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Vulnerability of Bangladesh to Cyclones in a Changing Climate

Potential Damages and Adaptation Cost

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Abstract

This paper integrates information on climate change, hydrodynamic models, and geographic overlays to assess the vulnerability of coastal areas in Bangladesh to larger storm surges and sea-level rise by 2050. The approach identifies polders (diked areas), coastal populations, settlements, infrastructure, and economic activity at risk of inundation, and estimates the cost of damage versus the cost of several adaptation measures. A 27-centimeter sea-level rise and 10 percent intensification of wind speed from global warming suggests the vulnerable zone increases in size by 69 percent given a +3-meter inundation depth and by 14 percent given a +1-meter inundation depth. At present, Bangladesh has 123 polders, an early warning and evacuation system, and more than 2,400 emergency shelters to protect coastal inhabitants from tidal waves and storm surges. However, in a changing climate, it is estimated that 59 of the 123 polders would be overtopped during storm surges and another 5,500 cyclone shelters (each with the capacity of 1,600 people) to safeguard the population would be needed. Investments including strengthening polders, foreshore afforestation, additional multi-purpose cyclone shelters, cyclone-resistant private housing, and further strengthening of the early warning and evacuation system would cost more than $2.4 billion with an annual recurrent cost of more than $50 million. However, a conservative damage estimate suggests that the incremental cost of adapting to these climate change related risks by 2050 is small compared with the potential damage in the absence of adaptation measures.

This paper—a product of the Environment and Energy Team, Development Research Group—is part of a larger effort in the World Bank to understand potential impacts of climate change and adaptation cost. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at sdasgupta@worldbank.org.

Vulnerability of Bangladesh to Cyclones in a Changing Climate: Potential Damages and Adaptation Cost

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1. Introduction

An increase in sea surface temperature is strongly evident at all latitudes and in all oceans. The scientific evidence indicates that increased sea surface temperature will intensify cyclone activity and heighten storm surges.[8,9] These surges[10] will, in turn, create more damaging flood conditions in coastal zones and adjoining low-lying areas. The destructive impact will generally be greater when storm surges are accompanied by strong winds and large onshore waves. Tropical cyclone Sidr[11] in Bangladesh (November 2007) and cyclone Nargis[12] in the Irrawady delta of Myanmar (May 2008) provide recent examples of devastating storm-surge impacts in developing countries.

Some recent scientific studies suggest that increases in the frequency and intensity of tropical cyclones in the last 35 years can be attributed in part to global climate change (Emanuel 2005; Webster et al. 2005; Bengtsson, Rogers, and Roeckner 2006). Others have challenged this conclusion; citing problems with data reliability, regional variability, and appropriate measurement of sea-surface temperature and other climate variables (e.g., Landsea et al. 2006). Although the science is not yet conclusive (IWTC 2006: Pielke et al. 2005), the International Workshop on Tropical Cyclones (IWTC) has recently noted that "[i]f the projected rise in sea level due to global warming occurs, then the vulnerability to tropical

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[8] A sea-surface temperature of 28^{o} C is considered an important threshold for the development of major hurricanes of categories 3, 4 and 5 (Michaels, Knappenberger, and Davis 2005; Knutson and Tuleya 2004).

[9] A rising sea level as thermal expansion and ice cap melting continue will be another contributory factor. The most recent evidence suggests that sea-level rise could reach 1 meter or more during this century (Dasgupta, et al. 2009; Rahmstorf 2007), although the likelihood of that magnitude of increase remains uncertain.

[10] *Storm surge* refers to the temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions: low atmospheric pressure and/or strong winds (IPCC AR4 2007).

[11] According to Bangladesh Disaster Management Information Centre (report dated Nov 26, 2007) 3,243 people were reported to have died and the livelihoods of 7 millions of people were affected by Sidr (http://www.reliefweb.int/rw/RWB.NSF/db900SID/EDIS-79BQ9Z?OpenDocument).

[12] In Mayanmar, 100,000 people were reported to have died and the livelihoods of 1.5 million people were affected by Nargis (http://www.dartmouth.edu/%7Efloods/Archives/2008sum.htm)

cyclone storm surge flooding would increase" and "[i]t is likely that some increase in tropical cyclone peak wind-speed and rainfall will occur if the climate continues to warm. Model studies and theory project a 3-5% increase in wind-speed per degree Celsius increase of tropical sea surface temperatures." The Intergovernmental Panel on Climate Change (IPCC AR4, 2007) using a range of model projections, also has asserted a probability greater than 66% that continued sea-surface warming will lead to tropical cyclones that are more intense, with higher peak wind speeds and heavier precipitation (IPCC 2007; see also Woodworth and Blackman 2004; Woth, Weisse, and von Storch 2006; and Emanuel et al. 2008).[13]

The historical evidence highlights the danger associated with storm surges. During the past 200 years, 2.6 million people may have drowned during surge events (Nicholls 2003). Although significant adaptation has occurred over time, and many lives have been saved by improved disaster forecasting, evacuation and emergency shelter procedures (Shultz, Russell, and Espinel 2005; Keim 2006); recent disasters in Bangladesh and Myanmar have demonstrated that storm-surge losses still remain huge in many areas. Allocating resources to increased disaster resilience along particularly vulnerable coastlines could reduce such losses. The need for disaster preparedness along vulnerable coastlines is especially pronounced in countries where concurrent scientific projections point towards more intense cyclones in a changing climate. However, setting a new course requires better understanding of expected changes in storm surge patterns in the future, associated damages and adaptation costs.

Currently, systematic studies of storm surge patterns in the future, location-specific potential damage and adaptation alternatives are scarce in developing countries. Analytical work to date has been confined to relatively limited sets of locations, impacts and adaptation measures (Ali 1999, Hoque 1994, Khalil, 1992). This paper is an attempt to

[13] Cyclones get their power from rising moisture which releases heat during condensation. As a result, cyclones depend on warm sea temperatures and the difference between temperatures at the ocean and in the upper atmosphere. If global warming increases temperatures at the earth's surface but not the upper atmosphere, it is likely to provide tropical cyclones with more power (Emmanuel et al. 2008).

narrow the gap by providing itemized estimates of potential damage and adaptation cost out to 2050 for Bangladesh- a tropical cyclone hotspot[14] in a changing climate.

The focus of this research is on 10-year return period cyclones -- cyclones with a 10% or greater probability of occurrence each year. In the computation of potential damage, this analysis concentrates on fatalities and injuries; and on housing, education, agriculture, non-agriculture productive sector, and infrastructure (roads, power, coastal protection), sectors experiencing serious damage in the most recent 10 year return period cyclone in Bangladesh (Sidr 2007). The primary objective of adaptation in this analysis is to avoid further damages associated with storm surge inundation as a result of climate change with a particular focus on various measures of adaptation to storm surges in Bangladesh. At the outset, we acknowledge several limitations in our analysis. This analysis has not addressed the likely problem of salinity intrusion nor has it addressed out-migration from the coastal zone that may be induced by sea level rise and more intense cyclones. We also have not attempted to estimate location-specific probability of 10-year return period cyclones.

The remainder of the paper is organized as follows. Section 2 presents the case of cyclones in Bangladesh. Our methodology and results are presented in Section 3, and Section 4 concludes the paper.

2. Cyclones in Bangladesh

Cyclones hit the coastal regions of Bangladesh almost every year, in early summer (April-May) or late rainy season (October-November). Between 1877 and 1995 Bangladesh was hit by 154 cyclones (including 43 severe cyclonic storms, 43 cyclonic storms, 68 tropical depressions)[15]. Since 1995, five severe cyclones hit coast of Bangladesh coast in May 1997, September 1997, May 1998, November 2007 and May 2009. On average, a severe cyclone strikes Bangladesh every three years (GoB, 2009).

Bangladesh is on the receiving end of about 40% of the impact of total storm surges in the

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[14] See UNDP, 2004; Nicholls, 2003.

[15] The Indian Meteorological Department (IMD) is responsible for tracking tropical storms and cyclones in South Asia including the Bay of Bengal. Tropical storms are classified based on the observed maximum sustained surface wind measured at a height of 10m averaged over 3 minutes as follows: Super Cyclonic Storm (greater than 220 km/hour), very severe cyclonic storm (119-220 km /hour), severe cyclonic storms (90-119 km/hour), cyclonic storms (60-90 km/hour), Deep depression (51-59 km/hour), Depression (32-50 km/hour) (IMD, 2010).

world (Murty and El Sabh, 1992). The reasons for this disproportional large impact of storm surges on the coast of Bangladesh were reported[16] to be the following:

- The phenomenon of recurvature of tropical cyclones in the Bay of Bengal,
- Shallow continental shelf, especially in the eastern part of Bangladesh[17],
- High tidal range[18],
- Triangular shape at the head of the Bay of Bengal[19],
- Almost sea-level geography of the Bangladesh coastal land,
- High density of population and coastal protection system.

The Meghna estuarine region is the area where most of the surge amplifications occur. UNDP has identified Bangladesh to be the most vulnerable country in the world to tropical cyclones (UNDP, 2004).

Inundation due to storm surges generated by severe cyclones pose a threat to lives and (their) properties in the coastal region. Historical (time series) records of storm surge height are scarce in Bangladesh. However, existing literature indicates a range of 1.5 to 9.0 meter high storm surges during various severe cyclones. Storm surge heights in excess of 10 m or even more are also not uncommon with an occasional reference in the literature. For example, the Bakerganj cyclone had the greatest reported surge height of 13.6 m in 1876 and another cyclone had the height of 10 m in 1970 (SMRC, 2000).

A surge can be even more devastating if it makes a landfall during high tide. In general, it has been observed that the frequency of a wave (surge plus tide) along Bangladesh coast with a height of about 10 m is approximately once in 20 years, and the frequency of a wave with a height of about 7 m is approximately once in 5 years (MCSP, 1993).

In addition to these exceptional surges, waves caused by wind also occur; the dimensions of which depend on wind speed and direction, water depth, and duration of wind blowing over

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[16] For example, see Ali, 1999 .

[17] The coast line of Bangladesh is characterized by a wide continental shelf, especially off the eastern part of Bangladesh. This wide shelf amplifies the storm surges as the tangential sea-level wind-stress field associated with the tropical cyclone pushes the sea water from the deep water side onto the shelf. Being pushed from the south by wind stress, the water has no place to go but upwards; which is the storm surge.

[18] Records indicate 7-8 m high tide in the Sandwip Channel.

[19] The triangular shape at the head of the Bay of Bengal helps to funnel the sea water pushed by the wind towards the coast and causes further amplification of the surge.

the bay. It has been observed that wind induced waves of up to 3.0 m height may occur under unfavorable conditions in the coastal regions (MCSP, 1993).Table 1 presents surge inundation characteristics for cyclones of varying strength in Bangladesh as documented by the MCSP (1993) (see Table 1).

According to the IPCC AR4, storm surges and related floods are likely to become more severe with increases in intense tropical cyclones in future (IPCC, 2007). For the Bay of Bengal, a study using dynamical models driven by RCM[20] simulations of current and future climates have shown large increases in the frequency of highest storm surges despite no significant change in the frequency of cyclones (Unnikrishnan et al, 2006).[21] Hence, from a practical perspective vulnerability of Bangladesh to cyclones/ storm surges may increase even more as a result of climate change.

3. Methodology and Estimates for Damage and Adaptation Cost

In order to estimate potential damage and cost of adaptation to potential intensification of storm surges, this analysis has followed a 5-step procedure:

1. Demarcation of potential vulnerable zone and projection of inundation depth from storm surges;
2. Identification of critical impact elements: assets and activities exposed to inundation risk;
3. Computation of potential damage and loss for a 10 year return period cyclone/ storm surges out to 2050;
4. Identification of existing adaptation measures and quantification of changes that will be required in a changing climate;
5. Costing of adaptation.

3.1 <u>Demarcation of vulnerable zone and storm surge height:</u>

This analysis has considered a sea level rise of 27cm[22], increased wind speed (10%)[23] and landfall during high tide[24] to approximate cyclones in a changing climate by 2050.

