Sediment dynamics along the fluvial-tidal transition: a case study from the Ganges delta

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CSDMS community surface dynamics modeling system

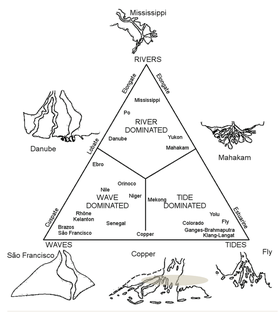
Introduction

The influence of hydrodynamics on delta morphology is well-understood: **fluvial**, **tidal** and wave processes sculpt deltas into characteristic shapes that serve as geomorphic signatures of the underlying dynamics.

Using a numerical modeling approach, we explore how floodplain deposition changes across the process transition in the Ganges-Brahmaputra-Meghna delta, which is dominated by fluvial processes in the north, mixed fluvio-tidal processes in the estuaries and backwater zone, and purely tidal processes in the western delta along the Bay of Bengal. This work addresses the following questions:

Do sedimentation patterns and transport rates change across the process (fluvial, tidal and mixed) regimes?

Can the rates of sedimentation compete with predicted rates of sea level rise or monsoon-driven flooding across the landscape?



The GBMD is considered tidally-dominated, but it also receives a large amount of fluvially-driven discharge and sediment. Example Galloway diagram taken from Witek and Czechowski (2015).

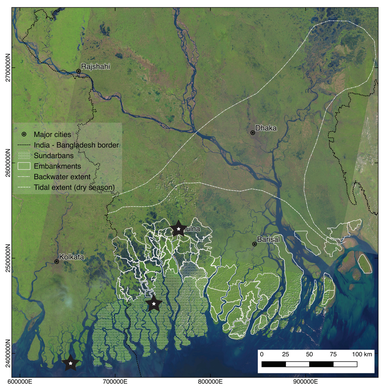
Study Area

The Ganges-Brahmaputra-Meghna Delta (GBMD) covers ~100,000 km^2 of Bangladesh and India. Approximately 80% of the GBMD area is subaerial, with low elevations and low gradients.

In the eastern and northern portion of the delta, fluvial processes dominate: the braided plains of the Ganges, Brahmaputra and Meghna rivers, and their distributary offshoots like the Gorai River, transport ~10^9 tons of sediment to the delta front.

The low-lying tidal plains to the south are characterized by wide channels and the Sundarbans mangrove forest. Tidal range increases moving from west to east, and tidal processes rework fluvial sediment back into the delta plains.

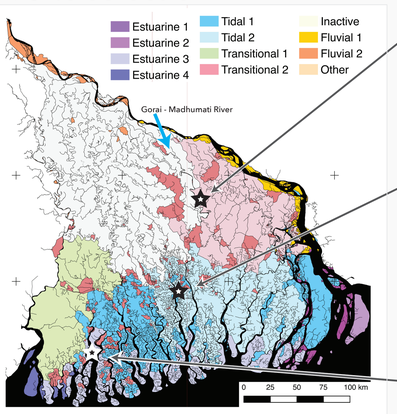
The GBMD was selected because of the clear transition in hydrodynamic processes, and because of the societal and ecological importance of the system. One of the most densely populated delta systems, it is susceptible to changes in climate (monsoon intensity) and sea level rise.



Location map indicating backwater extent and poldered areas across the GBMD. Three stars indicate the three study locations.

Experimental Design

1. Site selection



Output of cluster analysis of islands and channels in the GBMD. 5 primary zones are illustrated (estuarine, tidal, transitional, inactive and active fluvial).

Process zones were selected using machine learning techniques (cluster analysis and dimension reduction).

Island (e.g. area, aspect ratio and fractal dimension) and **channel** (e.g. channel width, number of outlet channels) characteristics were used in the analysis

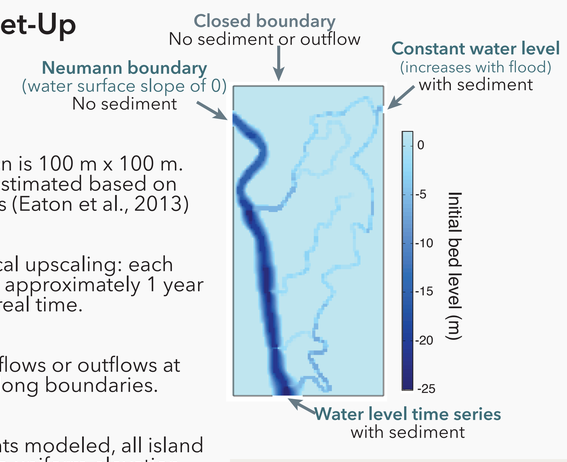
Site descriptions

Fluvial site falls along the Madhumati River, and is classified within the transitional zone.

