998 than 1988 flood. In 1998, the peak discharges of Ganges, Brahmaputra and Meghna were high and they were almost same, so the flood duration was prolonged. But in 1988 flood, peak discharge of Meghna was much higher than the Brahmaputra and Ganges Rivers and so the overall Flood Intensity Index was lower than 1998 flood. The figure also reveals information that the 2007 flood was third largest flood accrding to Flood Intensity Index. The figure also shows that although the 1998 flood is dominated by the floods in all rivers, the floods in 1988, 2007 and 2010 are dominated by the floods in Meghna basin. On the other hand, 2008 flood is dominated by the floods in Ganges basin.

4. CONCLUSIONS

Although the paper is mainly concentrated on temporal variation of floods in Bangladesh, the temporal changes of pattern of other disasters in Bangladesh are also discussed and compared with flood based on their occurrence rate, number of people killed, exposure to human and economic loss. Based on the analysis, following conclusions are made:

- Comparing the disaster parameters for two time spans, it is found that the disaster numbers, number of affected people and economic loss increases with time in an alarming rate. It is observed that the flood is the mostly devastating disaster in Bangladesh compared to other disasters as it ranked 1st in the world for the case of population exposed and 3rd in the case of economic exposure.
- Since the discharge in the river is highly influenced by the huge upstream flow outside the country, it is not expected to show a definite relationship between rainfall and river discharge pattern. But the 30 years average discharge curve of Ganges river is found to be similar pattern of rainfall (in Ganges Basin within Bangladesh) lagged by a months. Comparing 50 years data of rainfall anomaly with flood, it is observed that for more than 85% cases, the flood anomaly of Bangladesh is in phase with that of territorial rainfall anomaly.
- In wet season (June to October) the yearly increasing rate of Brahmaputra river discharge is about 54 cumec and that of dry season (November to May) is about 114 cumec. The Brahmaputra discharge at Bahaduarabad point has been increased about 7.5% in last 50 years.
- The historical time series of floods in Bangladesh shows that the top 5 floods in terms of inundation area are occurred in last 20 years in 60 years of history. It is observed that the number of moderate floods are decreased highly and they are converted to either extreme high floods or the extreme low floods. From the trend line for 50 years of rainfall data, it is found that the monsoon rainfall increases very gently as 2.65 mm/year. These changing phenomena in rainfall and flooding scenario in Bangladesh can be explain as the probable impact of climate change.
- The term 'Flood Intensity Index (FII)' is introduced to characterize the flood, which is considered as a function of inundation depth and duration. Flood Intensity Index is calculated for two mega floods of 1988 and 1998. It is observed that although the average depth of inundation among two mega floods does not differ too much, the Flood Intensity Index in 1998 was much higher (about double) than 1988 flood, and that is why the economic loss in 1998 flood was much higher (about 2.33 times) than that of 1988 flood.

Previous data and various future predictions showed that both the parameters in Food Intensity Index are in increasing trend due to climate change impact. The climate change induced increment in river discharge during monsoon will increase the inundation depth, and the increasing trend of Sea Level Rise will increase the duration of flood due to back water effect of sea. Therefore, the Flood Intensity Index will significantly be increased due to climate change. Since, the 'Flood Intensity Index (FII)' is a measurable index to characterize a flood accounting all the impacts of climate change, this index can be used in expressing the change in flooding scenario due to climate change.

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