River Salinity and Climate Change
Evidence from Coastal Bangladesh

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Overview

- River salinity in coastal Bangladesh
- Modeling salinity intrusion
- Likely effects of climate change
- Model simulation
- Results
- Limitations
- Potential use
River water salinity in coastal Bangladesh depends on the
- Volume of freshwater discharges from the upstream river systems,
- Surface water runoff from rainfall events,
- Salinity of the Bay of Bengal near the coast, and
- Tidal dynamics of the coastal river system.

Average Salinity is higher in the dry season than in the monsoon. Salinity generally increases linearly from October to late May.

At present, the rivers of the southwest coastal zone and eastern-hill zone suffer most from salinity intrusion.
River Salinity in the Southwest Region

Spatial variation of maximum river salinity during 2011-2012

Source: IWM, 2013
River Water Salinity Modeling

1. A Rainfall-Runoff model was applied to estimate the runoff from rainfall in various watersheds of the model area.
   - Inputs: watershed characteristics, rainfall, soil moisture, irrigation & water extraction from the surface or groundwater sources in the watershed, evaporation, percolation and other losses.
   - Output: Runoff from the catchment.

2. The hydrodynamic module of the MIKE 11 model system (the Southwest Regional Model, SWRM) was used to develop the water flow and the water level in the river systems of the southwest region.
   - Inputs: rainfall runoff estimates, water flow data recorded by river gauges at the upstream end of the rivers, water level data from the downstream end of the rivers, and cross-sectional river data.
   - Output: Water flow, water level, and flow velocity of the river systems.
3. Bay of Bengal model based on the MIKE 21FM module of the DHI was used to simulate the salinity of the Bay of Bengal.
   - Inputs: water flow estimates from the SWRM and measured salinity at the upstream boundary, time-series water level data and constant 32ppt salinity from the DHI Global Tides Model at the downstream boundary.
   - Output: Estimates of salinity of the Bay of Bengal.
Assumption: All 61 polders are functioning well and will not be overtopped by 2050.

4. Salinity model (the advection-dispersion module of MIKE11) is coupled with the hydrodynamic module to assess river salinity in the southwest coastal zone.
   - Inputs: Measured concentrations of salinity along the upstream boundary and estimates of salinity of the Bay of Bengal for the downstream boundary.
   - Output: Location-specific river salinity.
Model Set-up

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

Source: IWM, 2013
Model Calibration and Validation

- The water flow model was calibrated with hourly data on water level time-series from November 2011 to June 2012 and hourly data on water discharge time-series for one spring and one neap tidal cycle during February 2012 and March 2012.

- The salinity model was calibrated with the salinity time-series (monitored twice a day on alternate days during high and low tides) from November 2011 to June 2012.

- The models were validated against the time-series of measured data from November 2010 to April 2011.
## Model-Generated Results and Measured Data

<table>
<thead>
<tr>
<th>Location</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparison of Water Flow</td>
<td></td>
</tr>
<tr>
<td>Baleswar River at Char Doani</td>
<td>0.95</td>
</tr>
<tr>
<td>Buriswar River at Amtali</td>
<td>0.87</td>
</tr>
<tr>
<td>Pussur River at Akram Point</td>
<td>0.94</td>
</tr>
<tr>
<td>Pussur River at Mongla</td>
<td>0.91</td>
</tr>
<tr>
<td>Comparison of Water Level</td>
<td></td>
</tr>
<tr>
<td>Marichbunia River</td>
<td>0.84</td>
</tr>
<tr>
<td>Pussur-Kazibacha River</td>
<td>0.95</td>
</tr>
<tr>
<td>Comparison of salinity</td>
<td></td>
</tr>
<tr>
<td>Baleswar River at Char Duani</td>
<td>0.73</td>
</tr>
<tr>
<td>Pussur River at Mongla</td>
<td>0.99</td>
</tr>
<tr>
<td>Rupsa River at Khulna</td>
<td>0.83</td>
</tr>
<tr>
<td>Sibsa River at Nailan</td>
<td>0.97</td>
</tr>
</tbody>
</table>
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**:

