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# Developing Vulnerability Index for the Coastal Storm Surge Hazards Considering Climate Change

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## Abstract

*The intensity and frequency of natural disaster like cyclone, storm surge has been increasing significantly in the coastal region of Bangladesh. This paper has represented not only the impact of a storm surge hazard e.g. Aila in 2009, but also future vulnerability to storm surges under climate change perspective. Hence, a regional conceptual frame work named 'cycle way' has been developed to determine the future vulnerability of the coastal community. 'cycle way' frame work is used to comprehend the process of socio-economic condition, livelihood activities, resources availability and natural hazards in the coastal region. It interlinks with the causes behind the exposure to natural hazards and coping capacity of the community. Indicators as like drinking water availability, loss of rice production, loss of shrimp production, jlooded land, migration etc have been adopted for multi criteria analysis (MCA) for this study and Aila, 2009 has been used as a base year study. Secondary data trend analysis and focus group discussion (FGD) has been used to estimate the total vulnerability index (TVI) for upcoming storm surge disaster The Total Vulnerability Indices found as 6.22, 9.77 and 12.26 for the years 2009, 2030 and2050 respectively. This article represents the interaction among the pressure on the community, adaptation activities and climate changes on the same platform through quantification as TVI.*

**Key Words:** Climate change; Cycle way frame work; Cyclone Aila; Multi criteria analysis; Pressure and coping effect; Total Vulnerability Index.

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## 1.0 Introduction

The vulnerability to climate change is considered to have massive and disastrous consequences for Bangladesh resulting one of the most susceptible countries of the world (ADB, 2004). Coastal areas, especially heavily populated mega delta regions in South, East and South-East Asia, will be at greatest risk due to increased flooding from the sea (IPCC2007). During the past 200 ycars, 2.6 million people may have drowned during surge events (Nicholls 2003). Approximately 19.5% (391,812 $km^2$) of their combined coastal territory of 84 developing countries is vulnerable to inundation from a 1-in-100-year storm surge (by current reference standards). Homogenous 10% future intensification over the next 100 ycars (Nicholls et.al. 2007) increases the potential inundation zone to 25.7% of coastal territory, taking into account sea-level rise. This translates to potential inundation for an additional 52 million people; 29,164 $km^2$ of agricultural area; 14,991 $km^2$ of urban area; 9% of coastal GDP and 7% of wetlands. (Dasgupta et.al 2009)

Tropical cyclones hitting trend of the Bangladesh coast is not steady. It has vacillated in the past century. Presently, there is an increasing trend (Islam & Peterson 2009). Higher population density increases vulnerability to climate change especially water related disaster in Bangladesh (Agraweala *et.al.* 2003). Most of the casualties from cyclones in Bangladesh, as in other parts of the world, are caused by storm surges as for climate change will increase the height of storm surges, leading to greater coastal flooding (Ali, 1996). Under scenario A2 in year 2050 (SLR 27 cm) exposed population will be 5.0 million to high risk (inundation over 100 cm) and while 5.5 million at risk of inundation by 50-100cm. In case of 13 polders overtopped due to 62 cm sea level rise in the year 2080 under A2 scenario, 45% population will be exposed to medium to severe inundation (TWM & CEGIS, 2007).

The recent storm disaster 'Aila' have passed over the south west of Bangladesh and adjacent part of India with likely surge height 6-8 feet above normal astronomical tide (DMIC & DMB, 2009). In this

study the impact of present disaster and vulnerability for future as like disaster in 2030 and 2050 are estimated under climate change context.

## 2.0 Methodology

The intensity and frequency of natural disaster like storm surge has been increasing day by day of the coastal region in Bangladesh. Vulnerability to climate change is the degree to which these systems are susceptible to, and unable to cope with, the adverse impacts (IPCC, 2007). It is important to analyze the vulnerability to different risks and subsequently to enhance their abilities to cope with the hazard which is a multi-dimensional approach (Makoka & Kaplan, 2005). If the climate will change in present trend, the present disaster *e.g.* Aila must be intensified and magnified in future. So the*vulnerability obviously increases in future of that south west region. Cyclone Aila is selected for base year impact. This study has been conducted in a polder region e.g. encircle embankment (Figure-1) which was severely affected by the Aila event in 2009. A vast region inside a Polder-5 had been flooded due to storm surge flooding during Aila.

This study has been commenced through projecting storm surge flooding in future projected years (e.g. 2030 & 2050) through DEM analysis in GTS. Then, flooded area of Aila, vulnerable region to future flood and the sensitive area have been selected for the study.

