Vulnerability of Coastal Bangladesh in a Changing Climate

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Motivation

- With a virtual certainty that sea-level rise will continue beyond 2100 even if greenhouse gas emissions are stabilized today, low-lying coastal regions of the world need to prepare for <u>all</u> visible and not-so-visible threats of sea-level rise.

  - Inundation from sea-level rise
  - Inundation from cyclone-induced surges
  - Salinization of water and soil

- At present, 600 million people live in low-lying coastal areas.

Illustrative Case: Bangladesh

- Elevation of nearly two third of the country is less than 5 meter above sea-level.
- On average, severe cyclones strike Bangladesh every three years.
- High river and soil salinity in the southwest coastal region are apparent.

- Families in coastal Bangladesh are already on the “front line” of climate change. Their adaptation foretells future decisions by hundreds of millions of families worldwide who will face similar threats well before 2100.

Key Findings on Infrastructure Development

- **Vulnerability of Coastal Areas in Bangladesh from Sea-Level Rise and Cyclones**
- **Mangroves as a Protection of Storm Surges in Bangladesh**
- **Water Salinization in a Changing Climate**
- **Urban Flooding of Greater Dhaka in a Changing Climate: Building Local Resilience to Disaster Risk**

Overview

- Emergency Shelters
- Coastal Polders
- Mangrove Afforestation
- Desalinization Plants
- Pumps and Sluice Gates
- Complementary Flood Mitigation Measures

- **Vulnerability of Coastal Areas in Bangladesh from Sea-Level Rise and Cyclones**
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Vulnerability of Coastal Areas in Bangladesh with & without Climate Change

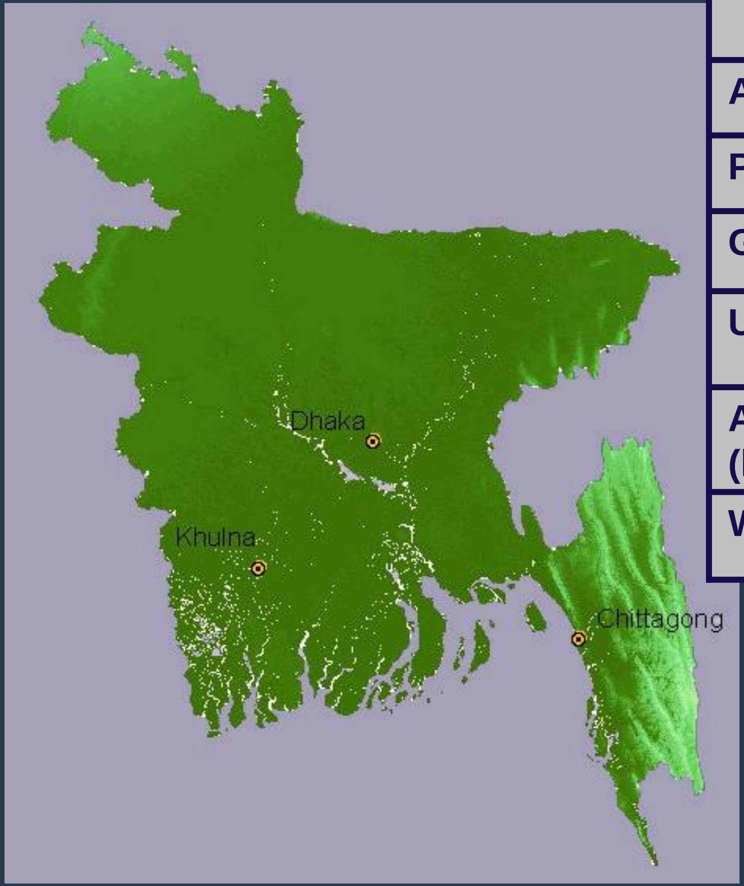
- Inundation from Sea-Level Rise
- Inundation from cyclone-induced surges
- Salinization of water and soil

Bangladesh: Coastal Region

- 19 districts (and 148 sub-districts).
- Accounts for 32% of the land area of Bangladesh and 26% population in Bangladesh (sustains livelihood of more than 37 million).
- High incidence of poverty: 11.8 million poor in 2010.
- Cyclones struck 154 times during 1877 and 1995, and 6 severe cyclones struck between 1995 and 2017.
- On average, severe cyclones strike Bangladesh every three years-producing storm surges that can reach heights of 10 m.
- High river and soil salinity in the southwest coastal region are apparent.

Bangladesh

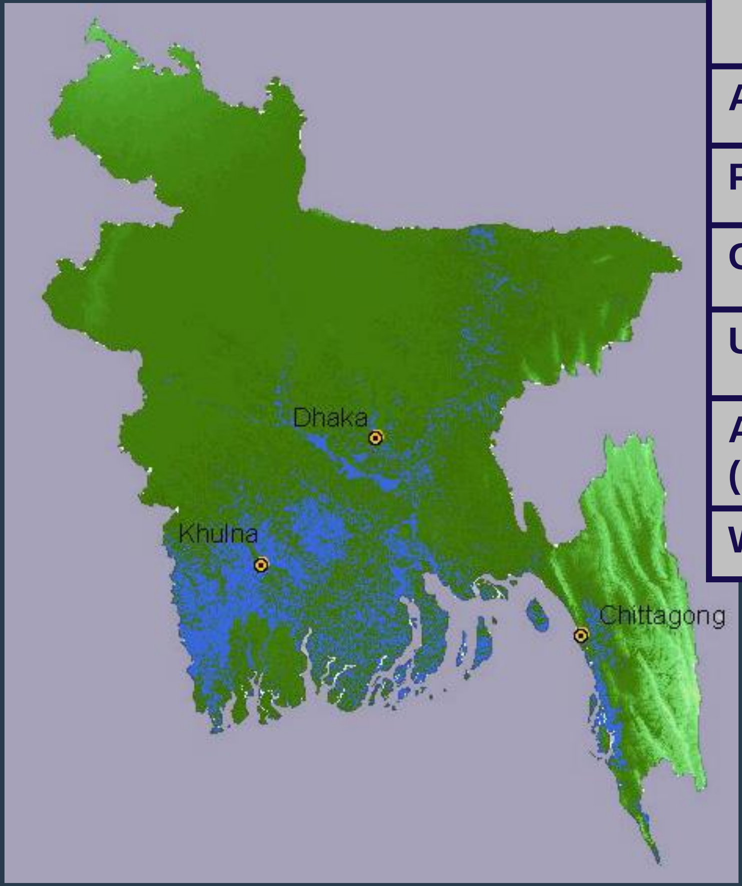
1 Meter Sea Level Rise



	Country Total	Exposed	% of Total
Area (km^2)	136,305	1,532	1.12
Population (10^3)	137,439	998	0.73
GDP (10^6 US$)	202,087	1,266	0.63
Urban Areas $(km)^2$	10,153	73	0.72
Agricultural Land (km^2)	104,389	679	0.65
Wetlands (km^2)	105,971	999	0.94

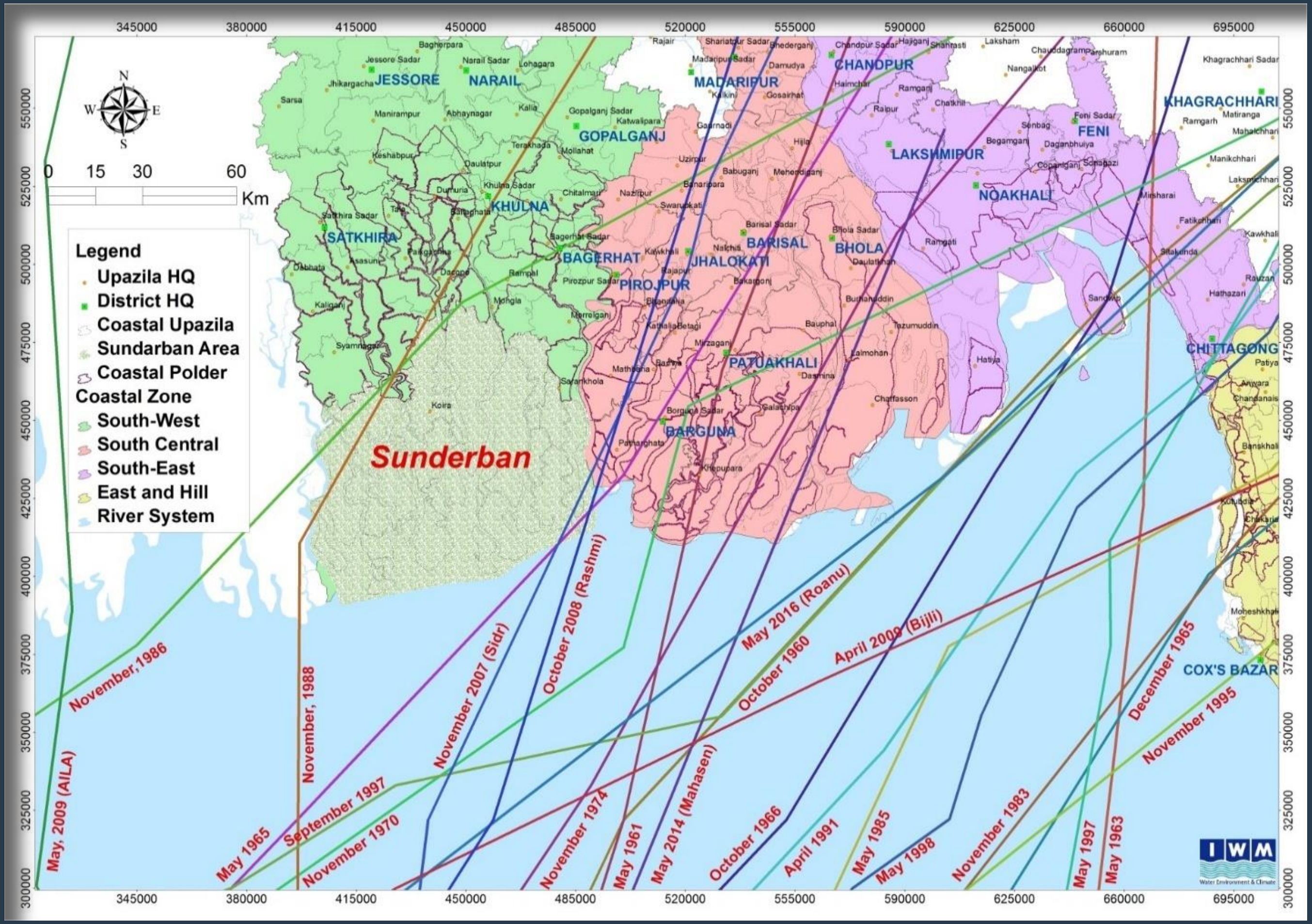
Bangladesh

5 Meter Sea Level Rise



	Country Total	Exposed	% of Total
Area (km^2)	136,305	17,611	12.92
Population (10^3)	137,439	16,721	12.17
GDP (10^6 US$)	202,087	22,790	11.28
Urban Areas (km^2)	10,153	1,200	11.82
Agricultural Land (km^2)	104,389	11,824	11.33
Wetlands (km^2)	105,971	14,715	13.89

Major Cyclones in Bangladesh
(1960 – 2009)



Aftermath of Cyclone Roanu

May 21, 2016

- Storm surge is the biggest threat to lives and properties.
- Typical cyclone storm surge height ranges from 1.5m to 9m.
- Surge heights excess of 10m or more are not uncommon.

