INDIVIDUAL ASSIGNMENT

Siarjganj Case Study

Fengbo Zhang
Locker: 333
Program: HWR
Student number: 1068520
Email: fzh001@un-ihe.org

Contents

List of Figure

List of Table

1. CURRENT SITUATION

Analyse the risk from flooding in Sirajganj and answer the following:

(a) (20 points) Briefly summarise the current risk from flooding. Provide a description, use numbers from this report or similar documents. Present the hazard and vulnerability separately. Prepare indicative hazard maps corresponding to different levels (danger level, warning level, max flood level).

Answer:

1. Study area

Bangladesh is surrounded by India, which is the largest active delta in a world with an area of 14750 km2. The study area, Sirajganj, is a district in the centre of Bangladesh under sub-tropical monsoon climate with mean annual precipitation of around 1600 mm, as shown in fig.1. Meanwhile, the most part of Sirajganj district is located in the right bank of Brahmaputra River with an area of about 2,497.92 km2, and it is very flat which have a high possibility for occurring the flood inundation. Thus, the flood risk analysis in this area is necessary.

Moreover, this famous city in Bangladesh has colleges, school and hospitals, with a population of around 390000. Also, there is a medium industries park (fig.2) and huge irrigated area with 2 to 3 crops per year, which need to be prevented from flood inundation for the reduction of economic damage. The most common crops are Aman rice (during the wet period, June to October/November), and Boro rice (dry period, December - May).

Importantly, some areas sited in the middle of the Brahmaputra River are extremely vulnerable to flooding, called chars. There are temporary chars and permanent chars, which both inhabited a huge number of people. The more vulnerability of the chars to flooding is a temporary one. And the high risk of losing life from flooding are in this area because illegal habitants are afraid of losing land and unwilling to move out. Thus, it is significant to flood forecast and evacuation in time in temporary chars.

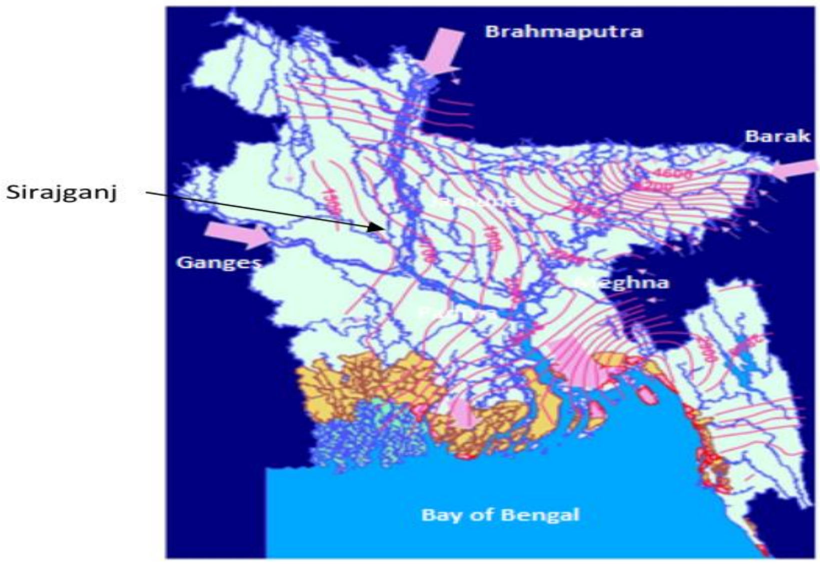

Figure 1 Boundary of Bangladesh and the location of Sirajganj (black arrow) with rainfall contour (Source: Assignment Handout)

2. Flooding characteristics

Sirajganj area is affected by monsoon river flood almost every year, and figure 3 present the extent of flooding corresponding to different return periods. Moreover, the occurrence of flood events usually caused by the high water level in the Brahmaputra River from July to October. Thus, there is long flood embankment along the right bank of the Brahmaputra for protecting the part of the Sirajganj district, as shown in fig.2. However, the left bank and chars are not protected. The area protected by embankment is largely not affected by the flood, except in 2007 when there is a breach of embankment caused flood damage to the entire district.

For assessing the hazard of a flood, the Bangladesh Water Development (BWDB) provide a water level gauge on Brahmaputra River by the collection of water level and rainfall data at Sirajganj and several other locations in Bangladesh. Significantly, the gauge represents the possibility of flood in Siraiganj, as shown in table 1. The water department should make increase vigilance when the water level is higher than 12.85 m above PWD, called "Warning Level". If the peak water level is higher than 13.35m above Public Works Datum (PWD), the district is considered to be flooded. This level is designated as the "Danger Level" for Sirajganj. There are "Severe flood" occurring when the water level is above 14.35m above PWD. The highest recorded water level at Sirajganj is 15.12m above PWD, and it occurs on 30 Aug 1988.

Table 1 Recorded water level at Sirajganj

Event	WL m above PWD	Remarks
Recorded highest water level	15.12	Recorded highest WL at Sirajganj on 30.8.1988
Severe flood	14.35	Severe flooding above this level
Danger level	13.35	No flooding below this level
Warning level	12.85	WL within 50 cm less than danger level (12.85 to 13.34 m)

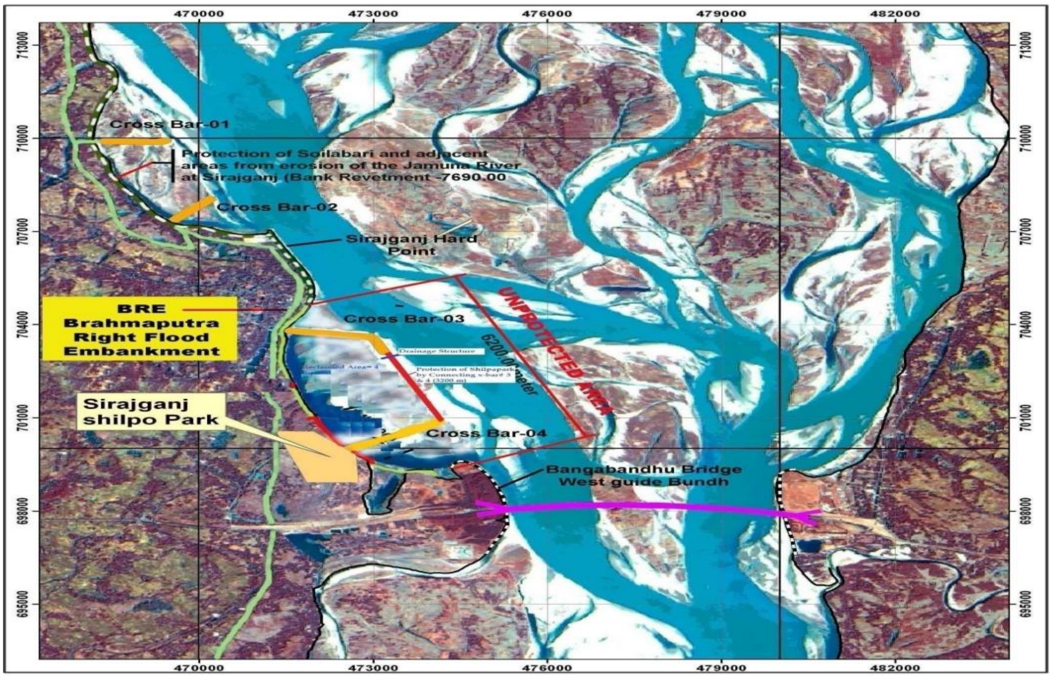

Figure 2 Embankments (line) for flood defence and industries park (yellow polygon) (source:(Presentation))

