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Sediment Delivery to Deltas Under Environmental Change

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Deltas are home to over 500 million people worldwide (Figure 1) and the majority are sinking relative to sea level due to a combination of factors. This sinking causes flooding, groundwater salinisation, damage to infrastructure, loss of life, and eventual loss of land. The factors affecting delta elevation relative to sea level are eustatic change, crustal movement, compaction, and aggradation. The main pressures on delta elevation, caused by anthropogenic activities, are ground subsidence, which occurs naturally but is accelerated by anthropogenic activities, sea level rise, and sediment deprivation.

For deltas to aggrade, and therefore rise relative to sea level, sediment must be input and retained on the delta surface. As both the delivery (Figure 2) and the retention (Figure 3) of sediment have been affected by anthropogenic activities, aggradation has reduced significantly on many major deltas. This interference has caused a fall in delta surface elevation relative to sea level because aggradation is the main process by which deltas can rise relative to sea level.

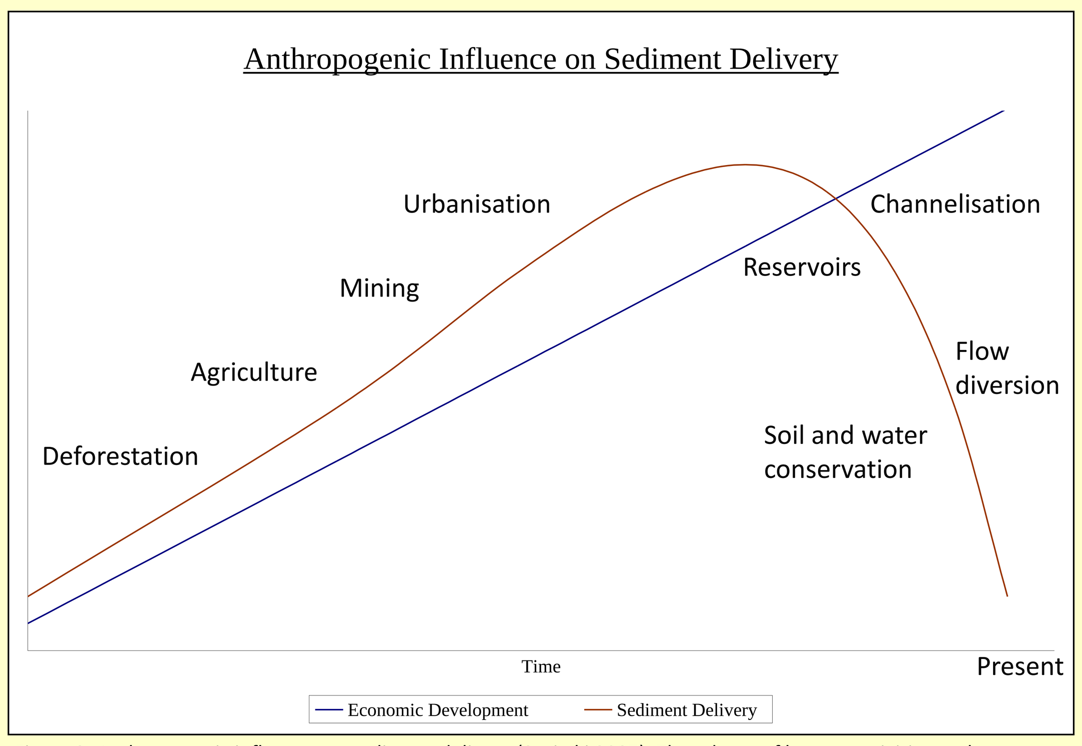


Figure 2: Anthropogenic influence on sediment delivery (Syvitski 2007). The advent of human activities such as deforestation and agriculture may have initiated delta development (McManus 2002). While activities such as channelisation reduce sediment delivery they can also affect sediment retention, reducing aggradation further.

Aim

The aim of this research is to investigate sediment delivery to deltas under future environmental changes. This contributes to the understanding of relative sea level change projection for deltas which is an important predictor of land loss, degradation, and flooding.

