Climate Change: A Major Threat to Sustainable Development
Case of a Sea-Level Rise in Ganges-Brahmaputra Delta in Asia
Sustainable Development: Core Elements

“Sustainable development is development that meets the needs of the present, without compromising the ability of future generations to meet their own needs.”

- *Our Common Future* (Burndtland Report), October 1987, United Nations
Multifaceted Impacts of Climate change

- Change in Temperature and Precipitation
- Shifting weather patterns
- Extreme weather events
- Rising Sea-level
Multifaceted Impacts of Climate change

- Change in Temperature and Precipitation
- Shifting weather patterns
- Extreme weather events
- Rising Sea-level
Dangers of Sea-Level Rise in a Changing Climate

- Land loss from permanent inundation in low-elevation coastal areas
- Intensified inundation from cyclonic storm surges
- Increase in coastal erosion
- Loss of critical wetlands, for example mangroves
- Progressive salinization of soil and water
- Drainage disruption
- Loss of critical assets and economic activities
1. Sea-level rise: Past and Future
2. Impacts of Sea-Level Rise
3. Illustrations from Mekong Delta and Nile Delta
4. Adaptation to Sea-Level Rise
5. Concluding Remarks
6. Research Questions of Interest
Sea-Level Rise: Past and Future
From about 3,000 years ago to about 100 years ago, sea levels naturally rose and declined slightly, with little change in the overall trend (NASA-JPL).

Trend of Global mean sea level:
Increased by 5.91 to 9.84 inches (or 0.15 to 0.25 m) between 1901 and 2018
- About half of that rise occurred since 1993

Rate of global sea level rise:
- 3.7 mm (0.15 inch) per year from 2006 to 2018
- 1.9 mm (0.08 inch) per year from 1971 to 2006
- 1.3 mm (0.05 inch) per year between 1901 and 1971.
Between about 21,000 years and about 11,700 years ago,
  - Earth warmed about 4 degrees C, and
  - The ocean rose about 280 feet.

After the warming ended,
  - Sea levels continued to rise another 150 feet
  - Sea levels reached its modern level about 3,000 years ago
Sea Level is measured by Satellite Altimeter
Sea Level Rise: Major Contributing Factors

1. Thermal Expansion
2. Melting of Polar Icesheets
3. Melting of Glaciers and Ice Caps other than polar icesheets
   - Sum of glacier and icesheet contributions is now the dominant source of global mean sea-level rise (IPCC AR6).
Sea-Level Rise: Future Projections

- Sea-level rise is not globally uniform but varies regionally.
- A rise in global mean sea level between 0.28 m to 1.01 m (11 inches - 40 inches approximately 1 ft to 3.5 ft) by 2100 relative to 1995–2014, across different future scenarios (IPCC AR6).
  - Icesheet dynamics related to global warming is very complex and uncertain.
- Sea level may rise up to 3 m by 2100.
- Sea level will continue to rise for centuries due to continuing deep ocean heat uptake and mass loss of the polar icesheets and will remain elevated for thousands of years (Source: IPCC AR6).
Impacts & Threats of Sea Level Rise
Impacts & Threats of Sea Level Rise

Case Study: Ganges-Brahmaputra Delta (Bangladesh)

- Elevation of nearly two third of the country is less than 5 meters above sea-level
  - Permanent Loss of Land
  - Progressive Salinization of Water and Soil
  - Intensified Inundation from Cyclonic Storm Surges

At present, 600 million people live in low-lying coastal areas worldwide. Families in coastal Bangladesh are already on the "front line" of climate change. Their experience foretells future decisions by hundreds of millions of families worldwide who will face similar threats well before 2100.
43.2 million people in Bangladesh live in poverty.

