Title: Profiling Risk and Sustainability in Coastal Deltas of the World

Authors: Z. D. Tessler[1]*, C. J. Vörösmarty[1,2], M. Grossberg[3], I. Gladkova[3], H. Aizenman[3], J. Syvitski[4], and E. Foufoula-Georgiou[5]

Affiliations:

[1]CUNY Environmental CrossRoads Initiative, City University of New York, NY, USA.

[2]Department of Civil Engineering, City College of New York, NY, USA.

[3]Department of Computer Science, City College of New York, NY, USA.

[4]Department of Geological Sciences, University of Colorado Boulder, Boulder, CO, USA.

[5]Department of Civil, Environmental, and Geo- Engineering, University of Minnesota, Minneapolis, MN, USA.

*Correspondence to: ztessler@ccny.cuny.edu

Abstract: Deltas are highly sensitive to increasing risks arising from local human activities, land subsidence, regional water management, global sea-level rise, and climate extremes. We quantified changing flood risk due to extreme events through an integrated set of global environmental, geophysical, and social indicators. Although risks are distributed across all levels of economic development, wealthy countries effectively bound their present-day threat by GDP-enabled infrastructure and coastal defense investments. In an energy-constrained future, such protections will likely prove to be unsustainable, raising relative risks 4-8 fold in the Mississippi and Rhine deltas, and 1.5-4 fold in the Chao Phraya and Yangtze. The current emphasis on short-term solutions on the world's deltas will greatly constrain options for designing sustainable solutions in the long-term.

One Sentence Summary: A new approach to quantify risk in the world's deltas suggests that present-day strategies for hazard management may impede long-term sustainability.

Main Text:

Deltas present a quintessential challenge for humans amid global environmental change. Home to some of the world's largest urban areas, deltas are also highly dynamic landforms shaped by river and coastal flooding (*1-3*). Human activities at the local and region scales can perturb the water and sedimentary dynamics necessary to maintain delta integrity, increasing the rate of relative sea-level rise (RSLR) - the combination of land subsidence and offshore sea-level rise - and increasing flood risk *(4, 5*).

Delta sediments naturally compact over time, requiring new sediment fluxes from the upstream river network and deposition on the delta surface to maintain land elevation (*4*). Upstream dams and reservoirs trap sediment (*6*), and soil conservation practices can reduce the mobilization of sediment (*7*). River channelization on the delta inhibits depositional processes (*8*), whereas urban construction and groundwater extraction can accelerate sediment compaction (*9, 10*). Land subsidence is compounded by rising sea levels and changing intensity and distribution of extreme events due to climate change (*11, 12*). Policies aimed at reducing the apparent levels of risk often employ costly engineering solutions that may be inherently unsustainable (*13-15*). A framework to enable comparative risk assessment for deltas across the globe that specifically accounts for dual natural and anthropogenic forces shaping these systems is a necessary precursor for strategies to improve their long-term resilience (*16*).

We provide a systematic global-scale assessment of changing risk profiles of coastal deltas. Most manifestations of risk are the immediate consequences of extreme events (*3*), such as fluvial and coastal flooding that act over short timescales. Overall risk, however, is conditioned over longer periods by anthropogenically-modified geomorphic processes such as changes in sediment supply, deposition, and compaction, which increase land subsidence and RSLR, and the socio-economic capability to prepare for and mitigate exposure to hazardous conditions (*17*). Focusing on inter-delta differences in risk, we use sufficiently mature global data sets that depict factors with well-documented impacts on delta state, together with established methods for spatial integration of qualitatively distinct data types (*18-20*). We focused on 48 major coastal deltas across a wide range of climate, biome and socio-economic contexts (Fig. 1A), with an estimated current combined population of over 340 million (*21*, see supplementary materials). At less direct risk are an additional 140 million people living within 25km of these deltas, who together with 3.5 billion people in upstream catchment basins produce additional human impacts. We define risk, *R*, or expected loss, to a delta population as a product of hazard (*H*), exposure (*E*), and vulnerability (*V*): $R = HEV$ (*17, 22, 23*). Hazard is the probability of a damage-producing event, defined as river and coastal flooding. Exposure is the expected number of people exposed to hazardous conditions for a given event, and vulnerability is the harm or loss caused by the exposure (Eq. S1).

