Geography and Environment

Earth Surface Dynamics

Engineering and the Environment

(Un)sustainability of Deltas Under Potential Future Changes in Sediment Delivery

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DECCMA

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Background

Deltas are densely populated, estimated to be home to a growing population of over 500 million people worldwide, 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, a situation which is increasingly exacerbated by anthropogenic activities. The controls on delta elevation relative to sea level are eustatic change, crustal movement, compaction, and aggradation.

For deltas to aggrade, and therefore rise relative to sea level, sediment must be input and retained on the delta surface. The flux of fluvial sediment to deltas is a first order control on delta aggradation and thus the potential for the surface elevation of a delta to rise relative to sea level. Both the delivery (Figure 1) and the retention of sediment have been affected by anthropogenic activities, and aggradation has been reduced significantly on many major deltas.

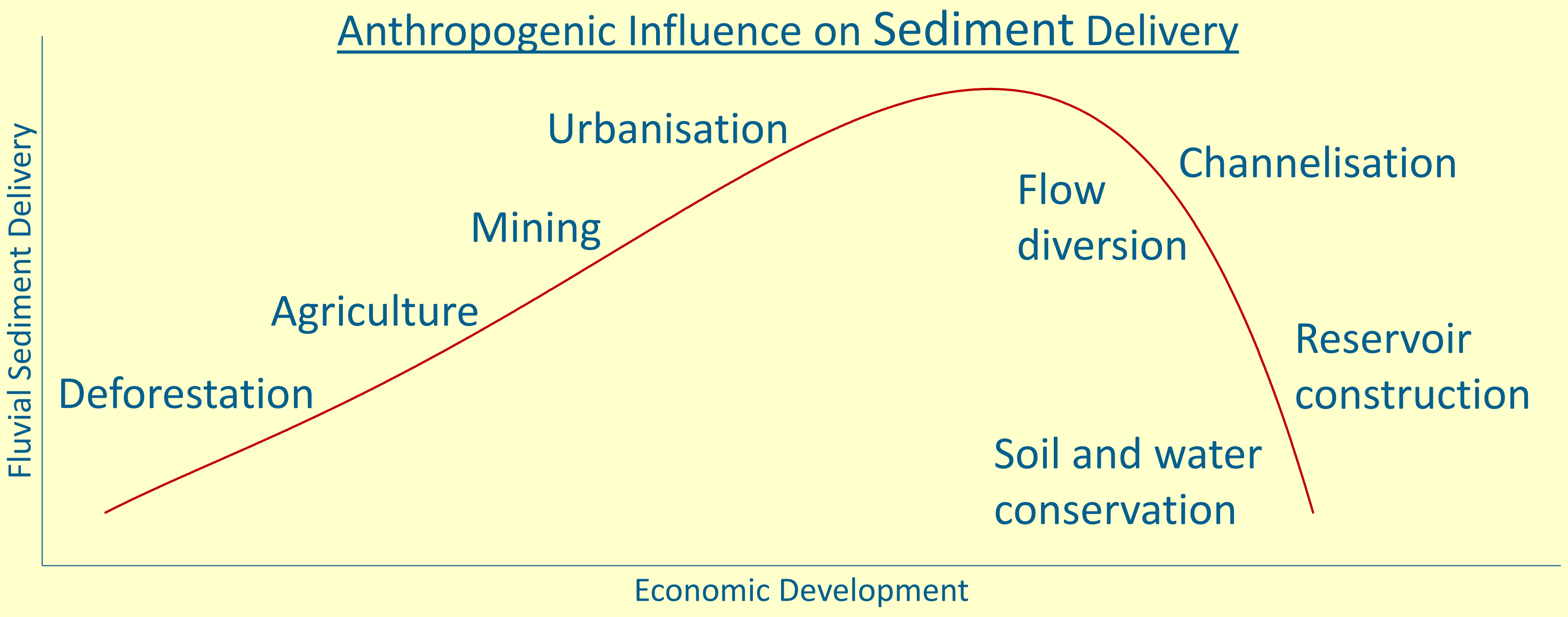

Figure 1: Anthropogenic influence on sediment delivery (Syvitski 2007). The advent of human activities such as deforestation and agriculture may have initiated delta development (McManus 2002). While activities such as channelisation reduce sediment delivery they can also affect sediment retention, reducing aggradation further. In some cases the reduction in sediment has lowered delivery to below pristine rates.