24.4 million extremely poor do not meet the basic needs of food expenditure.
River Salinity in Coastal Bangladesh

Spatial variation of maximum river salinity during 2011-2012

Source: IWM, 2013
Southwest Coastal Bangladesh: Water and Soil Salinity

- 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 and soil are highly saline.
- Scarcity of drinking water and water for irrigation in the area are apparent and serious.
- Salinity problem worsens after cyclones.
Progressive water salinization is expected with sea-level rise and shortage of freshwater from upstream river systems.

Expected Impacts of River Salinity

River area: freshwater (0-1 ppt)

Baseline: March 2012
Best March 2050
Worst March 2050

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

Baseline: March 2012
Best March 2050
Worst March 2050
In Sunderbans (UNESCO Heritage site), a shift in mangrove species is expected.

- A shift in species is expected from freshwater species to salt-tolerant species.
- A negative impact on standing stock of timber in the region is inevitable with growing dominance of salt-tolerant species.
▪ Changes in mangrove species will change the prospects for forest-based livelihoods of nearby communities.
▪ Overall honey production is likely to increase.
▪ Human and wildlife conflicts in Sundarbans will increase.
Impacts of Water Salinization on Fish

- Analysis is based on 83 fish species consumed in the region.
- Areas with poor population that lose freshwater fish species are 6 times more prevalent than areas gaining species.
- 9.9 million poor (including 5.9 million extreme poor) live near Sundarbans.
- Small low-value freshwater fish species are the most important animal-source food (essential protein, micronutrients etc.) for the poor.
- Significant impact on animal-source food intake of poor women and children is expected.

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.
Exposure of Poor to Increased River Salinity

<table>
<thead>
<tr>
<th>Change from the current situation to the best future (2050)</th>
<th>Total population</th>
<th>Poor</th>
<th>Extremely poor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+15 %</td>
<td>+17 %</td>
<td>+23 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Change from the current situation to the worst future (2050)</th>
<th>Total population</th>
<th>Poor</th>
<th>Extremely poor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+100 %</td>
<td>+111%</td>
<td>+130 %</td>
</tr>
</tbody>
</table>
Significant Increase in Soil Salinity by 2050

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

Source: Dasgupta et al. 2015. Ambio.
Health effects of increased drinking water salinity (dehydration, hypertension, infant mortality)

Scarcity of water for irrigation
Increased soil salinity
Agricultural productivity loss

Increased infrastructure maintenance costs
Reduced availability of fresh-water fish
Reduced timber yield

Reduced availability of essential nutrients (stunting/wasting, maternal anemia)
Loss of capture fishery

Loss of tourism from reduced biodiversity in UNESCO Heritage Forest
Cyclones in a Changing Climate

- Intensification of storm surges due to ocean surface temperature increase is controversial.
- Increase in the extent of inundation and increase in location-specific inundation depth due to sea level rise is certain.
Major Cyclones: 1960-2016
### High Risk Area in a Changing Climate 2050

<table>
<thead>
<tr>
<th>Inundation depth (m)</th>
<th>2050 without climate change</th>
<th>2050 in a changing climate</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m – 3 m</td>
<td>20,876 m²</td>
<td>23,764 m²</td>
<td>+14 %</td>
</tr>
<tr>
<td>More than 3 m</td>
<td>10,163 m²</td>
<td>17,193 m²</td>
<td>+69 %</td>
</tr>
</tbody>
</table>
Implications of Storm Surge for the Poor

<table>
<thead>
<tr>
<th></th>
<th>Total population</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current situation</td>
<td>15.4 million</td>
<td>4.3 million</td>
</tr>
<tr>
<td>Future (2050)</td>
<td>16.8 million</td>
<td>5.3 million</td>
</tr>
<tr>
<td>Change from the current situation to 2050</td>
<td>+ 9%</td>
<td>+ 22%</td>
</tr>
</tbody>
</table>
Multifaceted Impacts of Sea-Level Rise
Poverty and Out-migration

Progressive River and Soil Salinization

Intensified Inundation from Cyclonic Storm Surges

Increased Poverty and Out-migration
Households subject to high inundation and salinization threats 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.