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[20] Regional Climate Model
[21] For North Indian Ocean by 2100, a recent projection by Emanuel has indicated an increase in intensity of tropical storms, as measured by percent change in landfall power, for the Model for Interdisciplinary Research on Climate: MIROC (UN and World Bank, 2010).
[22] Source: UK DEFRA (2007).
[23] World Bank (2010).

The inundation effect of storm surges has been assessed using the two-dimensional Bay of Bengal Model recently updated and upgraded under the Comprehensive Disaster Management Program of Bangladesh (UK DEFRA 2007). The model is based on Mike 21 hydrodynamic modeling system, and its domain covers the coastal region of Bangladesh up to Chandpur and the Bay of Bengal up to 16º latitude. A detailed description of the model has been provided in Appendix 1.

For approximating a condition of cyclones in Bangladesh without climate change, cyclone tracks of all major 19 historical cyclones making landfall in Bangladesh during 1960 and 2009 (For details, see Appendix 2) have been used with corresponding observed wind and pressure fields. For simulating the storm surge and associated flooding, the Bay of Bengal model was then applied to generate the extent and depth of inundation without climate change. Resulting inundation map is based on the maximum level of inundation at every grid points of the model.

For approximating cyclones in a changing climate by 2050, potential cyclone tracks have been selected simulating 19 major cyclones making landfall in Bangladesh during 1960-2009, and the affected coastal regions. From the historical cyclone simulations, it has been observed that the Sunderban coast, the southwestern coast (Sunderban to Patuakhali), the Bhola and Noakhali coast in the Meghna Estuary and eastern coast (Shitakunda to Bashkhali) are covered by 1974, 1988, 1991 and 2007 cyclone tracks. In order to include the Sandwip coast and the part of the Noakhali and Chittagong coasts at the central region of the Meghna Estuary, an artificial track has been generated. Figure 1 shows the five cyclone tracks considered for the determination of inundation zones due to climate change induced storm surges (see Figure 1).

In order to determine potential future inundation zones in a changing climate by 2050, the storm surge model was run for the above mentioned five cyclone tracks covering the whole coastal area, incorporating a sea level rise of 27cm, 10% increase in wind speed, and landfall of the cyclones during high tide. Once again, inundation maps for 2050 with climate change have been generated based on the simulation results taking into potential intensification of cyclone induced inundation (See Figure 2).

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[24] Since scientific evidence to date is pointing towards an increase in frequency of intense cyclones in Bay of Bengal, probability of a potential landfall during high tide will also increase.

Resulting area estimates indicate a potential 69% increase in the vulnerable zone with more than 3 m inundation depth and 14% increase in the vulnerable zone with more than 1 m inundation depth with climate change (See Table 2).

3.2 Identification of critical impact elements exposed to inundation risk:

In order to identify critical impact elements exposed to inundation risk, geographic Information System (GIS) software has been used to overlay the best available, spatially-disaggregated data on current assets and activities in the coastal zone of Bangladesh, with the inundation zones projected for 2050 - with and without climate change.

Impact elements considered in this analysis include: housing - by building material type, education institutions, growth centers, mills/ factories (large scale), national highways, regional highways, feeder roads-type A, feeder roads-type B, bridges, power plants, power transmission lines, deep tubewells, mosques, temples, historical places and tourist destinations. Relevant exposure surface dataset for land area, population, poverty map, and agriculture extent were also used. Exposure surface data were collected from various public sources, such as Bangladesh Railways, Bangladesh Water Development Board, Local Government Engineering Department (LGED), Center for Environmental and Geographic Information Services (CEGIS), Public Works Department, Roads and Highways Department, Water Resources Planning Organization and the World Bank. Estimates of exposure for each indicator were calculated by overlaying the inundation zone with the appropriate exposure surface dataset.

For the exposure grid surfaces, three GIS models were built for calculating the exposed value. Exposure indicators, such as land surface, agriculture extent, road infrastructure and railways were measured in square kilometers or kilometers. The values of the pixels in population surfaces represent number of people, therefore the exposure is calculated by multiplying the exposure surface[25] with the inundation zone and then summing up by multiplying grid count and value. Exposure estimates of other impact elements were counts.

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[25] Population density of the lowest administrative unit, *Thana*, has been used in the computation.

Presently, our estimates indicate that 8.06 million inhabitants in coastal Bangladesh are vulnerable to storm surge related inundation depth of more than 1m; the number will increase 68% with population growth by 2050 even without climate change, and by 110 % by 2050 in a changing climate in the absence of further adaptation measures. Population exposed to inundation depth of more than 3m will increase by 67% from current trends to the 2050 scenario with climate change by 2050 (See table 3).

3.3 Potential Damage and loss from a 10 year return period cyclone/ storm surges in a changing climate by 2010:

Exposure estimates of critical impact elements derived from geographic overlays provide the basis for estimation of potential damage and loss from a 10 year return period cyclone induced storm surges in a changing climate by 2050. In addition, the assessment of exercise of potential damage and loss drew on the following:

a. Projection of growth in coastal population (1% per year) and GDP growth (6%-8% per year);

b. Experience of Bangladesh during the most recent devastating cyclone Sidr in 2007.[26] (The extent of storm surge inundation during Sidr was 8.7% more than an average inundated area of a historical 10 year return period cyclone of Bangladesh.[27] Accordingly, adjustment was made in computation of damage);

c. At present, average inundation area from one 10 year return period cyclone covers 26% of the total vulnerable area and inundation from one future 10 year return period cyclone (expected to be more intense) is likely to cover 43% of the total vulnerable area;

d. All estimates have been adjusted for 2009 price level as per 18% increase in the GDP deflator during 2007 and 2009.

In this analysis, ***damages*** include complete or partial destruction inflicted on assets (assets not portable as well as stock), and ***losses*** refer to the flows of goods and services that will

[26] It has been estimated that a cyclone like Sidr (wind speed of 223 km / hour) has a return period of 10 years in Bangladesh based on 21 major cyclone events from 1876 to 2009.
[27] The extent of inundation includes area with inundation depth of 1 m or more.

not be produced or rendered due to disasters. *Losses* also include disaster-induced increases in costs incurred for continuation of essential services.

Potential Human Casualty and Injury:

Approximately 3.45 million coastal inhabitants of Bangladesh were exposed to storm surge related inundation during Sidr, 2007. Post disaster assessments indicate 3,406 human casualties and 55,282 injuries. Although cyclone shelters saved thousands of lives, focus group interviews with the residents of cyclone-affected areas revealed that a large section of population was reluctant to move to cyclone shelters even during emergency. Distance from the homestead, difficult access to shelters, unwillingness to leave livestock behind unprotected, scarcity of sanitation facilities, lack of user friendly facilities for women, and overcrowded conditions in shelters are the primary reasons behind their reluctance. It has been estimated, under the assumptions of Bangladesh attaining replacement fertility rate by 2021 and an average 1.0% annual growth in coastal population per year between 2001 and 2050, a total of 5.34 million and 10.04 million coastal inhabitants will be exposed to the risk of a 10 year return period cyclone induced storm surge without and with climate change respectively by 2050. Extrapolation with the ratio of casualty to exposure (0.001), and the ratio of injury to exposure (0.016) experienced during Sidr indicates a risk of additional human casualties with an expected magnitude of 4,637, and an expected 75,268 injuries from a 10 year return period cyclone by 2050 as a consequence of climate change, in the absence of improved defensive measures.[28] Improved defensive measures would contribute to reduced fatality and injury risk from increased exposure without climate change, in addition to the additional risk engendered by climate change.

Attaching a monetary-equivalent value to these risks that can be combined with and compared to risks of financial damage and loss is enormously difficult. The most appropriate measure of the benefit from reduced risk of fatality is the "Value of Statistical Life" (VSL), which seeks to estimate the monetary equivalent of improved well-being for individuals from reduced mortality risk. In reality, VSL should reflect the context of the risk – for

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[28] Estimated human casualty is 5,274 without climate change by 2050, and in a changing climate the estimate is 9,911. Estimated injury is 85,609 without climate change by 2050; and in a changing climate the estimate is 160,877.

example, the risk of sudden fatality from an accident would be different from the risk of reduced future life span from long-term pollutant exposure.

Unfortunately, VSL values are all but non-existent for developing countries, so it is necessary to make rough approximations based on VSL estimates for developed countries, in particular the USA. In this analysis a VSL of Taka 15.5 million (approximately $0.2 million) has been used. This estimate for Bangladesh has been computed by updating the central estimate of VSL of USA., $7.4 million ($2006) available from the EPA with price adjustment between 2006 and 2008 and GDP differential between USA and Bangladesh[29]. Multiplying this figure by the expected value of the increased number of lives at-risk from a 10 year return period cyclone under climate change, an increased economic damage of $1.03 billion from greater fatality risk has been estimated.

To calculate the economic damages from increased injury risk, a crude lower-bound estimate based on the WHO figure for cost per outpatient visit at a secondary hospital visit in Bangladesh, $4.86 (Cropper and Sahin, 2009) has been adopted. This yields a total economic damage from increased injury risk of $0.352 million. This estimate, however, does not include any value of lost production and income from injury, or the more subjective losses of well-being resulting from being injured or incapacitated.

The balance of this section focuses on sectors experiencing high monetary damage and loss during Sidr, 2007 – namely housing, education, agriculture, non agriculture productive sector and infrastructure: roads, power, coastal protection. (See Box 1).

Potential damage in housing:

The housing sector experienced maximum damage and loss during the Sidr cyclone in 2007 and accounting by housing/ dwelling type further indicates that "*semi-pucka*"[30] houses, "*kacha*"[31] houses and "*jhupris*"[32] were the predominant categories of damage.

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[29] GDP Deflator 2008/ GDP Deflator 2006= 1.1; Per Capita USGDP ($ 2008, PPP) = 46,716 and Per Capita Bangladesh GDP ($ 2008, PPP) = 1,334 have been used in this computation.

[30] Housing with foundation made of earthen plinth or brick and concrete, walls made of bamboo mats, CI sheet and roof made of CI sheet with timber framing

[31] Housing with foundation made of earthen plinth with bamboo, walls made of organic materials and roof thatched made of straw, split bamboo etc.

Analysis of the 2001 census data in Bangladesh reveals only 2.23% of rural households with $470 per capita annual income[33] or more could afford a "*pucka*" house, a brick house with a concrete roof in 2001. However, Bangladesh is currently experiencing and expecting 6%-8% GDP growth per year for the coming decades. It is expected that approximately 98% of the households will be living in brick houses by 2050, even after accounting for inflation. This in turn implies a significant reduction in housing damages and a substantial increase in household asset damages during cyclones over time.

Projection of population in coastal regions by 2050 without and with climate change indicates that an additional 7.08 million inhabitants (i.e. an additional 1.45 million houses - under the assumption of an average family size of 4.89) will be exposed to significant damages from storm surges in a changing climate. Accounting for the larger areal extent of a cyclone under climate change an additional 1.6 million houses are projected to be damaged from a 10 year return period cyclone due to climate change.[34] The size of a standard house in Bangladesh is assumed to be 400 sq feet with 2,000 sq feet of brick wall surface and approximate value of household assets is $2,143 (Tk 150,000). Under the assumption that on average 50% of the walls and 50% of the household assets will be damaged during inundation, **re-plastering the houses will cost $229 million (at Tk 10/ sq. ft) and an estimate of household content damage is expected to be approximately $1.718 million**.

Potential damage in education infrastructure:

The population projection indicates that with an additional 7.08 million inhabitants in coastal Bangladesh exposed to storm surges in a changing climate by 2050; the expected exposure of primary school students will be 456,690 (in 2,283 primary schools) and that of secondary school students will be 312,957 (in 2,086 secondary schools).[35] Accounting for the larger

[32] In Jhupris, ceiling, which is less than four feet, is made of cheap construction materials straw, bamboo, grass, leaves, polythene, gunny bags, etc.

[33] Monthly income Tk 2,750 per capita.

[34] It has been assumed that inundation depth of 1m or less will have negligible impact.