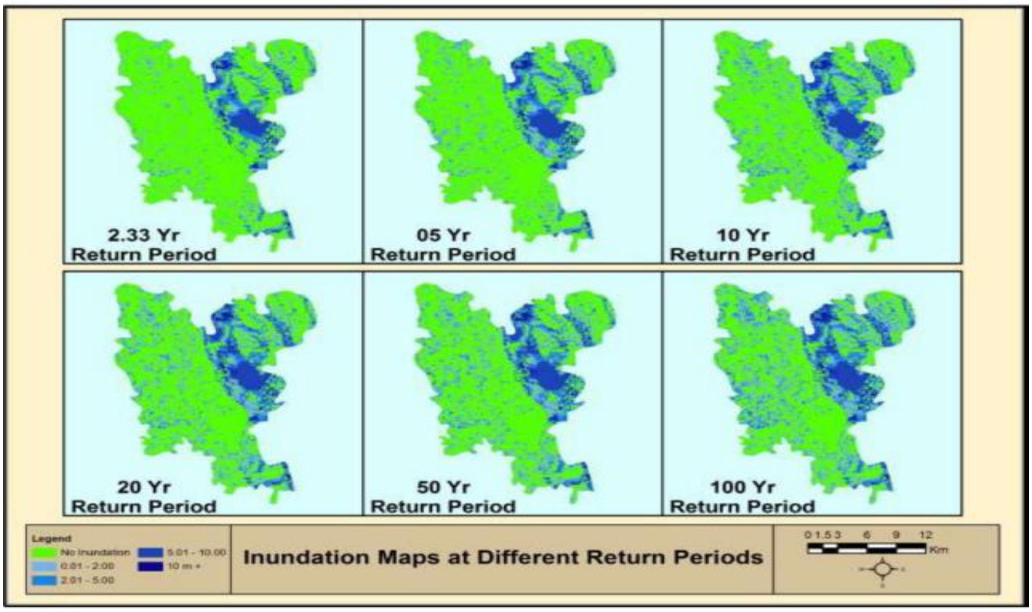

Figure 3 Inundation map of Sirajganj corresponding to different return periods (from Assignment Handout)

3. Flood Risk map and flood area

The flood risk map using Digital Elevation Model (DEM) data from STRM 1 was drawn for the visualisation of the flood risk area with the different water level at Sirajganj, as shown in figure 4. The drawback of this map is that the influence of the flood embankment and other human activities for flood defence were not considered. Note that the mean sea level is 0.46m higher than PWD, and we need to pre-process the water level to transform the unit.

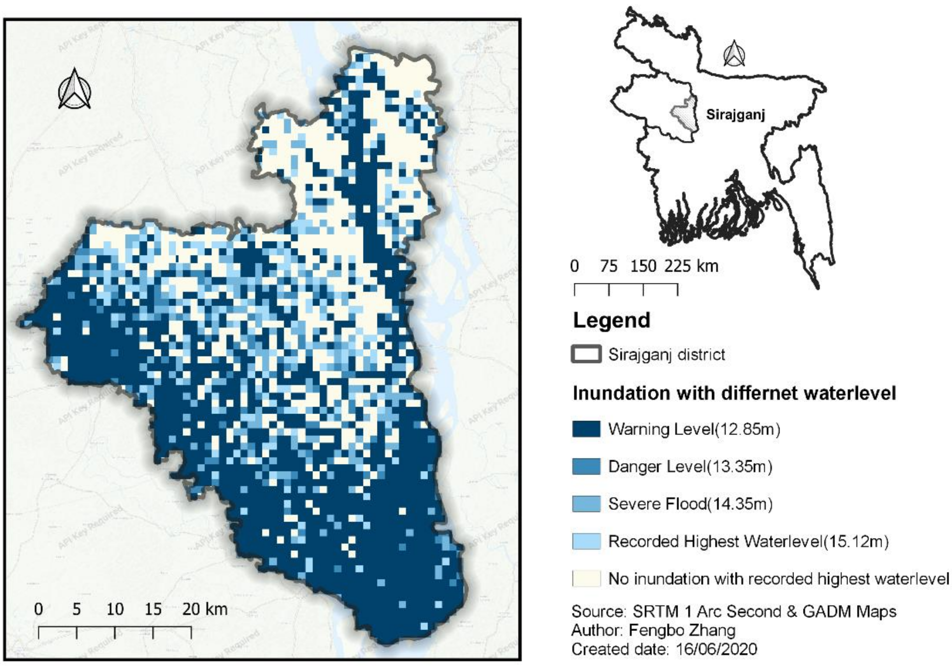

Figure 4 Flood risk map for Sriajganj

Figure 4 presents a flood risk map for Sriajganj based on DEM data from STRM 1. It is very clear that the Brahmaputra River is shown in dark-blue squares in the northeast of the map and the elevations are lower than warning level of 12.85 m. Moreover, the south and east areas in the map along the boundary is very flat and low elevation (lower than warning level), which have a high risk of flood inundation. The probability of the occurrence of flood risk from southwest to northeast decrease. Notably, the area in the northeast of the map is no inundation with recorded highest water level (white colour). The inundation area in different water is shown in table 2. It shows that the most area of 1035 km2 is easy to be inundated and the largest inundation area suffered from the worst flood recorded is 1815 km2. However, this risk map is estimated by DEM, which ignores the effect of mitigating measure for defencing the flood. Therefore, the reliability of this flooded map and flooded area is very low.

Table 2 Inundation area in different water level

Extent	Area(km2)	Water level	inundation Area(km2)
<12.85m	1035	Warning Level(12.85m)	1035
12.85m - 13.35m	280	Danger Level(13.35m)	1316
13.35m - 14.35m	268	Severe Flood(14.35m)	1583
14.35m - 15.12m	232	Recorded Highest Waterlevel(15.12m)	1815
>15.12m	676	No inundation with recorded highest Waterlevel	676

(b) (3 points, indicative max ½ page) Consult Google map to locate the place Bahadurabad on Jamuna River, Hardinge Bridge on Ganges River, Bhairab Bazar on upper Meghna River and Chandpur at the confluence of the three river systems. You may also refer to fig. 1 on pp-viii of the Annual Report 2014 of FFWC. Qualitatively describe whether an unfavourable synchronisation of flood peaks at the three rivers may increase the duration of flooding and enhance the flood risk in Sirajganj or not. Consult Fig. 1.7 above to inspect the variation of water level at the above-mentioned three locations. Note that major flooding was experienced in 1988 and 1998 whereas flooding in 2007 was not a major one (only Sirajgung was flooded due to high water level in Jamuna). Note that the water level at Sirajgunj varies similarly to that of Bahadurabad (with a lag of about 3 hours). Optional: you may also consult Fig 6 and Table 1 of Islam *et al*. (2010).

Answers:

Figure 5 Location of Bahadurabad, Hardinge Bridge, Bhairab Bazar and Chandpur, including Bangladesh Boundary (bold yellow line), Coastline (light yellow line) and Waterbody (blue line).

The locations of Bahadurabad on Jamuna River, Hardinge Bridge on Ganges River, Bhairab Bazar on upper Meghna River and Chandpur at the confluence of the three river systems are shown in figure 5.

Figure 6 shows the water level at Bahadurabad(red line), Harding Bridge(pink line) and Bhairab Bazar(green line) in 1988(a), 1998(b) and 2007(c). In 1988 and 1998, the water levels in all rivers overtook the danger level and reached to the recording highest water level, whereas water level in Ganges River recorded at Hardinge Bridge did not exceed danger level in 2007. Because the flooding in 2007 was not a major one and only Sirajgung was flooded due to high water level in Jamuna River. The duration of the flood inundation that the water levels of all three rivers are higher than the danger level in 1998 is the longest, compared with the other two years. Meanwhile, the water levels at Bahadurabad from 20 Jul to 18 Sep 1988, which were affected by the synchronisation of flood peaks at the three rivers, still remain the high-risk values closed to danger level, whereas the during of flooding was short in 2007.

