Sedimentation Patterns in the Ganges-Brahmaputra Delta System*

Irina Overeem¹, K. Rogers¹, P. Passalacqua², A. Canestrelli³, S. Cohen⁴, and K. Matin⁵

Abstract

The monsoon-driven Ganges-Brahmaputra river system transports large amounts of sediment from the Himalayas to the delta. The two rivers combined bring ∼1 billion tons into Bangladesh as reconstructed from observations at Hardinge Bridge and Bahabadur gauging stations from the late 1950's onwards. Downstream spatial distribution of sediment flux into the deltaic distributary channel network and deposition rates onto the floodplain and delta plain are remarkably unconstrained, yet of critical importance to the understanding of the overall delta sediment budget. We numerically model daily incoming sediment flux with a distributed hydrological basin model, WBM-SED. The model uses re-analysis climatology to calculate the water balance and routes water and sediment throughout the Ganges and Brahmaputra drainage basins. The estimated flux provides a boundary condition to the lowland sedimentary system. We present a simple approach to sediment routing over the delta distributaries and into tidal channels; we use channel network characteristics to distinguish between three orders of channels and route suspended load according to their plan view dimensions.

In the tidal delta, we reverse our simple routing scheme with sediment flux coming from the nearshore water. Characteristics of associated islands, such as nearest-edge to water distance, are determined for each of the characteristic channel order classes. We then use two cross-sectional process models, AquaTellUS and FV-SED, to calculate cross-channel sediment flux deposited on delta islands during river flooding and tidal flooding. Monsoonal flooding and a high tidal range are highly efficient mechanisms to re-deposit sediment onto the delta plain, especially in areas of high channel connectivity in the coastal zone. This finding is corroborated by our field data on sedimentation rates in the coastal zone, which highlighted that over a single monsoonal season as much as 1 cm/yr of sediment is deposited widespread in the tidally-controlled areas of the abandoned Western delta. Preliminary field data in the fluvial-dominated reach shows higher sedimentation rates locally (∼5 cm/yr), but exhibits a more spatially varied sedimentation pattern. These results are comparable to rapid near-channel sedimentation as
indicated by the numerical modeling. Our simplified concept helps highlight unknowns in the delta plain storage term in the source-to-sink system of the Ganges-Brahmaputra Delta.

Selected References


Sedimentation Patterns in the Ganges-Brahmaputra Delta System

SRTM-topography >10 m

Irina Overeem, CSDMS, University of Colorado at Boulder

K. Rogers, P. Passalacqua², A. Canestrelli³, S. Cohen⁴, K. Matin⁵

Presenter’s notes: One of the largest depositional features on Earth.
Ganges-Brahmaputra Delta System
Source to Sink

Depositional setting

1. Bengal Basin: tectonically deformed from continental collision of India into Eurasia
2. Asian monsoon: 80% of $Q_w$ and 95% of $Q_s$ from May-Sept. Peaks in August.
3. Large sediment discharge: $Q_s \sim 992 \times 10^6$ tons/y
4. ~80 cm sea level set up
5. Tidal range: 2-6 m
   Tidal velocities: 1-4 m/s
6. Recurring cyclones every ~2 years
Floodplain storage of 300 million ton/year

Existing estimates based on stratigraphic analyses, geochronologic dating of core material

(Kottke et al. 2003; Goodbred and Kuehl 1999; Allison 1998; Michels et al. 1998; Rogers et al., 2013)
What are depositional patterns over a single flood season and over ~50 years?

What are longitudinal trends in sedimentation?

What can simple numerical models tell us about the lateral distribution of sediment over the delta plain?
Channel widths in Ganges-Brahmaputra delta vary over 4 orders of magnitude

Largest channels 5-7 km, small tidal creeks ~1m

We use the network analysis to quantify dimensions for 3 channel orders to scale floodplain sedimentation experiments

Colormap of Island area, only channels >57m (Passalacqua et al., 2013)
Figure 11: Channel network of the GBJ Delta and map of island aspect ratio normalized by $\gamma_{min} = 2$. The majority of the elongated islands is located near the coast and along the main rivers (Ganges, Padma, Meghna), but the distribution of aspect ratio within the delta is heterogeneous.

Figure 12: Channel network of the GBJ Delta and map of the logarithm of nearest-edge distance $L$. The nearest-edge distance is calculated as the shortest straight-line distance from the nearest source of water (channelized or unchannelized) from any land pixel within the delta. The smallest values of nearest-edge distance are located near the coast, in particular within the mangrove forest.

