1.9　発展途上国における総合的な洪水リスクマネジメント方策の事例研究

(Case Study on Comprehensive Flood Risk Management in Developing Countries)

Budged：Grants for operating expenses General account
Research Period：FY2009-2010
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【Abstract】

We found out that the disaster risk mitigation countermeasures in Bangladesh could be categorized into three major scenarios according to their complimentary functions; i.e. embankment and bio-shield (Scenario A), cyclone shelter and early warning system (scenario B) and, housing reinforcement scheme with revised building code (Scenario C). We found out that an average of about 10% or at least 3% of the fatalities are thought to have been saved per kilometer length of embankment in case of 2007 cyclone Sidr and more than 70 cm inundation depth of 1.8m would have been reduced by bio-shield during the same cyclone. Therefore we can say that Scenario A is quite effective to save lives. Scenario B is effective during super cyclones where and if Scenario A cannot contain the surge, but only 7.3% or 2.8 million people could be accommodated in the shelters at present. Scenario C could be used as evacuation centers for neighbors especially who have small children, elderly and disabled family members. Scenario A is the most expensive however it has multiple benefits than just saving lives, and the Scenario C is the cheapest. Therefore, each scenario has unique property as a cyclone disaster countermeasure and is helpful to save lives and property hence each scenario should be treated and maintained as a unit to harvest its optimal efficiency.

Keywords: Flood risk, hazard, vulnerability, coping capacity, world water assessment

1.　Introduction

Bangladesh has an area of 144,000 square kilometers and extends 820 kilometers north to south and 600 kilometers east to west. Bangladesh is bordered on the west, north, and east by a 2,400-kilometer land frontier with India and, in the southeast, by a short land and water frontier (193 kilometers) with Burma (http://worldfacts.us/Bangladesh.htm)7. On the south is a highly irregular deltaic coastline of 580 kilometers, fissured by many rivers and streams flowing into the Bay of Bengal. Roughly 80 percent of the landmass is made up of fertile alluvial lowland called the Bangladesh Plain. The plain is part of the larger Plain of Bengal, which is sometimes called the Lower Gangetic Plain. Although Bangladesh has altitudes up to 105 meters above sea level in the northern part of the plain, most elevations are less than 10 meters above sea level; elevations decrease in the coastal south, where the terrain is generally at sea level (http://worldfacts.us/Bangladesh-geography.htm)8. With such low elevations and numerous rivers, water- and concomitant flooding- is a predominant physical feature. About 10,000 square kilometers of the total area of Bangladesh is covered with water, and larger areas are routinely flooded during the cyclone and monsoon period.

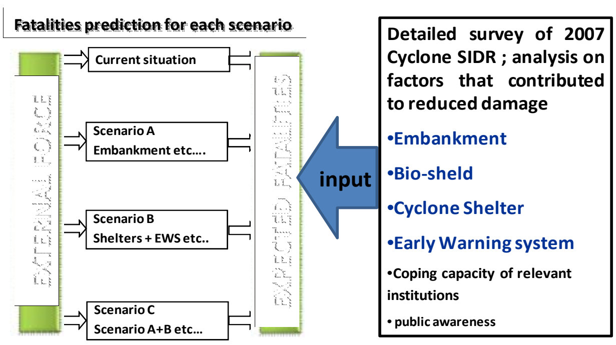

Fig. 1.　The development of scenarios those will help relate the mitigation measures to their effects.

The occurrence of cyclonic disasters cannot be prevented but the magnitude of the impact of a disaster risk could be significantly reduced through structural and non-structural countermeasures. The combination of various cyclonic disaster risk mitigation countermeasures is thought to be critical and with optimal care we proposed a method of development of different scenarios which could help reduce fatalities (Figure 1). In this study we collected data from the field, interviewed local officials, agencies and related government officials in the hope of developing scenarios helpful to save lives during cyclone disasters. From the available information from past cyclones, especially cyclone Sidr of 2007 and other investigation, best mix scenarios are developed in a hope to reduce cyclone disaster risk in Bangladesh or elsewhere.

2. State of the problem:

An estimated 4 million people live in Very High Risk Area (VHRA); another 5 million people live in High Risk Area (HRA) of which up to 30% are seasonal migrant laborers and 70% of this population is landless (Benson C. and Clay E., 2002)1. However Bangladeshi people have lived with floods and cyclones for a long time and the government has dealt with the risk since the beginning; they have constructed embankments, cyclone shelters, establish early warning systems, educated and trained professionals and locals to develop awareness to protect people and property from cyclone disaster risk.