The percentage of flooding area in Bangladesh from 1954 to 2014 is shown in Figure 7, indicating that the ratios of inundation area in 1988 and 1998 are much larger than that in 2007, with 61%, 68% and 42% respectively.

Moreover, the water level at Sirajgunj varies similarly to that of Bahadurabad due to located in the same river with a lag of about three hours. Thus, apparently, the unfavourable synchronisation of flood peaks at the three rivers may increase the duration of flooding and enhance the flood risk in Sirajganj.

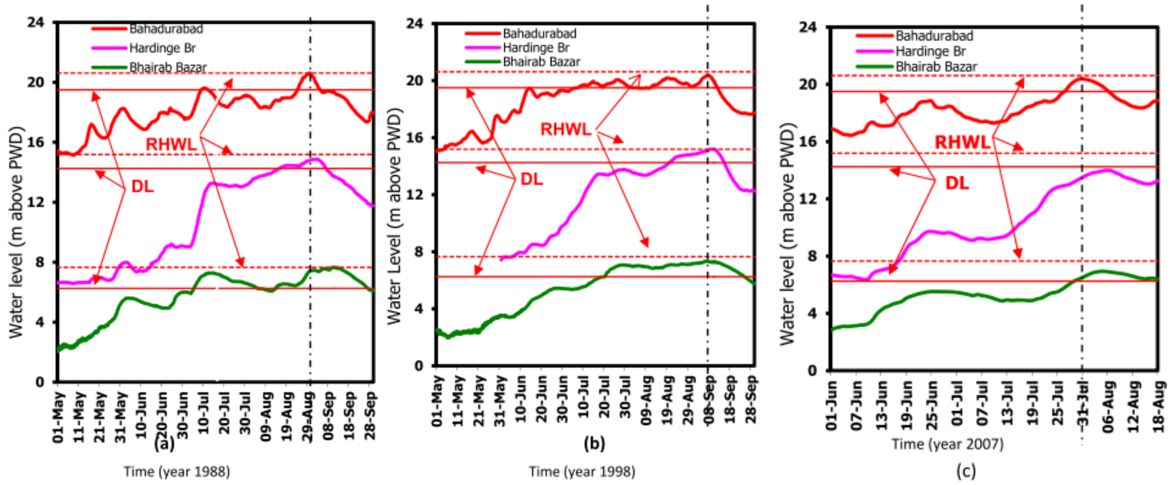

Figure 6 Water level at Bahadurabad(red line), Harding Bridge(pink line) and Bhairab Bazar(green line) in 1988(a), 1998(b) and 2007(c).RHWL stands for recorded highest water level and DL stands for Danger Level.(source: from Handout)

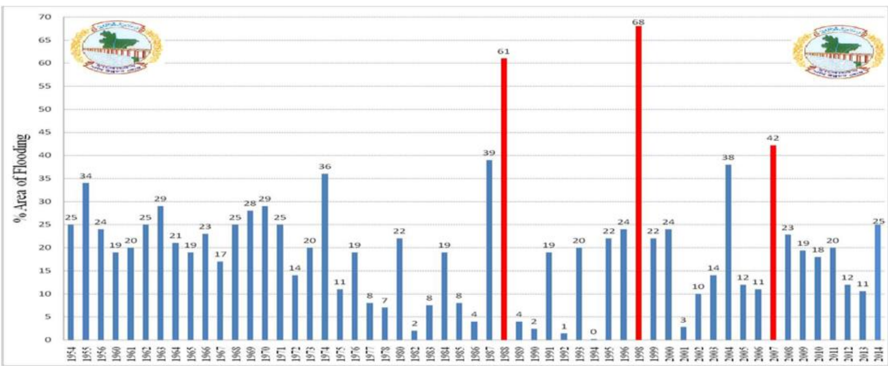

Figure 7 %Area of flooding in Bangladesh (source: from slides in class)

(c) (2 points, indicative max ½ page) At Chandpur the river is tidal. Qualitatively describe whether an unfavourable tidal phase may increase the duration of flooding and enhance flood risk in Sirajganj or not.

Answers:

The Location of Chandpur at the confluence of the three river systems, combining with a coastline (light yellow) is shown in figure 5. And the location of Sirajganj in the figure is quite close to the coastline, and it may influence in the tide, which is an astronomical phenomenon that is caused by the gravitational attraction of the moon and the sun on the earth(*Karim and Mimura*, 2008). Moreover, the place of Chandpur is sited at the interior coast, as shown in fig.8, where it is not easy effected by a tidal. Thus, the flood risk may increase in Sirajganj, if the river at Chandpur is tidal when the huge tidal impact on the coast in the south of Bangladesh.

One important evidence is that a severe flood event occurred at Sirajganj in 1998(fig 6), and a spring tide in conjunction with a solar eclipse on 11 Sep 1998 considerably delayed the recession of floodwater(*Mirza*, 2003). Therefore, an unfavourable tidal phase may increase the duration of flooding and enhance flood risk in Sirajganj.