A number of homogenous groups have been selected to collect social aggravated data through focus group discussion (FGD). The homogenous group is characterized by-

a. Geographically identical location (distance, elevation)

b. Assets are more and less same in that group

c. Lively hood or relation to the resource extraction must be same

d. Similar in social status e.g. ethnicity, gender, cast and culture.

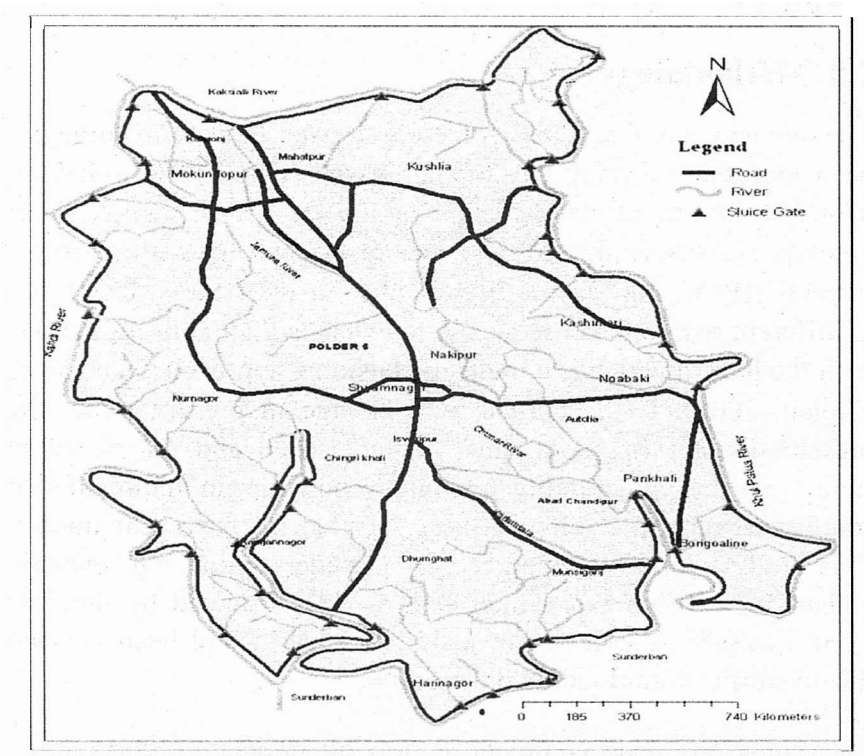


Figure 1: Polder-5 (e.g. encircled embankment)

From FGD and secondary literature survey a livelihood and resource use matrix (Table, 1) can be developed of the coastal population. It represents the changing of livelihood and opportunity of assets use in general of the coastal population.

**Table 1:** Livelihood and resource use matrix

| Location | Types of group | Types of livelihood | Natural Assets | Physical Assets | Economic Assets | Social Assets |
|---|---|---|---|---|---|---|
| Totally flooded in Aila | Agricultural farmer | Rice cultivation, Day labor, Rickshaw puller | 2 | 1 | 1.5 | 1.5 |
| | Shrimp farmer | Shrimp cultivation, business, | 1.5 | 2 | 2.5 | 3 |
| | Business men | Small and large business, Retails | 1 | 2.5 | 2 | 2 |
| | Day labors | Day labors, Rickshaw puller | 1.5 | 1 | 1 | 1.5 |
| Transition zone | Agricultural farmer | Rice cultivation, Day labor, Rickshaw puller | 2 | 1 | 1.5 | 2 |
| | Shrimp farmer | Shrimp cultivation, business, | 1 | 2 | 2.5 | 2 |
| | Business men | Small and large business, Retails | 1 | 2.5 | 2 | 2 |
| | Day labors | Day labors, Rickshaw puller | 1 | 1 | 1 | 1.5 |
| Tentative to flooded in future | Agricultural farmer | Rice cultivation, Day labor, Rickshaw puller | 2 | 2 | 1.5 | 2.5 |
| | Shrimp farmer | Shrimp cultivation, business, | 1 | 1.5 | 2 | 2 |
| | Business men | Small and large business, Retails | 1 | 2.5 | 2.5 | 3 |
| | Day labors | Day labors, Rickshaw puller | 1.5 | 1 | 1.5 | 1 |

***Note: 1= Fail; 2= Good,*** *3=Very good*

In case of 'Aila', 2009, about 147 people died, 3,694,874 people and 783,286 families were affected, 545,226 houses were destroyed and 340,660 acre crops were damaged (DMIC & DMB, 2009). Total 14 districts were affected among 19th coastal district of Bangladesh. About 70% resources of the three south west coastal districts have been directly and indirectly affected by cyclone 'Aila'.