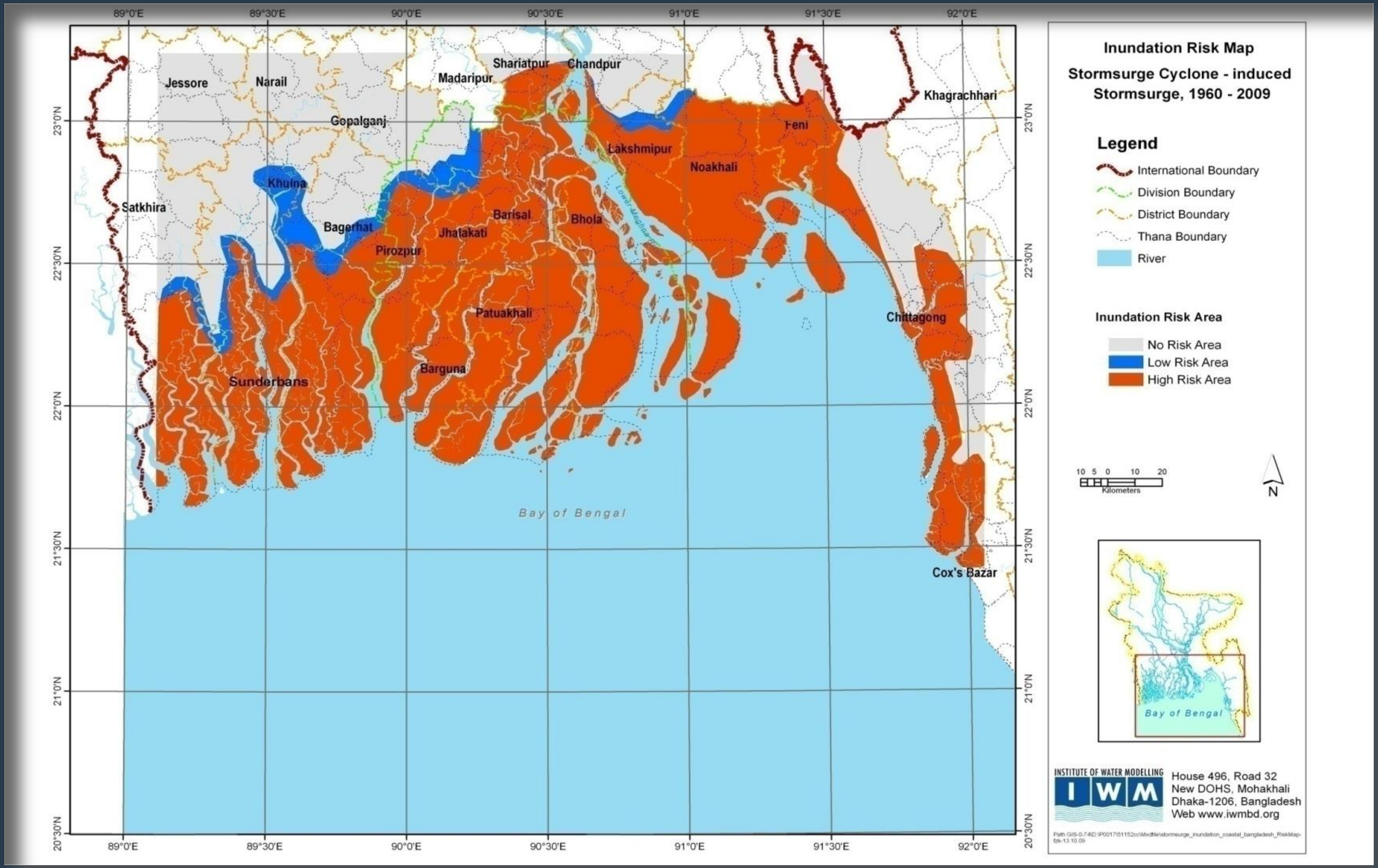
Image: European Pressphoto Agency

Demarcation of Inundation Area

Baseline Scenario: 19 historical cyclone tracks with actual observed meteorological parameters (*Maximum wind speed; radius of influence, cyclone tracks, forward speed and direction and central and neutral pressure*).

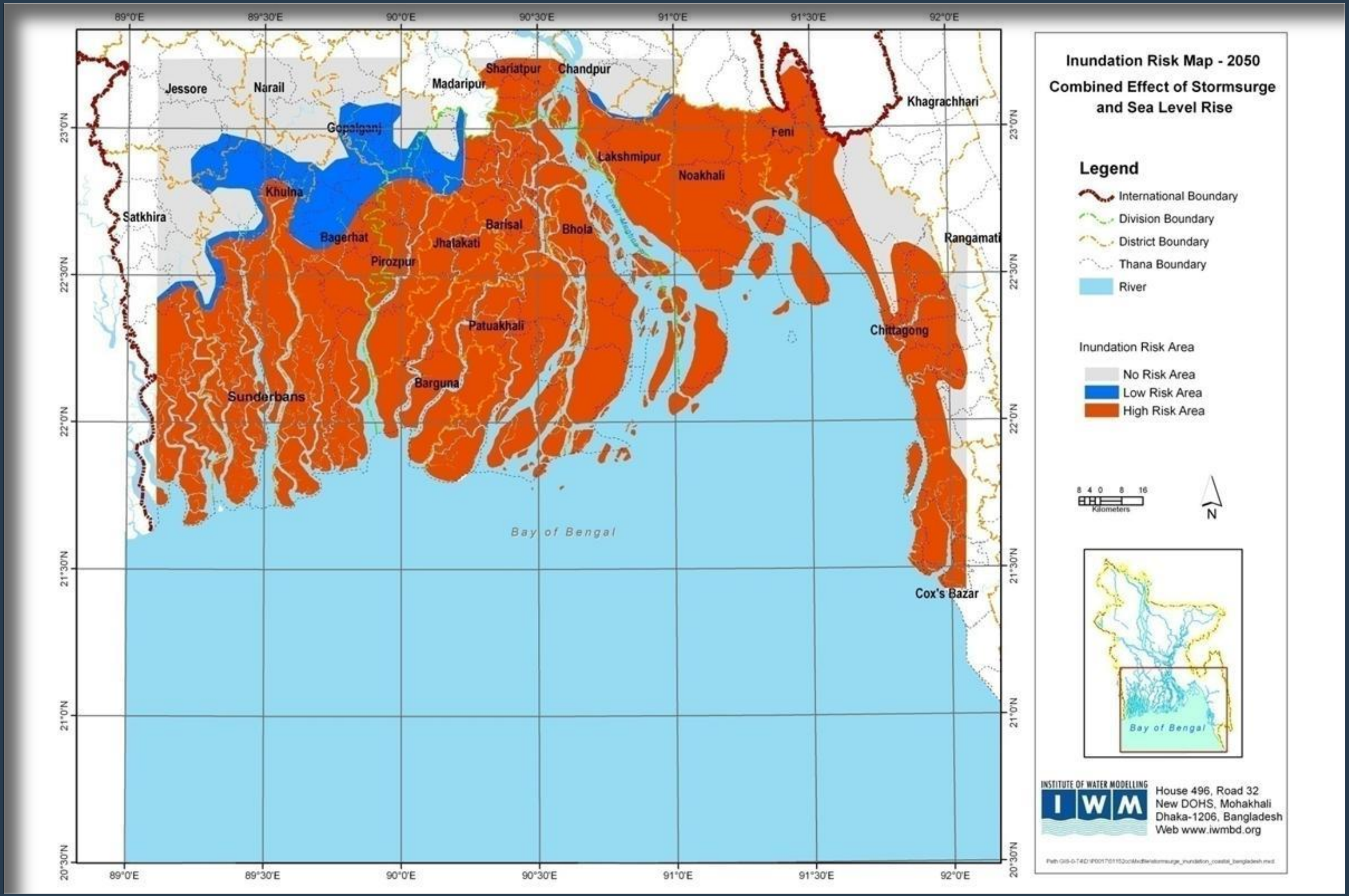
Climate Change Scenario: Five cyclone tracks to span the coast line, meteorological parameters as Sidr for the artificial track, 10% increase in wind speed, 27 cm sea level rise, Land fall at high tide.

Storm Surge Inundation Area under Baseline
(2050 without Climate Change)

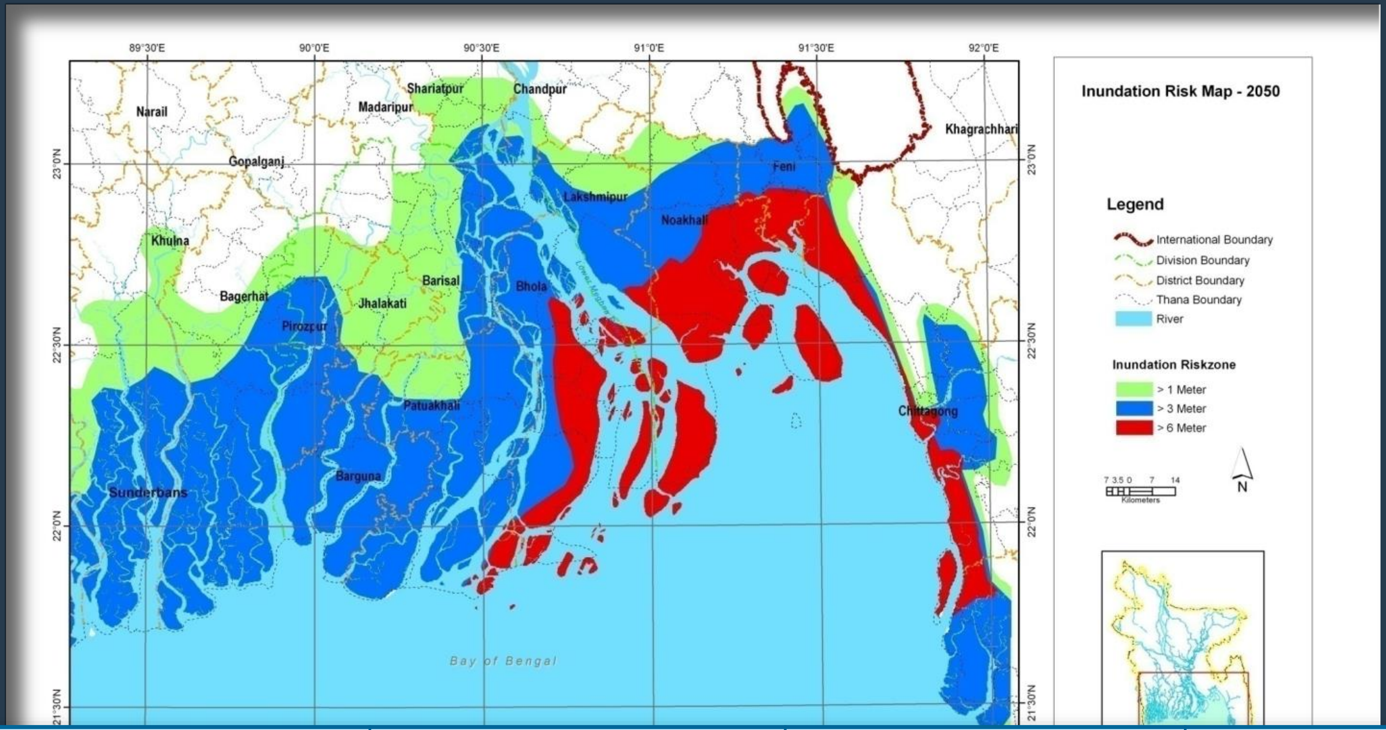


- Bay of Bengal model based on MIKE 21 Hydrodynamic modeling system has been used.

Storm Surge Inundation Area under Baseline
(2050 in a Changing Climate)



High Risk Area in a Changing Climate 2050

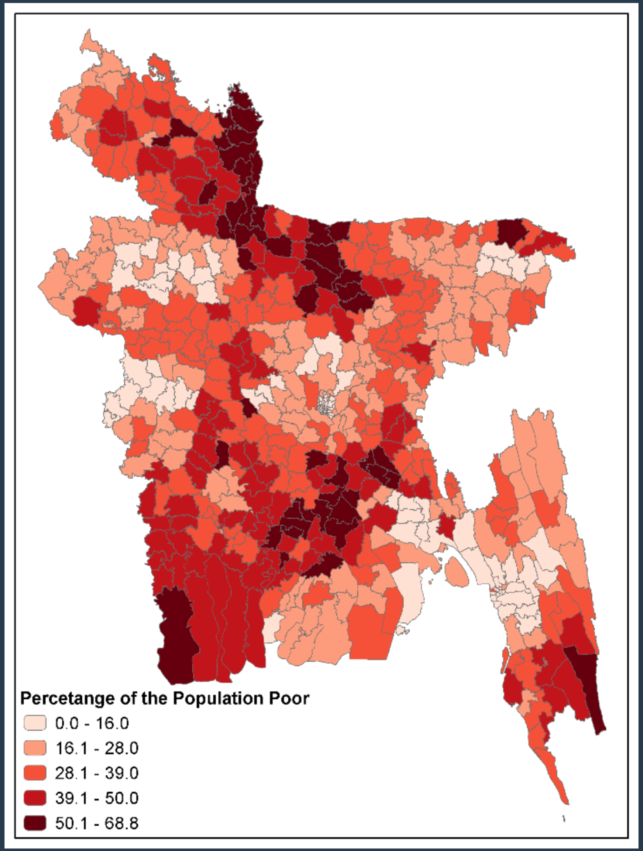


Inundation depth (m)	2050 without climate change	2050 in a changing climate	Change
1 m – 3 m	20,876 m^2	23,764 m^2	+14 %
More than 3 m	10,163 m^2	17,193 m^2	+69 %

Vulnerable Population Estimates

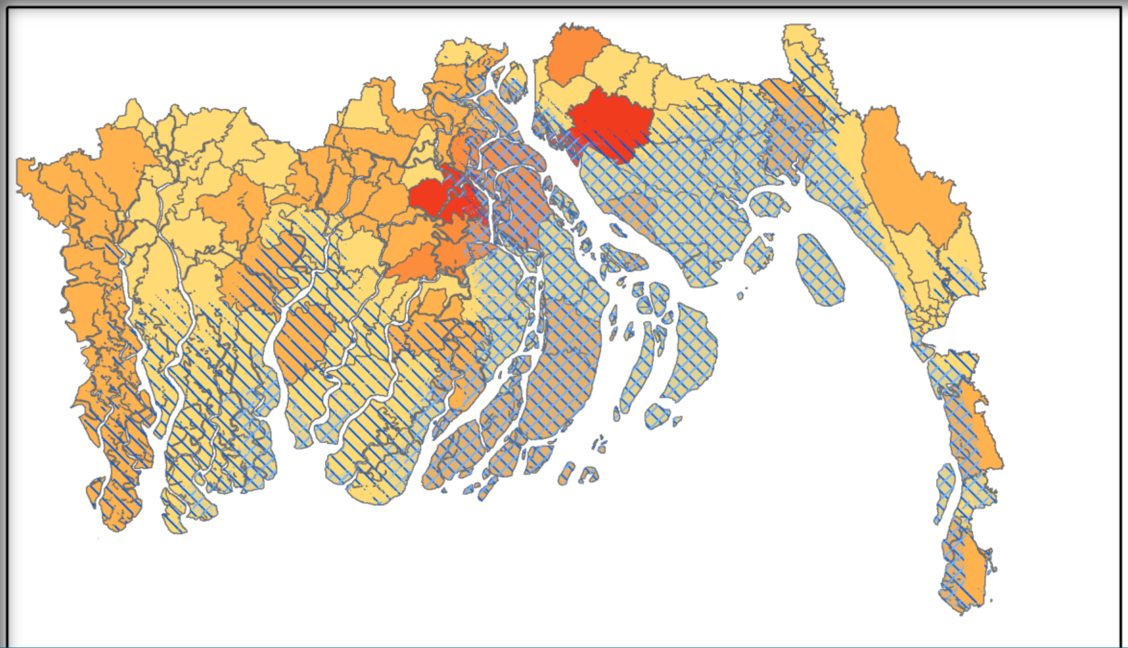
Inundation Depth	At Present	Expected Percent Change by 2050 without Climate Change	Expected Percent Change by 2050 with Climate Change
More than 1m	16.83 million	+68%	+26%
More than 3m	8.06 million	+68%	+67%