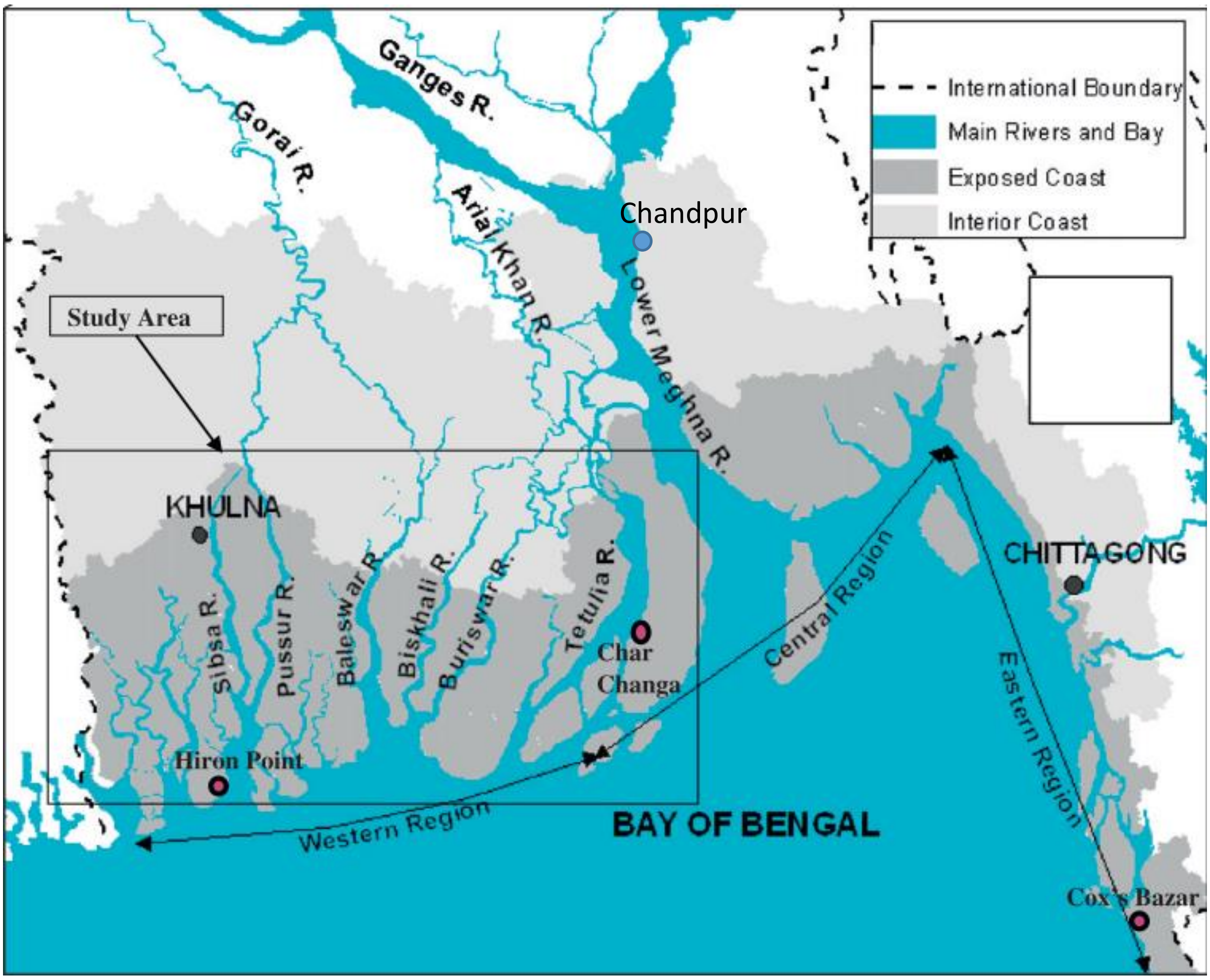

Figure 8 The coastal regions of Bangladesh and major rivers in the western coastal zone(Karim and Mimura, 2008).

(d) (10 points) Consider the Annual Flood Report 2014 (Chapter 4) of Flood Forecasting & Warning Centre (of Bangladesh Water Development Board). Analyse the accuracy of the forecast at Sirajganj along with the increasing forecast lead time.

Answers:

1. General information

The Flood Forecasting and Warning Centre (FFWC) of Bangladesh provides flood warnings with five days lead time (24, 48, 72, 96 and 120 hours). Forecast about flood water level is provided at the designated gauge locations, and one of them is near the city of Sirajganj, called Serajanj station, as shown in fig.9.

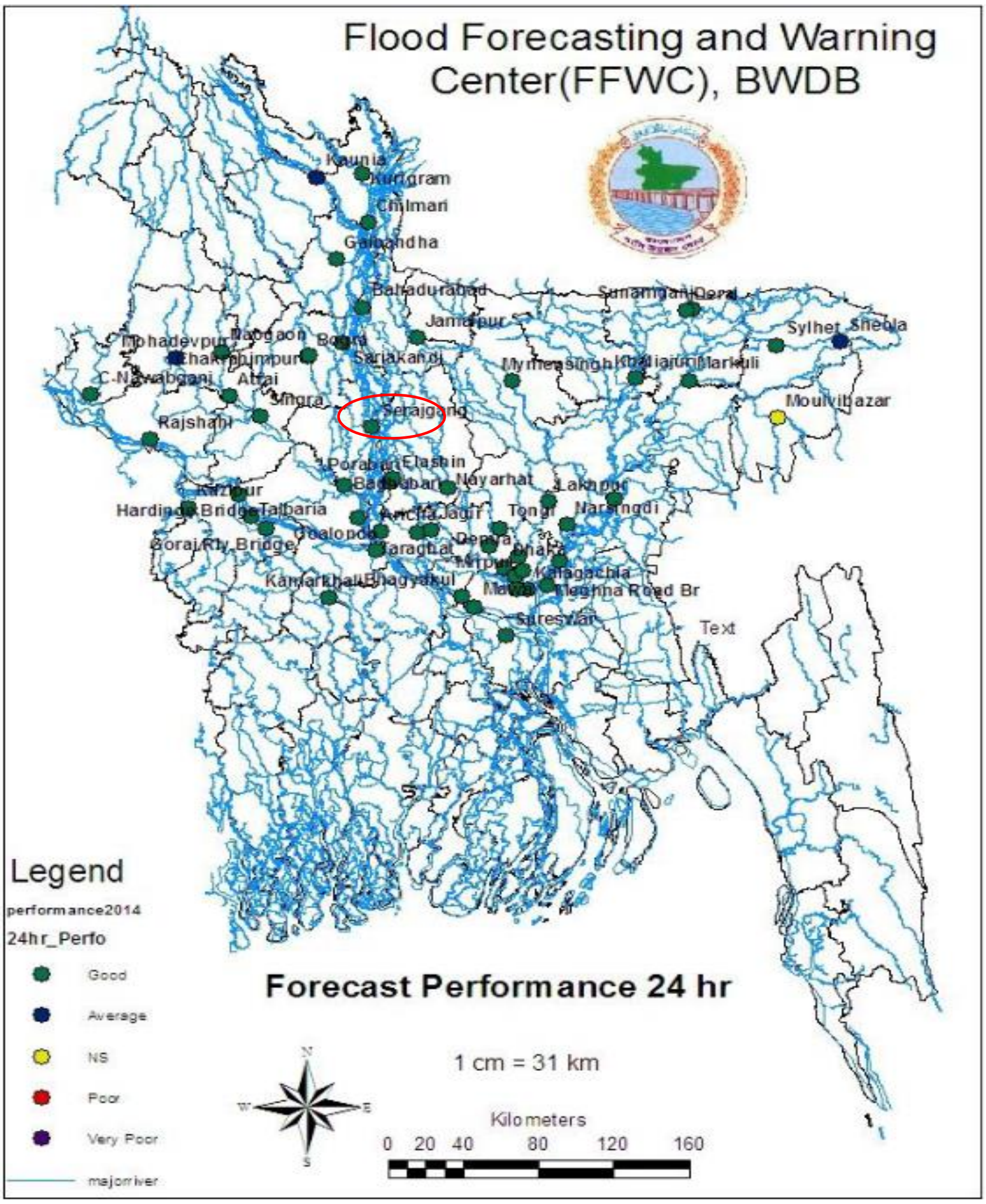

Figure 9 Forecasr Performance 24hr and location of Serajganj station(red circle)

The forecast model is NAM-Mike11 model and covers the areas in whole of Bangladesh. Moreover, the boundary conditions at the border of Bangladesh are generated by Mike Basin model. And FFWC generates a forecast at a river location. Meanwhile, probabilistic forecasts up to 10days are available at Serajganj station.

2. Criteria of forecast performance

The forecast performance is evaluated from the statistical components r^2 (Co-efficient of Determination) and MAE (Mean Absolute Error). Values of the above two components in their ideal case are generally assumed to be in the order of MAE = 0, r^2 = 1. Utilising above two indicators, five category scales have been used to describe forecast performance, as shown in table 3.

Table 3 Criteria for forecast performance(FFWC, 2015)

Sl. No.	Scale	Value
1	*Good*	$MAE <= 0.15$ meter & $r^2 >= 0.9$
2	*Average*	$MAE <= 0.2$ meter & >0.15 meter and $r^2 >= 0.7$ & <0.9
3	*Not satisfactory*	$MAE <= 0.3$ meter & >0.2 meter and $r^2 >= 0.4$ & <0.7
4	*Poor*	$MAE <= 0.4$ meter& >0.3 meter and $r^2 >= 0.3$ & <0.4
5	*Very Poor*	$MAE > 0.4$ meter or $r^2 < 0.3$

3. Forecast performance in Bangladesh, 2014

The annual flood report 2014 from FFWC presents the flood forecast at 54 stations/points within the model area are evaluated, as shown in figure 10 and table 4. Apparently, with the lead time increasing, the number of stations which has the 'Good' forecast performance decrease, and it can be observed that for the 1-day forecast, 50 out of the 54 stations (92.59%) achieved a "Good" rating. Therefore, generally, the accuracy of the flood forecast in Bangladesh reduce with the increase of lead time.