Previous direct estimates of *H, E,* and *V* have been carried out in a number of local and regional studies (*23-25*) using high resolution datasets that are not available currently at the global scale. Exposure data at the necessary scales exist for select deltas; however, for global-scale analysis the rate of change in exposure, *E'* is a more tractable measure for delta comparison. By reducing the relative elevation of a delta, RSLR results in increased population exposure to a given hazard, and thus increased expected loss. The rate of change in expected loss due to anthropogenic RSLR is termed the risk trend: $R' = HE'V$ (see supplementary materials).

We estimated *H*, *E*', and *V* for each delta using empirical indices derived from global datasets. The Hazardous Event Index (*HEI*) is a proxy for hazard, *H,* based on empirical indicators of the probability and intensity of delta flood events. *E*' is estimated by the Anthropogenic Conditioning Index (*ACI*), built from measures of long-term anthropogenic drivers of RSLR (Fig. S1). The vulnerability, *V*, strongly dependent on socio-economic conditions in the delta (*17, 22)*, is estimated as a function of per-capita GDP, aggregate GDP, and government effectiveness. High GDP provides the financial capacity to make vulnerability-reducing investments from household to delta-scales, when effective governments are present to leverage aggregate wealth to reduce vulnerability. An index representing the absence of this capacity, the Investment Deficit Index (*IDI*), is used as a proxy for V, the loss associated with flood exposure. The risk component estimates derived from the *ACI*, *HEI*, and *IDI* indexes are used to estimate the risk trend, R', resulting from RSLR (Eq. S7).

We mapped the 48 deltas into a delta risk space defined by each delta's specific anthropogenic, geophysical, and socio-economic characteristics (Fig. 1). These estimates are made in an index space, comparing delta systems to each other on a relative, per-capita basis. In quadrant I, which contains deltas with low *ACI* and high *HEI* the Limpopo stands out due to its high vulnerability from lack of infrastructure investment capacity. Most of the high R' deltas are in quadrant II, including the highest-scoring Krishna. The Ganges-Brahmaputra, in quadrant IV, with high *ACI* and moderate *HEI*, is brought to very high R' due to high vulnerability. In contrast, quadrant III contains deltas with low risk trends due to both low *ACI* and low *HEI*, including the high-latitude Yukon, Lena, and Mackenzie. Quadrant IV contains deltas with relatively low hazardous event intensities, but with high levels of anthropogenic change.

The Mississippi, Rhine, and Tone deltas have similar *ACI* and *HEI* scores as the Brahmani and Godavari, between 0.4 and 0.7, but far lower *IDI* scores, <0.2. Their resulting risk levels are much more stable, with risk trends among the lowest of all the deltas in the study. Although the results presented here are for per capita risk, the Ganges-Brahmaputra system has, by far, the greatest rate of change of risk when aggregating across delta populations. The Ganges-Brahmaputra has the second highest R' on a per capita basis, and at greater than 100 million people has more than twice the population of the Nile, the second-most populous delta.

Low *IDI*, indicating high capacity for investment in risk-reducing technologies, is the primary reason several wealthy, developed deltas today have relatively low risk trends. For instance, after catastrophic flooding of the Rhine Delta in 1953, the Dutch Deltaworks were constructed to reduce future flood risk using a network of storm-surge barriers, dams, levees, and other engineered structures. A long history of land subsidence, however, has left parts of this delta 6m below sea level (*26*). Modernization and improvement costs across the Netherlands are estimated to be €1-2B per annum over the next century (*27*). The long term sustainability of this and similar risk-reducing investments elsewhere has been called into question due to heavy reliance on external financial and energy subsidies (*14*).

To examine delta risk sensitivity to reduced infrastructure investment benefits, we consider a future scenario in which infrastructure costs have increased. For our analysis we use an increase in energy prices as a likely reason for a rise in the cost of infrastructure but we note that factors such as relative increase in the costs of labor or material, or rising interest rates would have a similar impact on infrastructure cost. We modeled this scenario by adjusting the Investment Deficit Index indicator weights, discounting GDP based on 100-year projections of energy price growth in excess of GDP (*28*, see supplementary text), reflecting expectations of higher costs for a given level of risk reduction. Estimates of future vulnerability increase for all deltas under this scenario (Fig. 2), but are greatest for systems with high GDP. The Mississippi, Rhine, Han, Chao Phraya, and Yangtze see the greatest increase in vulnerability under this scenario, though others, including the Parana, Rhone, and Pearl, are also strongly affected. Deltas in low-GDP regions like the Irrawaddy, Tana, and Fly are the least sensitive to these potential future changes. These and other less economically developed deltas are instead more sensitive to future risk increases stemming from increased exposure to hazardous events.