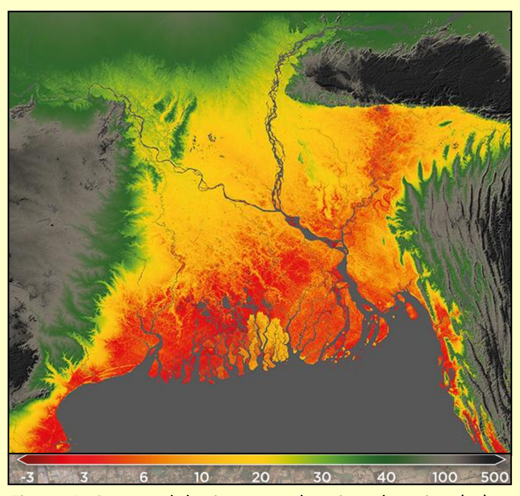


Figure 4: Ganges delta imagery showing elevation (m) and therefore areas at high risk from flooding (IGBP 2014)

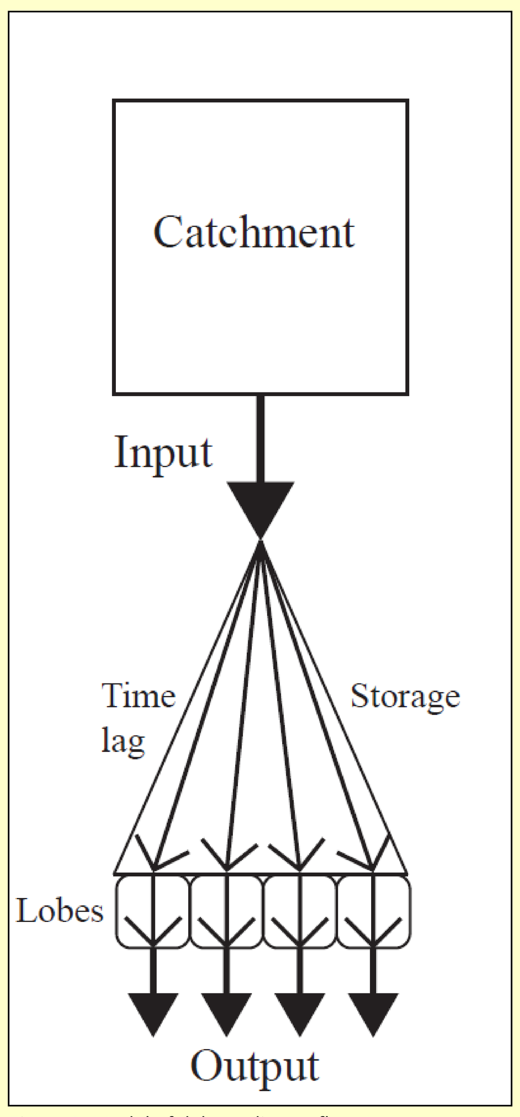


Figure 3: Model of delta sediment flux. A more complex portrayal of sediment flux than a black box with one input and one output is likely to be more realistic.

Delta Areas

While the sediment input to a delta is important for delta sustainability, the area over which that sediment is distributed is equally important as a larger delta area requires more sediment to remain at equilibrium with sea level. Figure 9 shows the range of areas published for a selection of major global deltas, with some of the differences shown to be significant.

In this current research a digital dataset of delta areas will be delineated using a consistent methodology. The methodology used here is to define delta areas as the area seaward of the apex (the location of the distributary splitting off) in between the outermost distributaries. As this will provide an underestimation of delta area due to the exclusion of land on the outer banks of the outermost distributaries which is under the influence of delta processes, work is ongoing on criteria to include land outside the outermost distributaries within a certain distance and/or under a certain elevation.