Table 4 Summary of forecast performance at 54 stations up to 5-days forecast for 2014 flood(FFWC, 2015)

Forecast Lead time	Number of stations/points (% of 54 – total points)				
	Good	Average	NS	Poor	Very Poor
Day-1 Forecast (24 hrs)	50(92.59%)	3 (5.56%)	1(1.85%)	0	0
Day-2 Forecast(48 hrs)	38(70.37%)	11(20.37%)	3 (5.56%)	2 (3.7%)	0
Day-3 Forecast(72 hrs)	27(50.0%)	14(25.93%)	5(9.26%)	6(11.1%)	2 (3.70%)
Day-4 Forecast(96 hrs)	20(37.04%)	13(24.07%)	9(16.67%)	6(11.11%)	6(11.11%)
Day-5 Forecast(120 hrs)	11(20.37%)	21(38.89%)	6(11.11%)	4(7.41%)	12(22.22%)

4. Evaluated flood forecast performance in Sirajganj

In the 2014 annual report, the performance of the flood forecast is evaluated in Sirajganj, as shown in table 5. It presents that the MAE increase from 0.08(forecast 24hrs) to 0.16 (forecast 120 hrs), and r^2reduce from 0.97 (forecast 24hrs) to 0.91 (forecast 120 hrs), but the performances of flood forecast are 'Good' rating for all forecast lead time in 2014. Thus, the level of the forecast accuracy in Sirajganj is high. Although, the accuracy of flood forecast in Sirajganj slightly declines, with the increase of the lead time.

Table 5 forecast up to 5-days in Sirajganj for 2014 flood

Forecast lead time	MAE	r^2	Performance
Day-1 forecast(24 hrs)	0.08	0.97	good
Day-2 forecast(48 hrs)	0.09	0.95	good
Day-3 forecast(72 hrs)	0.1	0.94	good
Day-4 forecast(96 hrs)	0.13	0.92	good
Day-5 forecast(120 hrs)	0.16	0.91	good

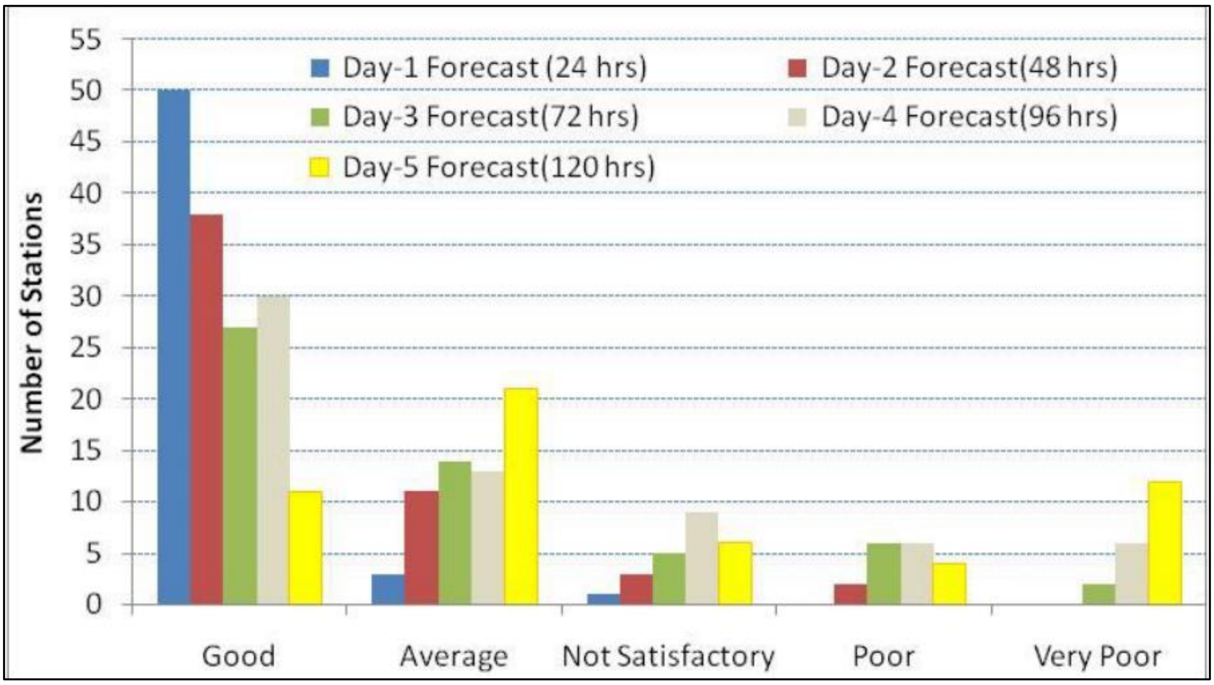

Figure 10 Performance of the flood forecast up to 5 days based on the Mean Absolute Error(MAE) and Co-efficient of Determination (total forecast stations 54)(FFWC, 2015)

2. MITIGATION MEASURES

The Source-Pathway-Receptor-Consequences model shown in fig. 11 is frequently used in analysing flood risk. The source of flooding may be rainfall in the upstream catchment causing a large flood discharge to pass through, or, for example, could be due to the rise in sea water level, or a combination of the two. When the flood water cannot be contained by river banks or man-made embankments either due to excessive high water level or due to breaching of embankments then flood water may flow over the flood plains and reach people and their properties (receptors), and can cause damage to properties and lives (consequences). Also refer to Fig 12 describing the three phases of the cycle of flood risk management practice.