The results of the factor analysis of water-related disasters and 1991 cyclone in Bangladesh conducted by ICHARM pointed out that both the structural and non-structural countermeasures against cyclonic storm surge have continuously produced positive results in fatalities reduction (Yoshitani et al. 2008 & Yoshitani et al. 2007)10, 11. However, the life loss in Bangladesh during extreme cyclones is still huge in number and there is enormous property damage. Therefore, it is important to categorize existing cyclone risk mitigation countermeasures into different scenarios for better maintenance, improved the functions and to understand which scenario is effective to save people.

3. Existing mitigation methods:

In Bangladesh, embankment is constructed with earth to a maximum crest height of 5.2m from the mean sea level, other embankments are only as high as 4 m which means that the storm surges above the embankment level will not be barricaded since the devastating 1970 (Bhola), 1991 and 2007 (Sidr) cyclones generated waves more than 6m which are well above the maximum height of the crest of the embankment (Chaudary, G.A., 2008) 3. There is 5017 Km length of embankment out of that 957 Km is sea-facing which encircle 49 sea-facing polders (Table 1). Out of 957 Km of sea-facing embankment only about 60 Km is protected by bio-shield.

Table 1. The countermeasure inventory of Bangladesh as of January 1011

Countermeasures	Type	Units
Embankment	Sea-facing (Km)	957
	Total Length (Km)	5017
Polders	Sea-facing (No)	49
	Total (No)	123
Bio-shield	Sea-facing (Km)	60
Cyclone shelters	Usuable (No)	2591
	Unusable (No)	262
	Washed away (No)	88
Early Warning Systems	News	?
	TV	?
	Radio	?

At present there are 2591 usable, 262 unusuable and 88 washed away shelters (Table 1). Shelter capacity is only to accommodate 50% of high risk area (HRA) population though their construction started way back in 1960s. Cyclone shelters are effective counter measures against storm surge flooding during cyclone to save lives; but however, there are also some constrains. The shelters are useful only when EWS function well but at present we do not know the efficiency and units of the EWS.

4. Cyclone disaster countermeasures categorization into scenarios:

From field observations, interviews, data and information gathered the cyclone disaster risk countermeasures were categorized into three major scenarios according to their complimentary functions as follow; 1) Embankment and Bio-shield Combination (Scenario A), 2) Cyclone Shelter and Early Warning System (EWS) Combination (Scenario B), and 3) Housing reinforcement scheme with revised building code (Scenario C).

1) Embankment and Bio-shield Combination (Scenario A)

The first scenario is the combination of embankment and bio-shield, i.e. Scenario A. The embankments protect the polders (enclosed by embankments) from waves or surges. If the waves or surge are stronger enough then there is a chance of overtopping or breaching the embankment flooding the polder. The bio-shields help reduce the velocity and depth or waves/surges (Das et al., 2010, Tanaka 2009, Feagin et al., 2009)4, 5, though the science of wave attenuation by vegetation is still under study, therefore the combination of embankment and bio-shield would reduce the destruction of the former, lower overtopping and/or prevent breaching thus help reduce the inundation depth saving lives in an effective way than only with a single measure. Scenario A is thought to be beneficial not only to protect lives but also render multiple functions including livelihood after the disaster and protection of embankment which is usually constructed with earth by hand.

To understand the effect of bio-shield in scenario A we calculated the volume (**$V= \sqrt{gH}*d*L*T$; where** $\sqrt{gH}$ is velocity, d is the breach depth, L is breach length and T is the duration which water flow inside the polder) of water entering the polder, then the area of the polder no 15 and finally the inundation depth during Aila and Sidr assuming that the embankment was 4m high, breached about 120m and water rushed inside the polder for 2 hrs. The polder no 15 (Dumuria) is near Sundarnan in Bangladesh which is little more than 21Km2. This assumption is based on actual 120m breaching of embankment during Aila of May 2009 along Kholpatua River due to the impact of 5m high wave/surge (Fig. 2.). We repeated the calculation with the same criteria except the increase of surge/wave height to that of cyclone Sidr (6m) for comparison taking into account that both the cyclones lasted for 2 hrs. The results showed that the inundation height was 1.4m and 1.8m for cyclone Aila and cyclone Sidr. The same calculation was repeated for both the events with the consideration of 200m bio-shield which reduced the surge/wave landward velocity by 43.0% (Das et al., 2010)4. The inundation height in both cases (Aila and Sidr) changed to 0.82m and 1.07m showing that the bio-shield could reduce inundation effectively.