[35] These estimates are based on the following assumptions: (a) ratio of children of primary school age to total population will be 6.45% and the ratio of secondary school children to total population will be 4.42% by 2050, (b) Bangladesh will attain 100% enrollment in primary schools and 70% enrollment in secondary schools by 2050, which is the current rate of school enrollment of Brazil, Lebanon, Malaysia, Uruguay –countries with per capita income similar to projected income for Bangladesh in 2050, (c) the standard capacity of a primary school is 200 students and a similar size school can accommodate up to 150 secondary students in Bangladesh.

areal extent of a cyclone under climate change an additional 4,840 primary and secondary schools are projected to be damaged in a 10 year return period cyclone. According to the standard specification of the LGED, the size of a standard school in Bangladesh is approximately 160 sq m and its contents are worth $2,857 (Tk 200,000). Under the assumption of expected average 50% damage to walls and contents during inundation, the **estimated** (total) **damage[36] in a changing climate is $8.96 million.**

The estimated total loss (cost of making alternative arrangements until the damaged facilities are ready for use again) **is $0.82 million**.

Potential damage in agriculture:

Computation of potential damage and loss in the agricultural sector focuses on likely impacts on crop production, livestock and fishery.

In the case of cereal production, this analysis is restricted to *Aman*, *Aus* and *Boro* variety of rice, which are the main cereal crops of Bangladesh. In a changing climate, these crops are expected to incur significant damage due to the expansion of storm surge inundation area. The following parameters have been used for their quantification of potential damage (See Table 4).

Historical records indicate the probability of Bangladesh being hit by a tropical cyclone in a post-monsoon season (67%) is higher than that in a pre-monsoon season (33%). The cropping calendar, planting - harvesting dates, of *Aman*, *Aus*, and *Boro* are different[37]. As a result, these crops are exposed to varying risk of storm surge inundation, and this difference has been taken into account in the damage estimation. Under the assumptions that cereal production will grow at the annual rate of 2.4% (observed annual growth rate during 2001-2007) in the future and there will be 50% damage in the yield if a 10 year return period cyclone strikes, the **estimated additional damage (primarily loss) for cereal is $788.83 million in a changing climate by 2050.**

Sidr (2007) has inflicted a damage of $19.3 million to livestock and losses and damages of $6.7 million to the fishery. Under the assumption that livestock and the fishery will grow at

[36] includes damage to the walls and therefore cost of re-plastering and damage of contents.
[37] *Aman* grows in monsoon, *Aus* grows in pre-monsoon and *Boro* grows in post-monsoon season.

the annual rate of 3% and 6% respectively (observed annual growth rate during 2001-2007) in the future, the **estimated additional damage and loss for the livestock and fishery are $55.62 million and $66.36 million, respectively, in a changing climate by 2050.** [38]

Potential damage in non- agricultural productive sector:

In 2007, Sidr triggered a total damage of $51.4 million to the non-agricultural productive sectors. In 2007, non-agricultural productive sectors (industries including small and medium size enterprises, commerce, tourism etc.) contributed to 82% of GDP of Bangladesh (World Bank, 2009). Economic structure of Brazil, Lebanon, Malaysia, Uruguay and South Africa - countries with present per capita income similar to the projected per capita income of Bangladesh indicates that the share of the non-agricultural productive sectors is likely to increase in Bangladesh by another 11% by 2050. GDP of Bangladesh is expected to increase 21.48 times between 2007 and 2050. Storm surge induced inundation area under Sidr, an average historical 10 year return period cyclone and a 10 year return period cyclone in a changing climate by 2050 are 588,512 hectares, 541,190 hectares and 1,017,008 hectares respectively. Combination of all the above implies **an additional potential damage of $87.9 million in a changing climate, by 2050**.[39]

The estimated potential additional loss is $1.084 billion.

Potential damage in road infrastructure:

In the case of storm surges, past experience suggests that roads are partially damaged when surge height/ depth of inundation is less than 1m, and fully damaged when the depth of inundation exceeds 1m. Under the assumption of 25% growth in road network between 2005 and 2050, geographic overlays of the road network and inundation zones indicate 3,998 km roads will be exposed to inundation depth of less than 1m and 8,972 km roads will be exposed to inundation depth of more than 1m by 2050 even without climate change. With climate change, the road exposure to less and more than 1m inundation depths will increase to 10,466 and 10,553 km respectively. Accounting for the larger areal extent of a

[38] Estimated damage to livestock is $63.26 million without climate change, and $ 118.88 million with climate change-by 2050. Estimated damage to fishery is $75.48 million without climate change, and $ 141.84 million with climate change-by 2050.

[39] Estimate of damage including loss but without climate change is $1.33 billion.

cyclone under climate change an additional 3,461 km of roads is projected to be partially damaged and 2,205 km fully damaged from a 10 year return period cyclone. Repair costs of Taka 1 million and Taka 2 million respectively in case of partial and full damage from the post damage loss assessment exercise of Sidr in 2007 have been applied in the computation. The post assessment of Sidr (2007) has further suggested that damages to bridges, culverts etc. were 1.13 times the damages to roads. The combination of all these damages indicates **an additional damage of $239.5 million to roads, bridges, culverts etc. in a changing climate by 2050**[40].

The estimated potential additional loss in a changing climate is $52.7 million.[41]

Potential Damage in power infrastructure:

In 2007, Sidr induced a damage of $8.2 million in the power sector of coastal Bangladesh. The projection of population indicates 1.53 times growth of coastal inhabitants in the coastal area between 2007 and 2050. The consumption of power in Brazil, Lebanon, Malaysia, Uruguay and South Africa -countries with the present per capita income similar to the projected per capita income of Bangladesh indicates per capita consumption of power is likely to increase 20 times in Bangladesh (and power infrastructure 5 times[42]) by 2050. Damages recorded during the Sidr (2007) coupled with the projection of the change in power infrastructure in the inundation areas (with and without climate change) indicates **an additional damage of $60.2 million.** [43]

The estimated potential additional loss is $150.0 million.

Potential damage in coastal protective infrastructure:

In the sixties, 123 polders and supporting infrastructure were constructed to protect low lying coastal areas against tidal flood and salinity intrusion in Bangladesh. In 2007, Sidr

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[40] Estimate of potential damages to roads, bridges, culverts etc. is $173.6 million by 2050 even without climate change, and the corresponding estimate with climate change is $413.1 million.
[41] Loss estimates have been computed using 22% ratio between loss and damage in post Sidr assessment.
[42] Experts of the Asian Development Bank working on Bangladesh power sector suggested this adjustment factor.
[43] Estimates of potential total damage without and with climate change are $239.1 million and $449.3 million respectively.

induced a damage of $70.3 million in the polders and related water regulators in coastal Bangladesh. Past experience has identified “overtopping” of an embankment of a polder to be the most important factor responsible for polder’s damage during cyclones.[44] Comparison of projected surge heights and heights of existing embankments of polders indicate an additional 15 polders are likely to be overtopped by 2050 in a changing climate,[45] and **the estimate of additional potential damage is $17.3 million**.

To sum up, Table 5 presents itemized additional potential damage and additional potential loss for an average 10 year return period cyclone induced inundation in a changing climate by 2050 without adaptation. **The estimates indicate if a 10 year return period cyclone (likely to be more intense than current cyclones with climate change) hits Bangladesh, additional potential damage is likely to be $2.437 billion and additional potential loss $2.123 billion** (See Table 5)**.**

3.4 <u>Mapping existing Coastal Protection in Bangladesh and gap analysis</u>:

Bangladesh has an extensive infrastructure such as polders, cyclone shelters, early warning and evacuation system to protect coastal regions.

a) *<u>Coastal Polders</u>*:

In the early sixties and seventies 123 polders, of which 49 polders are sea facing, were constructed to protect low lying coastal areas against tidal flood and salinity intrusion. Bangladesh Water Development Board (BWDB) maintains an extensive database of coastal polders, and it includes information on length, location, construction year and cost for each polder.[46] See Figure 3 for the lay out map of the costal polders (See Figure 3).

Geographic Information System (GIS) software has been used to overlay the best available spatially-disaggregated data on polders in the derived vulnerable coastal zone of

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[44] When water surge overtops an embankment, rapid and deep scours start to form on the country side slope of the embankment. The process rapidly weakens the structure and leads to its collapse.

[45] Computation has been explained in details in the next section.

[46] In addition, information on riverbank and shoreline protection and re-sectioning of embankment works has been extracted from the Coastal Embankment Rehabilitation Project (CERP) and South-Eastern Zone-Chittagong, South-Western Zone-Faridpur, Southern zone-Barishal maintained by the BWDB. It includes information on the ongoing projects, construction period and cost.

Bangladesh. Differences between the crest level of embankment of each polder and the inundation depths projected for 2050 - with and without climate change have been computed to identify polders likely to be overtopped by intensified storm surges in a changing climate and to quantify the potential extent of overtopping. The result indicates 26 interior polders and 33 sea facing polders in the coastal region will be overtopped in a changing climate by 2050.

b) *Foreshore Afforestation*:

In the past, foreshore afforestation scheme proved to be cost effective in dissipating wave energy, and in reducing hydraulic load on the embankments during storm surges[47], but Bangladesh has inadequate foreshore forests. At present, the total length of embankment of 49 sea facing polders is 957 km, of which only 60 km has forest belts; and in many areas the existing forest belt is degraded. Officials of the Department of Forests and experts of the Institute of Water Modeling (IWM) have commented on the successes, failures and sustainability of past foreshore afforestation measures. According to their recommendation, a minimum of 500 meter width of mangrove forest is required for protection of sea facing polders. In this analysis, existing length of coastal afforestation, between the coastline and polders, has been estimated from Google Earth using GIS methodology; and the gap between recommended 500 m wide mangroves and area-specific existing ones has been computed.

c) *Cyclone Shelters*:

At present, cyclone shelters in the coastal region of Bangladesh play a very important role in protecting human lives and livestock during cyclones[48]. Although the need for and use of

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[47] Benefit of foreshore afforestation was evident during the 1991 cyclone, Sidr (2007) and Aila (2009). It was reported that massive devastation to property and loss of lives during the 1991 cyclone, in Chokoria and areas around it, was primarily the result of virtual absence of mangrove forests along their coasts (BCAS). An in-depth study of the damages and losses inflicted by the Sidr (2007)has noted that even scattered and unplanned forestation on the foreshore of the embankments has substantially helped in breaking the velocity of storm surges (GoB, 2008).

[48] During the Sidr (2007), 15% of the affected population took refuge in cyclone shelters; and it has been estimated that cyclone shelters saved thousands of lives.

cyclone shelters is expected to decline if polders are raised adequately and maintained properly, cyclone shelters will still be needed in the following cases:

a) a number of smaller yet inhabited islands may turn out to be cost ineffective to be protected by polders. For those islanders, cyclone shelters will remain a vital necessity;

b) in localities where projected inundation depth exceeds 3 m and inhabitants of single storied houses would need evacuation.

The total number of additional cyclone shelters required will depend on, and have been calculated from the population likely to be exposed to inundation depth of more than 3m from accentuated storm surges in a changing climate and the capacity of existing cyclone shelters[49]. See figure 4 for location of existing cyclone shelters[50] (see Figure 4).

d) *Early Warning and evacuation System*:

In the past, the early warning and evacuation system of Bangladesh has played an important role in saving lives during cyclones. In general, Bangladesh Meteorological Department issues forewarning for any impending cyclone and storm surge; newspapers, television channels and radio stations broadcast the warning; and the local government administration and the local Cyclone Preparedness Program (CPP) volunteers run by the Red Crescent Society lead the evacuation of the people[51].

Although the overall quality of forecasting cyclones and storm surges has improved over the years, the general consensus is that there is scope for further improvement. At present, the forecast of an area likely to experience a storm surge is usually over-estimated and delineated over a large section of the coastal zone, which can lead to unnecessary repetitive evacuations and loss of popular faith in the early warning system. More precision in forecasting, especially in the landfall location and location-specific inundation depth, is

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[49] Data and information on existing cyclone shelters are from the IWM and CEGIS, compiled from the Public Works Department (PWD), LGED, Education Engineering Department, Red Crescent Society, donor agencies, NGOs and local experts.