A given increase in vulnerability will not affect risk trends in all deltas equally, but rather in conjunction with a delta's *ACI* and *HEI* scores. We start with each system's uncompensated *R*' based on anthropogenic and geophysical considerations alone (Fig. 3A). When considering contemporary vulnerability estimates (Fig. 3B), the wealthy, but otherwise at-risk, deltas such as the Rhine, Mississippi, and Han, benefit substantially from their capacity to sustain engineering and infrastructure investments. Low-GDP deltas which are not able to make risk-reduction investments move to higher risk rankings. The largest increases in *R*' rank are seen in the Limpopo and Irrawaddy deltas. Improved economic development and associated vulnerability reductions would result in the largest decreases in risk in these deltas, akin to a transition from Fig. 3B to 3A. In the future vulnerability scenario (Fig. 3C), where investment capacity less effectively reduces risk trends, high-GDP delta ranks revert back toward expectations based on geophysical hazards and anthropogenic change alone. While contemporary estimates of risk trends are found to be highest in South Asia (Fig. 4A), future increases in *R*', relative to current estimates, are greatest in the Rhine, Mississippi, Han, Tone, Chao Phraya, and Yangtze (Fig. 4B). These systems are highly stressed by anthropogenic activities and regularly contend with hazardous events, such that future increases in vulnerability will have a disproportionately larger risk impact than in other deltas. Management strategies that address the drivers of RSLR, particularly sediment supply and deposition, will be a core determinant of long-term sustainability over the next century.

Future changes to the intensity and distribution of hazardous events, still highly uncertain at the local scale, are also an important driver of future risk trends. Broad evidence suggests that climate change is impacting tropical cyclone intensity and river flooding (*11, 29*), global sea-level rise is accelerating (*12, 30*), and local sea-level rise may be substantially different than the global mean in some coastal areas due to regional patterns of ocean heat uptake and glacial isostatic adjustment (*30*). Land subsidence, taken as constant in time in our study, is also likely to change as future global population growth occurs predominantly in urban areas (*31*), driving further anthropogenic change in already-stressed deltas. Growing population, urbanization, and economic development is leading to increased interest in expanding hydropower infrastructure, already proliferating across many river systems (*32*, *33*). This will reduce sediment transport and the discharge capacity of river systems that are essential for nourishing deltas (*6*). Delta shorelines, for instance, are highly sensitive to the balance between sediment supply and absolute wave energy (*4*).

Future environmental, geophysical, and societal changes will reposition, in many cases greatly, most of the world's deltas into a future space of elevated risk. Although potential geophysical changes require additional research at the regional and local scales, our study demonstrates that economic ability and decisions to deploy engineering solutions will be a key factor determining how sustainable deltas become in the long term. Investments that manage the drivers of delta RSLR, rather than its symptoms, will be necessary to sustain deltas. Although the time horizons are long, acting now will be essential given that rehabilitation will be difficult if not impossible to realize once ground is lost to rising seas.

References and Notes:

1. C. D. Woodroffe, R. J. Nicholls, Y. Saito, Z. Chen, S. L. Goodbred, in *Global Change and Integrated Coastal Management*. N. Harvey, Ed. (2006), pp. 277–314.
2. M. VanKoningsveld, J. P. M. Mulder, M. J. F. Stive, L. VanDerValk, A. W. VanDerWeck, Living with sea-level rise and climate change: a case study of the Netherlands. *J*. *Coastal Res*. **242**, 367–379 (2008).
3. J. Day, D. Boesch, E. Clairain, G. Kemp, Restoration of the Mississippi Delta: lessons from hurricanes Katrina and Rita. *Science* **315**, 1679–84 (2007).
4. J. P. M. Syvitski, Y. Saito, Morphodynamics of deltas under the influence of humans. *Global Planet*. *Change* **57**, 261–282 (2007).
5. J. P. Ericson, C. J. Vorosmarty, S. L. Dingman, L. G. Ward, M. Meybeck, Effective sea-level rise and deltas: causes of change and human dimension implications. *Global Planet*. *Change* **50**, 63–82 (2006).
6. C. J. Vörösmarty *et al*., Anthropogenic sediment retention: major global impact from registered river impoundments. *Global and Planet*. *Change* **39**, 169–190 (2003).
7. H. J. Wang *et al*., Stepwise decreases of the Huanghe (Yellow River) sediment load (1950–2005): Impacts of climate change and human activities, *Glob*. *Planet*. *Change* **57**, 331-354 (2007).
8. J. P. M. Syvitski *et al*., Sinking deltas due to human activities. *Nat*. *Geosci*. **2**, 681–686 (2009).
9. S. Mazzotti, A. Lambert, M. Van der Kooij, A. Mainville, Impact of anthropogenic subsidence on relative sea-level rise in the Fraser River delta. *Geology* **37**, 771–774 (2009).
10. S. Higgins, I. Overeem, A. Tanaka, J. P. M. Syvitski, Land subsidence at aquaculture facilities in the Yellow River delta, China. *Geophys*. *Res*. *Lett*. **40**, 3898–3902 (2013).
11. T. R. Knutson *et al*., Tropical cyclones and climate change. *Nat*. *Geosci*. **3**, 157–163 (2010).
12. B. P. Horton, S. Rahmstorf, S. E. Engelhart, A. C. Kemp, Expert assessment of sea-level rise by AD 2100 and AD 2300. *Quat*. *Sci*. *Rev*. **84**, 1–6 (2014).
13. F. G. Renaud *et al*., Tipping from the Holocene to the Anthropocene: How threatened are major world deltas? *Curr*. *Opin*. *Environ*. *Sustainability* **5**, 644–654 (2013).
14. J. W. Day, M. Moerschbaecher, D. Pimentel, C. Hall, A. Yáñez-Arancibia, Sustainability and place: How emerging mega-trends of the 21st century will affect humans and nature at the landscape level. *Ecol*. *Eng*. **65**, 33–48 (2014).
15. S. Temmerman *et al*., Ecosystem-based coastal defence in the face of global change, *Nature* **504**, 79-83 (2013).
16. *Landscapes on the Edge: New Horizons for Research on Earth's Surface*. (National Research Council of the National Academies, Washington, DC, 2010).
17. N. Brooks, W. N. Adger, P. M. Kelly, The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environ*. *Change* **15**, 151–163 (2005).

18. V. Gornitz, Global coastal hazards from future sea level rise, *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **84**, 379-398 (1991).
19. B. Halpern, S. Walbridge, K. Selkoe, A global map of human impact on marine ecosystems. *Science* **948** (2008).
20. C. J. Vörösmarty *et al.*, Global threats to human water security and river biodiversity. *Nature* **467**, 555–561 (2010).
21. D. L. Balk *et al.*, Determining global population distribution: methods, applications and data. *Adv. Parasit.* **62**, 119-156 (2006).
22. S. Cutter, Vulnerability to environmental hazards. *Prog. Hum. Geog.* **20**, 529–539 (1996).
23. C. J. Vörösmarty *et al.*, Extreme rainfall, vulnerability and risk: a continental-scale assessment for South America. *Philos. Trans. R. Soc. London, Ser. A* **371**, (2013).
24. Y. Budiyono, J. Aerts, J. Brinkman, M. A. Marfai,. P. Ward, Flood risk assessment for delta mega-cities: a case study of Jakarta. *Nat. Hazards* **75**, 389–413 (2015).
25. Y. C. E. Yang, P. A. Ray, C. M. Brown, A. F. Khalil, W. H. Yu, Estimation of flood damage functions for river basin planning: a case study in Bangladesh. *Nat. Hazards* **75**, 2773–2791 (2015).
26. T. Bucx, M. Marchand, B. Makaske, C. van de Guchte, "Comparative assessment of the vulnerability and resilience of 10 deltas - synthesis report" (Delft-Wageningen, The Netherlands, 2010).
27. P. Kabat *et al.*, Dutch coasts in transition. *Nat. Geosci.* **2**, 450-452 (2009).
28. US Energy Information Administration, *Annual Energy Outlook 2015* (DOE/EIA-0554, 2015).
29. R. Dankers *et al.*, First look at changes in flood hazard in the Inter-Sectoral Impact Model Intercomparison Project ensemble., *Proc. Natl. Acad. Sci. U.S.A.* **111**, 3257–61 (2014).
30. S. Jevrejeva, J. C. Moore, A. Grinsted, A. P. Matthews, G. Spada, Trends and acceleration in global and regional sea levels since 1807. *Global Planet. Change* **113**, 11–22 (2014).
31. K. C. Seto, B. Güneralp, L. R. Hutyra, Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proc. Natl. Acad. Sci. U.S.A.* **109**, 16083–8 (2012).
32. C. Kuenzer *et al.*, Understanding the impact of hydropower developments in the context of upstream–downstream relations in the Mekong river basin. *Sustainability Sci.* **8**, 565–584 (2012).
33. C. Zarfl, A. E. Lumsdon, J. Berlekamp, L. Tydecks, K. Tockner, A global boom in hydropower dam construction. *Aquat. Sci.* **77**, (2015).
34. Z.W. Kundzewicz, I. Pińskwar, G.R. Brakenridge, Large floods in Europe, 1985-2009, Hydrolog. Sci. J. **58**, 1-7 (2013).
35. J. E. Vermaat, M. A. Eleveld, Divergent options to cope with vulnerability in subsiding deltas. *Clim. Change* **117**, 31–39 (2013).