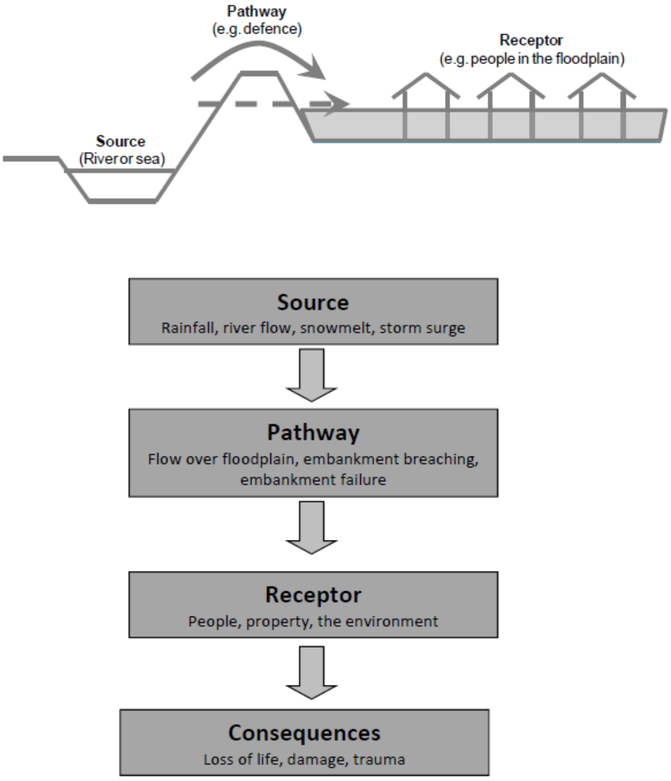

Figure 11 Source-pathway-receptor-consequence model

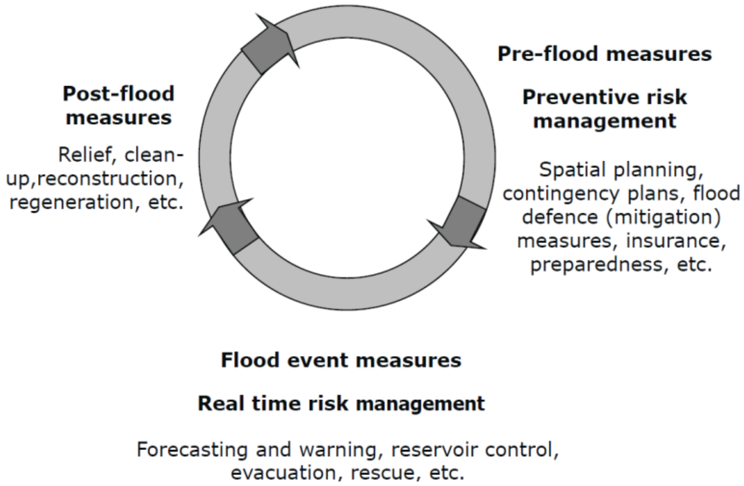

Figure 12 Three phases of flood risk management in practice

(a) (15 points) For each phase (Fig. 12) propose at least one flood mitigating measure that may reduce the current risk of flooding in Sirajganj. Use the source-pathway-receptor-consequences (SPRC) model to analyse the influence of the proposed measures on the flood source, the pathway, the receptors and the consequences. End result of this task should be a list of measures, positive and negative aspects of the measures with indication on which component of the SPRC will be affected with the proposed mitigation measure. Present your findings in a table. There is no need to write long explanatory text on the proposed measures.

Answers:

Table 6 A list of flood mitigating measures

NO.	Goal	Phase	SPRC	Character	Name
1	flood probability reduction	pre-flood	source	structure	retention in upstream catchment
2		pre-flood	pathway	structure	embankment construction/strengthening
3		pre-flood	source	structure	bypasses
4		pre-flood	source	structure	connect rivers to existing lake
5		pre-flood	pathway	structure	dredging river
6		pre-flood	pathway	structure	flood plain lowering
7	flood impact reduction	pre-flood	receptor	structure	compartmentalisation of areas
8		pre-flood	receptor	structure	flood proofing
9		pre-flood	receptor	non-structure	land use zoning
10		pre-flood	receptor	non-structure	regulation on storage of toxics/ chemicals
11		pre-flood	receptor	non-structure	Adaptation of agricultural practice
12		post-flood	receptor	non-structure	flood insurance
13		during flood	receptor	non-structure	flood forecasting
14		during flood	receptor	non-structure	flood risk map/evacuation

1. Retention in the upstream catchment

Positive/Negative aspects: it is a structure mitigation measure and is a pre-flood activity that influences the source of SPRC model, and it reduces the volume of discharge coming from upstream. Unfortunately, it may increase the flood risk in the upstream basin.

2. Embankment strengthening

Positive/Negative aspects: it is a structure mitigation measure and is a pre-flood activity that influences the pathway of SPRC model. Also, it can defend the flood, which water level is lower than an embankment. But, the measure may fail when the river has a high water level (higher than embankment) during the monsoon.

3. Bypasses

Positive/Negative aspects: it is a structure mitigation measure and is a pre-flood activity that influences the source of SPRC model. It effectively diverts the water flowing out of the city by artificial canal or other rivers to reduce flood risk. However, the discharge capacity of the artificial canal is limit, and it cannot endure the high discharge in an extreme event.

4. Connect rivers to the existing lake

Positive/Negative aspects: it is a structure mitigation measure and is a pre-flood activity that influences the source of SPRC model. This way is similar to Bypasses, and the difference is, here, discharging the water into a lake. Also, the water capacity of the lake is an important indicator for the measure performance.

5. Dredging Jamuna River

Positive/Negative aspects: it is a structure mitigation measure and is a pre-flood activity that influences the pathway of SPRC model. The river dredged has higher water capacity and lower water level than before to reduce the overtopping risk. Nevertheless, the drawback of this measure is that cost and work quantity is huge due to the area of the Jamuna River.

6. Flood plain lowering

Positive/Negative aspects: it is a structure mitigation measure and is a pre-flood activity that influences the pathway of SPRC model. The water capacity of flood plain increase due to flood plain lowering. And it can reduce the flood risk in other areas in Sirajganj.

7. Compartmentalisation of areas

Positive/Negative aspects: it is a structure mitigation measure and is a pre-flood activity that influences the receptor of SPRC model. It protects the important area in Siraiganj using flood wall. However, the flood risk in the area without flood walls increase.

8. Floodproofing

Positive/Negative aspects: it is a structure mitigation measure and is a pre-flood activity that influences the receptor of SPRC model. For example, increasing the building height is a way for avoiding the flood inundation, and the ground area of buildings can be used for agriculture.

9. Land-use zoning

Positive/Negative aspects: it is a non-structure mitigation measure and is a pre-flood activity that influences the receptor of SPRC model. According to a flood risk map, the land use in different areas should be different. The zone with high flood risk should classify a land use with low value.

10. Regulation on storage of toxics/ chemicals

Positive/Negative aspects: it is a non-structure mitigation measure and is a pre-flood activity that influences the receptor of SPRC model. The storage of toxics/ chemicals should locate in a safe place where don't have flood risk for preventing the pollution discharge during the flood.

11. Adaptation of agricultural practice

Positive/Negative aspects: it is a non-structure mitigation measure and is a pre-flood activity that influences the receptor of SPRC model. Similar to the land-use zoning, the agriculture area with high flood risk should plant corps with low economic value.

12. Flood insurance

Positive/Negative aspects: it is a non-structure mitigation measure and is a post-flood activity that influences the receptor of SPRC model. It reduces the social vulnerability of farmers and enhances flood resilience. However, it requires models which is able to define the spatial extent of flood relative to agricultural assets. Costs and efforts were required to keep updating.

13. Flood forecasting

Positive/Negative aspects: it is a non-structure mitigation measure and is a during flood activity that influences the receptor of SPRC model. The Flood Forecasting and Warning Centre (FFWC) of Bangladesh provides flood warnings with five days lead time (24, 48, 72, 96 and 120 hours). Forecast about flood water level is provided at the designated gauge locations, and one of them is near the city of Sirajganj, called Serajanj station. It reduces the loss of lives, decreases social vulnerability and enhances community preparedness. Importantly, uncertain errors in forecasting cannot be avoided.

14. Flood risk map/evacuation

Positive/Negative aspects: it is a non-structure mitigation measure and is a during flood activity that influences the receptor of SPRC model. It can evacuate the people on time when the flood is coming. But the area of flood inundation is difficult to be determined precisely, and some places may still suffer huge losses.

(b) (15 points) Rank your recommendation and present justifications. You may follow, for example, a multi-criteria analysis. You may make assumptions if you do not have sufficient data. End result of this task should be a table with ranking of measures. Point out if you would rank measures differently had it been a case in the developed world.

Answers:

The multi-criteria analysis is working with weighting criteria with respect to respective importance. According to FLOODsite(*Klijn*, 2009), the parameters selected for assessment are shown in the following:

1) Adopt the three domains of sustainability – **Economic, Environmental and Social** – as guidance for the selection of criteria for a full assessment of flood management strategic alternatives under various scenarios. Importantly, economic represents an economical cost. Environmental represents environmental damage, and social represents evaluating the impact to society and possibilities of affecting the livelihood of people.
2) Add the criteria **robustness and flexibility** to the other sustainability criteria in order to cover the issue of 'coping with uncertainty'. Robustness means working at possible situations (national holiday/ power cut), and flexibility means how easily can be adapted in the future

The degree of performance in those parameters is shown in figure 13.

