The Morphological Evolution and Sustainability of Deltas in the 21st Century

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Emergent phenomena represent the combined and repeated effects of smaller-scale processes. Consequently they play a vital role in determining the multidecadal evolution of complex morphological systems. Deltaic landscapes, built by processes such as channel avulsion and bifurcation, provide prime examples of complex systems that are dominated by emergent processes acting over numerous temporal and spatial scales. **Compared to terrestrial systems, there have been relatively few studies that focus on the successful simulation of long-term emergent phenomena in coastal catchments, and in particular those located in river deltas**[1]. Furthermore, compared to tributary systems, there are far fewer studies that attempt to quantitatively measure metrics that describe emergent features in distributary channel networks[2]. As well as being intriguing morphological landscapes, **deltas are also major socioeconomic and ecological centres**; rich in biodiversity and home to 500 million people worldwide. They are also widely recognised as being highly vulnerable to the impacts of climate change, in particular to sea-level rise and shifts between flood and drought events[3]. **It is therefore vital that this research gap is addressed in order to understand how these highly complex and vulnerable systems may respond to increasing conditions of climatic stress.**

Figure 1: Bank erosion along the Mahanadi River. *Source: The Telegraph, 2014*

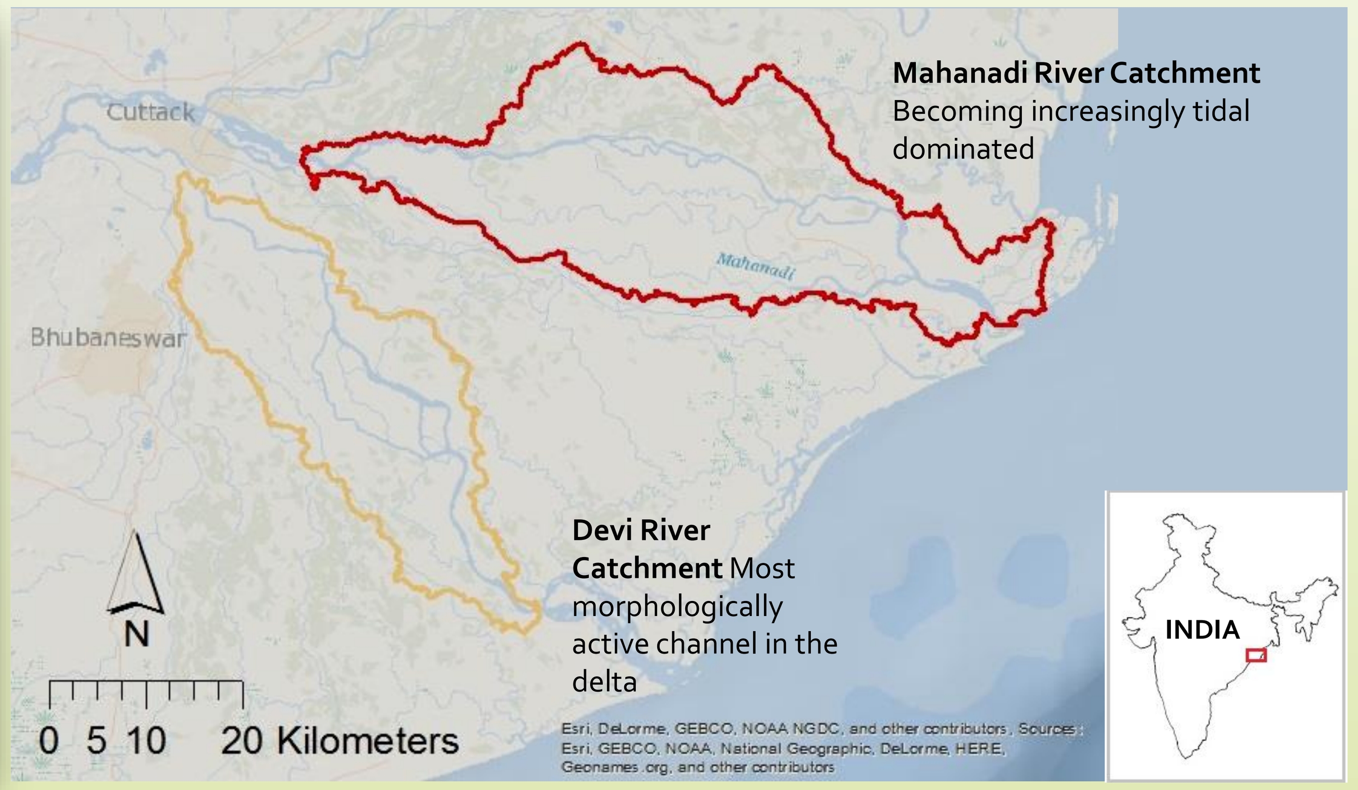

Figure 2: Study site location

Utilising the cellular automata model CAESAR-Lisflood, this research aims to enhance our understanding of how emergent processes influence the multidecadal evolution of deltaic environments. The chosen study site, the Mahanadi Delta, has regularly been highlighted in recent research as one at significant risk from climate change, and is expected to be the worst affected river basin in India in terms of the projected increase in flood intensity attributed to shifts in monsoon patterns[4, 5]. During flood events high rates of bank erosion occur (as shown in fig. 1) and regularly displace entire settlements. We