[50] Many of the existing cyclone shelters are in dilapidated condition. In a 2004 survey, CEGIS found that more than 65% of the shelters had no provision for the special needs of women; almost no facility was user friendly for people with disabilities; and 80% had no provision for livestock.

[51] Red Cross in Bangladesh

required. The Red Crescent Society officials, CPP volunteers and residents of major cyclone affected areas also pointed out the urgent need for broadcasting the warnings in the local dialects[52] and the need to raise awareness for the importance of timely evacuation. According to the CPP volunteers and residents of cyclone-affected areas, in the past, a significant number of fatalities could have been avoided had people not ignored/ resisted evacuation until the last minute.

Experts in the Meteorological Department and the Red Crescent Society were consulted on ways to improve the cyclone early warning and evacuation systems, and their recommendations on improvement of cyclone modeling, upgrading of equipment, training of personnel, and awareness raising programs have been considered for costing in this analysis.

3.5 Costing of Adaptation:

In this paper, focus of adaptation is to avoid further damage from storm surge inundation due to climate change. Hence, costing of adaptation relates to increase in inundation area and inundation depth for a 10 year return period cyclone in a changing climate. The cost of adaptation to an accentuated storm surge has been computed only for adaptation measures relevant to Bangladesh. Hence, the adaptation measures considered in this analysis are the following:

(i) Height enhancement of coastal polders;
(ii) Afforestation to protect sea-facing polders;
(iii) Multipurpose cyclone shelters;
(iv) Cyclone-resistant private housing;
(v) Strengthening the early warning and evacuation system;

Height enhancement of coastal polders:

For polders identified as “likely to be overtopped”, cost of height enhancement to avoid overtopping has been computed as follows:

[52] Illiterate poor people often experience difficulties in understanding sophisticated Bengali.

(a) Differences between the crest level of embankment of each polder and the storm surge level projected for 2050, with and without climate change have been computed to quantify the potential extent of overtopping of an embankment.

(b) The amount of earth needed for this purpose has been derived from engineering designs. Current local price for earthwork from the BWDB (Tk 109.96/ m^3 if collected from 300m to 1km distance; and Tk 133.44/ m^3 if collected from 1km to 5 km distance) has been used in the estimation. See appendix 4 for details.

(c) Compaction and turfing cost (Tk 7.07 per sq meter), used by the BWDB, have been used to derive total related costs.

(d) As "toe erosion" of the embankment of polders is a serious problem in Bangladesh, some sections of the polders would need hard protection. Cost of such hard protection has been computed using the rate for using cement concrete (CC) blocks with sand filters and geo-textile, Tk. 224,100/meter - the locally available technology, ranked as the best technology so far. [53]

(e) Height enhancement of embankments will require more land for strengthening the bases. For sea facing polders, foreshore land is usually government owned or *khas* land. For interior and marginal polders, however, neighboring land is often under private ownership. Hence, requisition of such land would involve compensating the landowners, and in some cases, their rehabilitation cost. This cost is included in the estimate.

(f) As per standard procedure of operation and maintenance (O&M) cost estimation, a fixed percentage (2%) of capital investment has been assumed to be the regular maintenance cost.

The result from this algorithm is in a projection of an adaptation cost of $892 million for coastal polders (26 interior polders and 33 sea facing polders) in a changing climate. Table 6 summarizes the projected cost(s) for "interior" and "sea facing polders" without and with climate change (See Table 6).

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[53] In order to protect minor erosion, the use of vetivera grass is often recommended. However, past experience with the vetivera grass option is not very encouraging. The growth and survival rate has been poor along the Chittagong belt, apparently due to a combination of factors including high salinity of the soil. As the soil along the south-western coast is even more saline, it's not clear whether vetiver is the right option for Bangladesh. However, in other regions Vetivera grass may work, and cost of the vetivera plantation is Tk 70700/ ha.

See Appendix 5 for itemized cost estimates for sea facing and interior polders.

Coastal afforestation measures:

As mangrove forests exist along some segments of the coastline of Bangladesh, only the additional cost of further afforestation is computed. At present, estimation from Google Earth using GIS methodology indicates 897 km length[54] of existing sea polders would require mangrove forests for protection. This in turn implies that for a 500m wide protective forest belt, as recommended by the IWM officials, a foreshore area of 448.5 sq. km (= 897km x 0.5 km) would need afforestation. At the current cost of afforestation of $168,000 / sq km[55], the projected cost is US $ 75 million.[56]

Multipurpose Cyclone Shelters:

Current consensus is in favor of multipurpose cyclone shelters with elevated space for livestock and overhead water storage, which can serve as a primary school / office space at times other than an emergency.

In coastal Bangladesh, 8,059,185 people were exposed to storm surge related inundation depth of more than 3m in 2001. In 2050, with a projected growth of population[57], 13,571,667 inhabitants will be exposed to storm surge related inundation depth of more than 3m even without climate change. In a changing climate with the projected expansion of the inundation zone as well as an increase in inundation depth coupled with a projected population growth, an additional 9,122,762 inhabitants will be exposed to a similar inundation risk. In estimation of the costing of multipurpose cyclone shelters, current cost and capacity of cyclone shelters have been collected from the World Bank funded projects. At present, a World Bank-funded multipurpose cyclone shelter, under-construction, with provisions for 1,600 people costs $214,000. In order to accommodate 9,122,762 inhabitants

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[54] At present, total length of 49 sea facing polders is 957 km, of which only 60 km has forest belts.
[55] The cost of afforestation per hectare used is from the CERP II project.
[56] With the addition of 500 m forest belt, requirement to enhance the elevation of embankments of sea polders may reduce by 30 cm in specific locations.
[57] Population for the coastal region in Bangladesh 2050 has been projected under the assumption that Bangladesh will attain replacement fertility rate by 2021, and 68.4% growth of coastal population between 2001 and 2050.

exposed to inundation risk due to climate change, additional 5,702 multipurpose shelters would be required at the estimated cost of $ 1.2 billion.[58]

Cyclone resistant private housing:

Inspection reveals that in the past cyclones, the housing sector has accounted for a significant portion of damage. For example, during the severe cyclone of 2007, Sidr, damage to the housing sector has been estimated to be $839 million accounting for 50% of total damages to the economy (GoB, 2008). In the coastal region, houses can be made cyclone resistant when suitable designs and building codes are followed. Upon consultation with local Architects and Civil Engineers, this analysis is recommending a revolving fund of $200million(for subsidizing construction material and extending subsidized housing credit)[59]to encourage the construction of brick-built houses with concrete roofs (on stilts, if necessary) in accordance with the proper building codes. It is expected that these houses, in turn, will serve as single/ multi-family cyclone shelters during storm surges.

Strengthening the early warning and evacuation system:

Focus group interviews were conducted with the experts of the IWM, Bangladesh Meteorological Department, the Red Crescent Society and residents of recent cyclone-affected areas on the requirements for strengthening the cyclone early warning and evacuation system in Bangladesh. Experts of the IWM emphasized the need for improved location-specific inundation projection; officials of the Bangladesh Meteorological Department emphasized the need for more accurate forecasting of cyclone landfall location and inundation depth; and the officials of the Red Crescent Society, CPP volunteers and residents of past cyclone affected areas emphasized the need for raising awareness to promote proper and timely evacuation.

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[58] In construction of cyclone shelters, selection of sites and proper accessibility should be considered with caution. Some of the cyclone shelters in the past were sited and designed inappropriately.

[59] Subsidy systems should always be designed with caution so that misuse of subsidies can be avoided.

For improvement in location-specific inundation projections (basis of forecasting and adaptation planning), the IWM has pointed out the need for the following:

Items	Area	Per unit cost	Estimated Total Cost (in millionUS$)
Topographic Survey LIDAR & RTK GPS Survey	23,500 sq km	US$200/ sq km	5
Mathematical Modeling			3
Total			**8**

Officials of the Meteorology Department have identified the following requirements for strengthening the cyclone early warning system: a) modernization of existing 35 observatories, b) establishment of additional 30 observatories, c) establishment of 5 new radio stations, d) modernization of existing workshop and laboratory of the BMD, and e) development of a training institute. Approximate costs of these requirements are as follows:

	Items	Estimated Cost in MillionUS$
1.	Modernization of the existing 35 (thirty five) observatories of BMD	6.00
2.	Establishment of additional 30 (thirty) modern observatories of BMD at different locations of Bangladesh	12.00
3.	Establishment of 5 (five) new Radio Sonde[60] stations of BMD at different locations of Bangladesh	2.00

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[60] The ***radiosonde*** is a balloon-borne ***instrument platform*** with radio transmitting capabilities. It contains instruments capable of making direct ***in-situ*** measurements of air temperature, humidity and pressure with height, typically to altitudes of approximately 30 km. These observed data are transmitted immediately to the ground station by a radio transmitter located within the instrument package. The ascent of a radiosonde provides an indirect measure of the wind speed and direction at various levels throughout the troposphere. Ground based radio direction finding antenna equipment track the motion of the radiosonde during its ascent through the air. The recorded elevation and azimuth information are converted to wind speed and direction at various levels by triangulation techniques.

4.	Modernization of existing workshop and laboratory of BMD	7.00
5.	Development of existing Training Institute facilities of BMD	3.00
Total		**30.00**

Operational & Maintenance cost:

	Items	**Estimated Cost in Million US$ per year**
1.	Operational cost of existing 3+additional 5 RS observatories for per year	2.00
2.	Operational cost and maintenance cost of existing 35+additional 30 observatories for per year	3.00
	Total	**5.00**

The current analysis has identified 19 coastal districts as vulnerable to accentuated storm surge related inundation. The Red Crescent Society has recommended an annual awareness promotion program of Tk 10 million (= US$ 142, 857) per district along with a Tk 20 million (= US $ 285,714) overhead cost for the Center, summing to a total cost of US$ 3 million.

On further Infrastructural Investment:

As strong structural protection measures, such as polders, are being suggested in this analysis, it reduces the need for making infrastructure (roads, bridges etc.) resilient to storm surge related inundation, except in regions where there will not be any full-scale structural protection, for example in islands which are not and will not be protected by polders. However, it should be noted that in these unprotected islands, there is not much infrastructure to protect.

To sum up, Table 7 presents the itemized estimated cost of adaptation for storm surge induced inundation in Bangladesh. The estimates indicate that an adaptation investment up to $2.462 billion by 2050 would be needed to implement the measures discussed, even without climate change. The estimate of the additional investment necessary to cope with climate change is $2.407 billion with an annual recurrent cost of more than $50 million (See Table 7).

Bangladesh is a cyclone-prone country. Cyclones hit the coastal regions of Bangladesh every year. History of cyclones indicates that each year, probability of a Super Cyclonic Storm (wind speed greater than 220 km/hour), a very severe cyclonic storm (wind speed of 119-220 km /hour), and a severe cyclonic storms (wind speed of 90-119 km/hour) are at least 10%, 20% and 30% respectively. Current scientific projections point towards more intense cyclones in a changing climate. Projection of fatalities and injuries alone from one super cyclonic storm out to 2010 in a changing climate indicates a conservative benefit estimate of $1.03 billion. Hence, investment of $1.24 billion towards early warning & evacuation systems and emergency shelters is well worth considering as these will protect lives from all severe cyclones, which are typically frequent in Bangladesh, in addition to the super cyclones. Comparison of the financial damage and loss projection of $4.257 billion with the estimate of adaptation cost of $1.168 billion further reinforces the case for investment in embankment enhancement, foreshore afforestation and cyclone resistant housing in coastal Bangladesh.

4. Conclusion

The scientific evidence indicates that climate change will aggravate storm surge-related inundation for two reasons. First, surges will be elevated by a rising sea level as thermal expansion and ice cap(s) continue to melt. Second, a warmer ocean is likely to intensify cyclone activity and thus heighten storm surges. The destructive impact of storm surges will generally be greater when the surges are accompanied by strong winds and large onshore waves. Larger storm surges threaten greater future destruction, because they will increase the depth of inundation and will move further inland - threatening larger areas than in the past. This scientific evidence points to the need for greater disaster preparedness in countries vulnerable to storm surges.