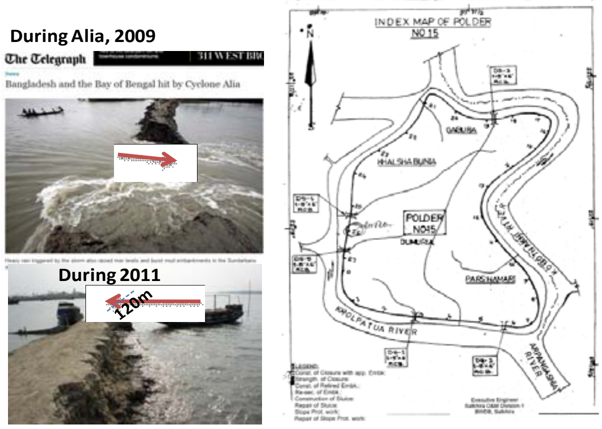

Fig. 2. During and after the breaching of 120m stretch of embankment of polder no 15 in Dumuria near Sundarban in Bangladesh

At present there are 123 polders encircled by 5,017Km of embankments of which 957Km encloses sea-facing 49 polders. Coastline maps available through Google Earth indicate that out of 957 Km length of sea-facing embankment in Bangladesh only about 60 Km length is protected by 500m or wider bio-shield perpendicular to the embankment. If the remaining length of the embankment i.e. 897Km be protected with the same width of coastal bio-shield then about 448.5Km^2 of afforestation is necessary with an estimated cost of $168,000 per Km^2 (Coastal Embankment rehabilitation project, Stage-II Final Report, Volume I/II, June 2003, Chittagong). Considering the benefits the coastal bio-shield or mangroves is thought to be a cost-effective method of protecting sea-facing polders from extreme cyclones like Cyclone Sidr. Therefore it is very important to consider the mechanics of storm surge involved in breaking or uprooting or destroying bio-shield. The following factors are relevant a) breaking strength and elasticity of tree stems, branches, and roots; b) rooting depth, and size; c) vegetation species behavior to storm surge; d) soil resistance to uprooting shear forces; e) combined drag and impact forces; and f) maximum height at which force applied, and these factors should be studied thoroughly the results of which will lead to make a recommendation to the government to consider coastal bio-shield or mangrove plantation to protect people, property and the embankment itself.

Our field observation points out that the embankment is protected by a coastal forest (Fig. 3.). It is understood that 20 to 30% of repair cost reduction of sea dykes and embankments is attributed to coastal forest (Forbes K. and Broadhead J. 2007 and Das et al. 2010)[6] 4. Besides, Das et al (2010) pointed that up to 48.9% of velocity and 8.8% of depth was reduced beyond 300m of coastal forest with a slope of 1:100m. Das et al results are true because the embankment next to the breached portion of polder No. 15 is intact and is circumferencial forest during our field visit whereas the breached portion is not. Therefore, had there been a bio-shield of more than 300m the inundation would have been only the rain water accumulation and life and property in polder No 15 would have been saved during Cyclone Aila. This means that scenario A is one of the best method to protect lives and property while reducing or protecting embankments from breaching due to overtopping, toe erosion, slope erosion and inadequate operation and maintenance during extreme cyclonic events. The idea is that the coastal bio-shield supplements the embankment to enhance its function and durability thus it is a "best match". But if there is no proper governance or institutional arrangements that are compatible to the local needs, the efforts might be in vain.