A conceptual frame work (e.g. cycle way) has been developed (Figure-2) for future vulnerability assessment with respect to present disaster. This frame work is like a rolling cycle over a way. It is actually a process related frame work. The shape of the wheel represents socio economic condition of the community. The center of the cycle is quite uneven that represents the livelihood situation of the community in resource extraction. In the coastal zone

maximum population are involve in habitat dependent livelihood. So the star is quite lower and adjacent to the way. Due to economic development of the country and improvement of social welfare enhance the cycle of the frame work in future.

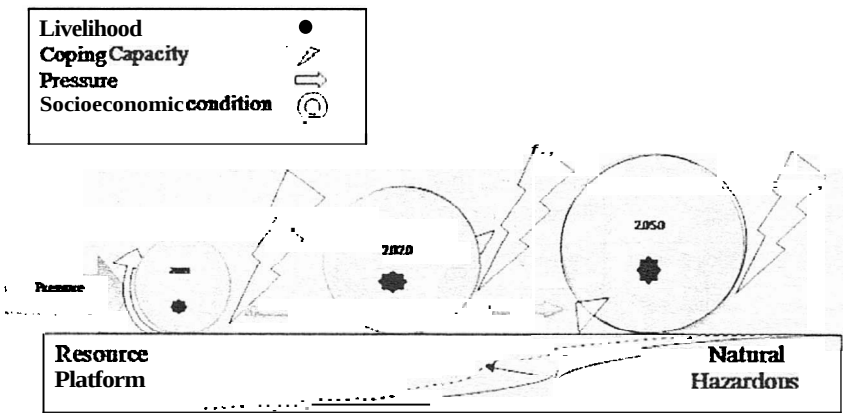


**Figure** 2: Cycle-way frame work for vulnerability analysis

The rotation of the cycle enriches resource from the resource platform with time interval for socio-economic development. Different kinds of pressure act as a driving force to move the community to more vulnerable stage. One the other hand coping capacity tends to obstruct or reduce this vulnerability. The major driving forces and related coping capacity of the south west region are identified in table-2.

| **Pressure** | **Coping capacity** |
|---|---|
| Population growth | Family planning, Out migration |
| Staple food production | Alternate food habit and import |
| Per capita income | Subsidy, Alternate livelihood opportunity |
| Salinity increases in water and soil | Salinity tolerant verities, move to different crops. |
| Land use vulnerability | Awareness and Management |
| Household structure | Protective structure, Govt. laws and policy |
| Social relationship | Local culture, media |
| Climate change | Warning system, laws and regulation |

**Table** 2: Identification of the pressure and coping capacity for the community

In the figure-1, a hazard zone can be found aside with the natural systems. I-lazard front increases toward the community with the changing climate. So vulnerability of the community increases in both intrinsic and extrinsic phenomenon of the system. Actually the position of the cycle, socio-economic structure, livelihood and hazard front over a time period determine the total vulnerability of the coastal community.

## 3.0 Result and Discussion

Total Vulnerability Index will be developed through the aggregation of various criteria and indicator with respect to their involved in storm surge hazard. Cyclone 'Aila' reflects the iinpactcd subjects which are adopted in future vulnerability study. By using the steps of the frame work, the qualitative and quantitative data can be collected by FGD from the field survey. Secondary data also are used for future impact projection.

**Table 3:** Field survey and projected qualitative and quantitative data

| Assets | Criteria | Indicator | Impact of Aila, 2009 | Vulnerability for 2020 | Vulnerability for 2050 |
|---|---|---|---|---|---|
| **Natural** | Loss of forest plant | % | 32 | 45 | 64 |
| | Loss of Livestock | % | 40 | 60 | 90 |
| | Availability of drinking Water | Population | 112 | 2/3 | 1 |
| | Inundated Area Coverage of polder No-5 | $Km^2$ | 22.5 | 28 | 48 |
| | Collection from wild animals | | less | rare | least |
| | Water Salinity | ppt | 14 | 23 | 35 |
| Physical | Roads, bridge, culvert | % | 40 | 60 | 75 |
| | Residential Status | | Damage in affected areas | Increasing than previous | More Damage than previous |
| | Vehicle, boat, Network | % | 50 | 60 | 65 |
| Economic | Loss of Agricultural land (ha) | % | 70 | 80 | 95 |
| | Loss of Shrimp farm (ha) | % | 50 | 55 | 60 |

| | | | | | |
|---|---|---|---|---|---|
| \ | Livelihood . Opportunity | | Decreasing | Highly decreasing | Least than previous |
| **Social** | Gender situation/ Sanitation | | Affected | Highly affect | Severely affect |
| | Migration | % | 13 | 30 | 35 |
| | Cultural entanglement | | Interrupted | Highly Interrupted | Severely Breakdown |

Different tools of PRA as like social mapping, chapatti diagram and chart drawing are used to estimate the future impact under climate change context. The concept of vulnerability requires a reduction of potentially gatherable data to a set of important indicators and criteria (Birkmann, 2006). The disaggregated data are justified through analysis of secondary literature.