At present, systematic studies of storm surge patterns in the future, location-specific potential damage and adaptation alternatives are scarce in developing countries; this research is an attempt to narrow this gap. In this analysis, the vulnerability of coastal areas in Bangladesh, a tropical cyclone hotspot, to larger storm surges and sea-level rise in a changing climate by 2050 has been assessed. Hydrodynamic models have been used to delineate future inundation zones and location-specific inundation depths associated with 27 cm sea-level rise and 10 percent intensification of wind speed from global warming. After estimating future inundation, geographic overlays have been used to identify coastal populations, settlements, infrastructure and economic activity at risk of inundation. Potential damage from a 10 year return period severe cyclone has been estimated. Cyclones hit the coastal regions of Bangladesh almost every year and cyclone risk spans the entire coastline; as a result Bangladesh has developed an extensive infrastructure such as coastal polders, cyclone shelters, early warning and evacuation system to protect the coastal region. The changes in the protective infrastructure that will be required in a changing climate have been quantified and the cost of adaptation to the future climate (2050) as well as current adaptation deficit has been computed.

The storm surge-induced inundation area estimates indicate a potential 69% increase in the vulnerable zone with more than 3m inundation depth and 14% increase in the vulnerable zone with more than 1m inundation depth with climate change by 2050. At present, a 10-year return period cyclone with an average wind speed of 223 km/ hour (as recorded during the cyclone Sidr, 2007) covers 26% of the vulnerable zone; estimates of this study indicate that a similar cyclone will be more intense with global warming and is likely to cover 43% of the vulnerable zone by 2050. The post disaster damage and loss estimates revealed the most recent 10 year return period cyclone in Bangladesh (eg Sidr in 2007) caused a financial damage and loss of $1.67 billion. The projection of damage reported in this paper suggests a 10-year return period cyclone out to 2050 will result in an additional financial damage and loss of $4.560 billion[61] in a changing climate. In addition, a conservative estimate of monetized loss from additional deaths and injuries is $1.03 billion.

At present, Bangladesh has 123 polders, an early warning & evacuation system and more than 2,400 emergency shelters to protect coastal inhabitants from tidal waves and storm surges. Yet, estimates point out that currently Bangladesh has an adaptation deficit of $2.462 billion. It has been further estimated that in a changing climate by 2050, 59 polders will be overtopped during storm surges and another 5,500 cyclone shelters (each with the capacity of 1,600 people) will be needed. The estimate of additional investment necessary to

[61] of which damage is $2.437 billion and loss is $2.123 billion.

cope with climate change is $2.407 billion with an annual recurrent cost of more than $50 million. Among the adaptation alternatives, polders, foreshore afforestation, multi-purpose cyclone shelters, cyclone-resistant private housing and further strengthening of the early warning & evacuation system have been taken into consideration.

The UNDP has identified Bangladesh as a tropical cyclone hotspot. Cyclones hit the Bangladesh coast every year, and on average a severe cyclone (wind speed of 90 – 119 kmph) strikes Bangladesh every three years. The vulnerability of Bangladesh may increase even more as current scientific evidence points towards a probable increase in the frequency of intense tropical cyclones in the Bay of Bengal. The estimates reported in this paper indicate that the cost of addressing current cyclone/ storm surge hazards is significant in Bangladesh and compounded by the fact that the country has an outstanding adaptation deficit. The comparison of even a conservative damage estimate from a single 10-year return period cyclone with the adaptation cost indicates the incremental cost of adapting to climate change by 2050 is small compared to the potential damage[62], which strengthens the case for rapid adaptation. [63]

The climate is expected to change gradually; hence required investments for adaptation can be phased. The itemized adaptation cost estimates provided in this paper could help spur the Government of the People's Republic of Bangladesh to develop location-specific coastal adaptation plans now in order to avoid future losses. Ratios of location-specific potential damage[64] and adaptation cost can be of use for prioritizing investments and undertaking them sequentially, as resources permit.

For the international community, this paper presents a detailed bottom-up methodology to estimate potential damage and adaptation cost to intensified storm surges in a changing climate. The approach integrates information on climate change, assets and activities at risk, growth projections, likely damage and cost estimates.

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[62] This comparison is a conservative one as damages from more frequent but less intense cyclones (nonetheless destructive) have not been considered.

[63] In addition, the large magnitudes of potential impacts on people and the economy provide strong evidence in support of rapid action from to reduce global warming by mitigating greenhouse gas emissions.

[64] Computation of location-specific damage estimates is subject of future research.

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Table 1: Typical storm surge characteristics for cyclones in Bangladesh

Wind Velocity (km/hr)	Storm-Surge Height (m)	Limit to inundation (km) from the coast
85	1.5	1
115	2.5	1
135	3	1.5
165	3.5	2
195	4.8	4
225	6	4.5
235	6.5	5
260	7.8	5.5

Source: MCSP, 1993

Table 2: Vulnerable Area Estimates (sq km)

Inundation Depth	2050 Without Climate Change	2050 with Climate Change	Percent Change
More than 1 m	20,876	23,764	+ 14%
More than 3 m	10,163	17,193	+ 69%

Table 3: Vulnerable Population Estimates (million)

<u>Inundation Depth</u>	(a) <u>At Present</u>	(b) <u>2050 Without Climate Change</u>	Percent Change between (a) and (b)	(c) <u>2050 with Climate Change</u>	Percent Change between (b) and (c)
More than 1 m	16.83	28.27	+ 68%	35.33	+25%
More than 3 m	8.06	13.54	+68%	22.64	+67%

Table 4: Parameters used for computation of Agricultural Loss

	Area exposed to storm surge inundation in 2050 without Climate Change (hectares)	Area exposed to storm surge inundation in 2050 with climate change (hectares)	Yield (ton/ hectare) in 2005
Aman	1,092,645	1,305,028	1.99
Aus	526,040	618,897	1.69
Boro	272,768	388,828	3.44

Table 5: Additional potential damage and loss from an average cyclone induced inundation in a changing climate by 2050

	Estimated Damage in $	Estimated Loss in S$
Housing	1,947.3 million	-
Education Infrastructure	9.0 million	0.8 million
Agriculture	75.4 million	835.4 million
Non-Agriculture Productive Sectors	87.9 million	1,084 million
Roads	239.5 million	52.7 million
Power	60.2 million	150.0 million
Coastal Protection	17.3 million	
Others	-	-
Total	2,436.6 million	2,122.9 million

Table 6: Estimated cost of height enhancement of coastal embankments

	Without Climate Change	Additional Cost with Climate Change
Interior polders	$ 317 million	$ 389 million
Sea facing polders	$ 2.145 billion	$ 503 million

Table 7: Cost of Adaptation (Investment cost and Recurrent Cost)

Adaptation Option	Without Climate Change	Additional Cost with Climate Change	
	Investment Cost	Investment Cost	Annual Recurrent Cost
Polders	2.462 billion	893 million	18 million
Foreshore afforestation		75 million	
Cyclone Shelters		1.2 billion	24 million
Cyclone Resistant Housing		200 million	
Strengthening of Early Warning & Evacuation System		39 million	8 + million
Total	2.462 billion	2.407 billion	50 million +

Figure 1: Cyclone tracks considered for demarcation of vulnerable zone in a changing climate