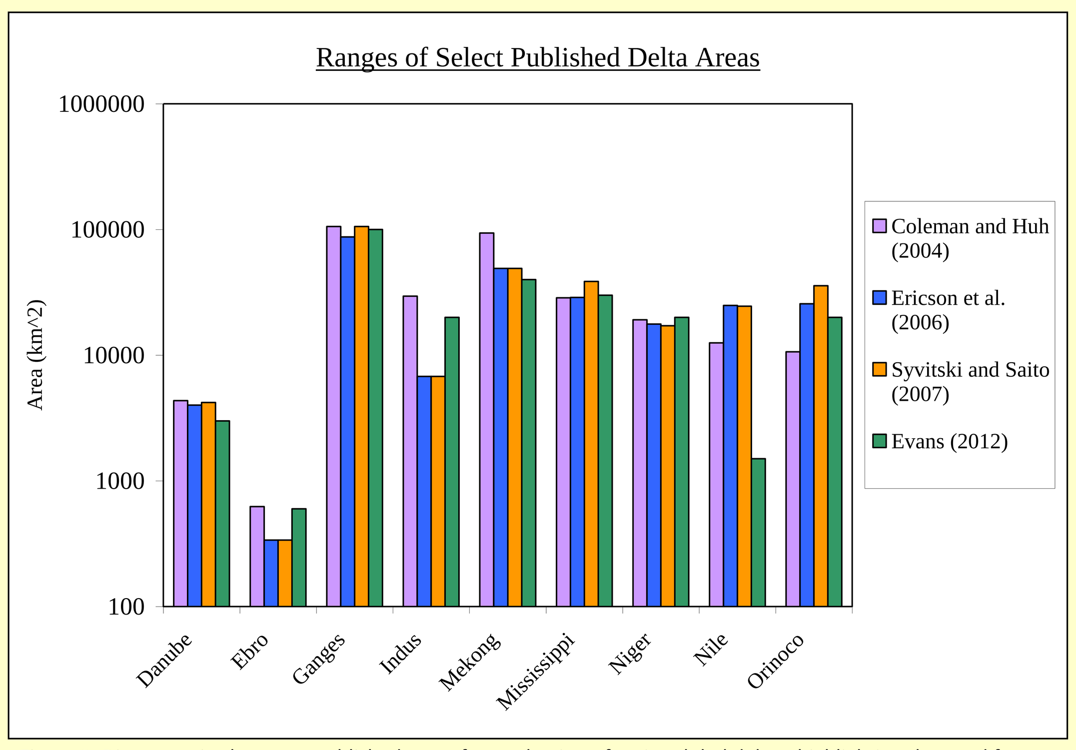


Figure 9: Discrepancies between published areas for a selection of major global deltas, highlighting the need for consistency in methodology, in both theory and implementation.

Figure 1: Examples of vulnerable deltas by potential population displaced (Nicholls *et al* 2007). Human vulnerability is more complex than numbers of people at risk but it is a significant factor.

Methods

In this research the environmental changes which will affect sediment delivery to deltas will be identified and their potential ranges established. The key environmental changes include reservoir construction, channel engineering, and land use e.g. agricultural practices and vegetation cover. To evaluate the effects of these catchment changes on fluvial sediment delivery, catchment numerical models will be calibrated for a selection of major vulnerable deltas. This calibration exercise involves the use of historical reference data for each delta.

Using HydroTrend (Kettner and Syvitski 2008) reconstructed and predicted sediment discharge Figure 6) and fluvial discharge (Figure 7) have been produced for the Ganges river basin (Figures 4). These outputs were firstly used to calibrate the model to the Ganges basin using the reconstructed output and historical data, and secondly to assess how changes within the basin might affect future sediment delivery.

Both the fluvial and sediment discharge were overpredicted by HydroTrend initially. Calibration of the model brought the outputs closer to available field data. Initial analysis of the HydroTrend outputs suggests that there are potentially boundary conditions within the model, indicated by several significant peaks in sediment output. However no time series data, only long term averages, are available for sediment output from the Ganges catchment so the existence of these peaks in reality is unconfirmed.

A second model being used to investigate fluvial sediment delivery is WBMsed (Cohen *et al.* 2014). This model, unlike HydroTrend, is spatially explicit, although it is not mass conserving, so sediment does not 'flow' downstream. An example output from WBMsed for South East Asia for August 2002 is shown in figure 5. WBMsed provides less possibilities for calibration due to the necessarily spatially explicit datasets.

Figure 8 shows a comparison between the monthly averages of sediment yield produced by HydroTrend and WBMsed, compared with the average of the measured sediment for 1971-2010. This preliminary analysis suggests that HydroTrend is better able to predict sediment fluxes for this particular catchment, although additional calibration and analysis of other catchments is necessary before a decision is made as to which one is the most optimum for predicting sediment delivery to deltas globally.