focus on two contrasting catchments within the delta that display differing rates of channel migration (fig. 2). Utilising historical data as a baseline, **we develop 12 scenarios** for the Mahanadi delta that encapsulate a broad range of environmental stressors. **In particular, we focus on the impacts of shifts in monsoon precipitation and the frequency of tropical cyclones.**

Here, we present a selection of preliminary results for a scenario in the Devi catchment. The combination of stressors for this scenario (as shown in table 1) represents the '**most likely pathway**' for the Mahanadi Delta. Each scenario is run in the model over two 30 year periods: 2015 – 2045, and 2045 – 2075.

Table 1: Scenario design for '4DWD'; the most likely pathway for the Mahanadi Delta

Scenario 4DWD: Drier, more variable monsoon; wetter post-monsoon; drier dry season; variable sediment supply								
Stressor	Monsoon precipitation (Jun - Sep)	Post-monsoon precipitation (Oct – Nov)	Dry season precipitation (Dec – May)	Annual average air temperature	Severe cyclone frequency	Eustatic sea-level rise	Sediment starvation	Accelerated subsidence
Set-up for 2015-2075	Seasonal total decreases up to 25% and daily variability increases	Seasonal total increases up to 15%	Seasonal total decreases up to 25%	Increases up to 1.1°C	Every 50 years	Local mean sea-level increases 0.36 m by 2075	Daily variability increases	3 mm.yr^{-1}

We utilise a range of model outputs to identify the rate of morphological change and areas of the catchment that may be at greatest risk. To understand how emergent processes have modified the distributary network we have adopted a number of metrics as used by Edmonds *et al* (2011) . These include: **the fractal dimension, the distribution of island sizes, and nearest-edge distance** (NED) (the shortest distance to channelised or unchannelised water). For the next stage of analysis we seek to identify important **connections between the emergent morphological system and ecosystem services that influence the habitability of the delta**, such as water quality and habitat cover. The model also provides a platform to investigate the viability of potential engineering strategies that could enhance the habitability of a given location.