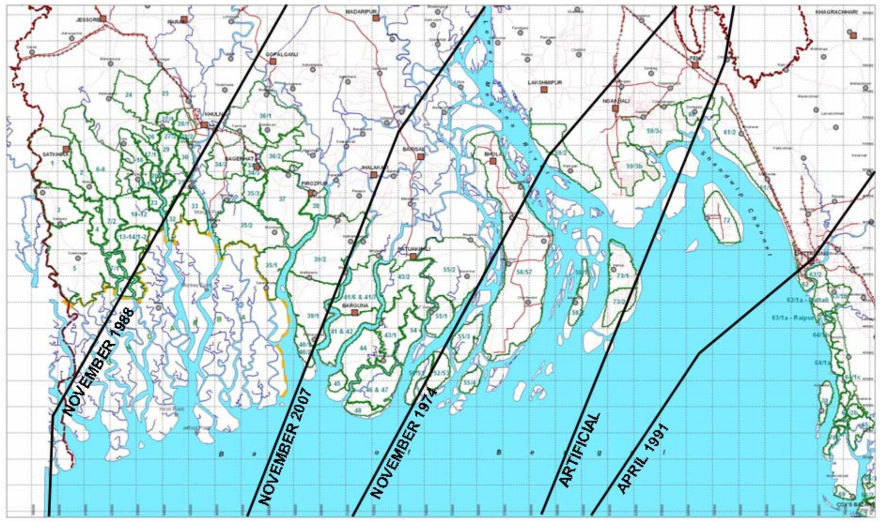


Figure 2: Projection of Storm Surge Inundation in a Changing Climate-2050

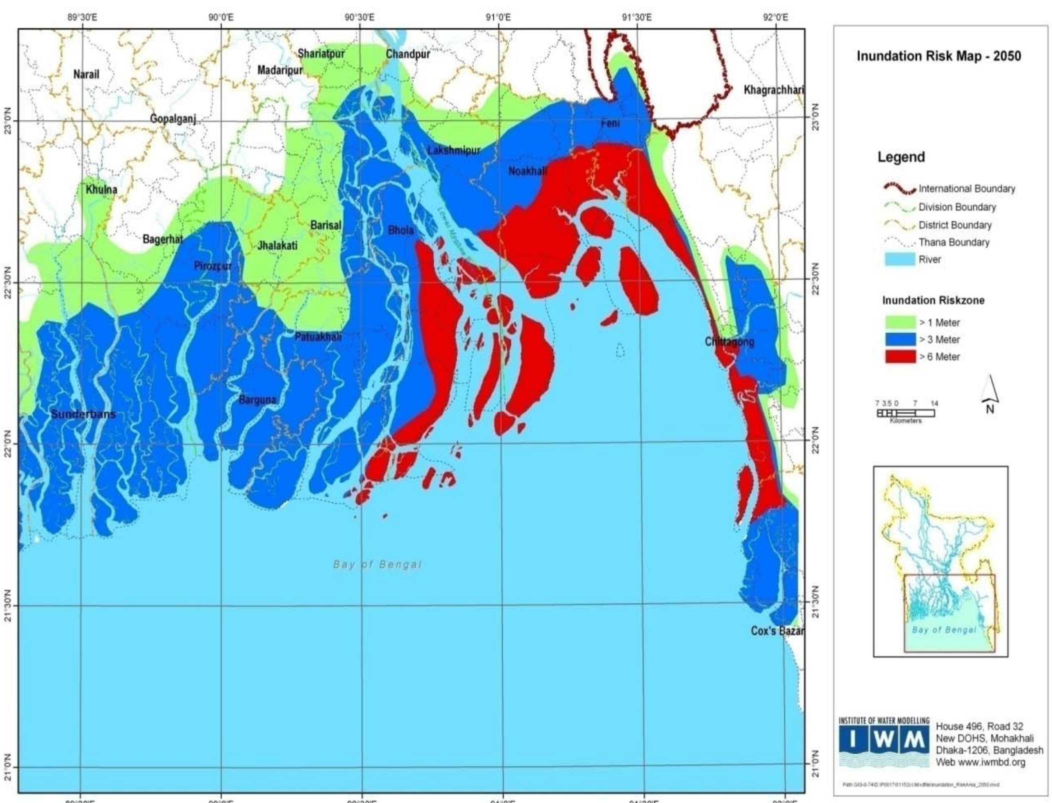


Figure 3 : Lay out map of coastal polders

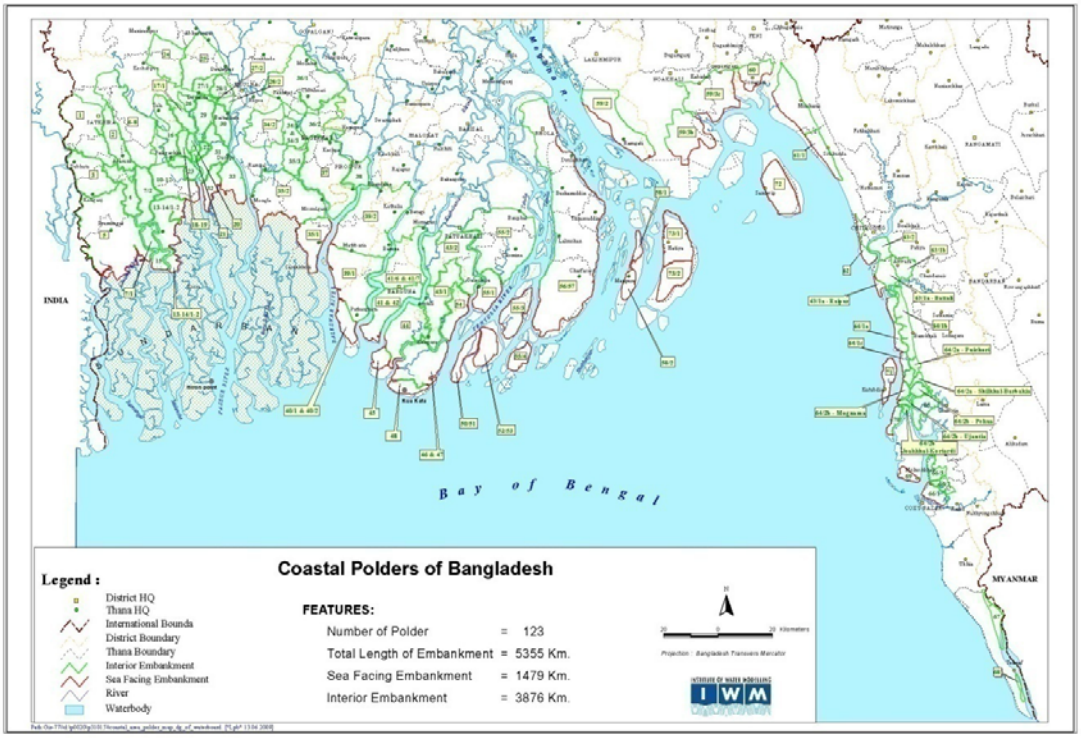
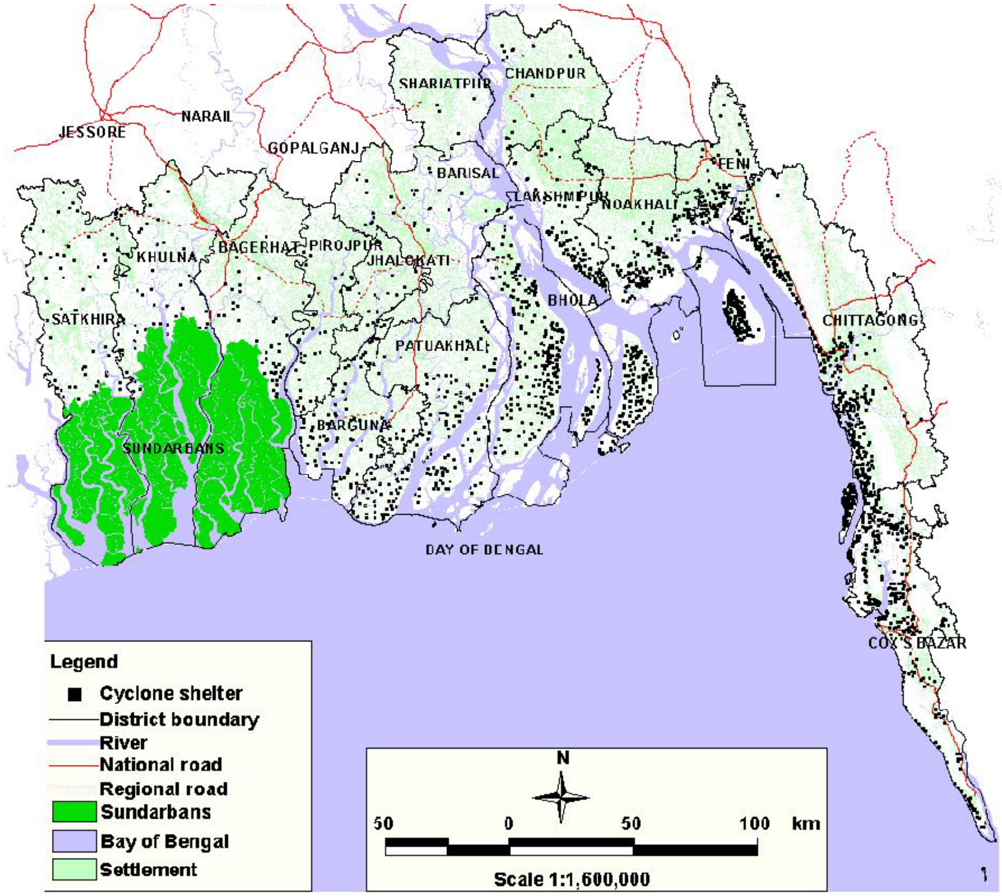


Figure 4: Spatial locations of existing cyclone shelters in the coastal area



Source: CEGIS

Box 1: Sidr Damage to the Economy

Total damage including indirect loss: $1.67 billion

Of which,

- Housing damage & loss: $839 million (50%)
- Agricultural damage & loss: $438 million (26%)
- Transport-related damage & loss: $141 million (8.4%)
- Water Resource Control- related damage & loss: $71 million (4.3%)
- Education infrastructure-related damage & loss: $69 million (4%)
- Other sectors (industry, electricity, water and sanitation, urban and municipal, health, nutrition, commerce, tourism, environment, etc.): 7.3%

Source: GoB (2008)

Appendix 1

The storm surge model used in this analysis is a combination of a Cyclone model and a Hydrodynamic model.

The cyclone model simulated a cyclone based on the following parameters:

1. Radius of maximum winds;
2. Maximum wind speed;
3. Cyclone tracks, forward speed and direction;
4. Central pressure; and
5. Neutral pressure.

Then the simulated cyclone is run with the hydrodynamic model to generate cyclone-induced storm surge and associated coastal inundation. In this analysis, the Bay of Bengal model based on MIKE21 hydrodynamic modeling system has been used. It is a two way nested two-dimensional model and its domain extends from Chandpur to 16º latitude in north-south direction. The grid size of the model is 200m in the Meghna estuary and coastal region of Bangladesh. A description of the Bathymetry data used to develop the Bay of Bengal Model is as follows:

Bathymetry Data:

The main source of bathymetry data for the modeling is the C-Map (an Electronic Chart System Database), Meghna Estuary Study, Phase II (MES II, 1998-99), Mongla Port Study (2004), IPSWAM (2008) and other projects of Bangladesh Water Development Board (BWDB). Figure 2.2 shows the nested bathymetry of the Bay of Bengal Model.

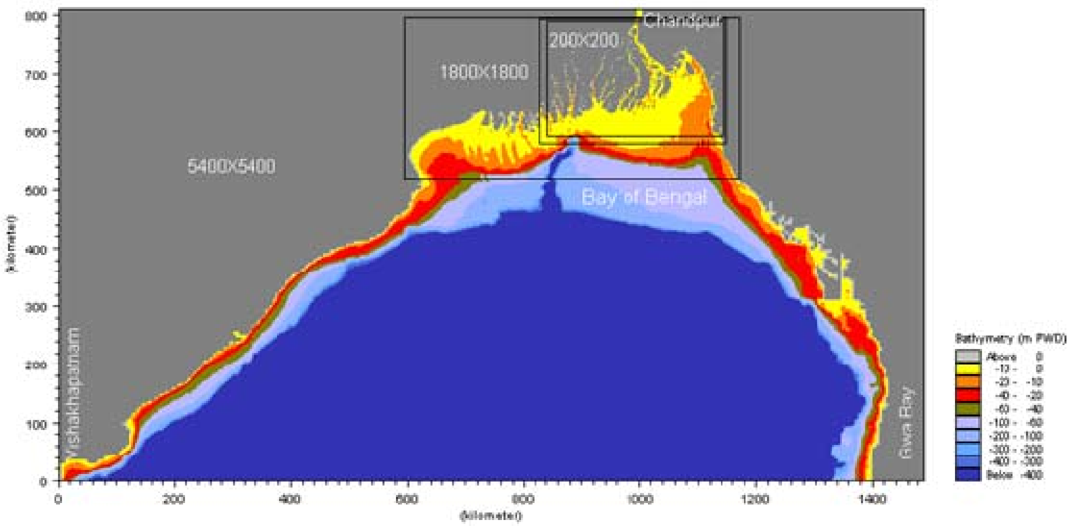


Figure 2.2: Nested bathymetry of Bay of Bengal Model

In order to simulate realistic flood depths, the following topographic data has been used in the analysis:

<u>Topographic Data (Digital Elevation Model)</u>

The main source of topographic elevation data for the coastal region of Bangladesh is the FINNMAP land survey, FAP 19- National DEM (1952-64) and projects of Bangladesh Water Development Board (i.e. Khulna Jessore Drainage Rehabilitation Project, 1997; Beel Kapalia project, 2008; and Beel Khuksia project, 2004). The FINNMAP topographic maps and other data were digitized to develop Digital Elevation Model (DEM) of the coastal region of Bangladesh. The grid size of the model is 50 m x 50 m. The DEM of the coastal region of Bangladesh is shown in Figure 2.3.