Poverty Map of Bangladesh
2010



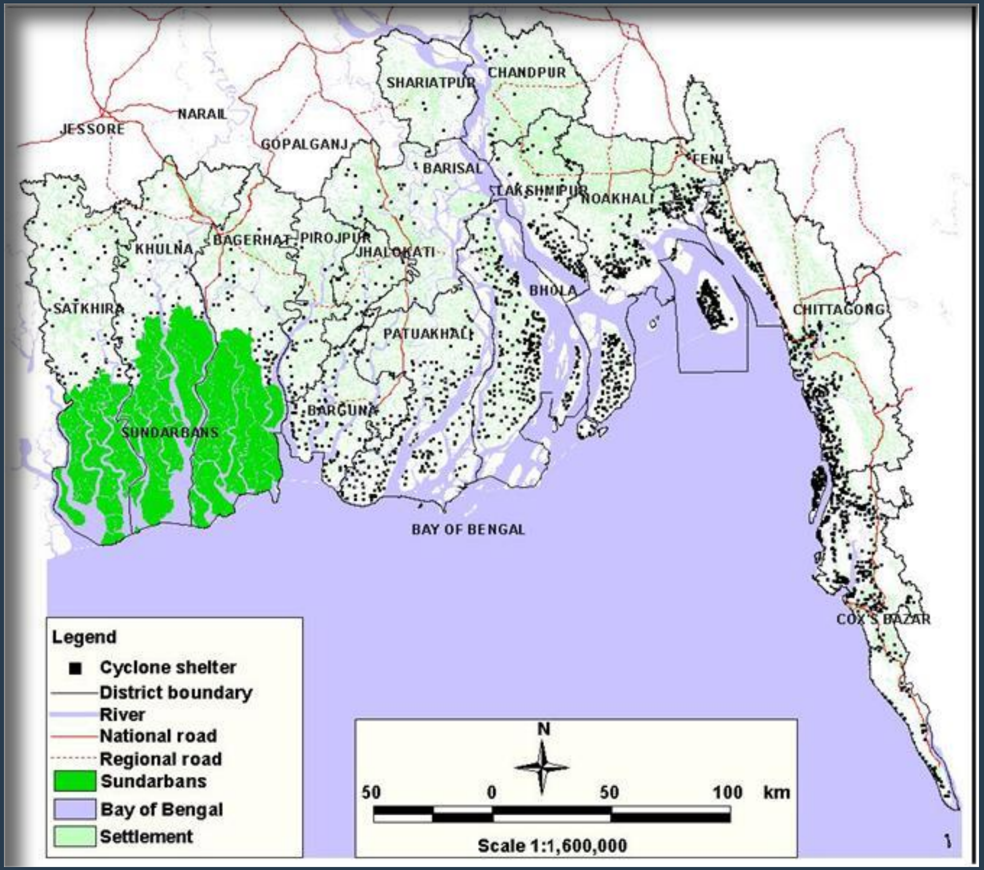
- 43.2 million people in Bangladesh live in poverty.
- 24.4 million extremely poor do not meet the basic needs of food expenditure.

Implications of Storm Surge for the Poor



	Total population	Poor
Current situation	15.4 million	4.3 million
Future (2050)	16.8 million	5.3 million
Change from the current situation to 2050	+ 9%	+ 22%

Emergency Shelters in Bangladesh



- Many of these cyclone shelters are in dilapidated condition.
- 65% of the shelters with no provision for the special needs of women.
- 80% of the shelters have no provision for livestock.

Emergency Shelters

- In coastal Bangladesh, 8,06 million people were exposed to storm surge inundation depth of more than 3m.
- In 2050, with 1% per year projected growth of coastal population, 13.6 million 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 9.1 million inhabitants will be exposed to a similar inundation risk.
- At present, a World Bank-funded multipurpose cyclone shelter, under-construction, with provisions for 1,600 people costs $214,000.

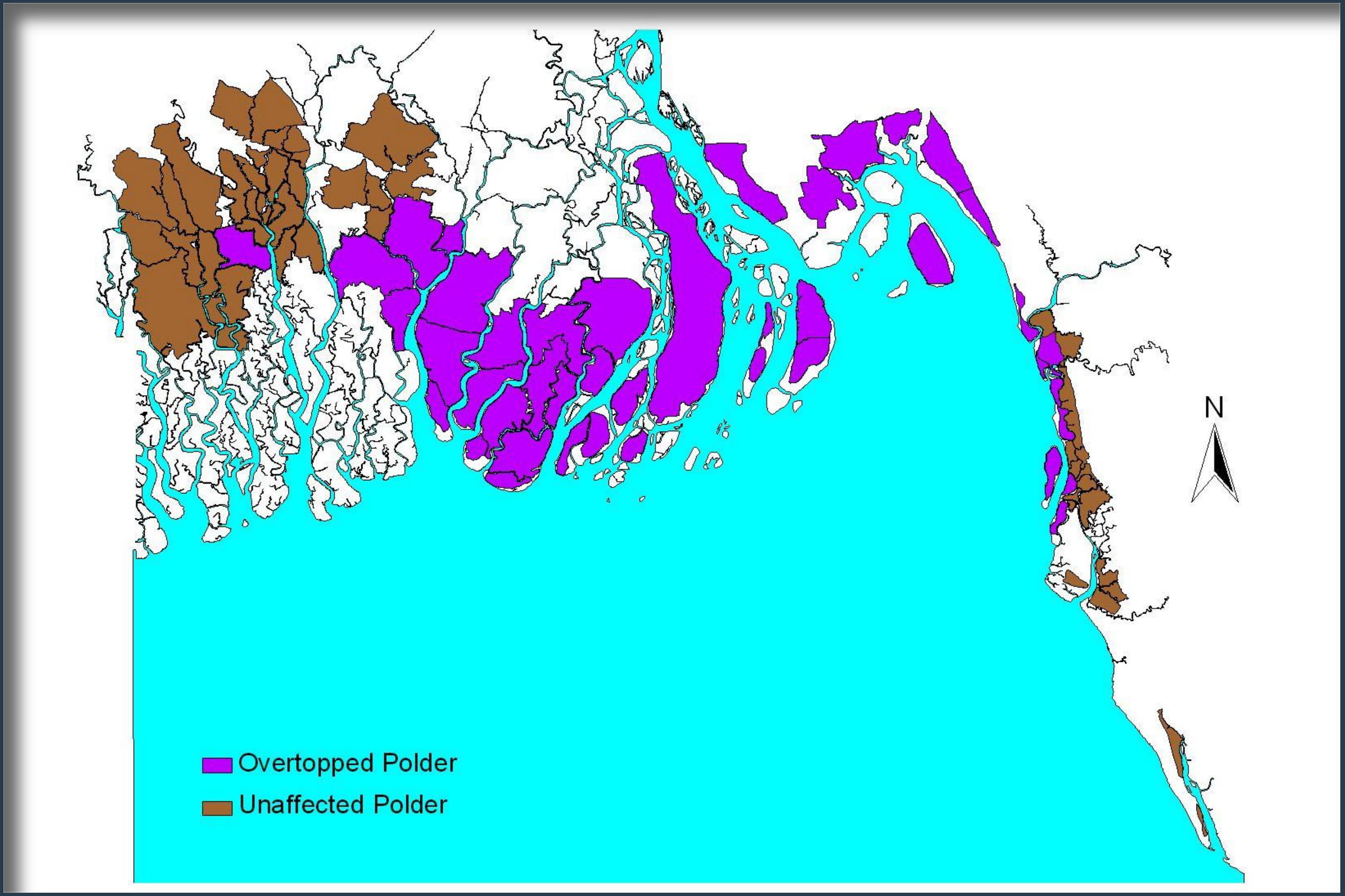
- In order to accommodate 9.1 million inhabitants exposed to inundation risk due to climate change, additional 5,702 multipurpose shelters would be required at the estimated cost of $ 1.2 billion.

- Alternative adaptation option: Promotion of concrete houses (estimated cost $200 million)
  - Subsidize credit facility
  - Subsidized construction material

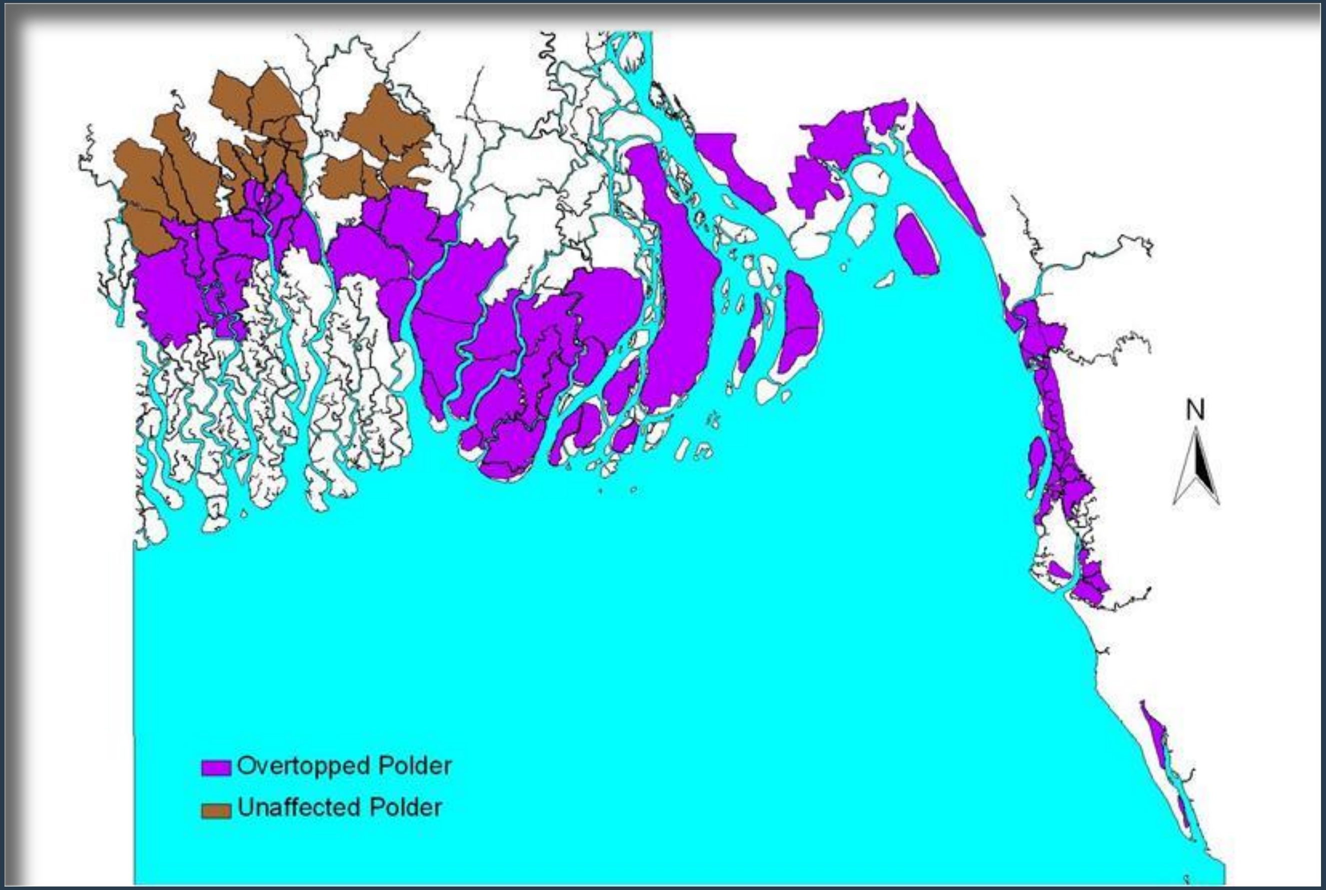
Coastal Polders in Bangladesh

- In the early sixties and seventies, 123 polders (of which 49 are sea-facing) were constructed to protect low lying coastal areas from tidal flood & salinity intrusion.

Coastal Polders at Risk of Overtopping
(2050 without Climate Change)



Coastal Polders at Risk of Overtopping
(2050 in a Changing Climate)



- 33 sea-facing polders and 26 interior polders are likely to be overtopped.