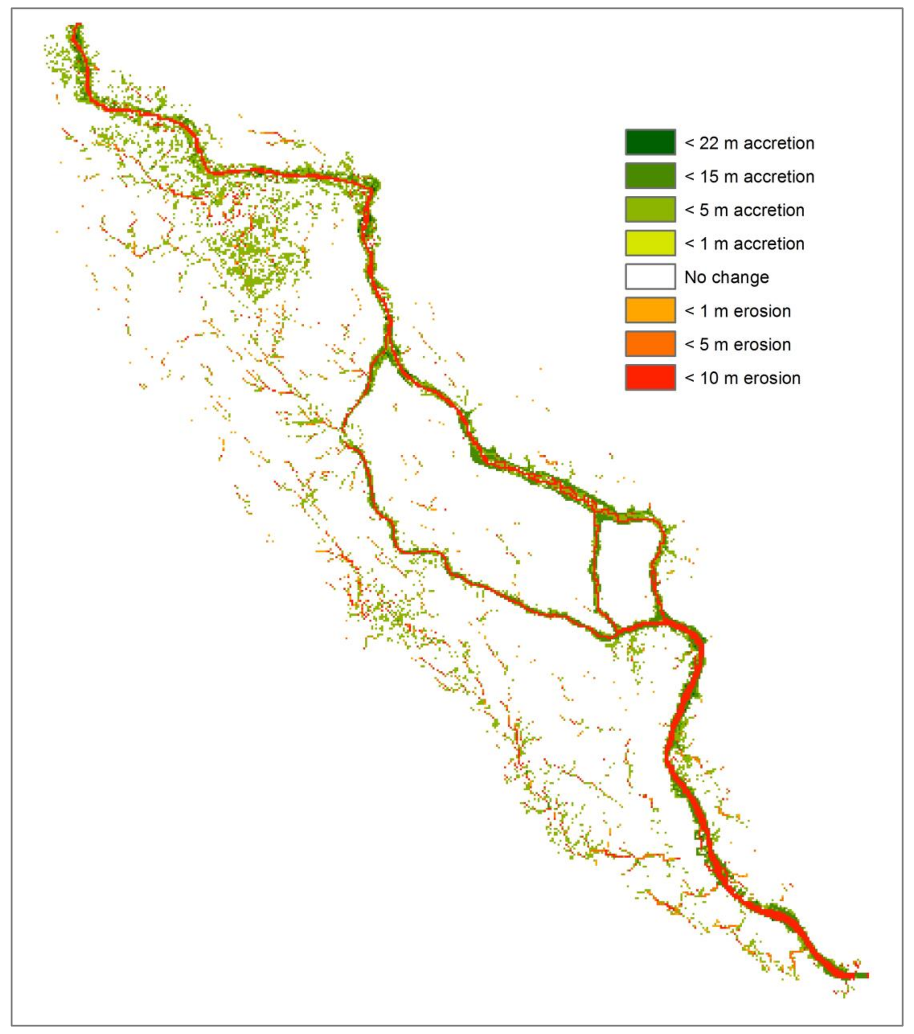

Figure 3: Elevation change for 2015 – 2045 under scenario 4DWD

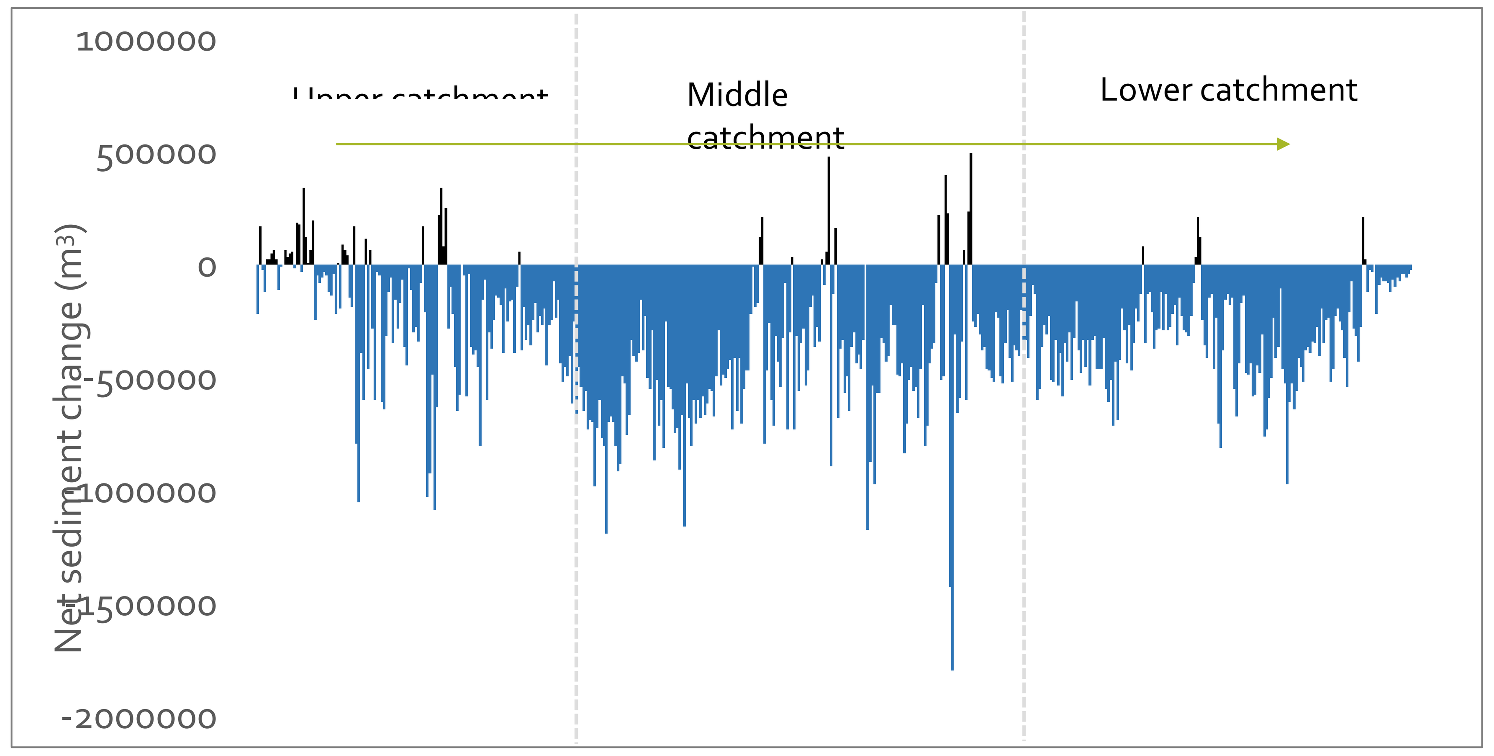

Figure 4: Net sediment change for 2015- 2045 under scenario 4DWD. Each column represents a horizontal cross section through the catchment