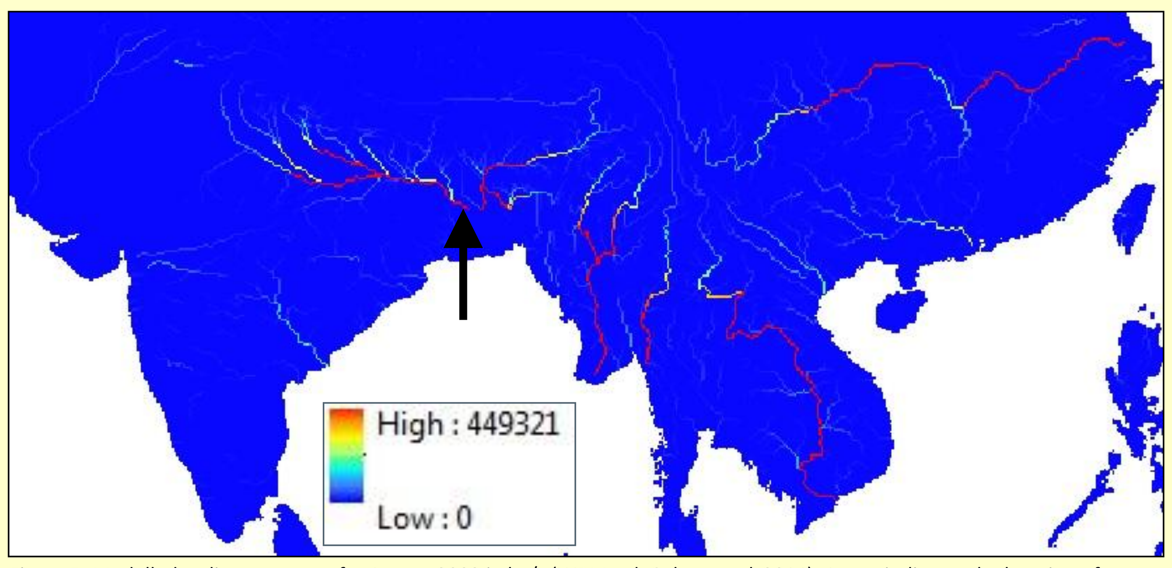