Other Protective Measures

- Height enhancement of Coastal Polders
- Afforestation to protect sea-facing polders
- Strengthening the early warning & evacuation system

Height Enhancement of Polders

- Polders at risk of storm surge inundation with & without climate change were identified from +ive differences between projected surge heights and existing height of polders.
- Difference between the projected storm surge height and the crest level of embankment of each polder at risk quantified the required height enhancement of the polder.
- The amount of earth needed for this purpose has been derived from engineering designs.
- The BWDB provided current local price for earthwork (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) , compaction and turfing cost (Tk 7.07 per sq meter).
- To prevent “toe-erosion”, cost of hard protection using cement concrete blocks with sand filters and geo-textile, Tk. 224,100/meter has been used.
- Height enhancement of polders will require more land for strengthening the bases. Cost of land acquisition has been added.

➢ Height enhancement of 26 interior and 33 sea-facing polders to prevent overtopping in a changing climate will cost $892 million.

Cost Components

- Coastal Polders: Earth work, Turfing, Vetivera Plantation, Land Acquisition, Toe Protection.
- Afforestation to protect sea-facing polders: Mangrove Plantation.
- Construction of Multipurpose Cyclone Shelters: Standard Capacity for 1600 occupants with provision for livestocks & safe drinking water.
- Construction of Cyclone-Resistant Private Housing: Brick Houses with Concrete Roofs (on stilts, if necessary), Proper Building Codes.
- Strengthening the early warning & evacuation system: Topographic Survey & Analysis, Modernization of Weather Monitoring Stations, Establishment of Additional Radio Stations, Institutional Capacity Building, Awareness Promotion.

Source of cost/ unit: World Bank, Bangladesh Water Development Board, Bangladesh Meteorological Department, Institute of Water Modeling, Red Crescent Society, Local architects & Civil Engineers.

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Mangroves as a Protection of Storm Surges in Bangladesh

Mangroves as Storm Buffer

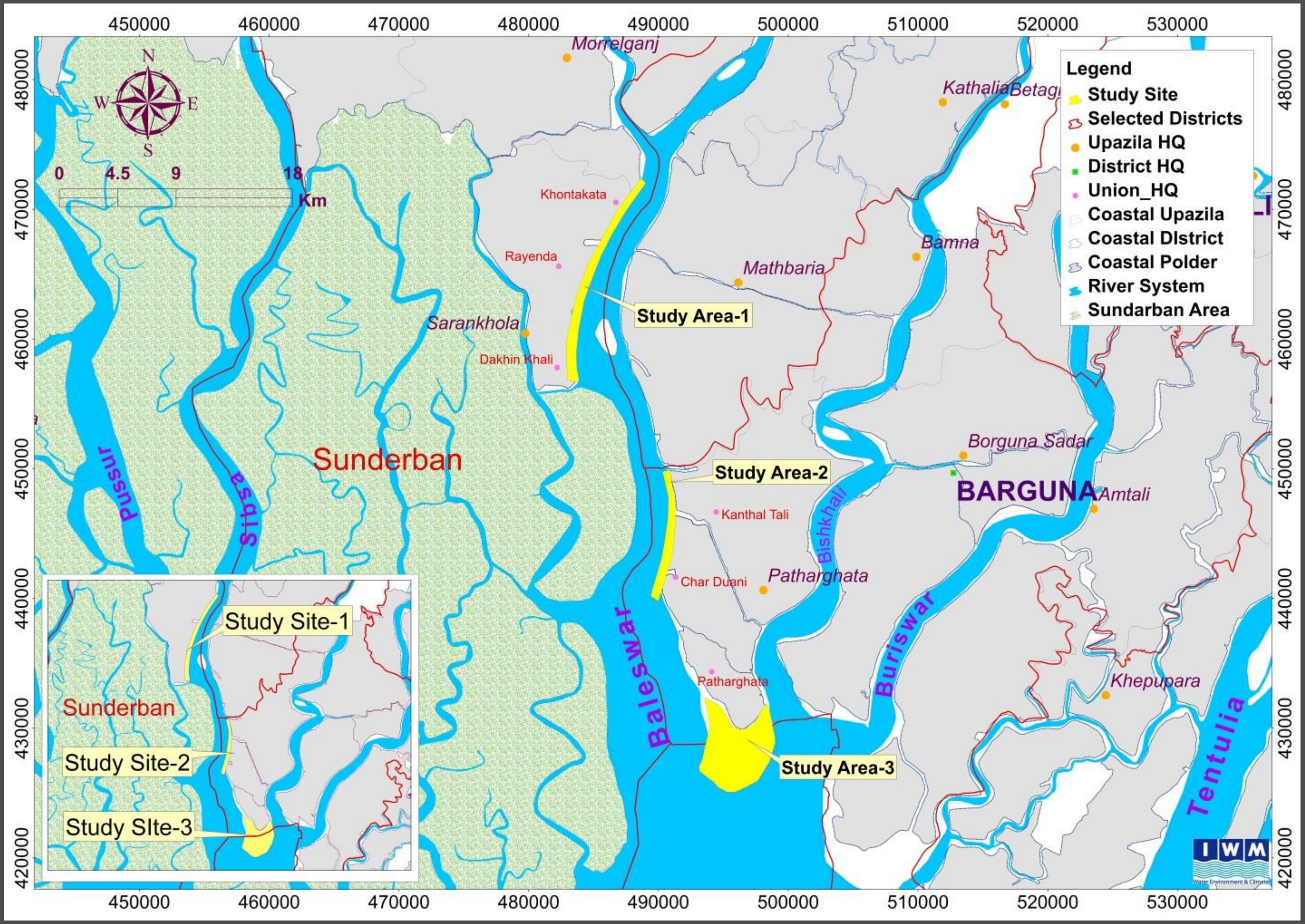
- Mangroves can substantially reduce vulnerability of coastal land from storm surges as the flow of water through the mangrove forest is obstructed by the matrix of roots, trunks and leaves of the mangrove trees.

Study Areas

Study Area	River/ Sea-facing	Mud Flat/ Tidal Characteristics	Maximum Salinity (PPT)	Setback Distance of the Polder (foreshore)
Area 1: adjacent to polder 35/1	**River facing** along the right bank of Baleswar river	Mud flat erosion	8.25	50-70m
Area 2: adjacent to Polder 40/2	**River facing** along the left bank of the Baleswar river	Mud flat accretion	10.80	100-150m
Area 3: adjacent to Polder 40/1	**Sea facing** and exposed to the estuary of Baleswar and Bishkhali River	Mud flat accretion	20.30	2 km

Study Sites

Coastal Bangladesh



Mangrove Species

Study Area	Selected Mangrove Species
Area 1	*Sonneratia apetala, Avicennia officinalis*
Area 2	*Sonneratia apetala, Avicennia officinalis*
Area 3	*Sonneratia apetala, Avicennia officinalis, Heritiera fomes, Exoecaria agallocha, Ceriops decandra*

Selection Criteria: Tidal Characteristics, Salinity Tolerance, Familiarity of the Local People with the Mangrove Tree, Economic value,

Field Measurement of Roots & Trunk System

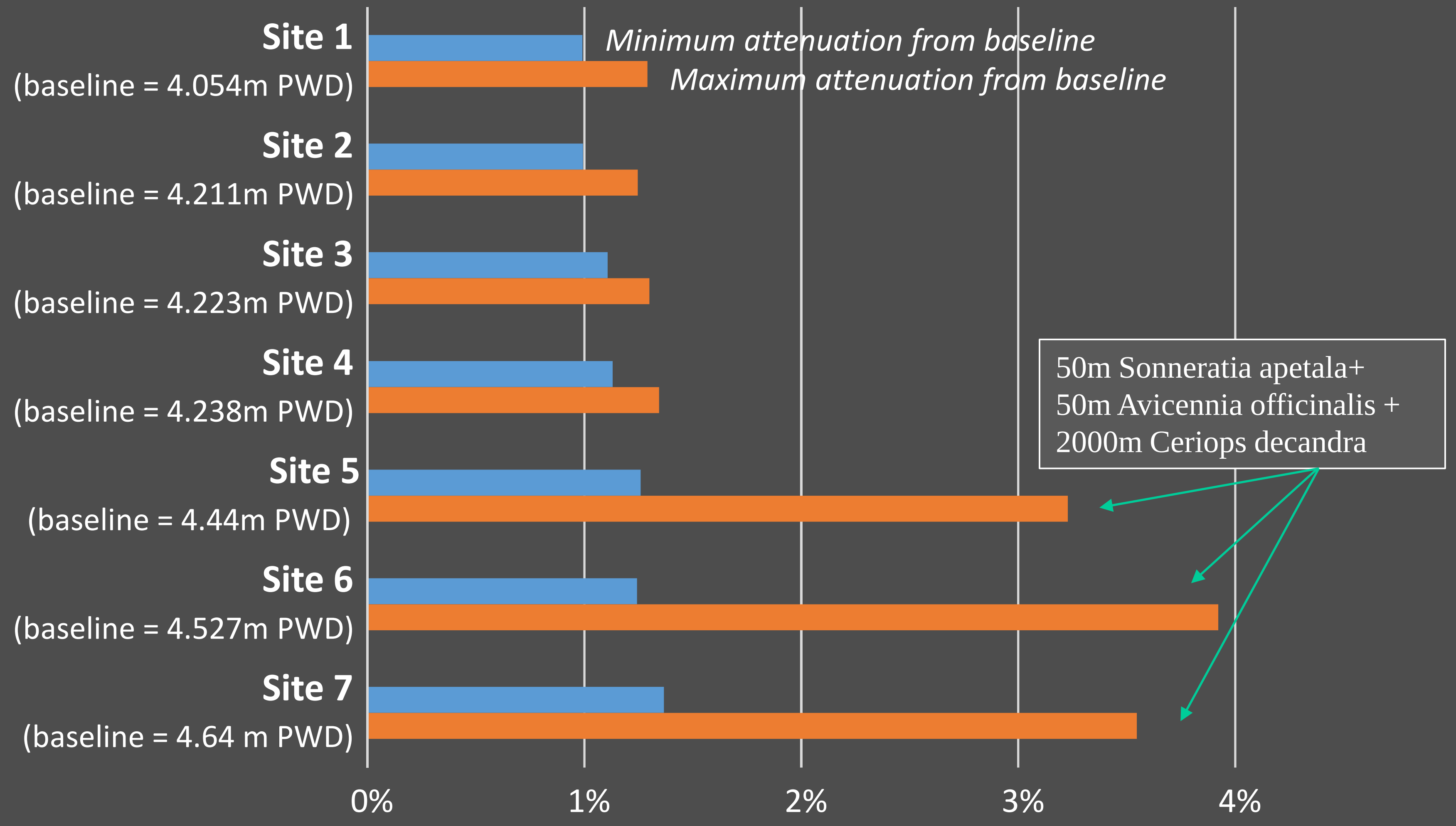
Avicennia officinalis

Sonneratia apetala

Manning's Number
Water Depth: 2.5 m

	Manning's Number from Root & Trunk System		
	5m Spacing	7.5m Spacing	10m Spacing
Sonneratia apetala	10.7	12.2	12.8
	4m Spacing	6m Spacing	8m Spacing
Avicennia officinalis	13.8	17.4	19.5
	5m Spacing	7m Spacing	10m Spacing
Heritiera fomes	13.5	16.9	18.8
Exoecaria agallocha,	15.1	17.8	19.1
Ceriops decandra	15.6	18.3	19.7

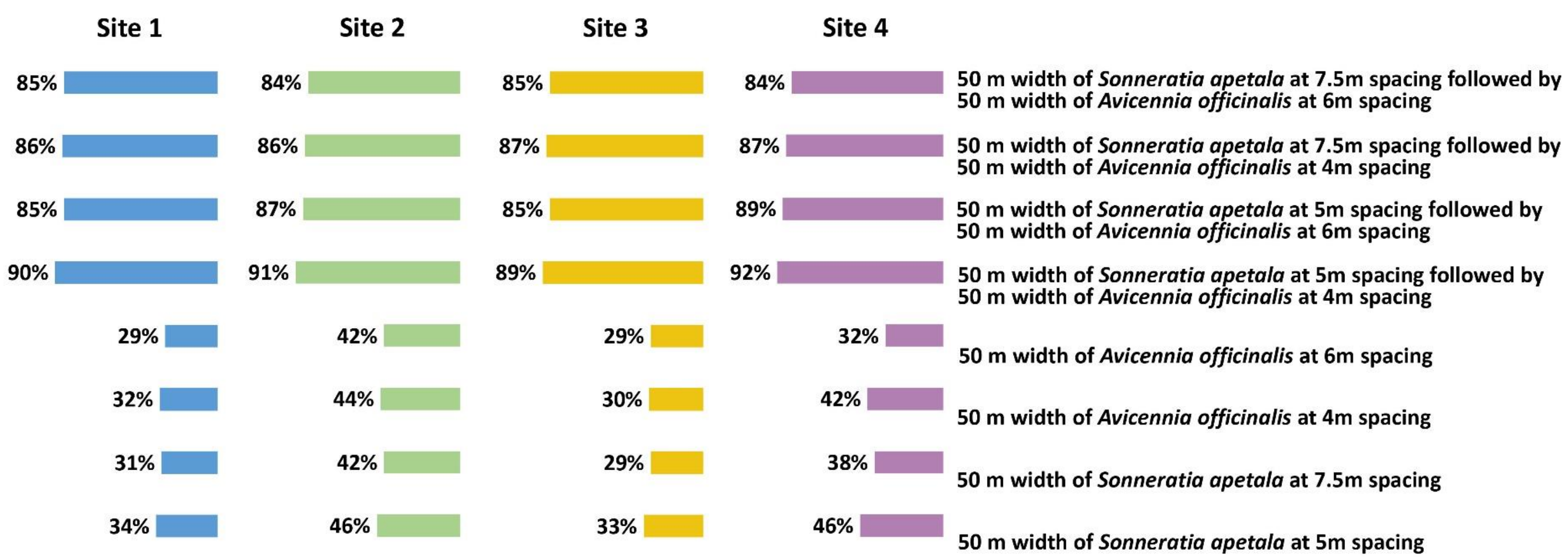
Change in Surge Height



Reduction in Water Flow

Reductions in water flow velocity from afforestation of mangrove species

Study Area 1: Site 1 Water flow velocity of Sidr (2007): 0.624 m/s
Study Area 1: Site 2 Water flow velocity of Sidr (2007): 0.593m/s
Study Area 2: Site 3 Water flow velocity of Sidr (2007): 0.687m/s
Study Area 2: Site 4 Water flow velocity of Sidr (2007): 0.651m/s



Findings

- Mangroves attenuate surge height and water flow velocity.
- Extent of attenuation is location specific, depends on mangrove species, width of mangrove strip and density of plantation (spacing between trees).
- Estimated surge height reduction is 4cm to 16.5cm from a 50m to 2km wide mangrove strips.
- Estimated reduction in water velocity is 29% to 92% from 50m or 100m wide mangrove forests of *Sonneratia apetala* and *Avicennia officinalis*.
- Experience of mangrove afforestation programs suggest *Sonneratia apetala* accounted for 94% of successful mangrove plantation in Bangladesh.