Figs. 3 and 4 show significant erosion occurring in the system at the end of the first 30 year period (2045). Scouring has occurred throughout the main channel with the accretion of levees predominantly occurring in the upper catchment. A bar has also developed at the mouth of the estuary.

Island size varies between 0.18 km² and 151.47 km² (mode = 0.36 km²) . This unimodal distribution (fig.5) dominated by smaller islands is typical of a younger, active region of the delta[2]. Fig. 6 shows a distribution of NED that matches closely to that found by Edmonds *et al* (2011). Areas with high NED will receive less sediment over time and become susceptible to drowning; and vice versa.

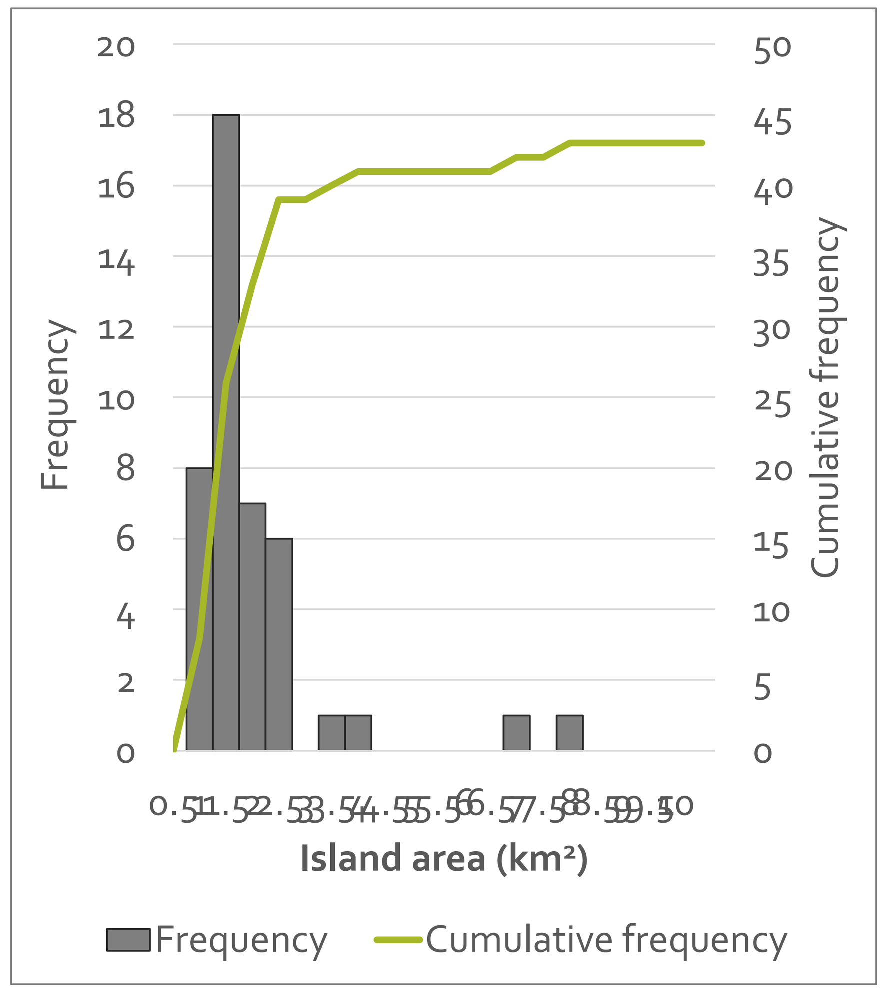

Figure 5: Island size distribution (Year 2045, scenario 4DWD)