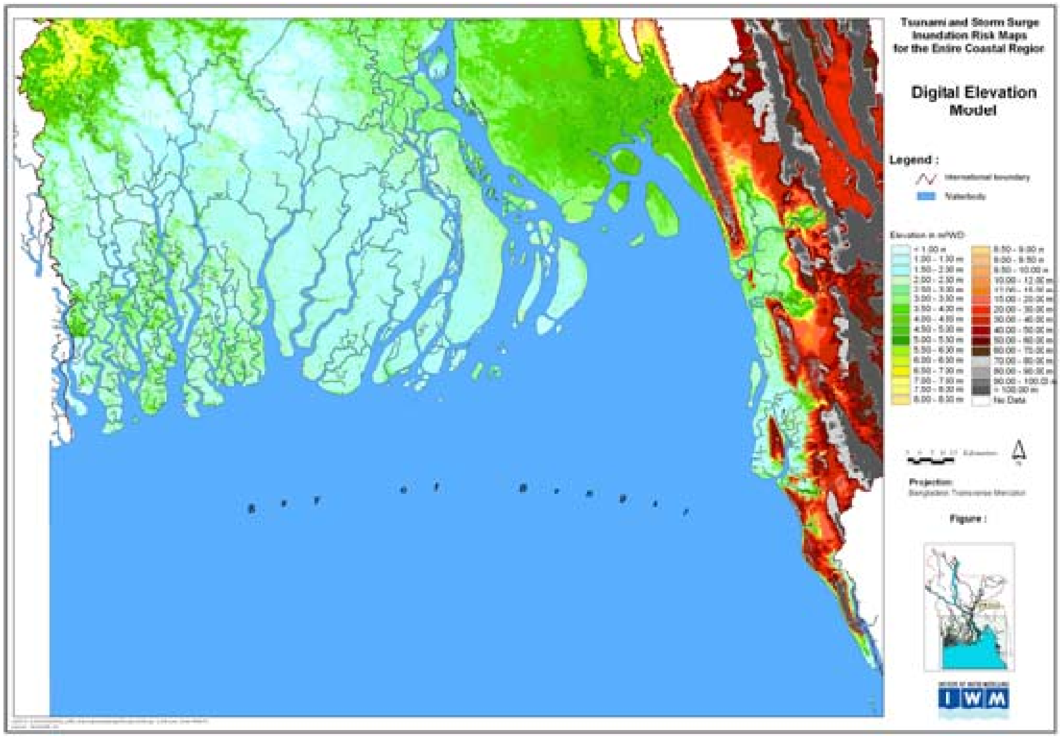
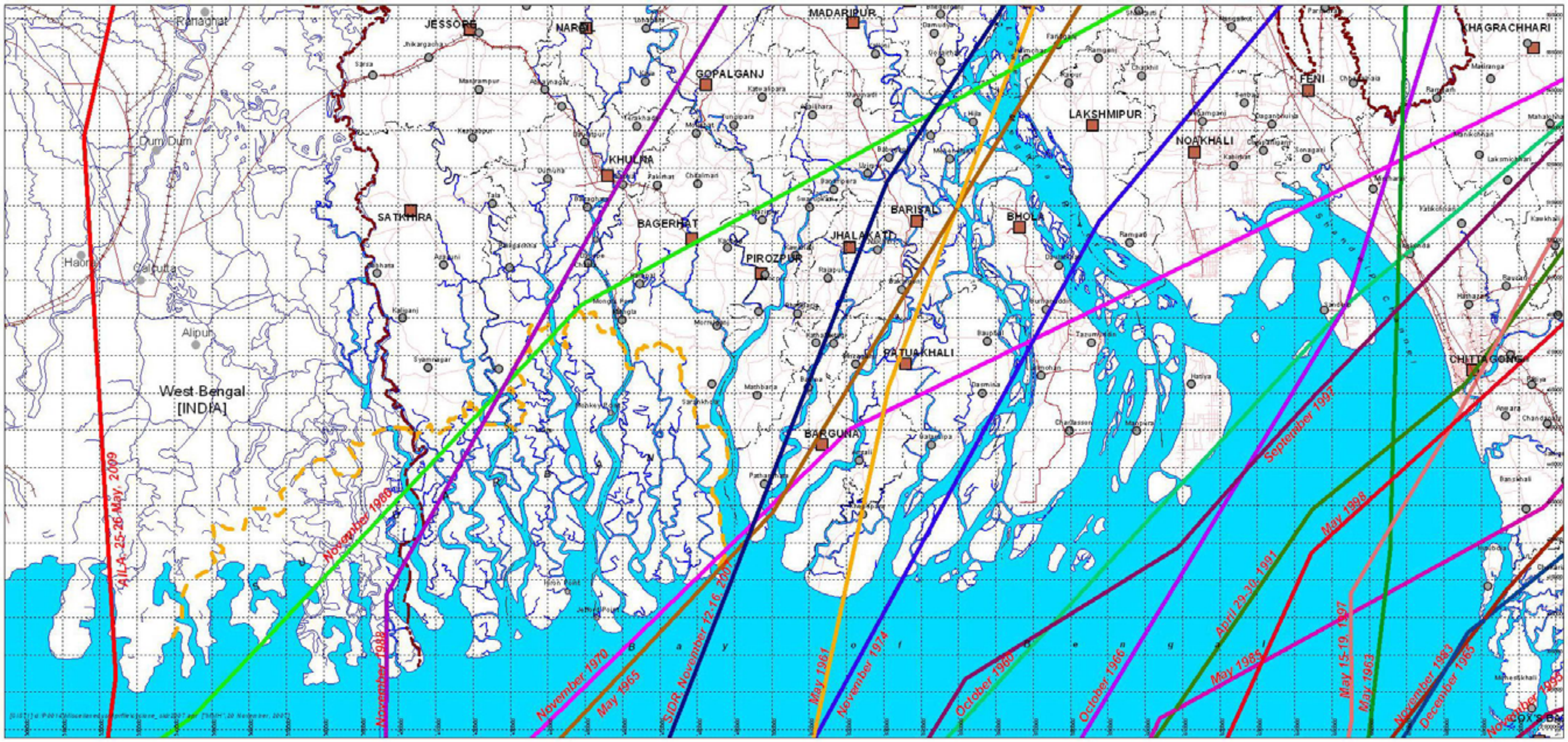


Figure 2.3: Digital Elevation Model of coastal region of Bangladesh

The MIKE 21 modeling system includes dynamic simulation of flooding and drying processes - important for a realistic simulation of flooding in the coastal area and inundation.

Appendix 2:

Tracks of major cyclones that crossed the coast of Bangladesh during the period 1960-2009



Appendix 3:

Major cyclones crossing Bangladesh Coast (1960—2009)

Year	Landfall date	Duration	Landfall Location	Wind speed (km/hr)	Storm Surges (m)	Human Casualties	Number of People Affected	Specific Economic Loss
1960	October, 31	October 30-31	Noakhali Chittagong	193	6.1	10000	200,000	Loss of livestock: 27,783, Destruction of Houses: 568,161, 5-7 Vessels capsized .
1961	May, 9	May 5-9	Meghna estuary	161	3.1	11468	NA	Estimated loss $11.9 billion. Loss of livestock: 25,000, Railway track between Noakhali and Harinarayanpur was damaged.
1963	May, 29	May 28-29	Noakhali Chittagong	202	6	11520	1,000,000	Estimated loss $46.5 billion. Loss of livestock: 32,617, Destruction of Houses: 376,332, 4787 boats were damaged
1965	May, 12	May9-12	Barisal-Noakhali	162	3.7	19279	15,600,000	Estimated loss $57.7 billion.

1965	December, 15	December 7-15	Cox's Bazar	184	3.6	873	60,000	Destruction of Houses: -35,636, Rice harvest loss 40-50%, Significant damage to fishing boats and nets.,40,000 salt beds were inundated
1966	October, 1	September 23- October 1	Noakhali	139	6.7	850	1,800,000	Estimated loss $22.4 billion. Loss of livestock: 65,000; Damage of poultry: 185,000, Destruction of Houses: 309000, damage of Food grains: 5,595 tons.
1970	November, 12	November 8-13	Bhola, Meghna estuary	224	10	300000	3,648,000	Estimated loss $86.4 billion.
1974	November, 28	November 24-28	Chittagong Cox's Bazar	161	5.1	50	NA	Loss of livestocks: 1,000, Destruction of Houses: 2,300 .
1983	November, 9	November 5-9	Chittagong Cox's Bazar near Kutubdia	135	1.5		NA	Destruction of Houses: 2,000, number of missing boats: 50, number of fishermen missing: 300.
1985	May, 25	May 22-25	Noakhali	154	4.5	4264	1,810,000	-

					5	(6805 missing)		
1986	November, 9	November 7-9	Patuakhali	110	0.61			-
1988	November, 18	November 16-18	Southeast coast of Teknaf	135			10,568,860	-
1991	April, 29	April 25-30	Noakhali Chittagong	235	7.6	133882	15,438,849	Estimated loss $1,780 billion.
1995	November, 25	November 25-15	Gulf of Bengal	110	3.6	172	250,000	-
1997	May, 19	May 15-19	Chittagong/ Sitakundu	200	4.6	155	3,052,738	Loss of livestocks: 3,118, Destruction of Houses: 211,717, damage of crops: 97,333 acres, damage to salt production: 2,232,000 acres.
1997	September 26	September 26-27		150	3	188	751,529	-
1998	May 20	May 17-20	Sitakundu	186			108,944	
2007	November 15	November 11-16	Sundarban Borguna	250	6-8	2388	8,978,541	Estimated Damage $ 2300 billion

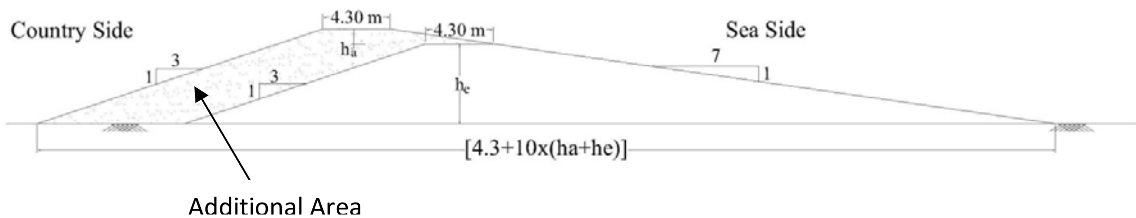
2009	May 5	May 5-6	West Bengal, India	95	4	190	3,935,341	Estimated Damage $ 270 billion

Source: Quadir and Iqbal (2008) and EMDAT

Appendix 4

Earthwork Computation with an illustrative Example:

Sea facing Polders



Additional unit volume of earthwork, A

$$= 0.5x\{4.3+4.3+10x(h_a+h_e)\}x(h_a+h_e)-0.5x\{4.3+4.3+10xh_e\}xh_e$$

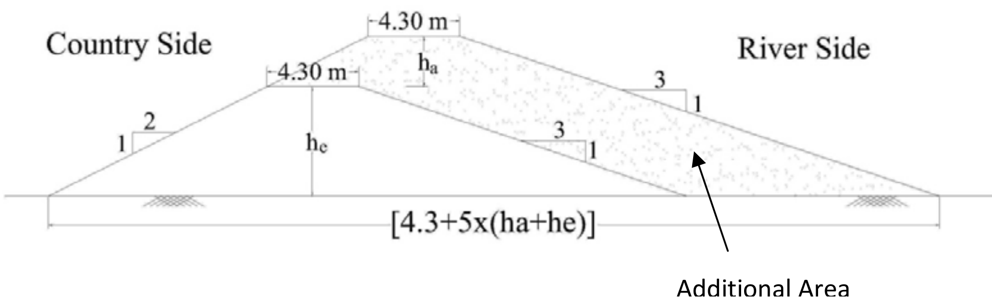
$$= 5\ h_a^2+4.3\ h_a+10\ h_a\ h_e$$

Where,

h_e =Existing Height

h_a =Additional Height

Interior polders:



Additional unit volume of earthwork, A

$$= 0.5x\{4.3+4.3+5x(h_a+h_e)\}x(h_a+h_e)-0.5x\{4.3+4.3+5xh_e\}xh_e$$

$$= 2.5\ h_a^2+4.3\ h_a+5\ h_a\ h_e$$

Total earthwork volume is computed by multiplying the unit volume of earthwork with the affected length of polder.

Appendix 5

Table A: Estimated cost to prevent overtopping of <u>interior</u> polders by 2050 (even without climate change)

INTERIOR DYKE

-	Polder	Length	Existing Height	Height to be Raised	Cost (million US$)							
		(m)	(m)	(m)	Earthwork (300 m to 1.0 km)	Earthwork (1.0 km to 5.0 km)	Turfing	Plantation (Vetivera)	Land Acquisition	Major Protection Work	Toe Protection	**Total**
1	P10-12	67,400	4	2.5	8.1	0.9	0.1	0.0	1.4	42.9	0.0	**53.3**
2	P35/1	61,600	4.5	2.5	8.0	0.9	0.0	0.0	1.3	0.0	32.0	**42.2**
3	P35/2	104,600	3	2.5	10.5	1.1	0.1	0.1	2.2	0.0	0.0	**14.0**
4	P37	100,100	3.5	2.5	11.0	1.2	0.1	0.1	2.1	0.0	0.0	**14.5**
5	P38	39,500	3.5	3.5	6.6	0.7	0.0	0.1	1.2	0.0	0.0	**8.6**
6	P39/1	96,200	5	3.5	20.1	2.1	0.1	0.1	2.9	10.3	0.0	**35.6**
7	P39/2	109,200	3	3	13.8	1.5	0.1	0.0	2.8	0.0	0.0	**18.2**
8	P41/6-7	95,100	4.5	2.25	10.9	1.2	0.1	0.0	1.8	0.0	0.0	**14.0**
9	P42	28,000	4.5	3.5	5.5	0.6	0.0	0.0	0.8	5.1	0.0	**12.1**
10	P43/1	113,520	4.5	3.3	20.6	2.2	0.1	0.1	3.2	0.0	0.0	**26.2**
11	P43/2	120,600	4.5	3.3	21.9	2.3	0.1	0.1	3.4	0.0	0.0	**27.8**
12	P44	83,700	4.5	3	13.5	1.4	0.1	0.0	2.2	10.3	0.0	**27.5**
13	P55/2	109,100	0.75	3.4	9.6	1.0	0.1	0.0	3.2	0.0	0.0	**13.9**
14	P63/1A - Battali	38,000	5	3.25	7.3	0.8	0.0	0.0	1.1	0.0	0.0	**9.1**
												<u>317.0</u>

Table B: Estimated cost to prevent overtopping of <u>interior</u> polders by 2050, in a changing climate