The mixed fluvio-tidal site is Polder 32, a monitored embanked area in the tidal island grouping, but also affected by fluvial processes.

The tidal site, in India, is only reworked by the ebb-flood cycle in the Bay of Bengal.

2. Model Set-Up



Grid resolution is 100 m x 100 m. Bathymetry estimated based on channel widths (Eaton et al., 2013)

Morphological upscaling: each model is run for approximately 1 year of real time.

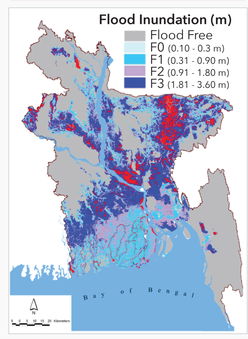
Water only inflows or outflows at channels along boundaries.

No embankments modeled, all island locations have uniform elevation (~1.5 m above sea level). Baseline water level is ~1 m above sea level.

Sample model set-up for the Polder 32 case study. Water level time series contains either ebb-flood (tidal sites) or constant flood (fluvial) conditions.

3. Flood inundation and sediment parameters

Flood inundation estimates under climate change conditions, adapted from Dasgupta et al. (2010).



	Flood Range		
	F1	F2	F3
Min. Inundation (m)	0.3		
Mid. Inundation (m)	0.6	1.35	2.7
Max. Inundation (m)	0.9	1.8	3.6

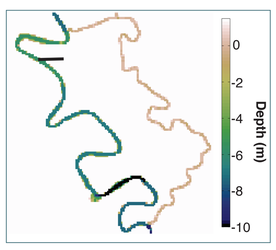
Flood inundation occurs for ~15 days in a modeled year. For each min, mid and max value in a given flood inundation range, three sediment concentrations were used: **low** (-50%), **average** and **high** (+50%) concentrations.

Tidal and fluvial SSC were drawn from field data provided by the IWM in Dhaka, Bangladesh. The values for each SSC were **0.470** and **0.0326** kg/m^3, respectively. Concentrations were broken into four suspended sediment classes, using distributions estimated by Rogers (2012):

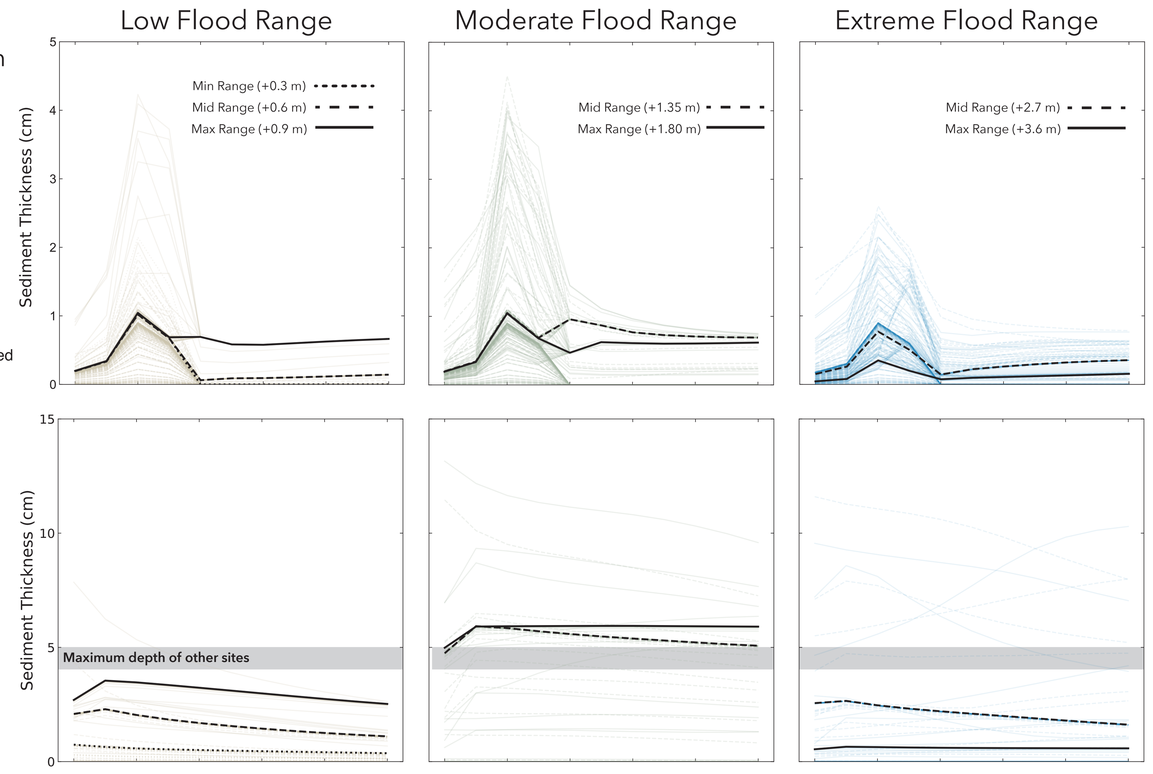
~4% Clay
~21% Fine Silt
~46% Medium Silt
~29% Coarse Silt