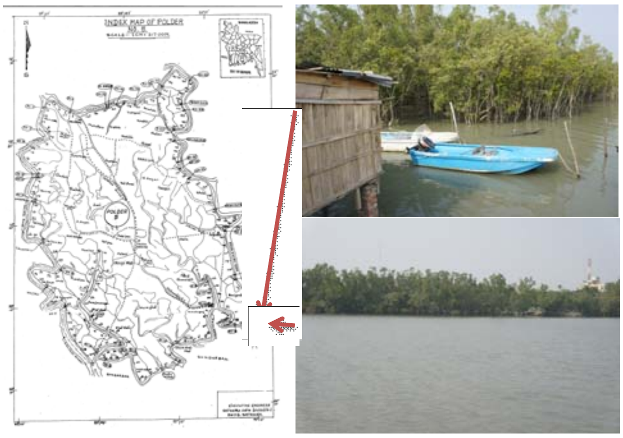

Fig. 3. The mangrove that protected the embankment at polder no 5 which is at the opposite bank of polder no 15 near Sundarban in Bangladesh

Bio-shields are getting more attention in recent years because they are environmental friendly, lower cost of plantation and capable to reduce the energy and height of storm surge. Bio-shields may require vast tracks of land and long time for the forest to grow to an effective age but these forests could be used in many ways; such as 1) environmental buffer, 2) grazing area for cattle, 3) tourism, 4) fire wood, honey and other forest products source, 5) job opportunity for local communities who manage the forest, 6) aqua culture, 7) herbal medicine, and 8) land reclamation.

Needless to say that Cyclone Sidr's damage vulnerability was severe along its path (Fig. 4.). Barisal area was hit hardest though the eye of Cyclone Sidr path was right through the Sundarban. It was observed that the damage was comparatively higher at the eastern part of the cyclone path. More people were affected at Barisal and Chittagong district as compared to Khulna where the cyclone passed through and similar results were obtained on the infrastructure damages such as roads and culverts (Fig. 5. & 6.). Among others, one of the reasons why the eastern part of the cyclone path incurred higher damage could be attributed to bio-shield effect of Sundarban which could attenuate the surge height and velocity as discussed earlier.

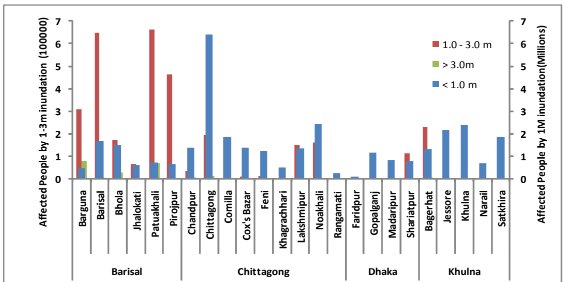

Fig. 4. Cyclone Sidr affected area population vulnerability distribution according to inundation depth

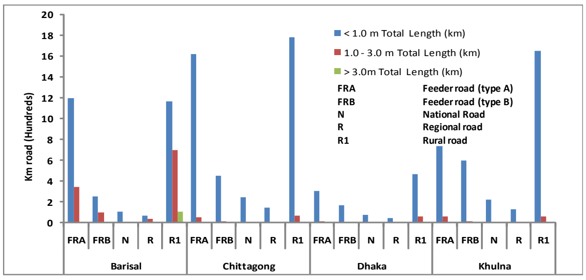

Fig. 5. Cyclone Sidr affected area road network vulnerability according to inundation depth

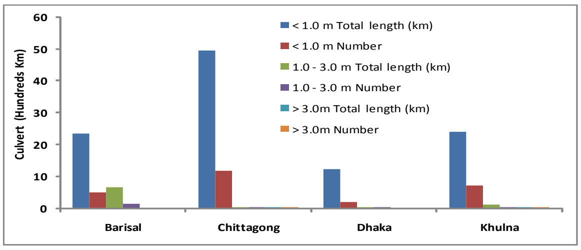

Fig. 6. Cyclone Sidr affected area culvert vulnerability according to inundation depth

Satkhira is adjacent to Sundarban and Khulna is inland to the north, this might be the reason why there is less damage in these two locations (Fig. 7.). On the other hand, the places towards the east of the cyclone path lying close to the coast of Bay of Bengal with little protection of bio-shield had incurred comparatively greater loss. Fully and partially destroyed embankments lengths were comparatively greater at the coastal area towards the eastern side of the cyclone track, e.g. Barguna; and the fatalities were also concentrated in such areas suggesting a direct relation between embankment destruction (Ministry of Food and Disaster Management, 2008)9. On the other hand, the ratio between fatalities and the fully destroyed embankment in average is about 10.5 per kilometer but the values ranged from about 142 to 3; leading us to think that an average of 10 people must have been saved by a kilometer of embankment. But the deviation from the mean is very high, this suggests that there might be other governing factors those play equally important role to protect people during cyclones. This is a first of this kind of study and we made very simple calculation to get to these results therefore further detailed studies are indispensable to understand the relation of scenario A and life loss during cyclones.