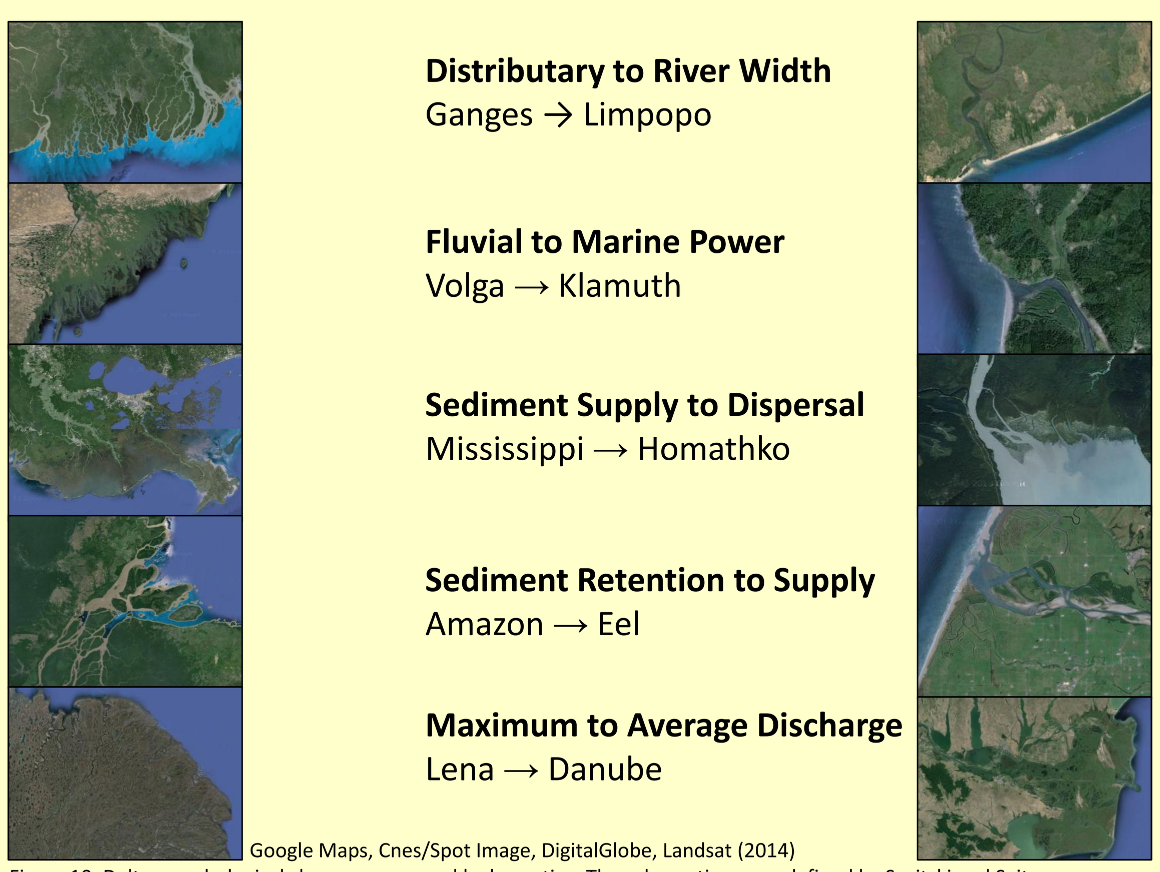