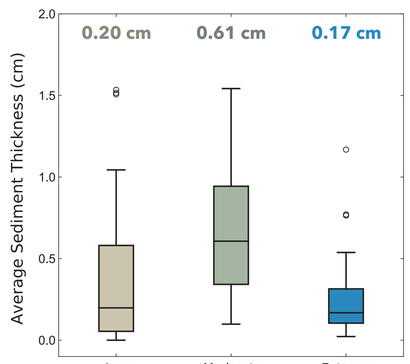
Results

Fluvial - upper delta plain



The fluvial site bound by two channels. Data drawn from the 10 km transect indicated along the western Madhumati River.

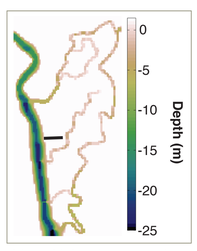




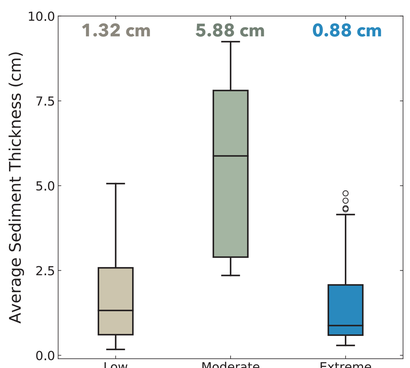
Median values of sedimentation along the cross-sections range from 0.20-0.61 cm/yr, lowest rates in all three model runs coincide with lowest SSC.

For all flood ranges, deposited sediments form levees. The **low** and **moderate** flood ranges cause greater depositon, likely due to greater velocities in the **extreme** case preventing deposition.

Mixed fluvio-tidal



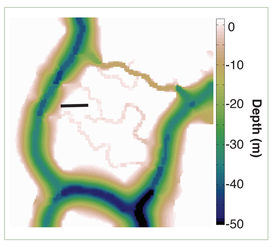
The poldered island surrounds a channel called the Nalian, that was breached by Cyclone Aila in 2007.