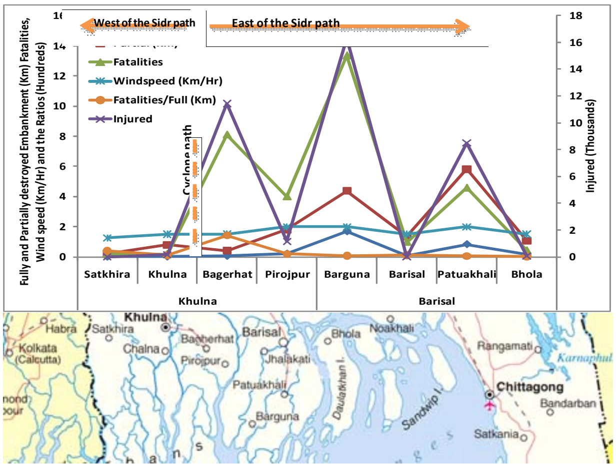

Fig. 7. The relation between fully and partially damaged embankment and corresponding fatalities、injured population and the wind speed in affected area during Cyclone Sidr, 2007.

2) Cyclone Shelter and Early Warning System (EWS) Combination (Scenario B)

Cyclone shelter and EWS consists scenario B. Cyclone shelter and EWS are complimentary, the existence of both is equally important for the people to evacuate and be safe. Furthermore, local people must be aware of the impending disaster, its intensity and consequence for them to take decision to evacuate. Scenario B is useful when the intensity of cyclone is very high; say the cyclones are extreme like cyclones Bhola or Sidr. This is because the high intensity cyclone means the strong winds blow away thatched houses roofs, trees will be uprooted, electricity cut off, the danger of falling/blowing objects and inundation will be high. During this period especially the children, elderly and women should evacuate to the shelter to be safe from the high winds and drowning. Greater importance is given to this scenario in recent years because the lives will be saved if people evacuate. At the same time shelters are expensive to construct and maintain, not meant to accommodate and protect livestock and cannot protect properties. Besides, only the people who evacuate to a shelter will be saved; people often do not evacuate because they prefer to stay at home to save their property and livestock. Furthermore, people have encountered many false warnings in the past, these repeated warnings inculcated a negative faith or distrust therefore people do not usually evacuate.

As mentioned earlier, there are 2591 useable, 262 unuseable cyclone shelters in coastal region of Bangladesh, 88 shelters were washed away and the consensus among experts and relevant government agencies is to build another 2000 to 2500 more new shelters as of 2010. The cost of one shelter that accommodates 1,600 people is approximately $214,000 or $134/person accommodated. Asian Development Bank will construct 398 shelters in the physical year 2011, World Bank plans to construct 50 more, and the Islamic Bank 800. In total there will be 3839 useable shelters and if those 262 unuseable shelters are repaired there would be a total of 4101 shelters immediate future. Bangladesh Government reported in 2008 that 15 percent of the affected population took refuge in the shelters. The 2591 shelters accommodate 2.8 million people or 7.3% of Bangladesh coastal population.

Early warning systems (EWS); Bangladesh Meteorology Department tracks tropical storms in close collaboration with other relevant organizations and issues alerts of approaching cyclones, storm surges and other atmospheric abnormalities in different geographic locations of the country. Newspapers, TV and radio disseminate the warning. The local government administration and local Cyclone Preparedness Program (CPP) volunteers of Red Crescent Society lead the evacuation following the warning. At present cyclone preparedness program in Bangladesh covers 32 of 51 upazilas/thanas that are exposed to cyclones and storm surges. Besides, Bangladesh government appointed a commander in chief to oversee relief and recovery actions with an establishment of decentralized operation center. Coordination of relief operation at the local, regional and national levels has been enhanced through transceiver radios of high frequency (HF) for long distance and very high frequency (VHF) for short distance. Furthermore, mobile phones are also used for communication during the disaster.