Figure 5: Modelled sediment output for August 2002 in kg/s (WBMsed, Cohen *et al.* 2014). Arrow indicates the location of the Ganges delta apex, where the Ganges basin discharges to the delta.

Delta Morphology

Due to the anthropogenic changes occurring and expected to occur to delta environments, the physical form of deltas is changing and expected to change. Syvitski and Saito (2007) demonstrated this using several key ratios. The parameters defining these ratios can be measured and therefore the change in delta morphology can be recorded. Globally, there is a general direction of change along these key ratios due to anthropogenic activities (illustrated using end-member deltas of each type in Figure 10).



Google Maps, Cnes/Spot Image, DigitalGlobe, Landsat (2014)

Figure 10: Delta morphological changes expressed by key ratios. These key ratios were defined by Syvitski and Saito (2007), showing the impact of anthropogenic activities on delta morphology and particularly emphasise the role of sediment delivery and retention. Arrows indicate general direction of global delta morphology change due to anthropogenic activites.

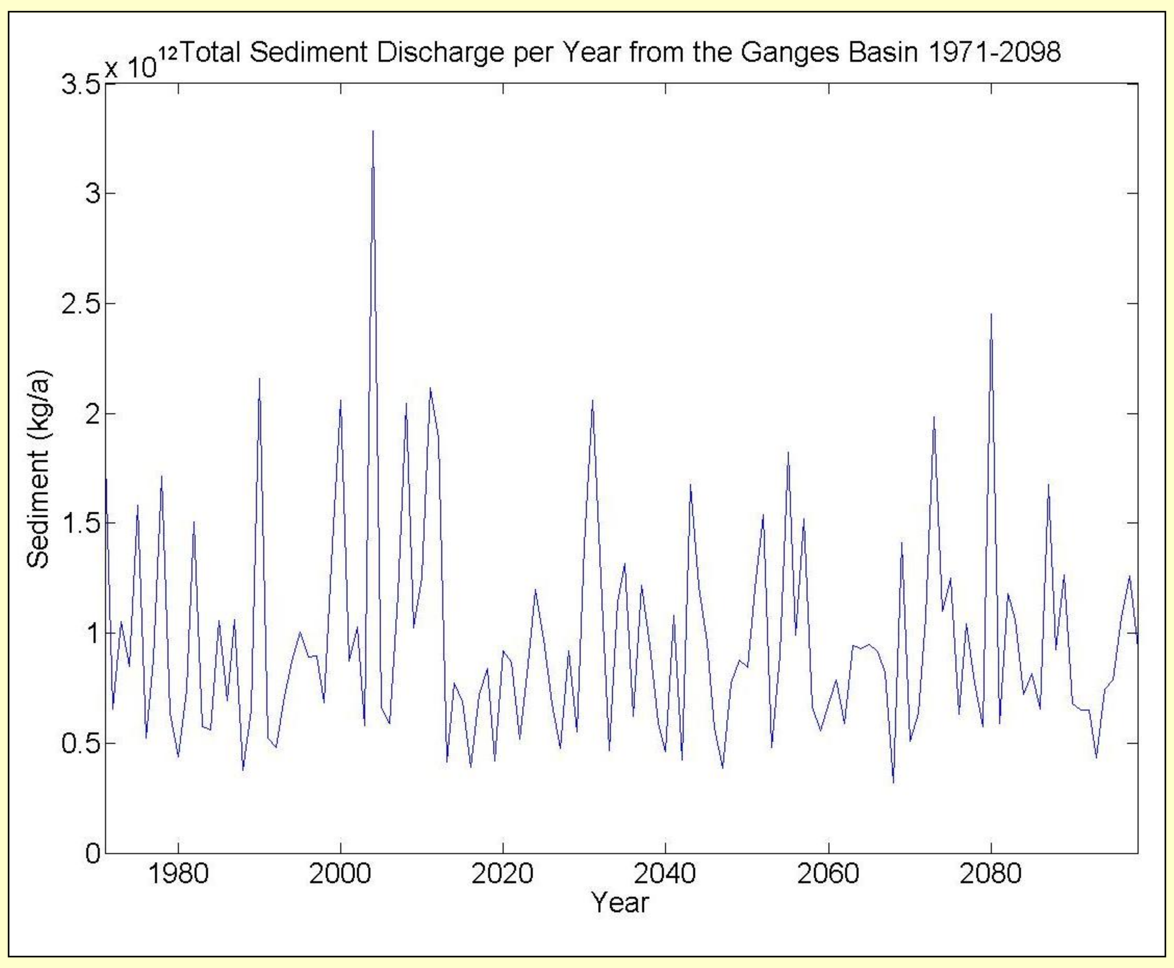


Figure 6: Modelled sediment output per year from the Ganges basin using daily time step climate data (HydroTrend, Kettner and Syvitski 2008). Important features of this output include the peaks in sediment discharge, suggesting critical boundary conditions within the model. Changes in anthropogenic activity such as reservoir construction were not taken into account in this model run.