36. B. M. Fekete, C. J. Vörösmarty, R. B. Lammers, Scaling gridded river networks for macroscale hydrology: development, analysis, and control of error. *Water Resour. Res.* **37**, 1955–1967 (2001).

37. B. Lehner *et al.*, High-resolution mapping of the world's reservoirs and dams for sustainable river-flow management. *Front. Ecol. Environ.* **9**, 494–502 (2011).

38. C. D. Elvidge *et al.*, Global distribution and density of constructed impervious surfaces. *Sensors* **7**, 1962–1979 (2007).

39. Y. Wada, L. P. H. van Beek, M. F. P. Bierkens, Nonsustainable groundwater sustaining irrigation: a global assessment. *Water Resour. Res.* **48**, (2012).

40. USGS World Energy Assessment Team, U. S. Geological Survey World Petroleum Assessment 2000 – Description and Results. (USGS Energy Team, Denver, CO, 2000).

41. B. R. A. Morton, J. C. Bernier, J. A. Barras, N. F. Ferina, "Rapid subsidence and historical wetland loss in the Mississippi Delta plain: likely causes and future implications." (U.S. Geological Survey Open-File Report 2005-1216, 2005).

42. J. A. Church, N. J. White, R. Coleman, K. Lambeck, J. X. Mitrovica, Estimates of the regional distribution of sea level rise over the 1950-2000 period. *J. Clim.* **17**, 2609–2625 (2004).

43. European Environment Agency, "Climate change, impacts and vulnerability in Europe 2012" (EEA Report No. 12/2012, 2012), p. 104.

44. J. Pethick, J. D. Orford, Rapid rise in effective sea-level in southwest Bangladesh: its causes and contemporary rates. *Glob. Planet. Change* **111**, 237–245 (2013).

45. D. Wisser, B. Fekete, C. J. Vörösmarty, A. Schumann, Reconstructing 20th century global hydrography: a contribution to the Global Terrestrial Network-Hydrology (GTN-H). *Hydrol. Earth Syst. Sci.* **14**, 1–24 (2010).

46. T. Durrant, M. Hemer, C. Trenham, D. Greenslade, CAWCR Wave Hindcast 1979-2010. (2013), doi:10.4225/08/523168703DCC5.

47. M. Dilley *et al.*, "Natural disaster hotspots: a global risk analysis." (Disaster Risk Management Series No. 5, The World Bank, Washington, DC, 2005).

48. G. Egbert, S. Erofeeva, Efficient inverse modeling of barotropic ocean tides. *J. Atmos. Oceanic Technol.* **19**, 183–204 (2002).

49. E. R. Thieler, E. S. Hammar-Klose, "National Assessment of Coastal Vulnerability for the U.S. Atlantic Coast." (U.S. Geological Survey Open-File Report 99-593, 1999).

50. W. Nordhaus, New metrics for environmental economics: Gridded economic data. *The Integrated Assessment Journal* **8**, 73–84 (2008).