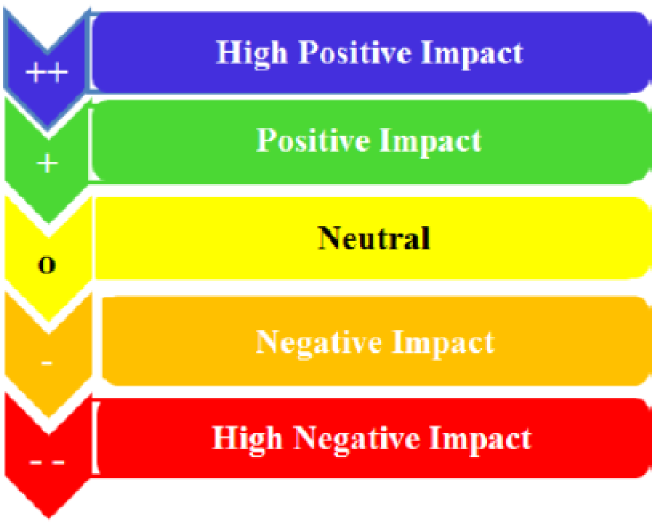

Figure 13 Degree of performance

Moreover, the weighting criteria is depended on the author that Economic of 4, Environmental of 2, Social of 5, Robustness of 3 and Flexibility of 1, according to the hydro-meteorological situation in Sirajganj. On the other hand, the weighting criteria will change in a developed country. Because it is a high economic level in a developed country and the weight of environmental and flexibility should be increased. The rank of measures is shown in table 7.

Table 7 Rank of measures in Sirajganj

	Social(*5)	Economic(*4)	Environmental (*2)	Flexibilty(*1)	Robustness(*3)	Final score(-28;+28) Rank[]
retention in upstream catchment	-	-	-	++	++	-3[8]
embankment construction/strengthening	++	--	O	+	++	9[3]
bypasses	-	--	-	++	++	-7[9]
connect rivers to existing lake	O	-	-	++	++	2[6]
dredging river	--	-	-	-	++	-11[11]
flood plain lowering	--	-	-	+	++	-9[10]
compartmentilsation of areas	++	--	O	O	++	8[4]
flood proofing	++	--	O	O	++	8[4]
land use zoning	O	O	O	++	+	5[5]
regulation on storage of toxics/ chemicals	+	O	+	++	+	12[2]
Adaptation of agricultural practies	-	O	O	++	+	0[7]
flood insurance	++	-	O	-	O	5[5]
flood forcasting	++	O	O	++	+	15[1]
flood risk map/evacuation	++	O	O	++	+	15[1]

(c) (15 points) Based on the above raking list choose 2 mitigation measures and write a brief essay to describe qualitatively how they are going to reduce the risks. Provide an outline of the study that will be needed to analyse the usefulness of the proposed measure. If models will be required to complete the study then indicate the types of models that will be needed. Indicate the data requirement to complete the study.

Answers:

1. Mitigation measures: Flood forecasting (rank: 1; Score:15)

The Flood Forecasting and Warning Centre (FFWC) of Bangladesh provides flood warnings with 5 days lead time (24, 48, 72, 96 and 120 hours). Forecast about flood water level is provided at the designated gauge locations, and one of them is near the city of Sirajganj, called Serajanj station. According to this information, people in Sirajganj will get action-based warning messages from the government for evacuation. The outline of the study is shown in the following:

1) Collecting geological, meteorological, hydrological and topographical data by different ways is necessary. Note that the rainfall data uses near real-time data.
2) NAM-Mike11 model is constructed and cover the areas in whole of Bangladesh. Moreover, boundary conditions at the border of Bangladesh are generated by Mike Basin model.
3) The water level is forecasted Serajanj station by model.

4) Using statistic components r^2 (Co-efficient of Determination) and MAE (Mean Absolute Error) evaluate the flood forecast performance.
5) The model is calibrated, according to the performance assessment, to increase the forecast accuracy and reduce flood risk

2. Mitigation measures: bypasses (rank: 9; Score:-7)

It effectively diverts the water flowing out of the city by artificial canal or other rivers to reduce flood risk. However, the discharge capacity of the artificial canal is limit, and it cannot endure the high discharge in an extreme event. The outline of the study for description qualitatively how to reduce the risks is shown in the following:

1) Collect discharge data in upstream and through the city at different water level (warning level, danger level etc.) in Serajanj station before using bypasses
2) Collect discharges in upstream, through the city and in artificial canals at different water level in Serajanj station (warning level, danger level etc.)
3) Estimate the maximum discharge in artificial canals without overtopping
4) Comparison between those two groups' data and determine the ability of defencing flood increased after using bypasses

3. FUTURE CHANGES

Analyse the ways future flood risk in Sirajganj may change. Consider the predicted climate change as described in Gain *et al*. (2011). Assume that the population density of the region is the same as the national density and the density increases at the same rate with the national population growth rate. Use the World Bank's projection on population growth to determine the future population of the region. In view of the probable changes in future flood risk, suggest some mitigation measures and discuss their individual merits and demerits.

Answers:

1. Predicted Climate Change(*Gain et al.*, 2011)

The hydrology cycle is significantly affected by climate change, especially on the streamflow. Gain et al. (2011) proposed a novel model of discharge-weighted ensemble models using model outputs from a global hydrological model forced 12 different global climate models (GCMs) for exploring the impact of climate change on streamflow in Bangladesh. According to the model predicted, extremely low flow conditions are likely to occur less frequently in the future. However, a very strong increase in peak flows is projected, which may, in combination with projected sea-level change during monsoon, have devastating effects for Bangladesh, as shown in fig 14. Figure 14 presents that the median values of discharge remain steady from 2011 to 2099, except in summer season, and the amount of discharge dramatically increase from 40000 m2/s to 60000 m2/s during 2011 to the 2099 year in the summer season. Therefore, the flood risk in Siarjganj will strongly increase in the next few decades.