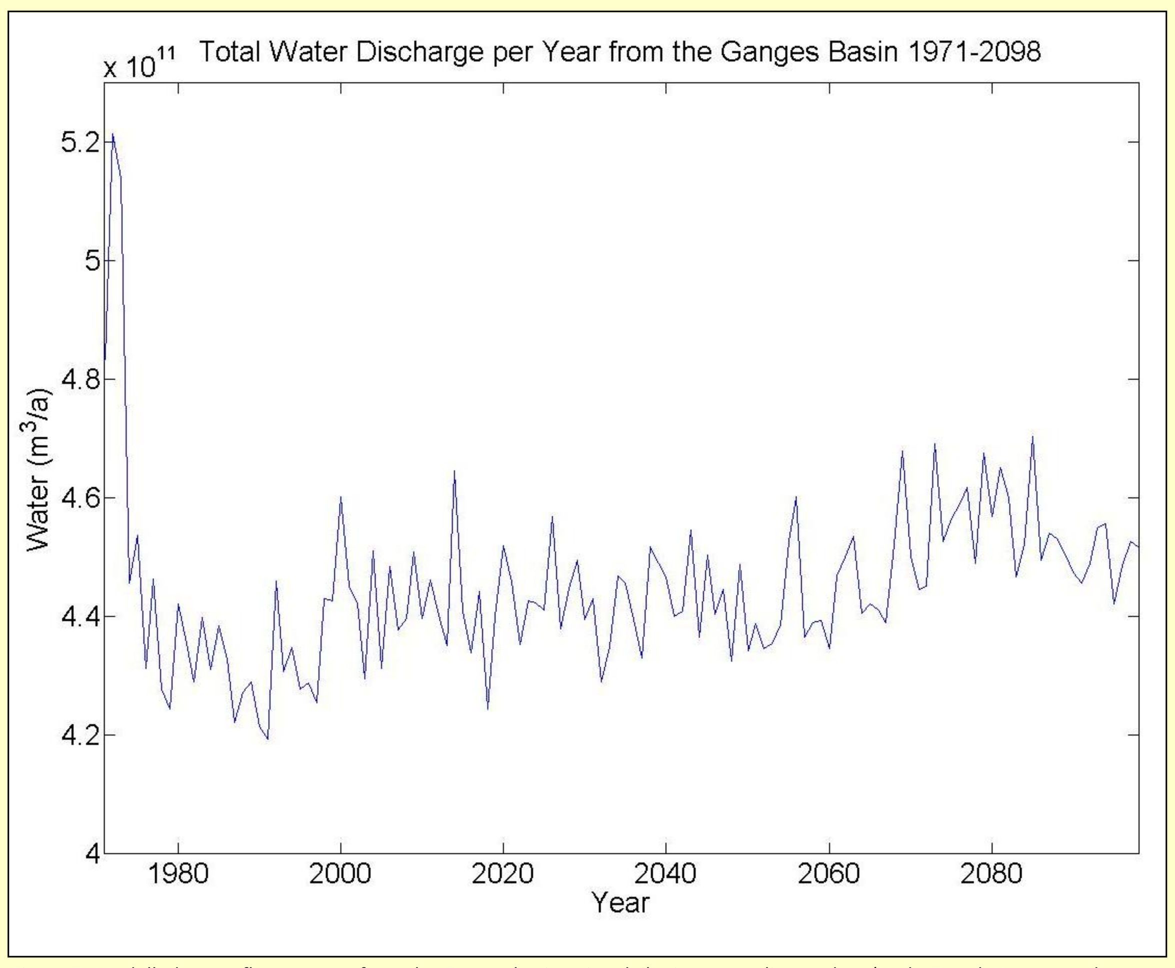


Figure 7: Modelled water flux per year from the Ganges basin using daily time step climate data (HydroTrend, Kettner and Syvitski 2008). The peak it the beginning is part of the run up period. Changes in anthropogenic activity such as reservoir construction were not taken into account in this model run, so the positive trend seen is purely due to climate change.

Conclusion

Proceeding with this research, HydroTrend will be refined for other delta basins worldwide. Other numerical models such as WBMsed are currently being investigated. This research will assist in prognosis for vulnerable delta areas and inform their short- and long-term management. As some aspects of delta sustainability are under anthropogenic control or influence the projections will indicate the consequences of various actions affecting delta elevation. While this could give forewarning for the residents and managers of unsustainable deltas, it could also be used as an argument for or against various anthropogenic activities.