Implications of Findings

- Mangroves alone will not be able to protect assets and activities at risk from storm surge, but must be used along with built infrastructure.
- Design of mangrove afforestation programs must be location-specific. Design of polders must take into account mangrove programs
- Although estimated surge height reduction from mangroves may appear nominal, significant savings in construction cost of embankments due to potential cost savings in land reclamation and earthwork are expected.
- Estimated reduction in water velocity from mangroves will protect embankments from “toe-erosion”, breaching and other damage.
- Mangroves help in reducing land erosion and in accretion of the foreshore area of embankments by trapping sediment in active delta.

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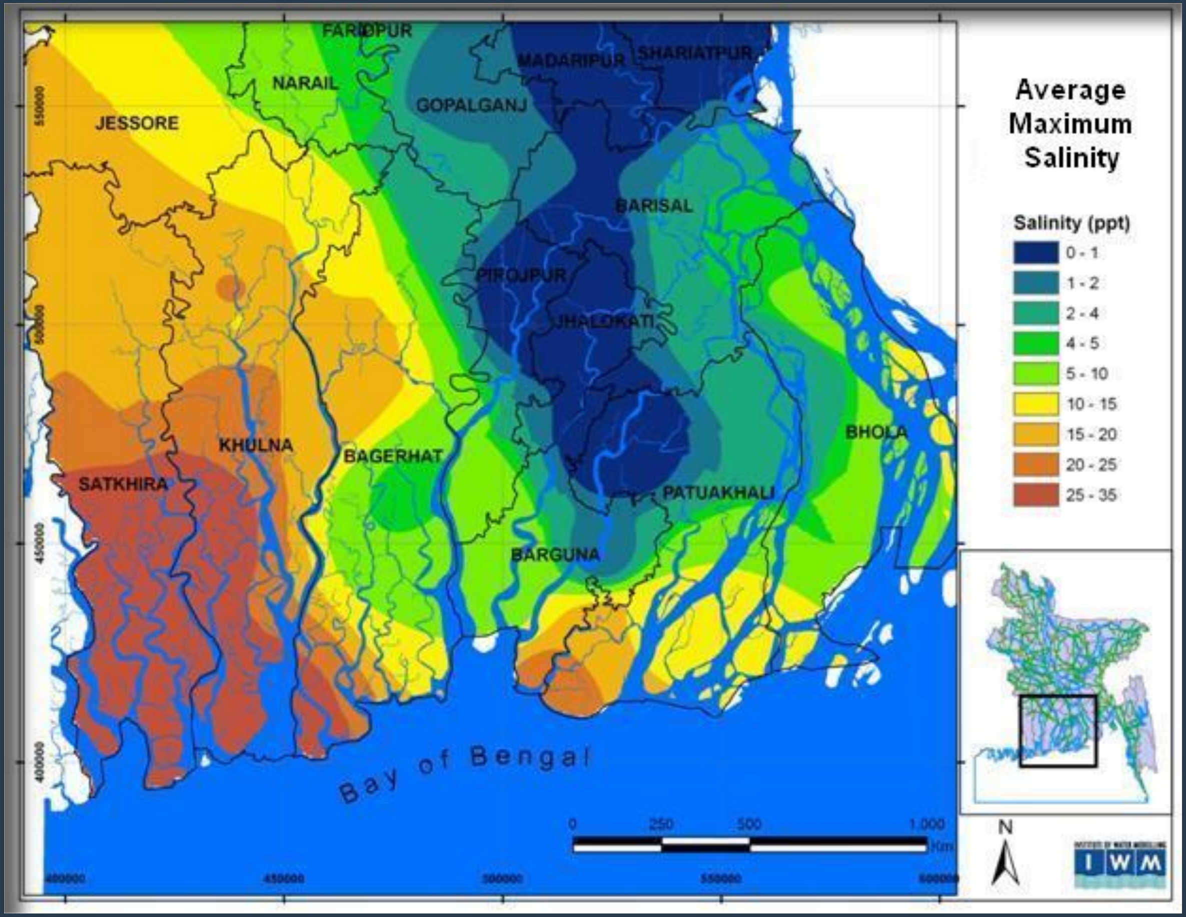
Water Salinization in a Changing Climate

River Water Salinity in the Coastal Region

- High river salinity in southwest coastal region is noticeable in the current climate.
- Average salinity is higher in the dry season than in the monsoon.
- Steady increase in salinity from October to late May.
- In early June, salinity drops sharply with the onset of monsoon rain.
- At present, the rivers of the southwest coastal zone are highly saline.
- Scarcity of drinking water and water for irrigation in the southwest coastal region are apparent and serious.

River Salinity in the Southwest Region

Spatial variation of maximum river salinity during 2011-2012



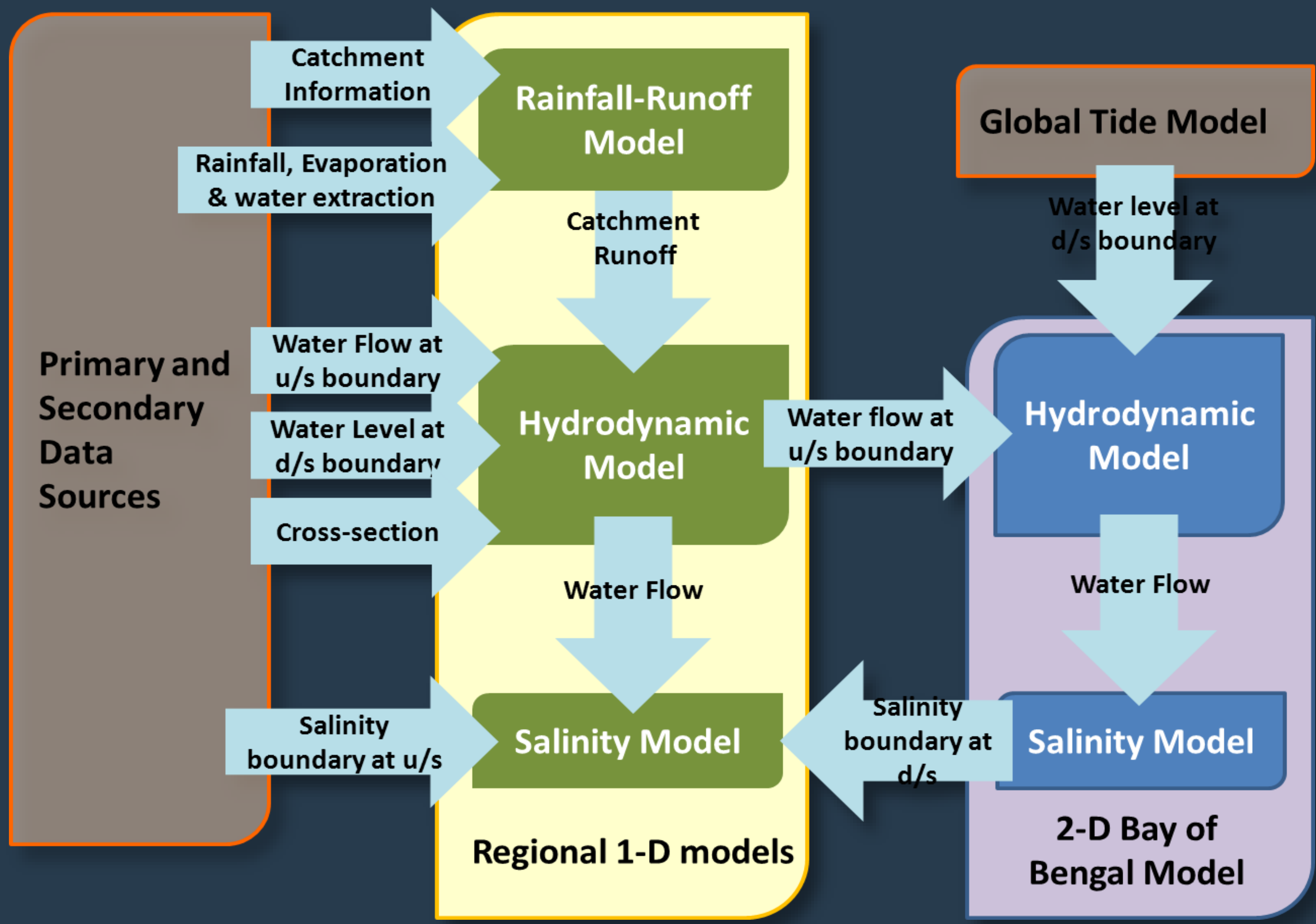
Source: IWM, 2013

River Salinity Modeling: Conceptual Framework

- River water salinity in coastal Bangladesh depends on:
  - Volume of freshwater discharges from the upstream river systems
  - Surface water runoff from rainfall
  - Salinity of the Bay of Bengal near the coast, and
  - Tidal dynamics of the coastal river system

Source: IWM, 2013

River Salinity Modeling



u/s: upstream boundary d/s: downstream boundary of a river

River Water Salinity in a Changing Climate

- Climate-induced changes in sea level, temperature, rainfall, altered riverine flows from the Himalayas are expected to affect the spread and intensity of salinization on river water in the coastal area.

- In a changing climate, saltwater intrusion is expected to worsen in low-lying coastal areas.

Modeling Climate Change

- Baseline: Historical data on the maximum measured salinity from December 2011 to May 2012 (Source: IWM).

- Climate Change by 2050:
  3 Alternative Emission Scenarios
  3 Alternative Climate Models
  3 Alternative Relative Mean Sea-Level Rise by 2050

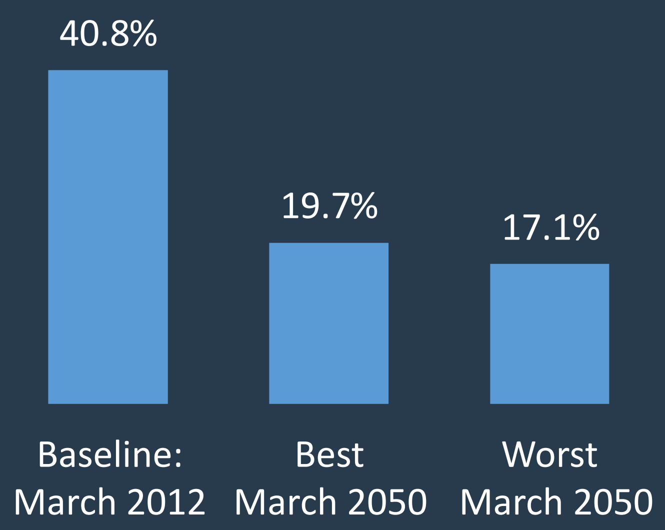
Area Estimates

Salinity classification* 1 dS = 1.75 ppt	Baseline (March 2012)	Best (March 2050)	Worst (March 2050)
Slight saline (<1 dS/m)	22 %	16 %	13 %
Slight to moderately saline (1-5 dS/m)	35 %	30 %	21 %
Moderate to high saline (5-10 dS/m)	8 %	17 %	27 %
Highly saline (>10 dS/m)	35 %	38 %	40 %

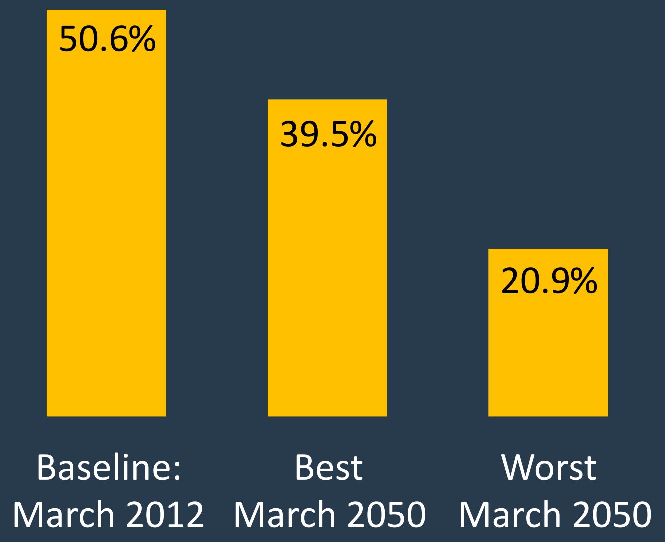
*WARPO-Bangladesh: National Water Management Plan