INTERIOR DYKE

	Polder	Length	Existing Height	Height to be Raised	Cost (million US$)							
		(m)	(m)	(m)	Earthwork (300 m to 1.0 km)	Earthwork (1.0 km to 5.0 km)	Turfing	Plantation (Vetivera)	Land Acquisition	Major Protection Work	Toe Protection	**Total**
1	P07/1	31,800	4.5	2.5	4.1	0.4	0.0	0.0	0.7	21.4	0.0	**26.7**
2	P07/2	64,000	4	2.5	7.7	0.8	0.0	0.0	1.4	25.7	0.0	**35.6**
3	P10-12	67,400	4	2.5	8.1	0.9	0.1	0.0	1.4	42.9	0.0	**53.3**
4	P13-14/2	122,400	4.5	2.5	15.9	1.7	0.1	0.0	2.6	0.0	0.0	**20.3**
5	P23	36,700	4	3	5.5	0.6	0.0	0.0	0.9	21.4	0.0	**28.5**
6	P31	62,700	4	2.5	7.5	0.8	0.0	0.0	1.3	42.9	0.0	**52.6**
7	P32	48,800	4	2.5	5.9	0.6	0.0	0.0	1.0	25.7	0.0	**33.3**
8	P33	51,500	4	2.5	6.2	0.7	0.0	0.0	1.1	25.7	0.0	**33.7**
9	P35/1	61,600	4.5	4	14.2	1.5	0.1	0.0	2.1	0.0	32.0	**49.9**
10	P35/2	104,600	3	4	19.3	2.1	0.1	0.1	3.6	0.0	0.0	**25.0**
11	P35/3	39,700	3	3	5.0	0.5	0.0	0.0	1.0	0.0	0.0	**6.6**
12	P36/2	87,400	3	3	11.0	1.2	0.1	0.0	2.2	0.0	0.0	**14.5**
13	P37	100,100	3.5	4.25	21.7	2.3	0.1	0.1	3.6	0.0	0.0	**27.8**
14	P38	39,500	3.5	4.25	8.6	0.9	0.0	0.1	1.4	0.0	0.0	**11.0**
15	P39/1	96,200	5	4	23.8	2.5	0.1	0.1	3.3	10.3	0.0	**40.0**
16	P39/2	109,200	3	4.75	25.4	2.7	0.1	0.0	4.4	0.0	0.0	**32.7**
17	P41/6-7	95,100	4.5	2.5	12.3	1.3	0.1	0.0	2.0	0.0	0.0	**15.8**
18	P42	28,000	4.5	4.75	8.1	0.9	0.0	0.0	1.1	5.1	0.0	**15.3**
19	P43/1	113,520	4.5	3.5	22.2	2.4	0.1	0.1	3.4	0.0	0.0	**28.1**
20	P43/2	120,600	4.5	3.5	23.6	2.5	0.1	0.1	3.6	0.0	0.0	**29.9**
21	P44	83,700	4.5	3.7	17.5	1.9	0.1	0.0	2.7	10.3	0.0	**32.4**
22	P55/2	109,100	0.75	4.25	13.6	1.5	0.1	0.0	4.0	0.0	0.0	**19.1**
23	P63/1A -B	38,000	5	7.1	19.9	2.1	0.1	0.0	2.3	0.0	0.0	**24.4**
24	P64/2A	59,100	4.5	6.5	26.0	2.8	0.1	0.0	3.3	0.0	0.0	**32.1**
25	P64/2b-jo	17,000	4	4.5	4.3	0.5	0.0	0.0	0.7	0.0	0.0	**5.4**
26	P64/2b-Pe	30,000	4.5	5.25	9.9	1.1	0.0	0.0	1.4	0.0	0.0	**12.3**
												706.4

Table C: Estimated cost to prevent overtopping of sea-facing polders by 2050 (even without climate change

SEA DYKE

	Polder	Length	Existing Height	Height to be Raised	Cost (million US$)							
		(m)	(m)	(m)	Earthwork (300 m to 1.0 km)	Earthwork (1.0 km to 5.0 km)	Turfing	Plantation (Vetivera)	Land Acquisition	Major Protection Work	Toe Protection	**Total**
1	P40/1-2	59,000	5	4	27.5	2.9	0.1	0.0	4.0	7.7	16.0	**58.3**
2	P41-42	80,500	4.5	3.5	29.6	3.2	0.1	0.0	4.8	7.7	16.0	**61.3**
3	P45	25,800	6	2.75	8.7	0.9	0.0	0.0	1.2	5.7	16.0	**32.6**
4	P46-47	79,600	5	3.25	28.7	3.1	0.1	0.0	4.4	14.7	0.0	**51.0**
5	P48	38,100	5.8	2.7	12.2	1.3	0.0	0.0	1.8	24.6	64.0	**104.0**
6	P50/51	48,300	5.18	3.3	18.2	1.9	0.0	0.0	2.7	0.0	0.0	**22.9**
7	P52/53	40,300	4.57	4	17.7	1.9	0.0	0.0	2.8	5.1	0.0	**27.6**
8	P54	60,000	4.5	3.3	20.5	2.2	0.1	0.0	3.4	10.3	0.0	**36.4**
9	P55/1	45,800	5	2.9	14.4	1.5	0.0	0.0	2.3	28.6	0.0	**46.8**
10	P55/3	52,700	5	2.75	15.5	1.7	0.0	0.0	2.5	25.7	0.0	**45.4**
11	P55/4	30,800	5.5	4.4	17.3	1.8	0.0	0.0	2.3	25.7	0.0	**47.2**
12	P56/57(E)	140,000	6.5	4	78.6	8.4	0.2	0.0	9.6	0.0	160.1	**256.8**
13	P56/57(W	90,000	5	3	29.4	3.1	0.1	0.0	4.6	0.0	0.0	**37.2**
14	P58/1	32,000	4.8	4.75	18.2	1.9	0.0	0.0	2.6	0.0	0.0	**22.7**
15	P58/2	28,000	4.8	4.8	16.1	1.7	0.0	0.0	2.3	0.0	32.0	**52.2**
16	P59/2	92,800	6	4.75	61.0	6.5	0.1	0.3	7.6	64.3	64.0	**203.8**
17	P59/3B	70,100	6	6	62.3	6.7	0.1	0.0	7.2	0.0	0.0	**76.3**
18	P59/3C	41,800	6	5.5	33.2	3.5	0.1	0.0	3.9	35.7	0.0	**76.4**
19	P60	44,900	7	5.75	41.8	4.5	0.1	0.0	4.4	0.0	0.0	**50.7**
20	P61/1	26,000	6	5	18.2	1.9	0.0	0.0	2.2	0.0	0.0	**22.4**
21	P61/2	45,100	6	2.5	13.6	1.5	0.0	0.0	1.9	0.0	0.0	**17.0**
22	P62	22,000	6	4	11.7	1.2	0.0	0.0	1.5	0.0	0.0	**14.4**
23	P63/1A-Ra	20,000	6	3	7.5	0.8	0.0	0.0	1.0	0.0	0.0	**9.3**
24	P64/1A	54,200	5.5	3.25	20.9	2.2	0.1	0.0	3.0	32.1	38.4	**96.8**
25	P64/2b-M	27,000	5	2.5	7.1	0.8	0.0	0.0	1.2	19.3	16.0	**44.3**
26	P70	29,200	6	2.5	8.8	0.9	0.0	0.0	1.3	30.0	0.0	**41.0**
27	P71	40,500	4.5	3.25	13.6	1.4	0.0	0.0	2.3	64.3	64.0	**145.6**
28	P72	61,700	5.5	5.5	46.3	4.9	0.1	0.0	5.8	75.7	128.1	**260.9**
29	P73/1AB	89,400	5.5	3.8	41.8	4.5	0.1	0.0	5.8	6.4	64.0	**122.6**
30	P73/2	47,600	5	4.1	22.9	2.4	0.1	0.0	3.3	32.1	0.0	**60.9**
												2144.9

Table D: Estimated cost to prevent overtopping of sea-facing polders by 2050 in a changing climate

SEA DYKE

	Polder	Length	Existing Height	Height to be Raised	Cost (million US$)							
		(m)	(m)	(m)	Earthwork (300 m to 1.0 km)	Earthwork (1.0 km to 5.0 km)	Turfing	Plantation (Vetivera)	Land Acquisition	Major Protection Work	Toe Protection	**Total**
1	P40/1-2	59,000	5	4.2	29.3	3.1	0.1	0.0	4.2	7.7	16.0	**60.5**
2	P41-42	80,500	4.5	4.75	43.9	4.7	0.1	0.0	6.6	7.7	16.0	**78.9**
3	P45	25,800	6	3	9.6	1.0	0.0	0.0	1.3	5.7	16.0	**33.7**
4	P46-47	79,600	5	3.5	31.4	3.4	0.1	0.0	4.8	14.7	0.0	**54.3**
5	P48	38,100	5.8	3.5	16.7	1.8	0.0	0.0	2.3	24.6	64.0	**109.4**
6	P50/51	48,300	5.18	3.75	21.3	2.3	0.1	0.0	3.1	0.0	0.0	**26.7**
7	P52/53	40,300	4.57	4.5	20.7	2.2	0.0	0.0	3.1	5.1	0.0	**31.2**
8	P54	60,000	4.5	3.75	24.1	2.6	0.1	0.0	3.9	10.3	0.0	**40.8**
9	P55/1	45,800	5	3.25	16.5	1.8	0.0	0.0	2.6	28.6	0.0	**49.4**
10	P55/3	52,700	5	3.5	20.8	2.2	0.1	0.0	3.2	25.7	0.0	**52.0**
11	P55/4	30,800	5.5	5.25	21.7	2.3	0.0	0.0	2.8	25.7	0.0	**52.6**
12	P56/57(E)	140,000	6.5	4.75	97.2	10.4	0.2	0.0	11.4	0.0	160.1	**279.2**
13	P56/57(W	90,000	5	4	42.0	4.5	0.1	0.0	6.2	0.0	0.0	**52.8**
14	P58/1	32,000	4.8	6.5	27.7	3.0	0.0	0.0	3.6	0.0	0.0	**34.3**
15	P58/2	28,000	4.8	5.75	20.5	2.2	0.0	0.0	2.8	0.0	32.0	**57.5**
16	P59/2	92,800	6	5.5	73.6	7.9	0.1	0.3	8.7	64.3	64.0	**218.9**
17	P59/3B	70,100	6	7.5	84.1	9.0	0.1	0.0	9.0	0.0	0.0	**102.2**
18	P59/3C	41,800	6	8	54.8	5.8	0.1	0.0	5.7	35.7	0.0	**102.1**
19	P60	44,900	7	8	64.5	6.9	0.1	0.0	6.2	0.0	0.0	**77.6**
20	P61/1	26,000	6	7.9	33.5	3.6	0.0	0.0	3.5	0.0	0.0	**40.6**
21	P61/2	45,100	6	8	59.1	6.3	0.1	0.0	6.2	0.0	0.0	**71.7**
22	P62	22,000	6	7	24.0	2.6	0.0	0.0	2.6	0.0	0.0	**29.3**
23	P63/1A-Ra	20,000	6	6	17.8	1.9	0.0	0.0	2.1	0.0	0.0	**21.8**
24	P64/1A	54,200	5.5	7.75	64.7	6.9	0.1	0.0	7.2	32.1	38.4	**149.4**
25	P64/2b-M	27,000	5	5	16.8	1.8	0.0	0.0	2.3	9.6	16.0	**46.6**
26	P64/2b-Uj	22,000	4	5	12.0	1.3	0.0	0.0	1.9	9.6	9.6	**34.4**
27	P66/3	36,600	6	2	8.5	0.9	0.0	0.0	1.3	0.0	0.0	**10.7**
28	P69	29,000	6	2.75	9.8	1.0	0.0	0.0	1.4	18.0	0.0	**30.2**
29	P70	29,200	6	3.25	12.0	1.3	0.0	0.0	1.6	30.0	0.0	**44.9**
30	P71	40,500	4.5	5.75	28.6	3.0	0.0	0.0	4.0	64.3	64.0	**164.0**
31	P72	61,700	5.5	7	64.0	6.8	0.1	0.0	7.4	75.7	128.1	**282.1**
32	P73/1	89,400	5.5	5	59.2	6.3	0.1	0.0	7.7	6.4	64.0	**143.7**
33	P73/2	47,600	5	4.5	25.8	2.8	0.1	0.0	3.7	32.1	0.0	**64.5**
												2648.2