Results

Between the first and last decades of the 21st century there is a **net reduction** of sediment delivery to the 47 deltas of **2.5bt/a (38%)** on average across the scenarios (Table 2). The **cumulative loss** of sediment over the century is **226bt**. More deltas (29) deltas have a reduced sediment load by the 2090s than show an increase (16).

Figure 3 shows the differences in percentage and absolute change in sediment delivery. The x axis order (by % change) illustrates that while changes in sediment load may be substantial for individual deltas, the change may not have a great impact on global sediment delivery, with the reverse also being true.

Figure 4 shows the contributions of the key drivers of sediment flux change to the overall change for each river. The analysis shows that climate change is predominantly a positive influence on sediment fluxes, but that this effect is often overwhelmed by the negative influence of socioeconomic change and reservoir construction.

The results of this research indicate the consequences of anthropogenic activities which affect delta elevation and assist in prognosis for vulnerable delta areas. This could forewarn residents and managers of unsustainable deltas and inform their short- and long-term management.

Representative Concentration Pathways

Shared Socioeconomic Pathways	Sediment loss (bn t/a)	RCP2.6	RCP4.5	RCP6.0	RCP8.5
SSP1		2.7 (41%)	2.6 (40%)	2.6 (40%)	2.5 (39%)
SSP2		2.6 (40%)	2.6 (39%)	2.6 (40%)	2.5 (38%)
SSP3		2.4 (36%)	2.3 (35%)	2.3 (35%)	2.2 (34%)

Table 2: Matrix of scenario results, showing the reduction in sediment delivery (in billion t/year and percent) in total to the 45 deltas between 2000-2009 and 2090-2099.