51. D. Kaufmann, A. Kraay, M. Mastruzzi, The Worldwide Governance Indicators: methodology and analytical issues. *Hague Journal on the Rule of Law* **3**, 220–246 (2011).

52. M. L. Carroll, J. R. Townshend, C. M. DiMiceli, P. Noojipady, R. A. Sohlberg, A new global raster water mask at 250 m resolution, *Int. J. Digital Earth* **2**, 291–308 (2009).

Acknowledgments: Data is available in supplementary materials at *Science* online. This work was supported by NASA (Land Cover/Land Use Change Program Grant NNX12AD28G) and the National Science Foundation (Belmont Forum Coastal Vulnerability Awards 1343458 and 1342944, and Dynamics of Coupled Natural and Human Systems Program Award 1115025). The authors report no conflicts of interest. The authors thank B. Fekete and P. Green for helpful comments on the manuscript.

Supplementary Materials:

www.sciencemag.org
Methods
Figures S1-S4
Tables S1-S3
References (*34*-*52*)

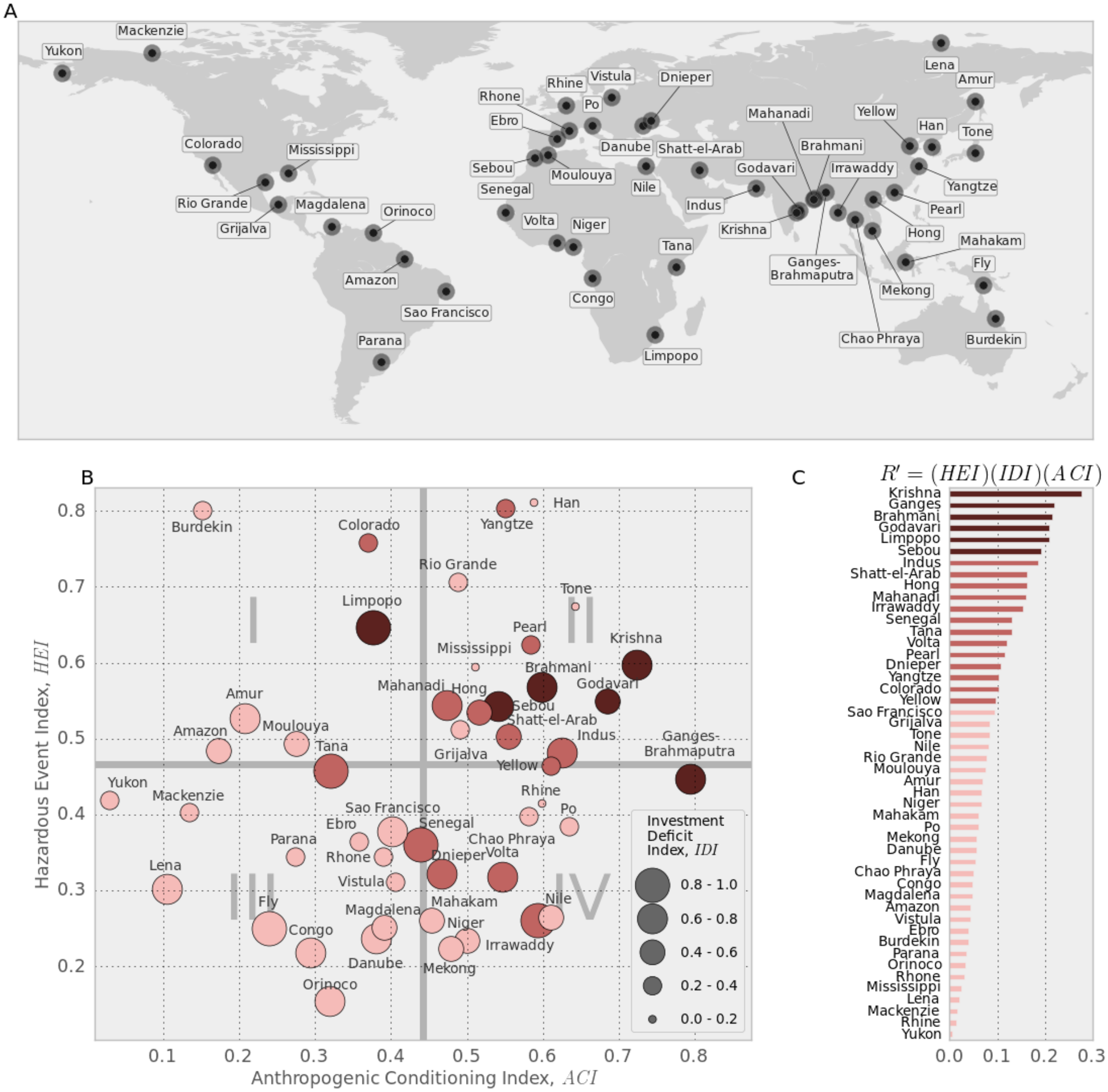

Fig. 1: Global delta risk trends **(A)** Map of 48 deltas included in this study. **(B)** Contemporary delta risk assessment phase diagram showing the three component proxy indexes constructed to estimate per-capita R'. The horizontal axis is the long-term Anthropogenic Conditioning Index (*ACI*), a proxy for the change in a delta's aggregate exposure to hazardous events. The vertical axis denotes the Hazardous Event Index (*HEI*), a proxy for the frequency and intensity of short-term hazards relating to coastal or fluvial flooding. Dot size indicates the Investment Deficit Index (*IDI*), a proxy for vulnerability to flood exposure; color density represents overall risk trend score. Quadrant III deltas