Expected Impacts

River area: freshwater (0-1 ppt)



River area: water for dry season agriculture (< 2ppt)



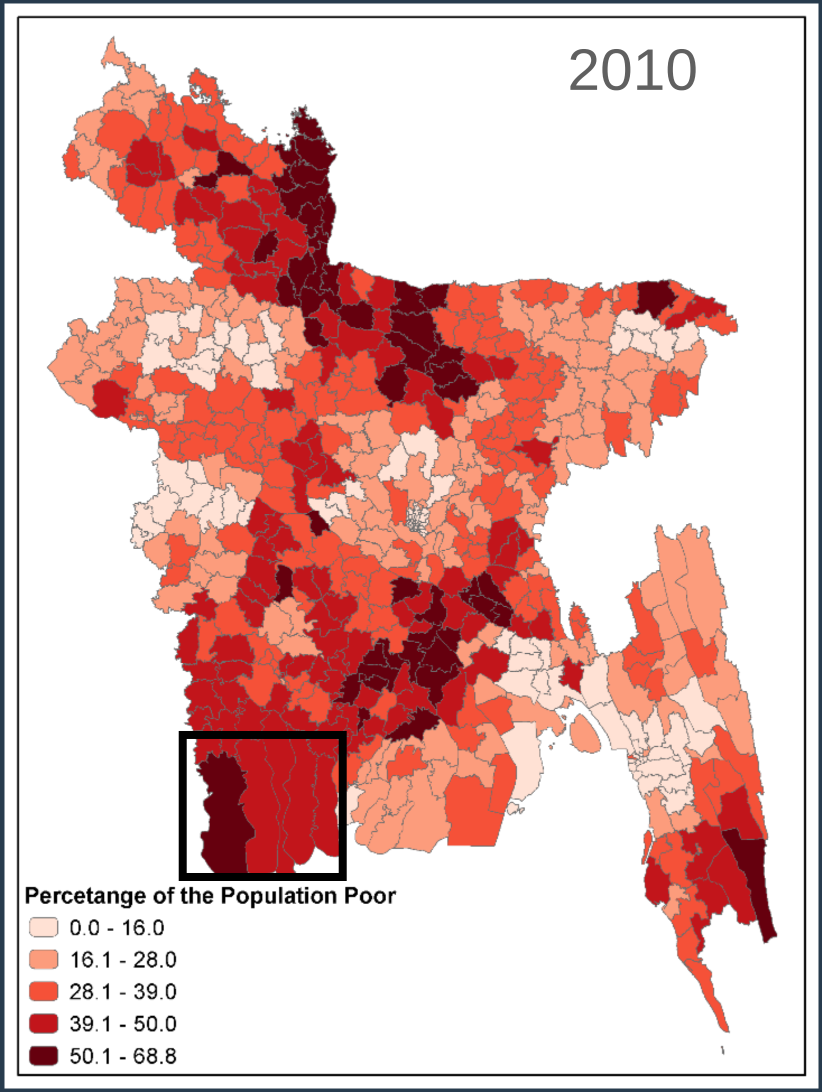
- Expected increase in river salinity is likely to impact wild habitats of fresh water fish.
- In Sunderbans (UNESCO Heritage site), a shift in mangrove species is expected.

Expected Impacts: Freshwater

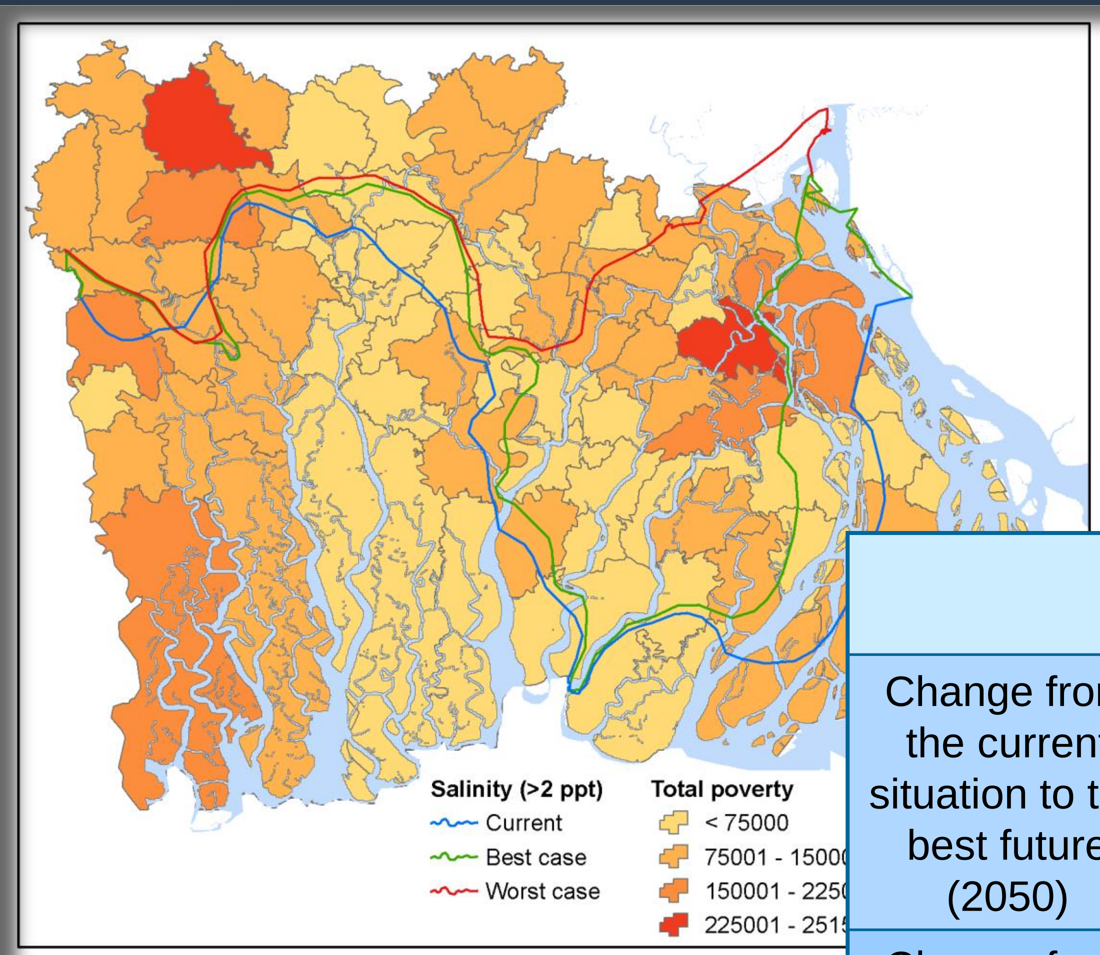
- Freshwater (0–1ppt) zones will be lost entirely in Barguna, Jhalokoti, Khulna, and Patuakhali Districts in the best case future scenario.
- Freshwater zones will reduce in Barisal, Pirojpur, and Bagerhat Districts by 85, 81, and 71 percent respectively in the best case scenario.
- In the worst case scenario, 100 percent of fresh river water in Pirojpur, 93 percent in Bagerhat, and 91 percent in Barisal will be at risk.

Poverty Map of Bangladesh

- 9.9 million people in Southwest coastal Bangladesh live in poverty.
- 5.8 million extremely poor do not meet the basic needs of food expenditure.



Exposure of Poor to Increased River Salinity



	Total population	Poor	Extremely poor
Change from the current situation to the best future (2050)	+15 %	+17 %	+23 %
Change from the current situation to the worst future (2050)	+100 %	+111 %	+130 %

Health Implications of Increased Water Salinity

- Controlling for many other determinants of infant mortality, the econometric analysis found high significance for salinity exposure of mothers during the last month of pregnancy.

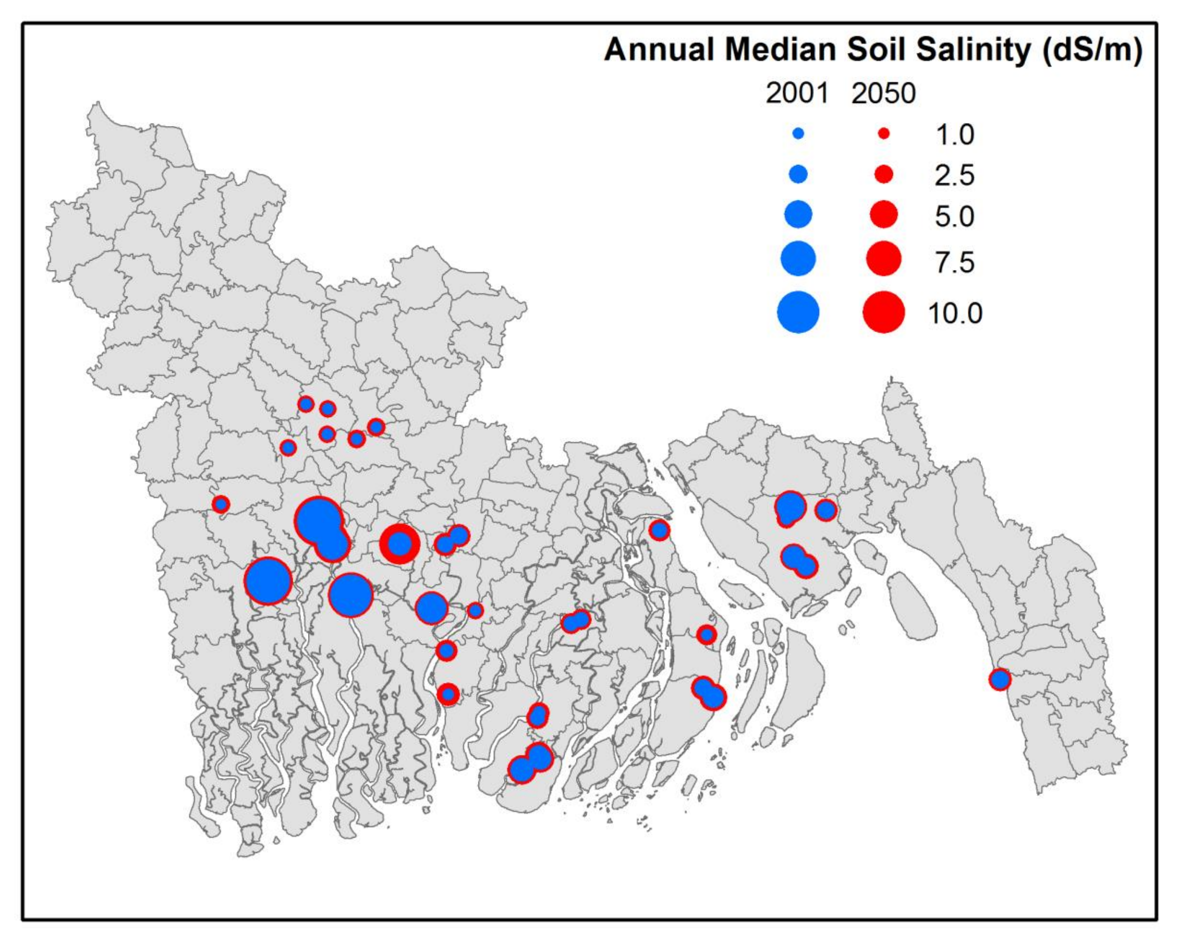
- The estimated impact of salinity on infant mortality is comparable in magnitude to the estimated effects of traditionally-cited variables such as maternal age and education, gender of the household head, household wealth, toilet facilities, drinking water sources and cooking fuels.

Impacts: Change in Mangroves

- Significant impact on mangrove species in Sunderbans (UNESCO Heritage site) is anticipated,
- A shift in species is expected from *Heritiera fomes* to *Ceriops decandra* and *Excoecaria agallocha*.
- A negative impact on standing stock of timber in the region is inevitable.
- Overall honey production is likely to increase.
- Human and wildlife conflicts in Sundarbans will increase.

Analysis is based on 14 mangrove species and mixed species.

Significant Increase in Soil Salinity by 2050



Range of increase: 2% - 73% across 41 monitoring stations.

Soil Salinity in a Changing Climate

- By 2009, a general pattern of salinity increase is apparent. The shift continues through 2050.
- Across 41 monitoring stations
  - Median projected increase is 26.2%.
  - 25% of the stations have changes of 41.8% or higher
  - 10% have projected changes greater than 55.7%.
- 24 or more *upazilas* are expected to cross 4.0 dS/m within a few decades after 2050.

Soil Salinity and HYV Rice Yield

- Many sub-districts have already suffered large yield losses from rising soil salinity.
- Losses will be compounded by further salinity increases in the coming decades.
- Estimates suggest that HYV rice output will decline by 15.6 percent in nine coastal sub-districts where soil salinity is expected to exceed 4 deciSiemens per meter before 2050.
- Predicted change in soil salinity will lead to significant income declines from HYV rice production in many areas, including a 10.5% loss in Barisal region and 7.5% loss in Chittagong region.