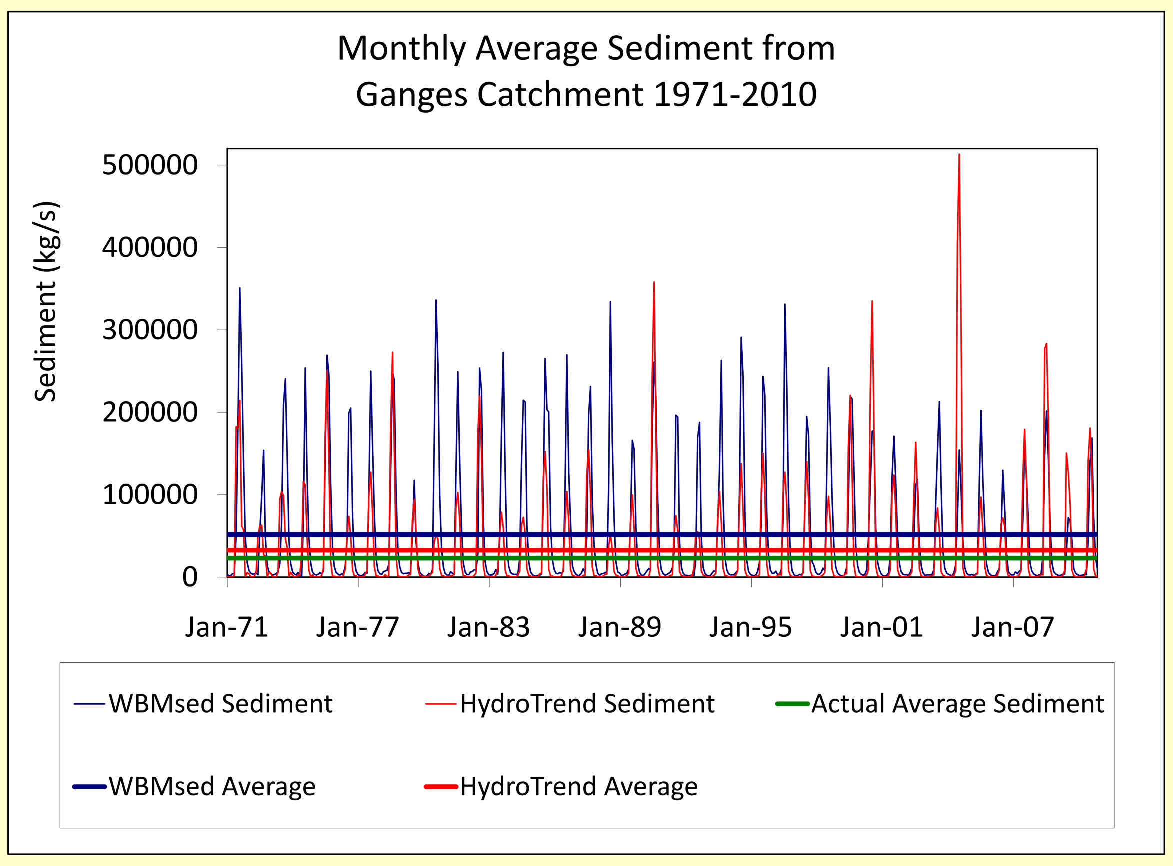


Figure 8: Comparison between HydroTrend and WBMsed modelled sediment delivery from the Ganges basin, monthly averages in kg/s frin 1971-2010 inclusive. Graph includes the average of measured sediment, indicating that HydroTrend provides a better fit to the gauge data.

References

Coleman, J. M., and Huh, O. K. (2003) Major world deltas: A perspective from space, *Louisiana State University*
Cohen, S., Kettner, A. J., and Syvitski, J. P. M. (2014) 'Global suspended sediment and water discharge dynamics between 1960 and 2010: Continental trends and intra-basin sensitivity', *Global and Planetary Change*, 115: 44-58
Ericson, J. P., Vörösmarty, C. J., Dingman, S. L., Ward, L. G., and Meybeck, M. (2006) 'Effective sea-level rise and deltas: Causes of change and human dimension implications', *Global and Planetary Change*, 50: 63-82
Evans, G. (2012) 'Deltas: the fertile dustbins of the continents', *Proceedings of the Geologists Association*, 123: 397-418
Google Maps, Cnes/Spot Image, DigitalGlobe, Landsat (2014) 'Google Maps', last access: 19/04/2014
IGBP (2014) 'Deltas at risk – IGBP', 21/05/2014, last access: 26/05/2014, http://www.igbp.net/multimedia/multimedia/deltasatrisk.5.62dc35801456272b46d351.html
Kettner, A.J., and Syvitski, J.P.M. (2008) 'HydroTrend version 3.0: A climate-driven hydrological transport model that simulates discharge and sediment load leaving a river system, *Computers & Geosciences*, 34 (10) 1170-1183
McManus, J. (2002) 'Deltaic responses to changes in river regimes', *Marine Chemistry*, 79: 155–170
Nicholls, R.J., Wong, P.P., Burkett,V. R., Codignotto, J. O., Hay, J. E., McLean, R. F., Ragoonaden, S., and Woodroffe, C. D. (2007) 'Coastal systems and low-lying areas. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change', M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 315-356
Syvitski, J. P. M. (2007) 'Deltas at risk', *Sustainable Science*, 3: 23-32
Syvitski, J. P. M., and Saito, Y. (2007) 'Morphodynamics of deltas under the influence of humans', *Global and Planetary Change*, 57: 261-2821