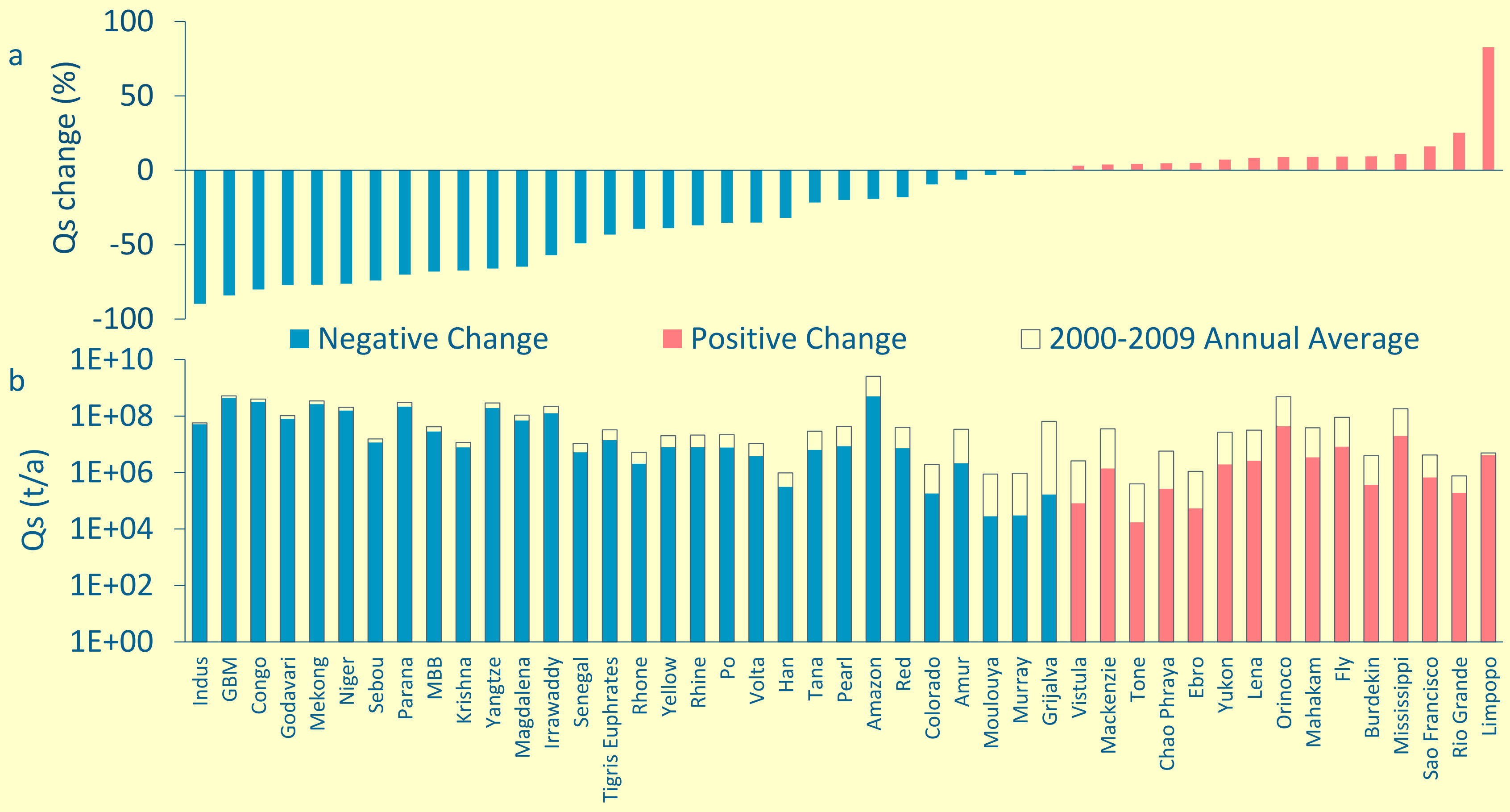

Figure 3: Percentage (a) and absolute (b) change in annual sediment flux over the 21st century (2000-2009 and 2090-2099) with initial baseline sediment flux to compare for 45 deltas for the scenario average. Note logarithmic y axis for subplot b.

Representative Concentration Pathways

Shared Socioeconomic Pathways	RCP2.6	RCP4.5	RCP6.0	RCP8.5
SSP1	Low climate change Low socioeconomic challenges	Medium-low climate change Low socioeconomic challenges	Medium-high climate change Low socioeconomic challenges	High climate change Low socioeconomic challenges
SSP2	Low climate change Medium socioeconomic challenges	Medium-low climate change Medium socioeconomic challenges	Medium-high climate change Medium socioeconomic challenges	High climate change Medium socioeconomic challenges
SSP3	Low climate change High socioeconomic challenges	Medium-low climate change High socioeconomic challenges	Medium-high climate change High socioeconomic challenges	High climate change High socioeconomic challenges

Table 1: Matrix of future scenarios run by WBMsed, constructed using all 4 RCPs (Jones *et al.* 2011) and SSP1-3 (Yamagata and Murakami 2015). For all scenarios a single reservoir construction timeline is employed, using the future dam database from Zarfl *et al.* (2015) and calculated reservoir volumes using the linear regression model from Grill *et al*. (2015).

Methods

Catchment numerical model WBMsed (Cohen *et al.* 2013) was applied to 45 coastal deltas (Figure 2, areas from Tessler *et al.* 2016) to project sediment delivery to the deltas up to 2100. WBMsed was forced using future reservoir data (Zarfl *et al.* 2015, Grill *et al.* 2015), 4 climate projections (Jones *et al.* 2011), and 3 socioeconomic pathways (Yamagata and Murakami 2015). The combination of input data resulted in 12 future scenarios (Table 1), the average of which is presented in Figure 2 and Figure 3.