Important Source of Dietary Protein

Wild, small freshwater fish are the most common fish consumed in rural Bangladesh

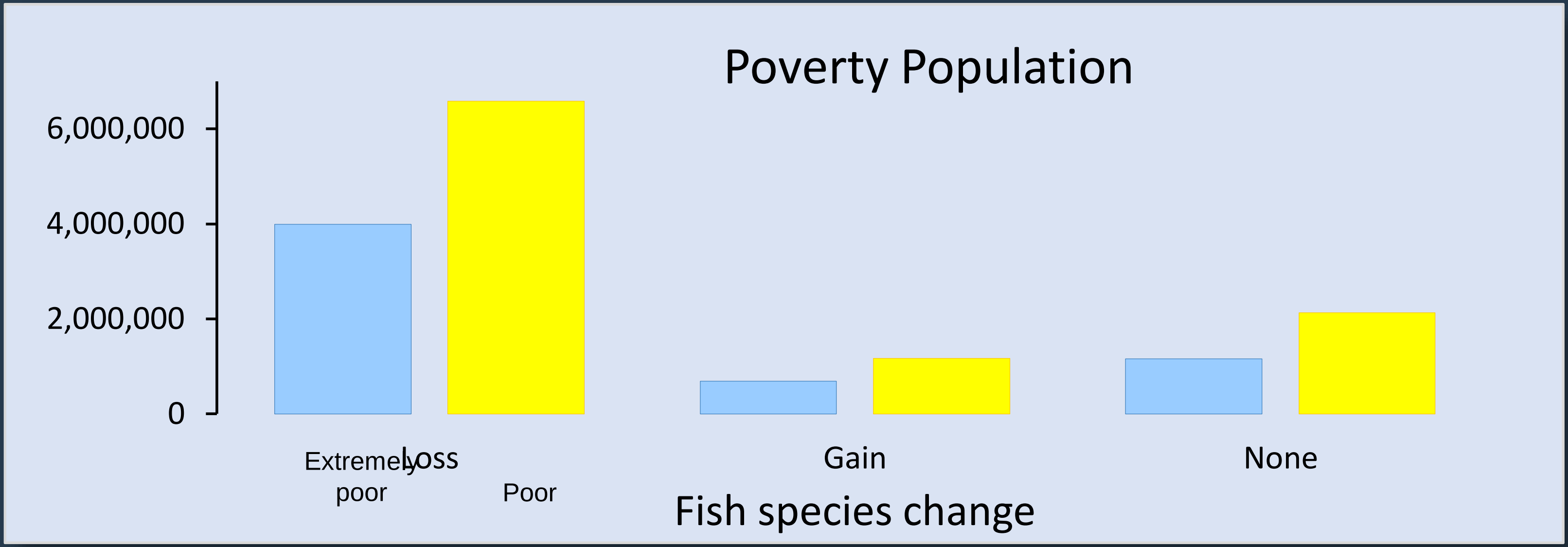
Image: Pritthijit Kundu

Implications for Fish Habitats

- Analysis is based on 83 fish species consumed in the region.
- Adverse impacts on reproductive cycles, reproductive capacities, extent of spawning areas and feeding/breeding/longitudinal migrations of fresh water fish species are expected.
- GIS overlays of maps of river salinity and fish habitats by salinity tolerance of fish species are conducted to predict impacts of salinization on prevalence of fish species from 2012 to 27 climate scenarios in 2050.
- Analysis is conducted for 101,600 pixels (one pixel has an area of 0.327 sq. km, which is equivalent to a square cell with side length of 571.54 m).
- Exposure of the poor to changes in fish habitats (loss, gain and no change) is calculated from GIS overlays of the count of poor from the poverty map at sub-district level and mean percent changes in fish species for the sub-districts.

Findings: Implications for Fish Habitats

- Areas with poor population that lose species are 6 times more prevalent than areas gaining species



- Livelihood of fishermen in the region will be adversely affected.
- Significant impact on animal protein intake of poor women and children is expected.

Livelihood Threats and Household Responses

- Agricultural productivity loss, loss of fresh water fish species are affecting the livelihood of coastal families adversely.
- Economic necessity drives more working-age adults to seek outside earnings in households threatened by inundation and salinization, particularly those that are relatively isolated from market centers.
- Households in coastal areas have out-migration rates for working-age adults (particularly males), dependency ratios, and poverty incidence that are **significantly higher** than their counterparts in non-threatened areas.
- Those left behind face a far greater likelihood of extreme poverty than their counterparts in less-threatened areas.

Critical Zone in Coastal Region

- The critical zone for inundation risk lies within 4 km of the coast, where about 8% of the population of Bangladesh currently resides, with lesser impacts observed for coastal-zone households at higher elevations.

Potential Adaptation Measures for Ingress of Salinity

- River Training
- Desalinization of Drinking Water & Rainwater Harvesting
- Widespread use of Saline Resistant Crops
- Expansion of Tilapia Farming and Crab (*Scylla serrata*) Culture
- Cooperative Management of fishing
- Expansion of Honey Production
- Vocational training for women (e.g., training for textile industry) and men (e.g., driving of commercial vehicles) will be of use.
- Reduction of travel times for isolated settlements to market centers by 2 1/2 hours (from current condition of 9 hours)

Alternative Interventions

- Standard adaptation measures focus on direct compensation for welfare losses, and are necessary.

  In addition,

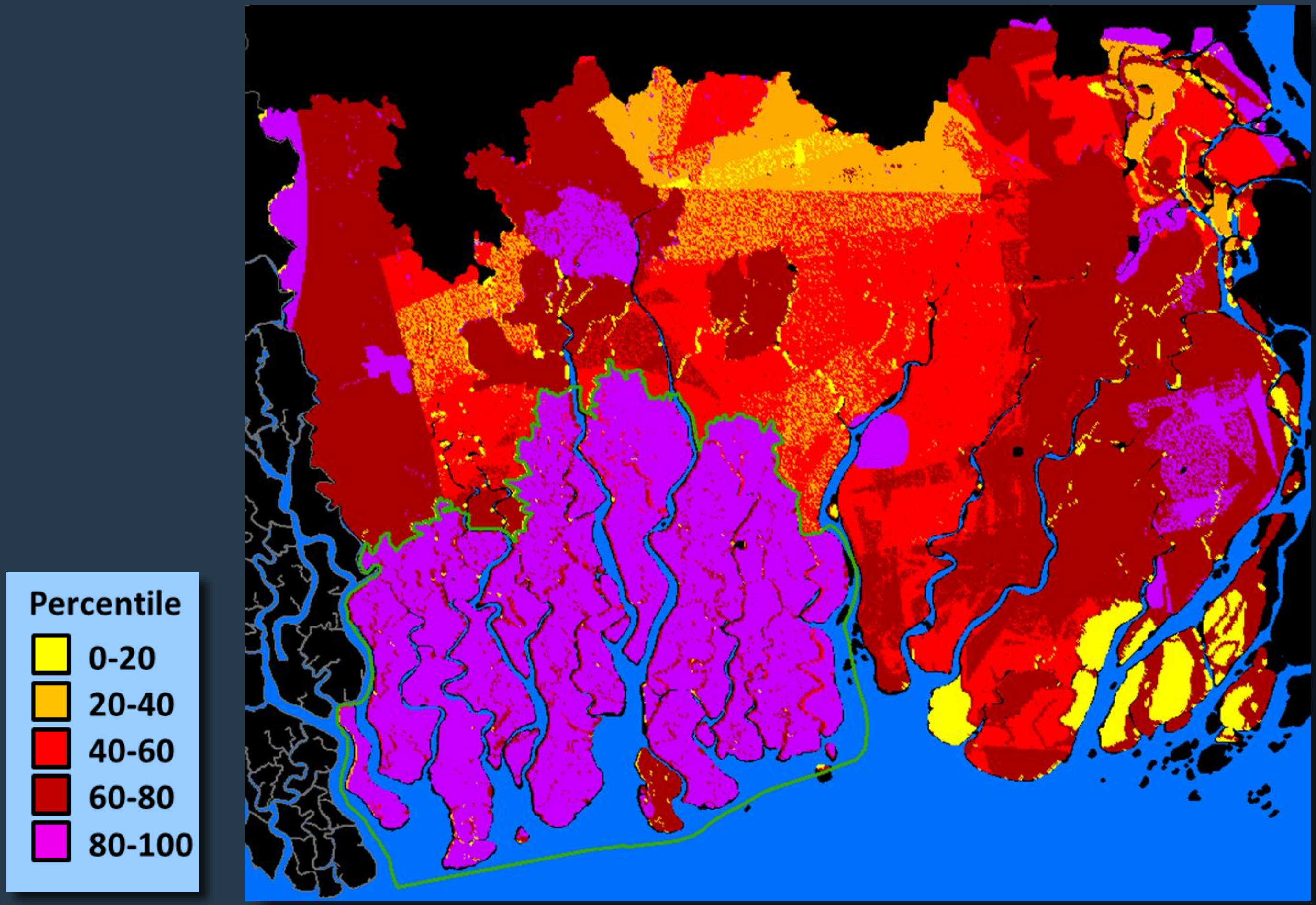
- Vocational training for women (e.g., training for textile industry) and men (e.g., driving of commercial vehicles) will be of use.

- Reduction of travel times for isolated settlements to market centers by 2 1/2 hours (from current condition of 9 hours) would significantly improve their economic welfare.

- Benefits of increased mobility are enlarged by the threat of climate change, making such investments an attractive low-regret option.

Critical Biodiversity

Indicator based on count, threat status, endemicity and extinction probability of species



Improvement of market access should take into account critical biodiversity of the region

- **Vulnerability of Coastal Areas in Bangladesh from Sea-Level rise and Cyclones**
- **Mangroves as a Protection of Storm Surges in Bangladesh**
- **Water Salinization in a Changing Climate**
- **Urban Flooding of Greater Dhaka in a Changing Climate: Building Local Resilience to Disaster Risk**

Urban Flooding of Greater Dhaka in a Changing Climate

Building Local Resilience to Disaster Risk

Urban Flooding : A Recurring Problem in Dhaka

- Flooding batters the city, affecting communications, livelihoods and service facilities every monsoon.
- The fringe areas, slums and shanties suffer more.
- Recent Devastating Floods: 1974, 1987, 1988, 1998, 2004, 2007, 2009.

Research Motivation

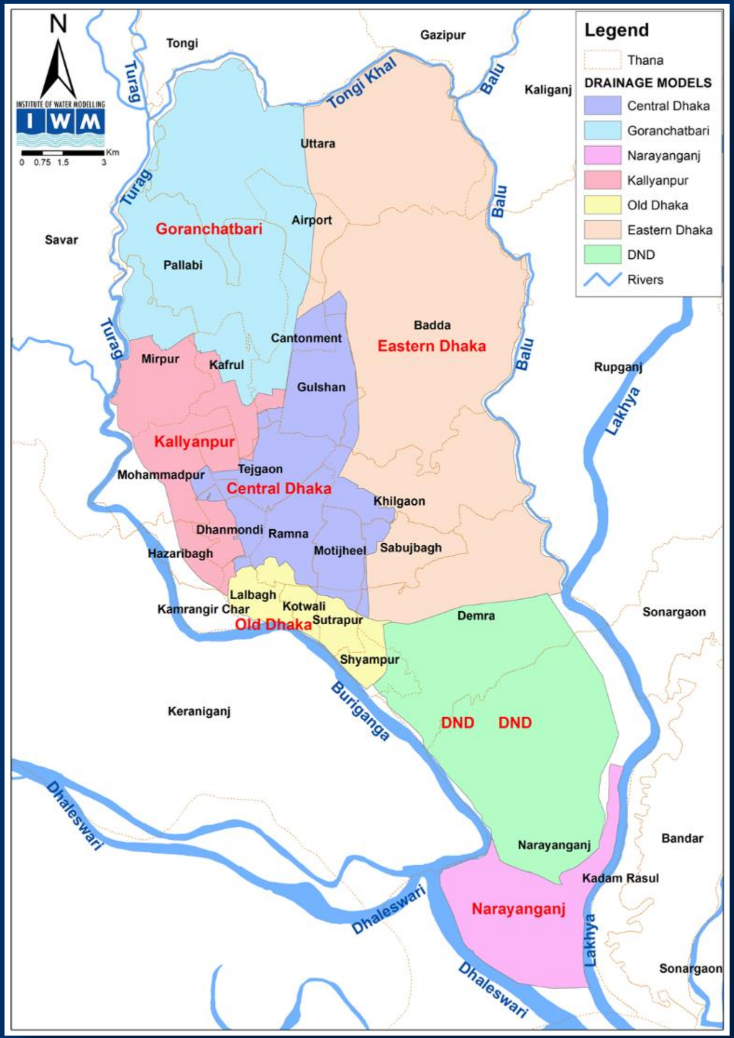
- Gradual filling up of flood plains, rivers, canals and other water bodies with rapid urbanization will aggravate the water logging over time.
- More erratic rainfall and increase in the frequency and intensity of extreme rainfall events with climate change may further worsen Dhaka's flood vulnerability in the future.
- This study will provide local decision-makers an effective planning approach to minimize the damage from urban flooding.

Study Components

- ***Assessment of Disaster Resilience***: Local preparedness for urban flooding emergencies of constituent wards was analyzed.
- ***Hydrological modeling***: Location-specific depth and duration of flooding from an intense rainfall event was estimated.
- ***Flood vulnerability***: The 10 most vulnerable wards of Greater Dhaka Area taking into account their exposure to flood as well as socioeconomic vulnerability and disaster resilience were identified.
- ***Design of adaptation*****:** Recommended adaptation measures for each study area were developed and itemized adaptation costs were estimated.
- ***Estimation of expected damage***: Expected economic damage from an intense rainfall event in 2050 and cumulative damage from similar rainfall between 2014 and 2050 with and without adaptation were estimated.
- ***Complimentary flood mitigation measures*** were recommended.