Raw information of quantitative and qualitative data are arrange in tabular form for multi-criteria analysis. Cyclone Aila, 2009 destroy almost 70% resources of the south west coastal districts (Accounted from DMIC & DMB, 2009). In case of future vulnerability assessment Aila, 2009 is used as a base year situation. Adaptation to climate change impacts is necessary, that it is already occurring, and will occur with greater urgency in the future (Adger *et.al.* 2005). The causes of increasing vulnerable and the coping capacity are highly considered in future impact assumption. Finally we use equation-1 for the standardization of the score.

$$STD_{k,j} = \frac{ACT_{k,j}}{Best(1...N)} \quad \ldots\ldots\ldots\ldots 1$$

N= Number of years (2009,2030 and 2050)
k= Situations
j= Criteria
STD= Standardized score (Base year condition)
ACT= Actual score

After standardization we apply weighted sum method for giving preference to subjective issues and multiply the score with normalizing coefficient and weighted coefficient. At the end we added the score of different year vulnerability and find the total vulnerability index (TVI). So the index for 2009, 2030 and 2050 is consequently 6.22, 9.77, and 12.26 (Table No-4).

Table 4: Total vulnerability Index estimation table

| Assets | Criteria | Weighted Coefficient | Normalizing Coefficient | Impact of Aila, 2009 | Vulnerability for 2020 | Vulnerability for 2050 | Results | Impact of Aila, 2009 | Vulnerability for 2030 | Vulnerability for 2050 |
|---|---|---|---|---|---|---|---|---|---|---|
| Natural | Loss of forest plant | 1 | 0.17 | 1 | 1.41 | 2 | $STD_{kj} = \frac{ACT_{kj}}{Best(1..N)}$ | 0.17 | 0.24 | 0.34 |
| | Loss of Livestock | | 0.17 | 1 | 1.5 | 2.25 | | 0.17 | 0.26 | 0.38 |
| | Availability of drinking Water | | 0.17 | 1 | 1.5 | 2 | | 0.17 | 0.26 | 0.34 |
| | Inundated Area Coverage | | 0.17 | 1 | 1.25 | 2.13 | | 0.17 | 0.21 | 0.36 |
| | Collection from wild life | | 0.17 | 1 | 2 | 2.5 | | 0.17 | 0.34 | 0.43 |
| | Land salinity coverage | | 0.17 | 1 | 1.64 | 2.5 | | 0.17 | 0.28 | 0.43 |
| Physical | Roads, bridge, culvert | 1.5 | 0.33 | 1 | 1.5 | 1.88 | | 0.50 | 0.74 | 0.93 |
| | Residential Status | | 0.33 | 1 | 1.4 | 1.75 | | 0.50 | 0.69 | 0.87 |
| | Vehicle, boat, Network | | 0.33 | 1 | 1.2 | 1.3 | | 0.50 | 0.59 | 0.64 |
| Economic | Loss of Agricultural land (ha) | 1.75 | 0.33 | 1 | 1.14 | 1.36 | | 0.58 | 0.66 | 0.79 |
| | Loss of Shrimp farm (ha) | | 0.33 | 1 | 1.1 | 1.2 | | 0.58 | 0.64 | 0.69 |
| | Livelihood | | 0.33 | 1 | 1.5 | 2 | | 0.58 | 0.87 | 1.16 |
| Social | Gender situation/ Sanitation | 2 | 0.33 | 1 | 2 | 2.5 | | 0.66 | 1.32 | 1.65 |
| | Migration | | 0.33 | 1 | 2.31 | 2.69 | | 0.66 | 1.52 | 1.78 |
| | Cultural entanglement | | 0.33 | 1 | 1.75 | 2.25 | | 0.66 | 1.16 | 1.49 |
| **Total Vulnerability Index (TVI)** | | | | | | | | **6.22** | **9.77** | **12.26** |

## 4.0 Conclusion

If cyclone Aila is representative all of the year but TVI remains increasing with time. From the frame work we find that location, socio-economic condition, livelihood and climate change are responsible for agitate TVI. Just after Aila, they become vulnerable due to poor socioeconomic condition and livelihood opportunity. In 2030 and 2050 their socioeconomic condition and livelihood opportunity may improve but their position and climate change influencing hazard front enhance TVI. Pressure behind the society and easy resource enrichment process drive the community to increase exposure. Different adaptation options pull them to safer place. Finally, climate change intensified natural hazard and exposure of the assets simultaneously make the coastal community more vulnerable in future.

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