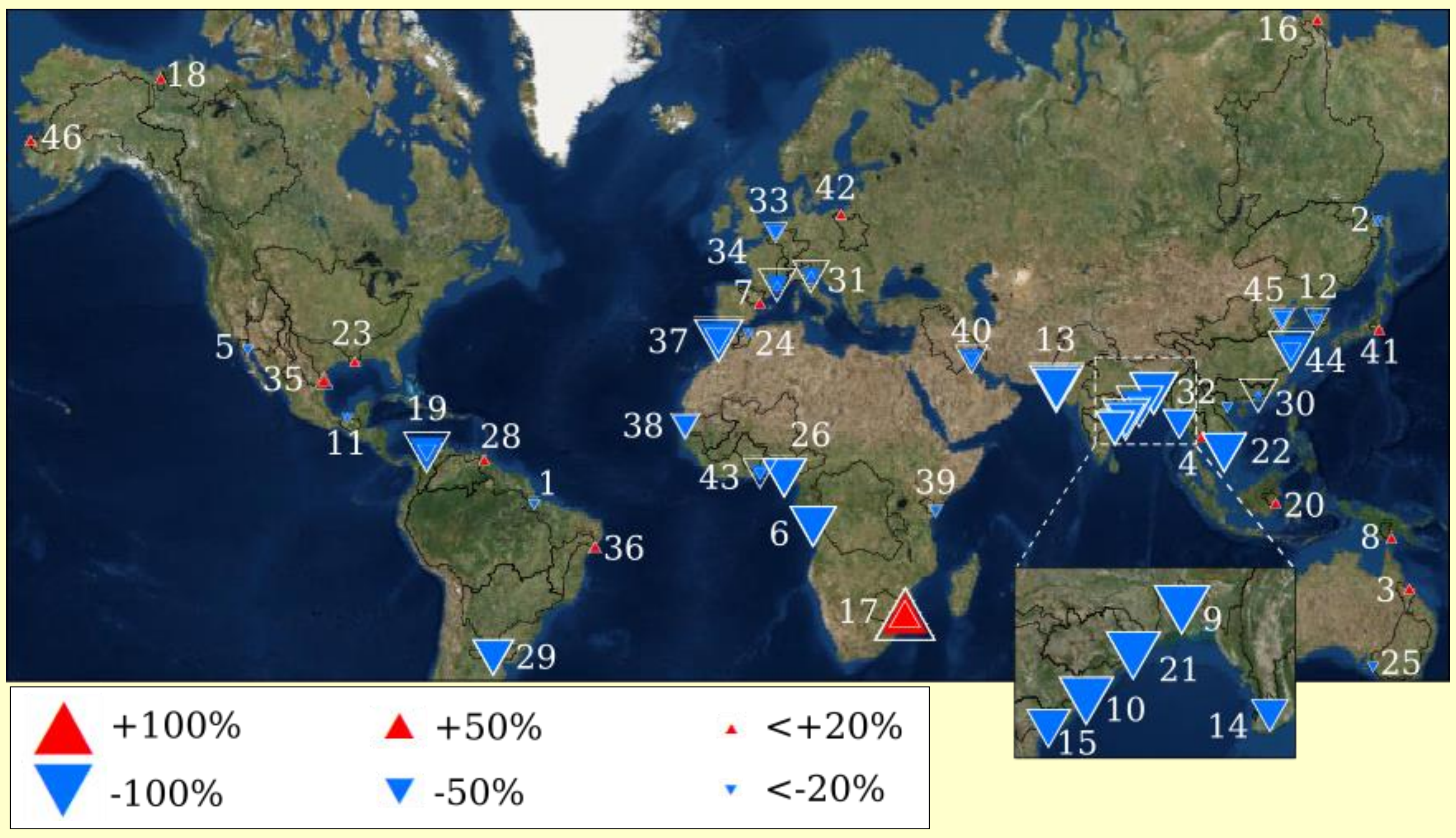

Figure 2: Map of percentage change of sediment delivery between 2000-2009 and 2090-2099 to 45 deltas. Coloured arrows are the scenario average, white arrows are maximum and minimum change. Black outlines are catchment boundaries. 1 Amazon, 2 Amur, 3 Burdekin, 4 Chao Phraya, 5 Colorado, 6 Congo, 7 Ebro, 8 Fly, 9 GBM, 10 Godavari, 11 Grijalva, 12 Han, 13 Indus, 14 Irrawaddy, 15 Krishna, 16 Lena, 17 Limpopo, 18 Mackenzie, 19 Magdalena, 20 Mahakam, 21 MBB, 22 Mekong, 23 Mississippi, 24 Moulouya, 25 Murray, 26 Niger, 28 Orinoco, 29 Parana, 30 Pearl, 31 Po, 32 Red, 33 Rhine, 34 Rhone, 35 Rio Grande, 36 Sao Francisco, 37 Sebou, 38 Senegal, 39 Tana, 40 Tigris Euphrates, 41 Tone, 42 Vistula, 43 Volta, 44 Yangtze, 45 Yellow, 46 Yukon