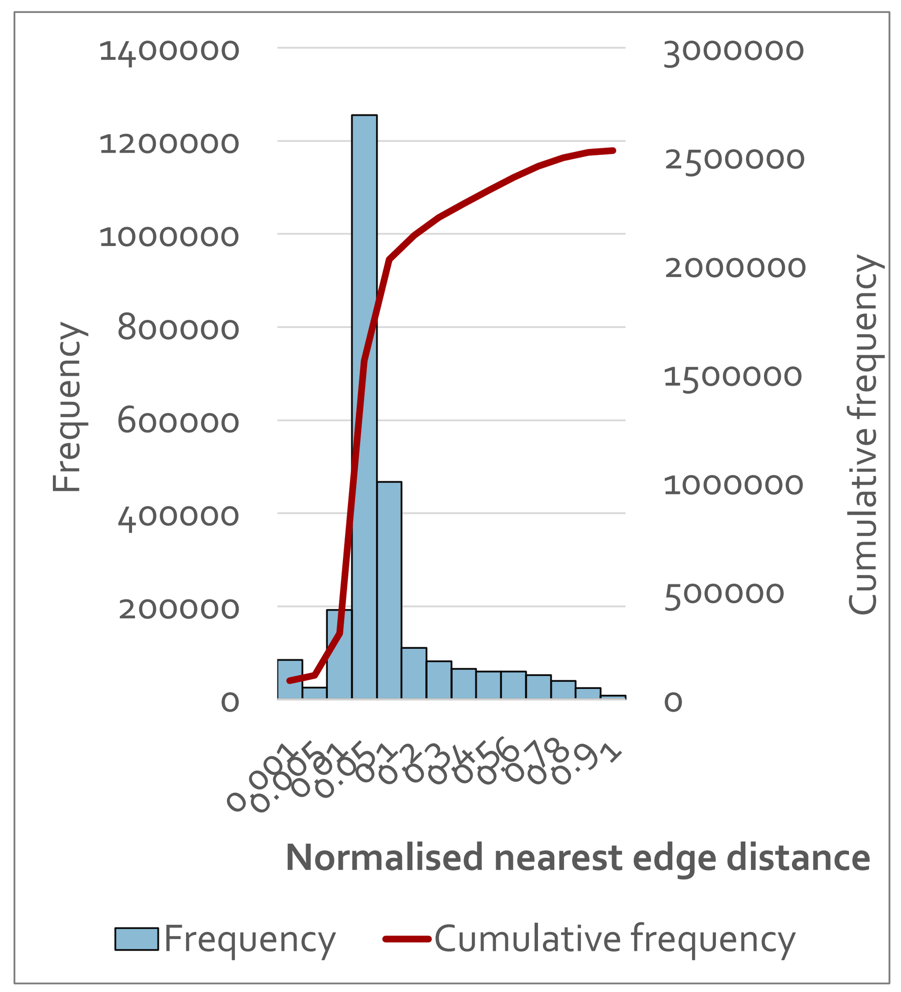

Figure 6: Normalised nearest edge distance (Year 2045, scenario 4DWD)

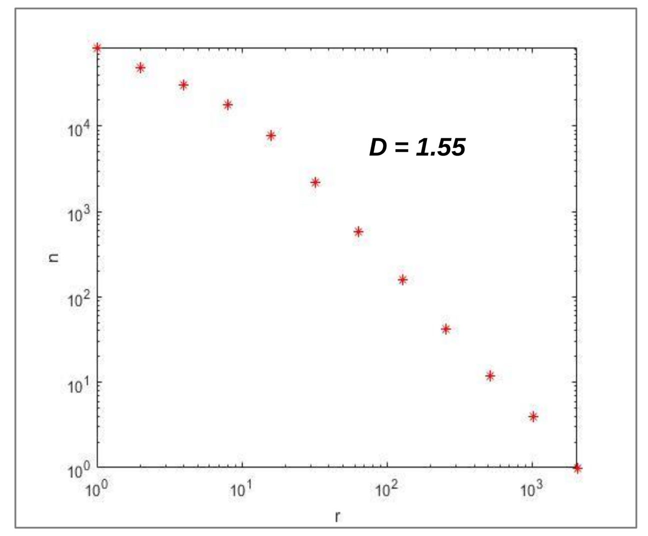

Figure 7: Box-counting dimension (D) (Year 2045, scenario 4DWD)

Fig. 7 shows the box-counting dimension (D) calculated using the slope of the best fit linear regression, where r the size of the boxes and n = the number of boxes required. This value for the Devi is slightly higher than found by Edmonds *et al.* (2011), but is not outside the expected range.

References: 1: Dearing, J. *et al.* 2006 Phil. Trans. Royal Soc. 364(1841); 2: Edmonds, D.A. (2011) J. Geophys. Res, 116; 3: Olesen, K.W. (2011) Mega Deltas and the Climate Change Challenges, International Network on Erosion and Sedimentation, Beijing; 4: Syvitski, J.P.M *et al.* (2009) Nature Geoscience, 2: 681-686; 5: Jena *et* al. (2014) Journal of Hydrology, 517:847-862