are predominately low-R' while Quadrant II are high-R'. **(C)** Estimate of relative rate of change of risk, or risk trend, for each delta due to increasing exposure associated with RSLR. The Krishna and Ganges-Brahmaputra deltas, despite being only moderately susceptible to short-term hazardous events, are increasingly at risk due to high rates of RSLR and high socio-economic vulnerability. Note use of "Ganges" in place of "Ganges-Brahmaputra" in some figure panels for brevity.

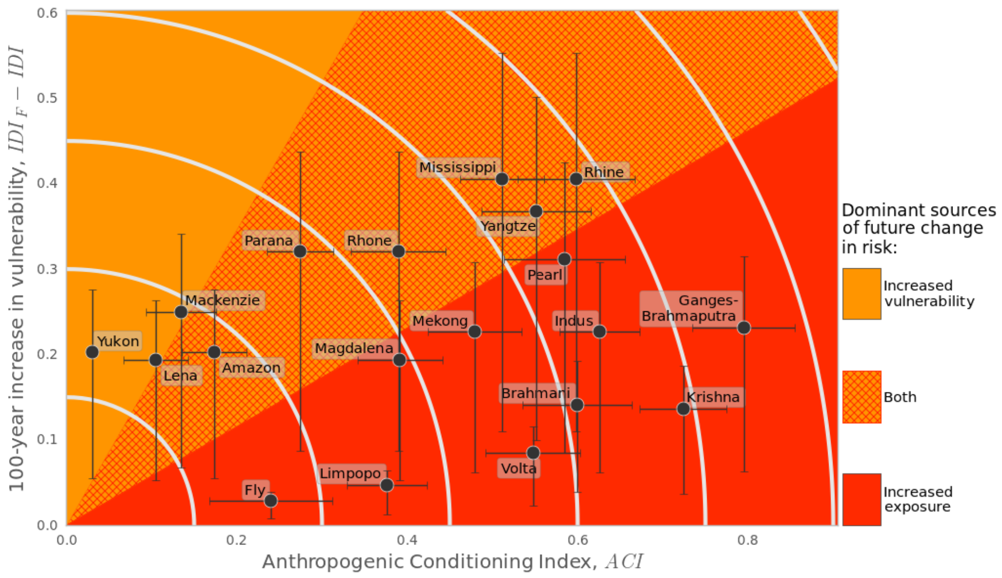

Fig 2: Estimated future change in exposure and vulnerability for selected deltas. The horizontal axis shows the Anthropogenic Conditioning Index (*ACI*), the estimated rate of change in exposure due to land subsidence, sea-level rise, and loss of protective coastal wetlands. The vertical axis, showing one scenario of change in vulnerability, is the difference between the 100-year future Investment Deficit Index, IDI_F, and the current index, *IDI*. The origin represents current conditions. Both axes indicate a change over time for the two risk components: exposure increase is taken as proportional to the current rate of change, and vulnerability increase is based on the difference between current and future estimates. Colors highlight three approximate sectors of future change. Future change in risk is either associated predominately with increases in exposure, in red, or increases in vulnerability, in orange. Several systems (Mississippi, Rhine, Yangtze), are at risk both of RSLR, leading to increased exposure to flooding, as well as reduced effectiveness of risk reduction strategies that may not be sustainable over the century-scale.