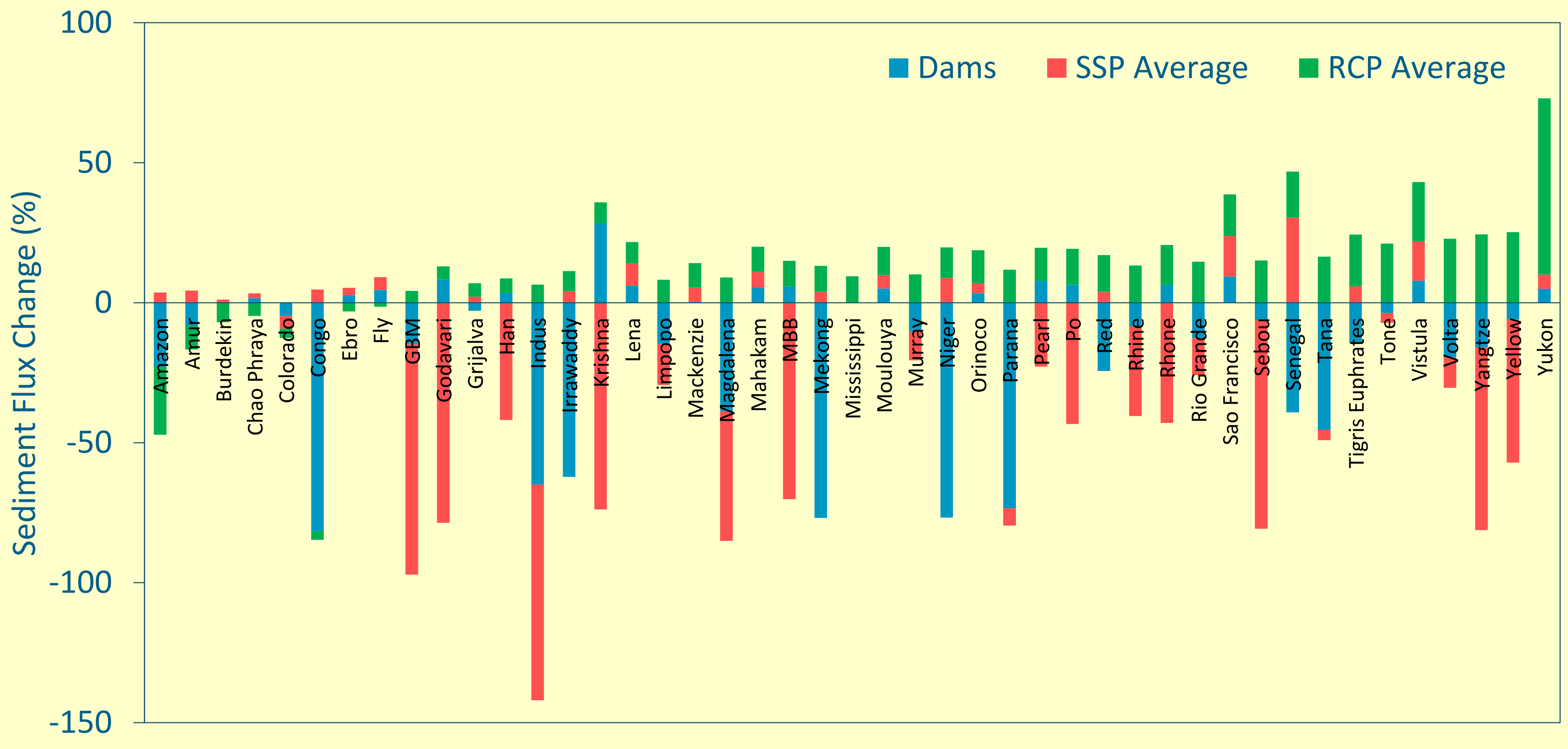

Figure 4: Sediment flux change projected by the key drivers for each of the 45 rivers. These figures were produced by running the model with a single environmental change driver, isolating the effects of each change, so the cumulative effect may add up to more than -100% of sediment when the results are stacked. The averages of the socioeconomic and climate change pathways are shown in this graph.

References

Map Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Cohen, S., Kettner, A. J., Syvitski, J. P. M., and Fekete, B. M. (2013) WBMsed, a distributed global-scale riverine sediment flux model: Model description and validation, *Computers & Geosciences*, 53: 80-93

Grill, G., Lehner, B., Lumsdon, A. E., MacDonald, G. K., Zarfl, C., and Reidy Liermann, C. (2015) An index-based framework for assessing patterns and trends in river fragmentation and flow regulation by global dams at multiple scales, *Environmental Research Letters,* 10, 015001

Jones, C. D. *et al*. (2011) The HadGEM2-ES implementation of CMIP5 centennial simulations, *Geoscientifc Model Development Discussions,* 4 (1) 689-763

McManus, J. (2002) Deltaic responses to changes in river regimes, *Marine Chemistry*, 79: 155–170

Syvitski, J. P. M. (2007) 'Deltas at risk', *Sustainable Science*, 3: 23-32

Tessler, Z. D., Vörösmarty, C. J., Grossberg, M., Gladkova, I., Aizenman, H., Syvitski, J. P. M., and Foufoula-Georgiou, E. (2015) Profiling risk and sustainability in coastal deltas of the world, *Science,* 349 (6248), 638-643

Yamagata, Y., and Murakami, D. (2015) Global dataset of gridded population and GDP scenarios, http://www.cger.nies.go.jp/gcp/population-and-gdp.html, accessed 28/11/2015

Zarfl, C., Lumsdon, A. E., and Tockner, K. (2015) A global boom in hydropower dam construction, *Aquatic Sciences.* 77, 161-170