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.
# Impact: Total Population

1 Meter Sea Level Rise

<table>
<thead>
<tr>
<th>Region</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Asia &amp; Pacific</td>
<td>37.2 million</td>
</tr>
<tr>
<td>Middle East &amp; North Africa</td>
<td>8.3 million</td>
</tr>
<tr>
<td>South Asia</td>
<td>5.9 million</td>
</tr>
<tr>
<td>Latin America &amp; Caribbean</td>
<td>2.9 million</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>2.1 million</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>56.4 million</strong></td>
</tr>
</tbody>
</table>
Percent Impact: Population

1 Meter Sea Level Rise

![Graph showing the percentage impact of 1 meter sea level rise on different regions of the world.]

- South Asia
- Sub-Saharan Africa
- Latin America & Caribbean
- East Asia
- Middle East & North Africa
Percent Impact: Population

Middle East & North Africa

Bar chart showing the population impact for countries in the Middle East and North Africa:
- A.R. Egypt: Highest impact
- United Arab Emirates
- Libya
- Morocco
- Tunisia
- South Arabia
- Rep. of Yemen
- Oman
- Kuwait
- I.R. Iran
- Algeria

Map showing the geographical distribution of these countries.
Nile Delta - 2000
Nile Delta – 1 m Sea Level Rise
Nile Delta
Nile Delta - 1990
Nile Delta - 2000
Nile Delta – 1 m Sea Level Rise
Percent Impact: Population

East Asia & Pacific

- Vietnam
- Taiwan China
- China
- Indonesia
- Myanmar
- Thailand
- Philippines
- Cambodia
- South Korea
- Brunei
- Malaysia
- North Korea
- Papua New Guinea

[Map of East Asia & Pacific with population impact percentages]
## Vietnam

<table>
<thead>
<tr>
<th>Vietnam 1 m Sea Level Rise</th>
<th>Country Total</th>
<th>Impacted</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (km²)</td>
<td>328,535</td>
<td>16,977</td>
<td>5.17</td>
</tr>
<tr>
<td>Population (10³)</td>
<td>78,137</td>
<td>8,437</td>
<td>10.8</td>
</tr>
<tr>
<td>GDP (10⁶ US$)</td>
<td>154,787</td>
<td>15,805</td>
<td>10.21</td>
</tr>
<tr>
<td>Urban Areas (km²)</td>
<td>5,904</td>
<td>634</td>
<td>10.74</td>
</tr>
<tr>
<td>Agricultural Land (km²)</td>
<td>192,816</td>
<td>13,773</td>
<td>7.14</td>
</tr>
<tr>
<td>Wetlands (km²)</td>
<td>46,179</td>
<td>13,241</td>
<td>28.67</td>
</tr>
</tbody>
</table>
### Vietnam

**2 m Sea Level Rise**

<table>
<thead>
<tr>
<th>Vietnam 2 m Seal Level Rise</th>
<th>Country Total</th>
<th>Exposed</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (km²)</td>
<td>328,535</td>
<td>28,090</td>
<td>8.55</td>
</tr>
<tr>
<td>Population (10³)</td>
<td>78,137</td>
<td>14,036</td>
<td>17.96</td>
</tr>
<tr>
<td>GDP (10⁶ US$)</td>
<td>154,787</td>
<td>25,522</td>
<td>16.49</td>
</tr>
<tr>
<td>Urban Areas (km²)</td>
<td>5,904</td>
<td>1,095</td>
<td>18.55</td>
</tr>
<tr>
<td>Agricultural Land (km²)</td>
<td>192,816</td>
<td>23,641</td>
<td>12.26</td>
</tr>
<tr>
<td>Wetlands (km²)</td>
<td>46,179</td>
<td>22,527</td>
<td>48.78</td>
</tr>
</tbody>
</table>