Detailed Study Area

- Old Dhaka
- Central Dhaka
- Kallyanpur
- Goranchatbari
- Eastern Dhaka
- DND (Dhaka-Narayanganj-Demra)
- Narayanganj



Future Scenarios

- Baseline Rainfall (without climate change scenario): Historic September 2004 rainfall event (341 mm rainfall in 24 hours)

- Climate Change Rainfall Scenario: A 16 percent increase in 24-hour rainfall in Dhaka in 2050 as compared to the baseline.

Central Dhaka – Extent and Duration of Flood with and without Climate Change

Extreme rainfall in 2050	Flood free	0.1m-0.25 m	0.25m-0.75m	0.75m-1.5m	> 1.5m	Average Duration above 0.1m (hours)
341 mm/ 24 hour	26.4	8.8	1.9	0.3	1.8	10
396 mm/ 24 hour	25.1	10.1	1.9	0.3	1.8	12
341 mm/24 hour without Adaptation deficit	36.4	0.7	0.3	0.1	1.7	1
396 mm/ 24 hour but without Adaptation deficit	35.7	1.1	0.5	0.2	1.8	2
396 mm/ 24 hour without Adaptation deficit and with adaptation for climate change	36.1	0.9	0.4	0.1	1.8	1

Central Dhaka-Adaptation Cost

	Tk. Million
Addressing Current Climate Deficit:	
Pump station, Bashabo *	849.5
Pump station, Panthapath	600.00
Total	1,449.5
Addressing Climate Change Deficit:	
Total estimated cost, sluice gates at Russel Square	91.1
Total Combined Cost	1,540.6

* Calculation based on price of pump, related mechanical, electrical and civil works, land acquisition and sluice gate.

Central Dhaka – Cumulative Damage from Extreme Rainfall Events during 2014-2050

- Cumulative damage between 2014 and 2050 from an intense rainfall event based on random assignment of 1 % probability of occurrence during each year:
  - If there is no climate change and no action is undertaken: Tk. 56,315 million
  - If current climate adaptation deficit is met: Tk. 11,460 million
  - If there is climate change (no change in frequency-only more intense rainfall) and no action is undertaken: Tk. 65,754 million
  - If current climate adaptation deficit is met and climate change adaptation is undertaken: Tk. 12,367 million

- Cumulative damage between 2014 and 2050 from an intense rainfall event based on random assignment of 5 % probability of occurrence during each year:
  - If rainfall intensity remains the same and no action is undertaken: Tk. 65,322 million
  - If current climate adaptation deficit is met: Tk. 13,119 million
  - If there is climate change and no action is undertaken: Tk. 76,205 million
  - If current climate adaptation deficit is met and climate change adaptation is undertaken: Tk. 14,159 million

Cost-Benefit Comparison

- Potential cumulative damage from intense rainfall events between 2014 and 2050 even without climate change is Tk 110 billion.
- Potential cumulative damage from intense rainfall events between 2014 and 2050 with climate change is Tk 139 billion.
- With recommended Tk 2.7 billion investment made to mitigate the historic September 2004 waterlogging in current climate:
  - Potential cumulative damage will reduce to Tk 37 billion without climate change.
  - Potential cumulative damage will reduce to Tk 49 billion with climate change.
  - This estimate of potential savings in damage is conservative.

Top 10 Flood-Vulnerable Wards

Kallyanpur	09
DND	87
Old Dhaka	82
DND	86
Central Dhaka	25*
Kallyanpur	10
Kallyanpur	58
DND	88
DND	90
Eastern Dhaka	Khilgaon outside DNCC

* Flood extent, Flood duration, high Population density, high population of informal settlers, high number of children and elderly, low literacy rate, low access to internet, lower number of public awareness programs/ disaster drills, Education and awareness, low level of community participation, low ability to reach consensus, inadequate interaction between social class,

Message to Policy Makers

- Invest to address historic waterlogging in the current climate - the city is already facing the risk even without climate change.
- Benefits of these recommended investments to mitigate waterlogging in current climate exist even in the absence of climate change, making such investments an attractive low-regret option.
- Develop additional measures to mitigate climate risks sequentially after addressing the current climate risks.
- Climate and disaster resilience is not uniform in all parts of megacity Dhaka. There is room to improve local disaster resilience. Facilitate area-specific action planning for strengthening the local climate disaster resilience.

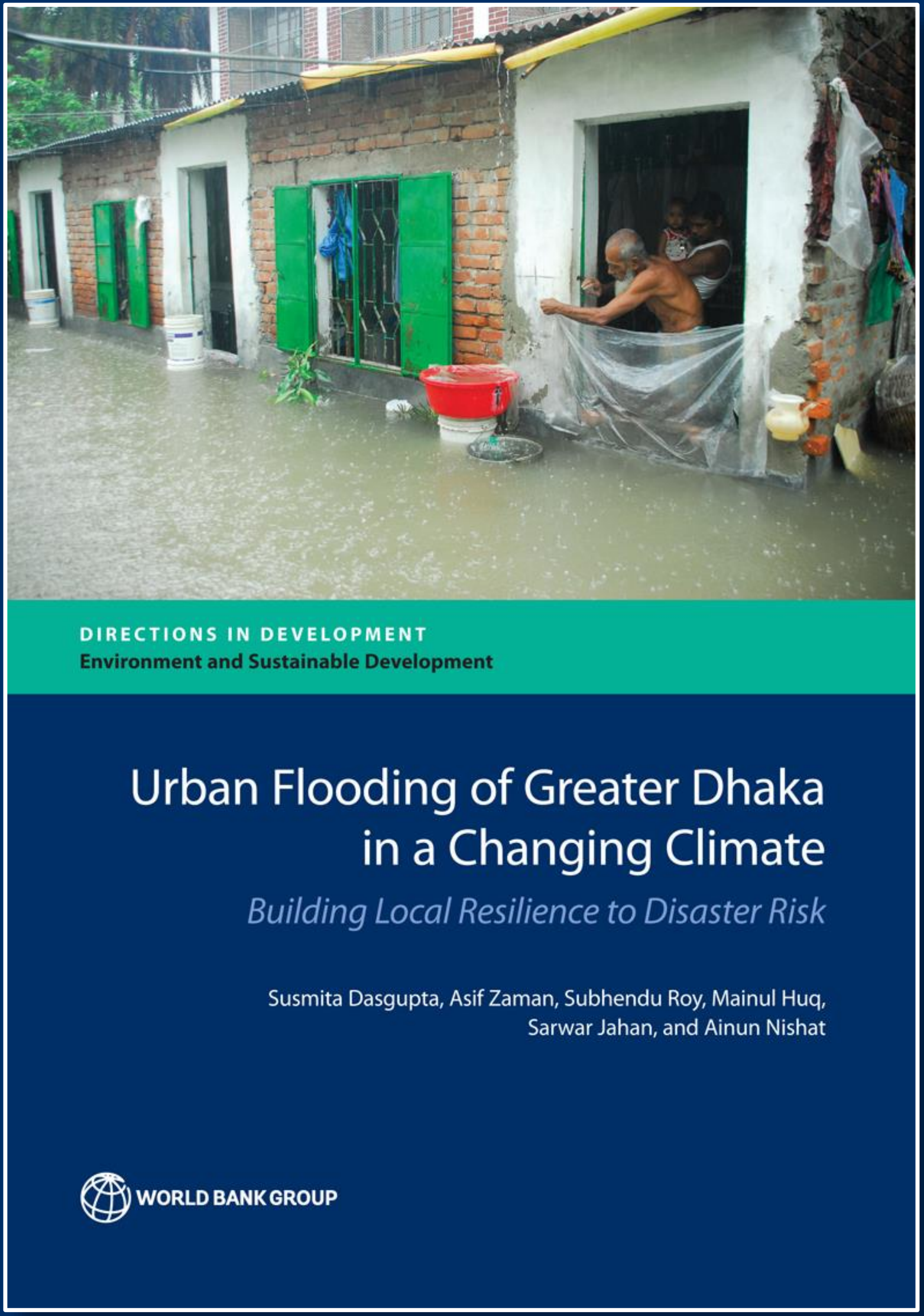
Complementary Flood-mitigation Measures

- Routine Cleaning of Drains: Sludge Removal
  - Hydraulic Jetting and Vacuum Suction Machines for DWASA and DCC (8 sets for Tk 120 million each)
  - Remote-Controlled Excavators for DWASA (3 machines for Tk 40 million each)
- Shaving Peak Flow
  - Green Roofs
  - Management of Impervious Surfaces
- Use of Water Bodies as Detention Ponds
- Last Resort: Truck-Mounted Water Pumps

Book Launch

World Bank, Dhaka

23 November 2015



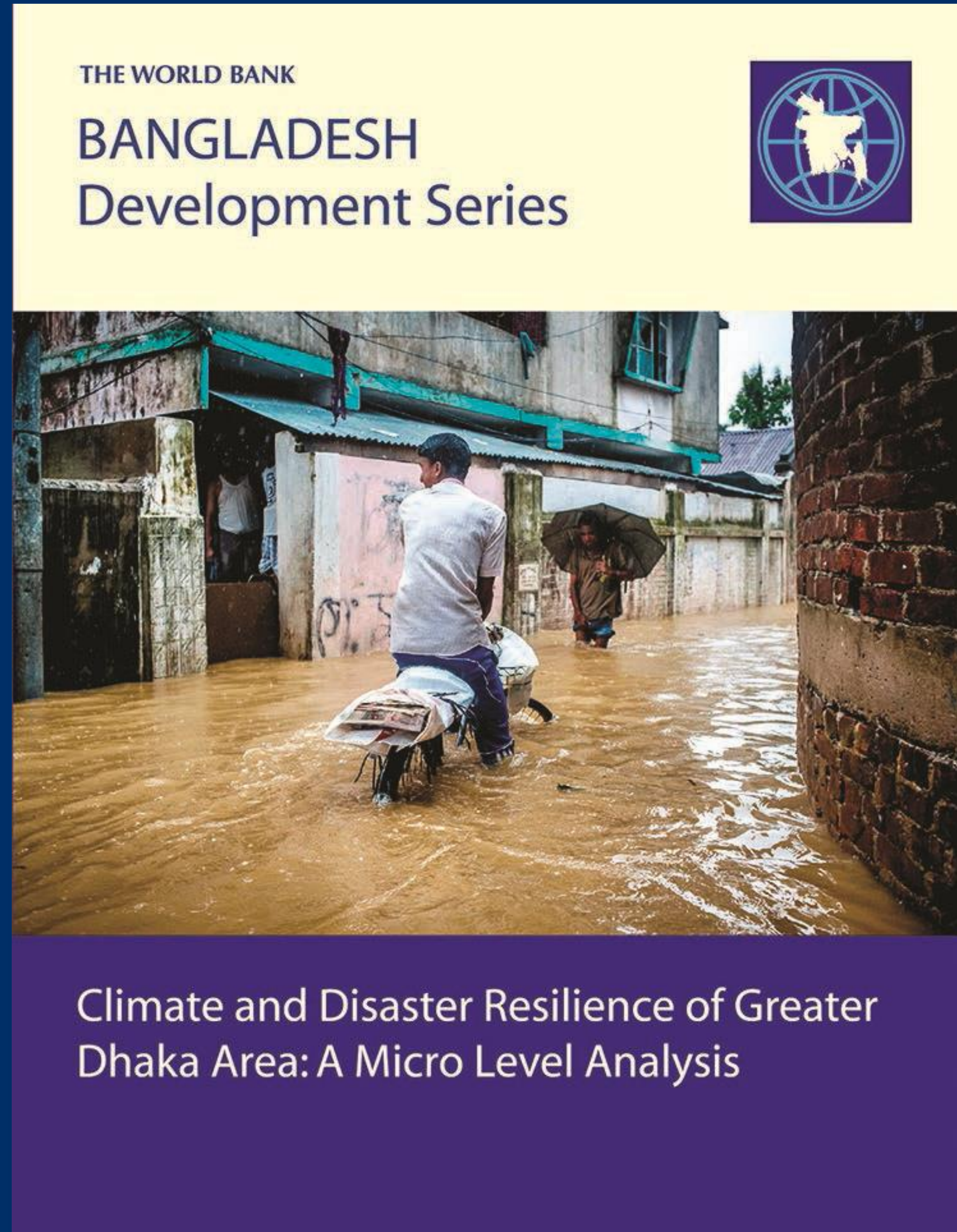
Can be downloaded from:

https://openknowledge.worldbank.org/handle/10986/22768

Report Launch

World Bank, Dhaka

23 November 2015



Can be downloaded from:

http://documents.worldbank.org/curated/en/2015/11/25477835/climate-disaster-resilience-greater-dhaka-area-micro-level-analysis

Book Launch ■ ■ ■ World Bank, Dhaka - 23 November 2015

Potential Use of the Book

- This analytical work will assist to mitigate current waterlogging and to further climate-proof drainage infrastructure in Greater Dhaka Area.
- Recommended list of investment options will help decision-makers to formulate more effective flood-control strategies, prioritize interventions, and sequence activities as resources permit.
- Identified priority zones and priority sectors to improve disaster resilience.
- Facilitate area-specific action planning for strengthening the local climate disaster resilience.
- Major reference resource for researchers, practitioners and students.

Co-Researchers

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Q & A

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