The Cyclone shelters could only accommodate 7.3% of coastal population of Bangladesh during disaster that means the shelters are still lacking. The first thing is to increase the number of the shelters which the government is working hard in collaboration with international community. Besides, the road networks to these shelters should be maintained so that people could evacuate easily. The shelters should be compartmentalized to accommodate male and female evacuees separately. Local women expressed their uncomfort to spent time in evacuation centers with men thus they may be reluctant to evacuate. The facilities should have separate lavatories for female and male evacuees too. There must be a system in place where women and children could evacuate smoothly to the shelters. Improvement of the warning precision and raising awareness is a must. Finding a mode of communication in local dialects for the improvement of EWS will be helpful.

3) Housing reinforcement scheme with revised building code (Scenario C)

In coastal Bangladesh there are only 2.23% of strong houses built with bricks and concrete roofs which could withstand cyclones with minimal damage which are affordable for the households whose annual per capita income is $470 or more; these houses are called pucca houses locally. The pucca houses are often two storied and if reinforced with the revision of Bangladesh National Building Code 1993 with an addition of a new clause taking care of the building standers for extreme cyclone events, could be used as evacuation centers for neighbors where there is harmony and cooperation among community people. There is a rumor that the Bangladesh Government is planning to subsidize these houses so that they will be reinforced and used as the shelters which is a positive prospective (Personal communication with CEGIS colleagues). Field investigation suggests that the houses in the coastal area are very feeble and cannot resist the cyclonic storms. Furthermore, the houses are constructed on a 60 cm or so elevated platform which will be easily submerged during cyclonic storm and the thatched roof of the house will easily be blown off, therefore a reinforced pucca house could act as a shelter. The pucca houses are cost effective, a two storied pucca house with floor area of 152m2 costs about US$11090 (Table 2). It is estimated that another US$5545 would cost to reinforce the house to withstand a cyclone and this house will accommodate 152 people. The comparative per person accommodation cost of a pucca house is about US$110 and cyclone shelter is about US$134, thus it is cheaper to reinforce a pucca house and use it as shelter.

Table 2. Comparison between the coast of a pucca house versus cyclone shelter in coastal Bangladesh. Note that the reinforcement cost of a pucca house to withstand an extreme cyclone is estimated to be half the coast of building a house itself

	Cost of a 2F house (USD)	Estimated cost of reinforcement	Total Cost (USD)	Space per person (m	No of people	Cost per person
Pucca House	11090	5545	16635	$1m^2$	152	109.44
Cyclone Shelter	214000	0	214000	$1m^2$	1600	133.75

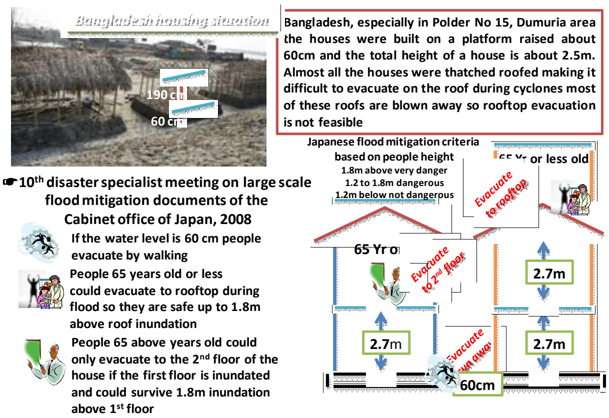

Fig. 8. The housing situation in Bangladesh that cannot withstand flood and wind during cyclone as recommended by Japanese flood mitigation criteria based on age and house structure and height.

The pucca house may be reinforced according to the criteria outlined by the Japanese Government Cabinet Office to save citizens from drowning during flood (Fig. 8.). The Japanese criteria are based on three factors, house height, the age of a person (65 years or older and less than 65 years old) and the height of the people. It is estimated that there is 60 cm space between ground and the ground floor of a house and the height of each floor of a house is 2.7m. If the inundation is 60cm everybody can evacuate by walking to a nearest shelter, if it is more than that then the old person can only evacuate to 2nd floor of a house where as the younger person can climb to the roof top and also help her/his children and wife/husband climb to the roof and additional 1.2m is thought to be safe considering a person's height. This means that older people are thought to be safe if water level is 4.5m (0.60+2.7+1.2) where as younger people could survive 7.2m (0.60+2.7+2.7+1.2). But in the case of Bangladesh, the roofs are normally thatched and no two storied houses are built by ordinary people in coastal Bangladesh, therefore only 1.8m (0.6+1.2m) of inundation is safe. This means that if people raised the foundations of houses and built stronger houses this could help save more lives. The solution would be to revise the Bangladesh National Building Code 1993 adding a new clause that will take care of construction standards in cyclone and storm surge prone coastal Bangladesh so that the houses built by comparatively rich families would be stronger where poor neighbors could immediately evacuate during cyclone disasters (Bureau of Research Testing and Consultancy, 2010)[2].