<table>
<thead>
<tr>
<th>Emission Scenario</th>
<th>2050 Temperature</th>
<th>2050 Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IPS-CM4L</td>
<td>MIROC 3.2</td>
</tr>
<tr>
<td>A2</td>
<td>8.03</td>
<td>2.61</td>
</tr>
<tr>
<td>A1b</td>
<td>8.16</td>
<td>3.32</td>
</tr>
<tr>
<td>B1</td>
<td>7.11</td>
<td>3.34</td>
</tr>
</tbody>
</table>

RMSLR by 2050: 35 cm, 40 cm, 47 cm, 52 cm, 62 cm, 67 cm
1. The Rainfall-Runoff model estimated the runoffs from various catchments for the IPCC: A2, A1b, and B1 emission scenarios with each of the three GCMs for changing climate (temperature and rainfall) in 2050.

2. Nine sets of runoff estimates from the Rainfall-Runoff model, projections of water abstraction for 2050, the observed flow in the Ganges and Gorai Rivers over the past 16 years, and the dry season water flow of the Brahmaputra in 2012 as proxies for 2050 dry season water flow from major rivers upstream were used in the hydrodynamic module of the MIKE 11 model to estimate alternative water flow and flow velocity along 230 river branches in the southwest region.
Model Simulation

3. The Global Tide model estimated the tides and the water level along the coast for alternative scenarios of RMSLR: 35cm, 40cm, 47cm, 52cm, 62cm, and 67cm RMSLR by 2050.

4. Estimated river flows, tidal effects, salinity of the river flows, and salinity of the tides were used to estimate location-specific river salinity for the southwest coastal region for December 2049 to March 2050.

In sum, 27 alternatives for the future were considered:
- 40cm, 52cm, and 67cm RMSLR for three scenarios of upstream water flows for the A2 scenario;
- 40cm, 52cm, and 67cm RMSLR for three scenarios of upstream water flows for the A1b scenario; and
- 35cm, 47cm, and 62cm RMSLR for three scenarios of upstream water flows for the B1 scenario.
Findings

- Climate change will cause *significant* changes in river salinity in the southwest coastal area of Bangladesh by 2050.
- Extent of the landward intrusion of the salinity frontier is primarily determined by RMSLR.
- Variation across GCMs are not significant.
- The B1 emission scenario with 35cm RMSLR is the best future scenario (least increase in salinity from the baseline).
- The A2 emission scenario with 67cm RMSLR is the worst future scenario (largest increase in salinity from the baseline).
## Area Estimates

<table>
<thead>
<tr>
<th>Salinity classification*</th>
<th>Baseline (March 2012)</th>
<th>Best (March 2050)</th>
<th>Worst (March 2050)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slight Saline (&lt;1 dS/m)</td>
<td>22%</td>
<td>16%</td>
<td>13%</td>
</tr>
<tr>
<td>Slight to Moderately Saline (1-5 dS/m)</td>
<td>35%</td>
<td>30%</td>
<td>21%</td>
</tr>
<tr>
<td>Moderate to High saline (5-10 dS/m)</td>
<td>8%</td>
<td>17%</td>
<td>27%</td>
</tr>
<tr>
<td>Highly Saline (&gt;10 dS/m)</td>
<td>35%</td>
<td>38%</td>
<td>40%</td>
</tr>
</tbody>
</table>

*WARPO-Bangladesh: National Water Management Plan
Isohalines in the Southwest Region

Baseline: March 2012

Salinity Intrusion in Coastal Zone of Bangladesh Due to Climate Change

Salinity Line for March Base Condition
Year: 2012

Bay of Bengal
Isohalines in the Southwest Region

Best Future (March 2050) Scenario

B1 emission scenario and 35 cm RMSLR
Isohalines in the Southwest Region

Worst Future (March 2050) Scenario

A2 emission scenario with 67 cm RMSLR
Expected Impacts

- Freshwater river areas (0-1ppt) is expected to decrease from 40.8% at the baseline to 19.7% and 17.1% in the best and worst scenario.