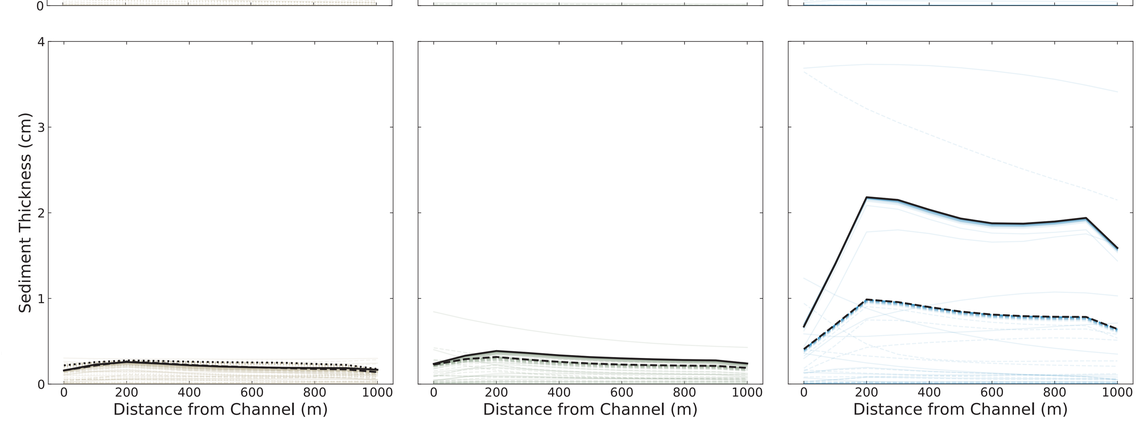
Median values of sedimentation along the cross-sections range from 0.88-5.88 cm/yr, higher rates of sedimentation due to greater SSC and more confined flow

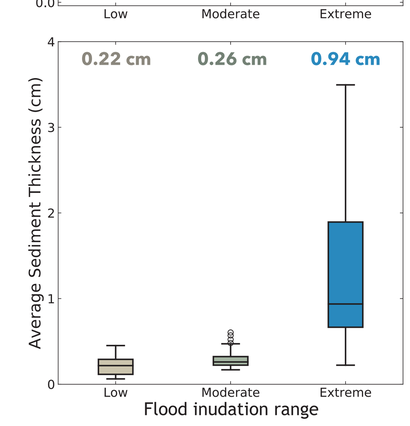
Patterns of deposition are more laterally uniform, due to the ebb-flood cycle. Highest rates are in the moderate flood case, lowest in the extreme flood case.

Tidal



This tidal island, located along the delta front, is bisected by several small channels.





Median values of sedimentation along the cross-sections range from 0.22-0.94 cm/yr, similar to the fluvial case. Deposition is likely low due to high velocities and unconfined flow.

Deposition is laterally uniform, except in the most extreme case which has small platforms forming. Most sediment is entrained in channels.

Conclusions

Do sedimentation patterns and transport rates change across the process (fluvial, tidal and mixed) regimes?

- In fluvial regime, levees form along the channel, while the ebb-flood cycle causes laterially uniform sediment patterns.
- Although SSC is lower in the fluvial than tidal regime, rates are comparable in the two endmember cases, likely due to sediment entrainment within tidal channels.

Can the rates of sedimentation compete with predicted rates of sea level rise across the landscape?

- Syvitski et. al, (2009) indicated 0.8 to 1.8 cm/yr RSL rise in the GBMD. In the upstream, fluvial, domain, rates of sedimentation do not compete with RSL, although those zones will be less affected than the delta front.
- In the mixed zone, deposition does meet or exceed rates of RSL. In the tidal zone, only the most extreme case competes with RSL.

References

Dasgupta, S., Huq, M., Khan, Z. H., Masud MdS, A. M., Mukherjee, N., & Pandey, K. (2010). Climate proofing infrastructure in Bangladesh: the incremental cost of limiting future inland monsoon flood damage (Washington, DC: World Bank, November, Policy Research Working Paper 5469).

Eaton, B. C. (2013). Hydraulic geometry: Empirical investigations and theoretical approaches. Treatise on geomorphology, 9, 313-329.

Rogers, K. G. (2012). Spatial and temporal sediment distribution from river mouth to remote depocenters in the Ganges-Brahmaputra delta, Bangladesh (Doctoral dissertation, Vanderbilt University).

Syvitski, J. P., Kettner, A. J., Overeem, I., Hutton, E. W., Hannon, M. T., Brakenridge, G. R., .Day, J., Vörösmarty, C., Saito, Y., Giosan, L. & Nicholls, R.J.(2009). Sinking deltas due to human activities. Nature Geoscience, 2(10), 681.

Witek, P. P., & Czechowski, L. (2015). Dynamical modelling of river deltas on Titan and Earth. Planetary and Space Science, 105, 65-79.

Acknowledgments

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