Nearest-Edge Distance to Channel (Passalacqua et al., 2013)
WBM-water and sediment flux model

\[ Q = Q_{rain} + Q_{snow} + Q_{ice} + Q_{gw} \]

Empirical model for suspended sediment discharge, \( Q_s \):

\[ Q_s = (1 - \text{TE}) \alpha_6 Q^{\alpha_7} R^{\alpha_8} e^{kT} \]

- \( \text{TE} \): trapping efficiency by lakes and reservoirs
- \( R \): relief
- \( T \): basin-wide temperature

\( \alpha_6 = 2.0 \), \( \alpha_7 = 0.45 \), \( \alpha_8 = 0.57 \), \( k = -0.09 \) (tropical regions)

Modified Bagnold equation for bedload, \( Q_b \):

\[ Q_b = \left( \frac{\rho_s}{\rho_s - \rho} \right) \rho g Q^{\beta} s e_b \frac{g \tan f}{s} \]

Distributed Model (6 arc-mins)

Driven by 50 yrs of daily climate reanalysis data

Cohen et al., 2013

All rivers are dominated by the Indian Summer Monsoon. Model predictions compare well with observed data. (e.g Coleman, 1969; Webster et al., 1998; Islam et al, 1999)
Intra-annual variability in influx of water and sediment – 50 years

Brahmaputra mean: $Q = 2.01 \times 10^4$ m$^3$/sec (Jian et al., 2009)
WBM predicts: $QB = 2.31 \times 10^4$ m$^3$/sec

Ganges mean: $Q = 1.14 \times 10^4$ m$^3$/sec (Jian et al., 2009)
WBM predicts: $QB = 1.26 \times 10^4$ m$^3$/sec

\[ y = -1.7 \times 10^9 x + 3.8 \times 10^{12} \]
Model the fluvial-dominated delta

- Variable Discharge and Sediment input (t)

WBM model dictates magnitude and variability of annual flood

Simple approach: models flood events only, no tides, no storms.
AquaTellUs Model

Topography (H) depends on sediment flux (F):

$$\frac{\partial H}{\partial t} = \frac{\partial F}{\partial x}$$

Erosion depends on slope (S) and discharge (Q) in fluvial domain, grainsize-independent:

$$\frac{\partial F_{er}}{\partial x} = k_{c(x,t)} S_{(x,t)}^m Q_{(x)(t)}$$

Sedimentation depends on sediment flux (F) and streampower (u), $k_{sed}$ is grainsize dependent:

$$\frac{\partial F_{sed(x,t)}}{\partial x} = \frac{k_{sed}}{u_{(x,t)}} F_{(x,t)}$$
Basic principles of sedimentation across channel belt and floodplain: exponential with distance from channel (Pizutto, 1987; Goodbred & Kuehl, 2000).

Variability in floods creates Gaussian distribution; and error function solution (Paola, 2000; Overeem, 2005).

\[ F(y) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(y-\mu)^2}{2\sigma^2}} \]

\[ erf(y) = \frac{2}{\sqrt{\pi}} \int e^{-t^2} dt \]

y = horizontal distance normal to channelbelt
σ = standard deviation across sedimentation zone
μ = position of flowpath axis
Flood deposition maps- 50 yrs

1) Lateral sedimentation
   >2500 m, h ~ 1.5m
2) Rapid sedimentation causes natural avulsions,
50 yr deposition >1.5m
Overbank sands amalgamate

50 yr deposition ~ 0.2 -1m
2nd order channels disconnected

50 yr deposition ~ 0.1 -0.7m
2nd order channels disconnected
Flood deposition maps – 50 years

3rd order channels
(500-250m)

Lateral deposition still
~1500m, but finer grainsizes

Connectivity of sediments is lower, due to more stable channel belts
Observations from Sediment Traps

2012 mixed tidal-fluvial delta plain sediment trap sites
Observed Sedimentation Rates

Regional vertical accretion: 2.3±0.9 cm y⁻¹
Conclusions and Future Steps

- Sedimentation rates in tidal delta are ~1.1 cm/yr. Preliminary results for fluvial-dominated part of delta plain are as much as 2.3 cm/yr.

- Modeled sedimentation has a strong longitudinal grain size trend; highest aggradation and sandiest near ‘apex’ and again near coastal boundary. Model predicts strong downstream fining; predominantly a consequence of sediment availability. Siltier, lower channelbelts occur towards the coastal floodplain.

- Model predicts significant interconnectivity of sandy sediments in 2\textsuperscript{nd}-order channel simulations, channels or 3\textsuperscript{rd} order contribute to floodplain but appear more isolated treads.

- In future: combine nearest-edge maps, channel width classes and channel sedimentation patterns.

- In future: design similar experiments with tidal channel model (FV-Sed)