**3 m Sea Level Rise**

<table>
<thead>
<tr>
<th>Vietnam 3 m Seal Level Rise</th>
<th>Country Total</th>
<th>Exposed</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (km²)</td>
<td>328,535</td>
<td>28,860</td>
<td>11.83</td>
</tr>
<tr>
<td>Population (10³)</td>
<td>78,137</td>
<td>2,003</td>
<td>25.60</td>
</tr>
<tr>
<td>GDP (10⁶ US$)</td>
<td>154,787</td>
<td>37,419</td>
<td>24.17</td>
</tr>
<tr>
<td>Urban Areas (km²)</td>
<td>5,904</td>
<td>1,584</td>
<td>26.83</td>
</tr>
<tr>
<td>Agricultural Land (km²)</td>
<td>192,816</td>
<td>33,064</td>
<td>17.15</td>
</tr>
<tr>
<td>Wetlands (km²)</td>
<td>46,179</td>
<td>31,094</td>
<td>67.33</td>
</tr>
</tbody>
</table>
Almost all industrial parks in the South and a significant portion of handicraft villages in the North would go under water.
Adaptation to Sea-Level Rise
Adaptation must be location-specific.

Adaptation Alternatives:
1. Hard Protection
2. Sediment-based Protection
3. Nature-based Protection
4. Other Adaptation Measures/ “Accommodation”
5. Hybrids

A one-size-fits-all approach will not work.
Hard Protection: Built Structures on/near the Edges of the Ocean

Examples: Seawalls, Breakwater, Embankments, Dikes, Surge Barriers
- Commonly found in Northwest Europe, East Asia & around many coastal cities and deltas

Advantages:
- If properly maintained, provide predictable protection & work well for protecting densely populated areas.

Disadvantages:
- Costly to build and maintain
- Alter the hydrodynamic and morphodynamic patterns
- Lock-in to a development pathway in which development intensifies behind higher and higher defenses.
- Social conflicts between those favoring protection and those being negatively affected.
Sediment-based Protection

Examples: Beach & Shore Nourishments, Dune Management

Advantages:
- Preserve and encourage tourism.

Disadvantages:
- Seabed dredging of sand and gravel can have negative impacts on marine ecosystems such as seagrass meadows and corals.
- Nourishment practices on sandy beaches may have drawbacks for local ecosystems.
- Social conflicts between those favoring protection and those being negatively affected
Nature-based Protection

Examples: Mangroves, Coral Reef

Mangroves

Advantages:
- Reduce impacts of disasters, e.g. cyclone-induced storm surges
- Reduce coastal erosion
- Provide habitats for biodiversity.
- Positive impacts on livelihoods of coastal inhabitants.
- Adaptation with mitigation co-benefits.

Disadvantages:
- Land requirement / Require land and land may not be available.
Other Adaptation Measures: “Accommodation”

Examples from our Ganges-Brahmaputra Delta Study:

- Rainwater Harvesting
- Local Water desalinization plants
- Saline Resistant Seeds for Agriculture
- Saline Resistant Crops
- Pond-based Aquaculture
- Crab Culture
- Precautionary Measures before Construction of Buildings
- Vocational training for men and women (e.g., training for textile industry, commercial vehicle driving)
Hybrid Adaptation Measures

Examples:

- Embankments with mangroves in the foreshore areas
- Cyclone shelters and mangroves
- Rainwater Harvesting and Water Desalinization Plants
Concluding Remarks

- We have no choice but to adapt to rising sea levels.
- We will have to be much more flexible in our approach to environmental uncertainty in coastal areas.
- Regional and national decision-makers will need to make hard decisions based on a cost-benefit analysis.
Research Questions of Future Interest

- Compensation for the population losing from Climate Change.
- History and Equity in Carbon Budget Allocation.
  - Who is accountable for Climate Change?
- Compensation/s for countries suffering and/or losing from Climate Change.