5. Discussions:

Comprehensive cyclone disaster management in coastal Bangladesh pertains to the combination of all the scenarios A, B and C as mentioned earlier and illustrated in Fig. 9. These scenarios are developed keeping in mind that the combinations of each cyclone mitigation measures are complimentary to each other. The evaluation of the effectiveness of each scenario quantitatively is very difficult due to a lack of data, however, we think that these scenarios are independent, important, unique, and are advantageous in their own way.

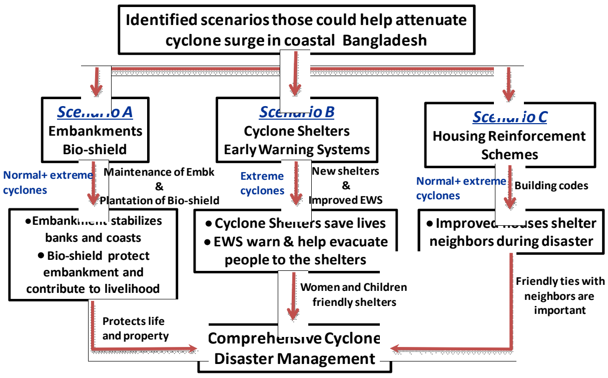

Fig. 9. The new scenario development concept and process of comprehensive cyclone disaster management in coastal Bangladesh

Table 3. Comparison between basic functions and construction cost of scenarios A, B and C.

Scenarios	Scenario A (Embankment & Bioshield)		Scenario B (Cyclone Shelter and EWS)		Scenario C (Housing Reinforcement Schemes)	
Saves what?	Life and property		Life of evacuees		Life of evacuees	
Saves how many?	Many people		1000 to 2000 people		50 to 60 people	
When useful?	Normal & Extreme Cyclones		Extreme Cyclones		Normal & Extreme Cyclones	
How much (US$)?	256275/Km Embankment	168000/Km² Bioshield	214000/unit Cyclone Shelter	EWS?	16635/unit	EWS?

Scenario A would be effective to not only save life and property inside the embankment or polder during regular annul cyclones but also during extreme events (Table 3). Scenario B comes into action during extreme events such as Cyclone Sidr or Cyclone Bhola during which breaching and overtopping of embankment and high winds are expected therefore evacuation becomes indispensable to protect people. And the Scenario C is useful when people cannot evacuate to the cyclone shelters easily; those families with small children, elderly and disabled or where the road networks to cyclone shelters are damaged during the event. The initial costs of scenario A seems to be the most expensive and scenario C the cheapest but their functions and effectiveness vary between location and disaster intensity. Therefore, further field studies are recommended to allocate a well balanced combination of scenarios since the importance of each is unique.

Mitigation efforts made by the government and people of Bangladesh are very fruitful resulting to the reduction of the fatalities during comparable events of 1970, 1991 and 2007 (Fig. 10). In 1970 nearly 500,000 people were killed by cyclone and in our comparison we assume the fatalities of this event as 100%, in 1991 more than 138863, i.e. 27.7% of 1970 and in 2007 more than 3363, i.e. 0.67%. Though the number of fatalities is still very high the reduction in number is huge. Besides, the fatalities ratio per 1000 injured people in 1970 is 142.9, 1991 is 30.8 and 2007 is 0.34 but it is not clear which measure or measures reduced the number of fatalities to what extent. In a closer look, an average of about 10% or at least 3% of the fatalities are thought to have been saved per kilometer length of embankment if the embankment had not been destroyed during cyclone Sidr. It is important to gather data concerning different scenarios during and after disaster events to predict which combination, where and to what extent would be effective since no information that could correlate the countermeasures and disasters is available except few details on embankment.