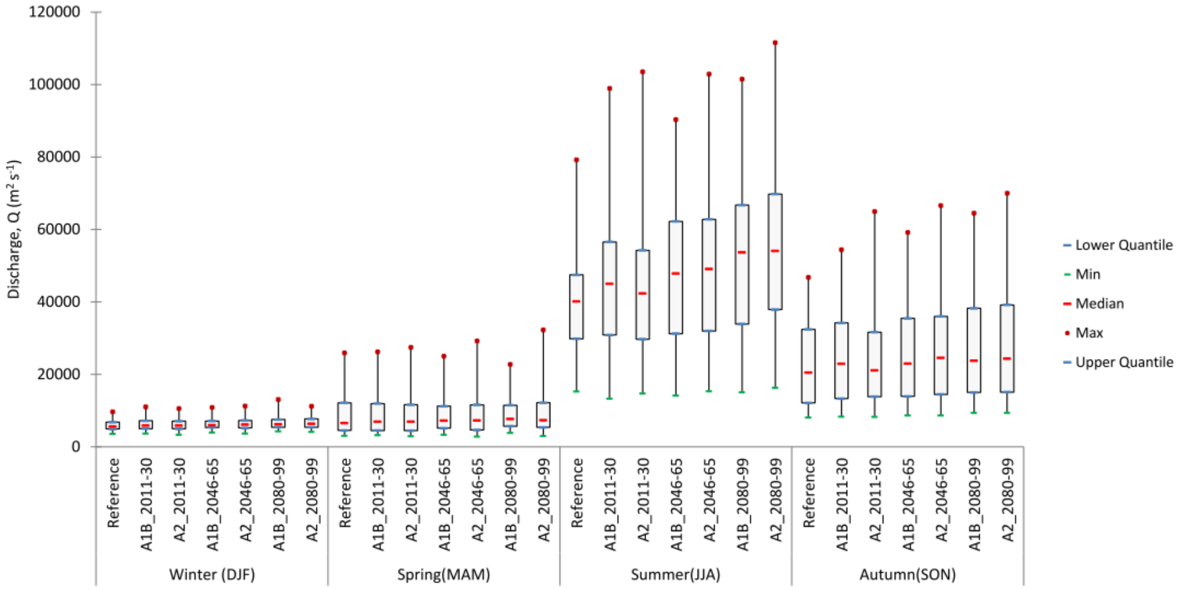

Figure 14 Discharge of streamflow predicted from 2011-2099 in Bangladesh

2. Future demographic trends in Bangladesh

The estimation of future demographic trends in Bangladesh is done by Population estimates and projections from the World Bank (retrieved from https://databank.worldbank.org/source/population-estimates-and-projections#). Figure 15 shows the future demographic trends in Bangladesh from 2021 to 2050. Total population will increase to close 200 million, and the ratio of urban population to the total population will rise during this period, compared with that of rural over the total population. There is a continuous decrease in the rural population by 20 million until 2050. Therefore, the population in Siarjganj will gradually grow, according to the prediction from the World Bank's project.

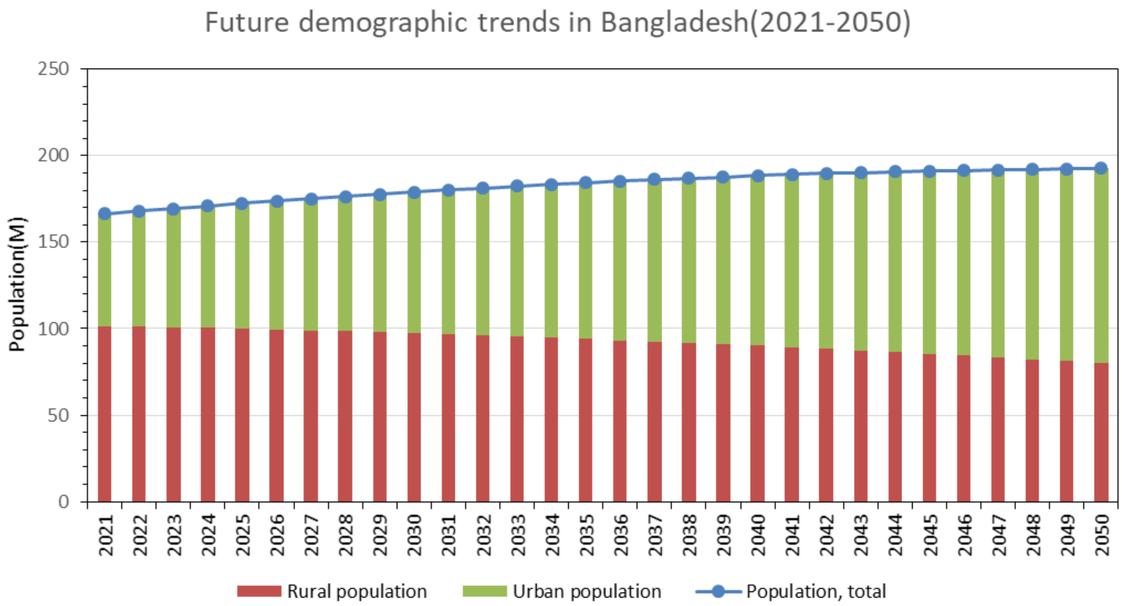

Figure 15 Future demographic trends in Bangladesh (2021-2025)

3. Suggestions for future flood risk

- The government should reduce the development of high-risk flood areas, and put the main buildings in the low flood risk areas. The demerit of these measures is the flood inundation area may change due to the development and construction in the region.
- Importantly, some areas sited in the middle of the Brahmaputra River are extremely vulnerable to flooding, called chars. There are temporary chars and permanent chars, which both inhabited a huge number of people. Therefore, in future years, the policy of the migration of people in chars should be proposed from the government for protecting the health and wealth safe.
- Flood insurance promotion should be increased to increase flood insurance coverage and reduce the flood vulnerability in people n Siarjganj. But, there are still poor people who cannot be protected.
- Increasing the accuracy of the flood forecast model is necessary for the coming years to reduce flood risk. However, the uncertain errors, like the errors from predicted rainfall data and so on, cannot ignore in forecasting water level.

4. TRANS-BOUNDARY

Consider the trans-boundary nature of the problem and suggest as a flood manager your vision for a sustainable flood risk management of the region.

Answers:

Bangladesh has a total of 57 transboundary rivers where 54 rivers are with India and three are shared with Myanmar. Only 7% of the total Brahmaputra-Ganges-Meghna catchment resides in Bangladesh, while the rest of it follows among India, China, Nepal, Bhutan and Myanmar. As the main bulk of the catchment lies outside Bangladesh, flood control requires regional cooperation. Thus, the trans-boundary nature of the problem should be considered.

Moreover, India shared the water from the trans-boundary river according to their will and took the advantages to be the upper riparian country(*Parven and Hasan*, 2018). In existing water sharing policy, there is a lack of integrated water-sharing management. Moreover, the political party in Bangladesh is another factor to expose the policies unsuccessfully. The existing policies are not working well because of the lack of regional cooperation and conventional wisdom in water sharing issues with these countries.

There are so many reasons behind this lack of consensus about the transboundary issues such as lack of political and national consensus, selective foreign policy, poor water governance, water scarcity in countries(*Parven and Hasan*, 2018). The following recommendation is proposed.

- Increase the access to the information: This access to data is not only for the state sharing but also increase the public accessibility into the data.
- Discuss the interchange of tradable and sharable benefits in the water sharing a negotiable table.
- Civil Society Organization (CSO) should come forward with advocacy and intermediary roles, but trust-building is more important to engage in these issues. CSO should more link with the grassroots people and help to mobilise them for coalition about the shared interest.

- Donor organisation should come forward for capacity building and provide support in the negotiation process as a non-state actor.
- It is also recommending that Bangladesh and other South Asian countries may build up a hydro-community like EU water framework Directive that is based on the soft power of peer review rather than a penalising measure. It is to notify that the inter-state water conflict in this state in the adverse situation never understood and addressed in the same way that the European Union faces in their water conflict issues. Therefore, the trans-disciplinary water conflict is unique for an individual country.

5. REFERENCE

1. FFWC (2015), Annual Flood Report 2014, Bangladesh Water Development Board.
2. Gain, A. K., et al. (2011), Impact of climate change on the stream flow of the lower Brahmaputra: trends in high and low flows based on discharge-weighted ensemble modelling, *Hydrology and Earth System Sciences*, *15*(5), 1537-1545.
3. Karim, M. F., and N. Mimura (2008), Impacts of climate change and sea-level rise on cyclonic storm surge floods in Bangladesh, *Global environmental change*, *18*(3), 490-500.
4. Klijn, F. (2009), Flood risk assessment and flood risk management; an introduction and guidance based on experiences and findings of FLOODsite (an EU-funded integrated project), *T29-09-01*.
5. Mirza, M. M. Q. (2003), Three recent extreme floods in Bangladesh: a hydro-meteorological analysis, in *Flood problem and management in South Asia*, edited, pp. 35-64, Springer.
6. Parven, A., and M. Hasan (2018), Trans-boundary water conflicts between Bangladesh and India: water governance practice for conflict resolution, *International Journal of Agricultural Research, Innovation and Technology*, *8*(1), 79-84.
7. Presentation Industrial Park, edited.