- River water for dry season agriculture irrigation (< 2ppt) is expected to decrease by 11.1% in the best future scenario and by 29.7% in the worst future scenario.

- Expected increase in river salinity is likely to impact wild habitats of fresh water fish and giant freshwater prawn (Golda).

- In Sunderbans (UNESCO Heritage site), a shift in species is expected from Sundari to Guran-Gewa.
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.
Expected Impacts: Agriculture

- River water will no longer be utilisable for agriculture in Barguna, Bhola, Jhalokati, Khulna, and Patuakhali Districts in the worst case future scenario.
- Tentulia River, which currently provides water to the Bhola Irrigation Project, will be nonoperational, with estimated salinity exceeding 2ppt.
- Scarcity will be severe even in the best case future scenario. For example, 98 percent of the rivers in Khulna and 97 percent of the rivers in Bhola will be adversely affected.
- Bishkhali River, Buriswar River, and the upstream stretch of the Baleswar River, with estimated salinity lower than 2ppt, are expected to remain functional for irrigation in the best case scenario.
Isohaline (2 ppt) in Barisal Division
Expected Impacts: Fishery

- Even in the best case future scenario, optimum river area for Catla, Rui, and Mrigal is likely to decrease in Khulna, Bagerhat, and Satkhira Districts by 49, 20, and 15 percent, respectively.

- Wild habitats ideal for Golda prawn are expected to decrease by 88 percent in Khulna, 35 percent in Bagerhat, 25 percent in Gopalganj, and 14 percent in Satkhira Districts.

- In the worst case future scenario, expected reductions in the prime habitats for Catla, Rui, and Mrigal will be 100 percent in Khulna, 81 percent in Bagerhat, 43 percent in Bhola, and 34 percent in Satkhira; and that for Golda prawn will be 99 percent in Gopalganj, 97 percent in Khulna, 57 percent in Bagerhat, 26 percent in Satkhira, 23 percent in Patuakhali, and 14 percent in Barguna.

- Significant changes in the freshwater small fish species in the wild are probable.

- An increase in brackish water will enhance opportunities for brackish water aquaculture, for example, farming of *Tilapia Nilotica* and Bagda.
Cautionary Note

The incidence of poverty is very high in Bagerhat, Barguna, Bhola, Khulna, Patuakhali, and Satkhira Districts. Assessment of location-specific economic impacts of the changes in river salinity, identification of suitable adaptation alternatives, and costing of adaptation are high priorities for further analysis.
Limitations of the Analysis

1. Probable changes in the salinity of soil have not been assessed.
2. Predictions of the future water flows of the trans-boundary Brahmaputra River were not attempted because of geopolitical complications.
3. The analysis assumed that the Ganges Water Treaty will hold between Bangladesh and India in the future.
4. The analysis assumes away potential overtopping and breaches of polders and embankments in the coastal area.
5. Analysis of impacts is restricted to exposure to salinity and does not take into account the extent to which adaptive capacity exists in the affected areas to encounter potential changes.
Potential Use

- This analysis presents information that the Government of the People’s Republic of Bangladesh can use to develop location-specific coastal adaptation plans at this time to prepare for future changes.

- The analysis will be of interest to other developing countries and to those experts and organizations concerned with the impacts of climate change on coastal areas in developing countries.

- Given the general lack of studies on salinity intrusion in the developing world, this analysis may raise awareness and prompt countries (vulnerable to sea-level rise) to initiate detailed, country-level assessments of potential impacts of climate change on salinity in coastal areas, including analysis of the socioeconomic impacts of the resulting salinity changes. Such estimates may then trigger various actions aimed at protecting or facilitating increased resilience of coastal assets and activities to imminent climate risks.