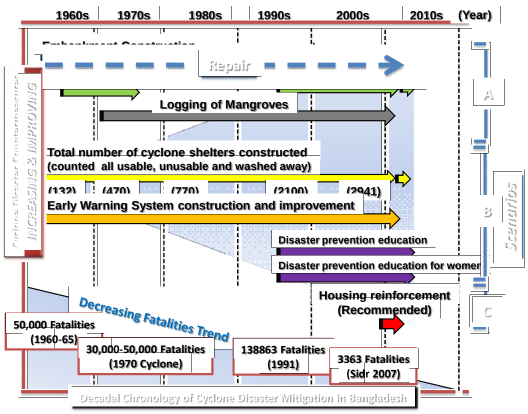

Fig 10. Bangladesh government 's increasing effort to mitigate cyclone disaster categorized into three scenarios and the corresponding decreasing trend of fatalities

Conclusion

In 1970 cyclone killed nearly 500,000 people and in our comparison we assume that the fatalities of this event as 100%, in 1991 more than 138863, i.e. 27.7% of 1970 and in 2007 more than 3363, i.e. 0.67% which is a drastic reduction of fatalities. The fatalities ratio per 1000 injured people in 1970 is 142.9, 1991 is 30.8 and 2007 is 0.34 but it is not clear which countermeasure(s) reduced the number of fatalities. In a closer look, an average of about 10% or at least 3% of the fatalities are thought to have been saved by per kilometer length of embankment if the embankment had not been destroyed during cyclone Sidr.

Bio-shield is helpful to reduce surge height and velocity, and protect embankment from erosion and provides livelihood to people as well. Inundation depth during cyclone Sidr would have been reduced from 1.8m to 1.07m in polder No. 15 (Dumurai) had there been a coastal bio-shield of width at least 200m, this reduction would have saved lives.

Scenario B is effective during super cyclones where embankment and coastal forest cannot contain the surge but only 7.3% or 2.8 million people could be accommodated in the shelters. Therefore there is a need to increase the number of shelters and EWS as well.

Scenario C, the **pucca** houses reinforcement scheme, according to the revision of Bangladesh National Building Code 1993, to withstand extreme cyclone events will serve as shelters. Pucca house reinforcement is comparatively cheaper than cyclone shelter and is easily accessed by the neighbors especially with small children, elderly and disabled family members which makes evacuation easy and fast.

The way forward

It is recommended to consider coastal bio-shield or mangrove plantation to protect people, property and the embankment from erosion since the construction material is earth. The coastal bio-shield supplements the embankment to enhance their function and durability thus it is a "best match". But if there is no proper governance or institutional arrangements that are compatible to the local needs, the efforts might be in vain. Furthermore, construction material of the embankment should be considered.

Improvement of the warning precision, raise awareness and find a mode of communication in local dialects for the improvement of the EWS is advised.

The pucca houses if reinforced with revised building code could be used as evacuation centers for neighbors during cyclonic storms. Therefore it is wise to set up a proper country building standard and reinforce the pucca houses to save people.

It is important to gather data from the field of different scenarios of the events to predict which combination, where and to what extent would be effective since no information that could correlate the countermeasures and disasters is available except few details on embankment.

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1.9　発展途上国における総合的な洪水リスクマネジメント方策の事例研究

研究予算：運営費交付金（一般勘定）
研究期間：平21～平22
担当チーム：水災害研究グループ（防災）
研究担当者：三宅　且仁、ｱﾃﾞｨｶﾘ ﾖｶﾞﾅｽ、清水　孝一

洪水リスクマネジメントは、現状のリスク評価、リスク軽減策の立案、その効果評価を経て、実施することが求められる。本研究は、洪水予警報システムや洪水ハザードマップの導入や、その他のソフト・ハード対策による洪水リスク(死者数)軽減効果の評価手法を開発するものである。洪水被害軽減体制の研究対象地域のひとつとして、度々大きなサイクロン災害を受けてきたバングラデシュを対象に、洪水リスクを最も効果的に軽減する対策群を分析し、総合的洪水リスク軽減方策として提案するものである。
具体的には、ほぼ10年おきに大規模なサイクロン災害を被っているバングラデシュにおいて、ハード、ソフトの防災施策の進展により、ほぼ同じ規模のサイクロンの来襲に対して人命被害を低減することに成功してきた。その要因を分析し対策の組み合わせを検討すると共に、今後さらに被害を軽減するためのシナリオを提案した。

キーワード： 洪水リスク、加害外力、脆弱性、防災力、世界水アセスメント