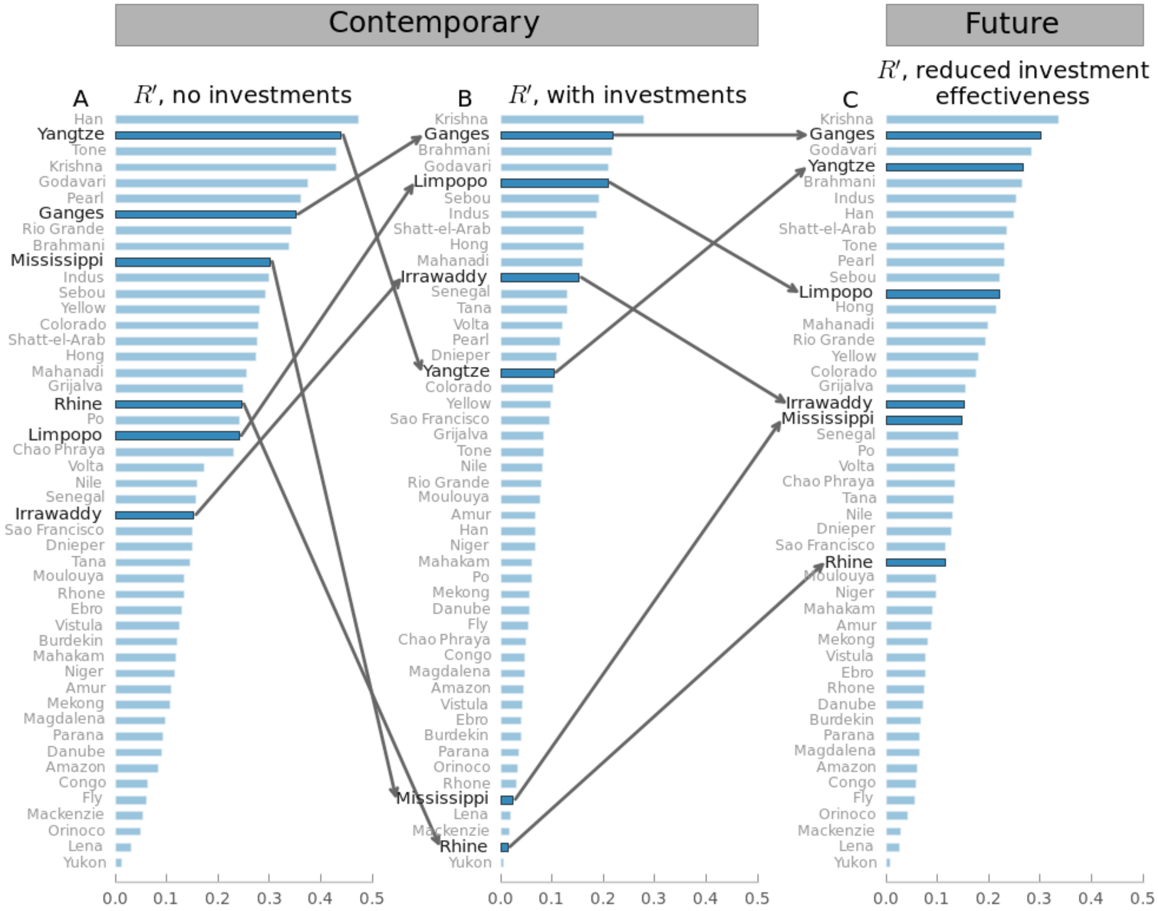

Fig. 3: The impact on risk trend rankings of current and future investments. For the present-day: (**A**) Change in risk when only considering the anthropogenic and geophysical setting of each delta. (**B**) When also considering relative vulnerability, which is low for deltas that can make risk-reducing investments, the overall risk trend changes, in many cases dramatically. The Mississippi and Rhine deltas (bold) show substantially reduced risk. In the future: (**C**) Current risk reduction strategies become more expensive and less sustainable, given a more energy constrained future scenario (*5*). In the long-term, deltas that today are protected by enormous compensating infrastructure are likely to see their risk profiles approach those in the uncompensated scenario (**A**).

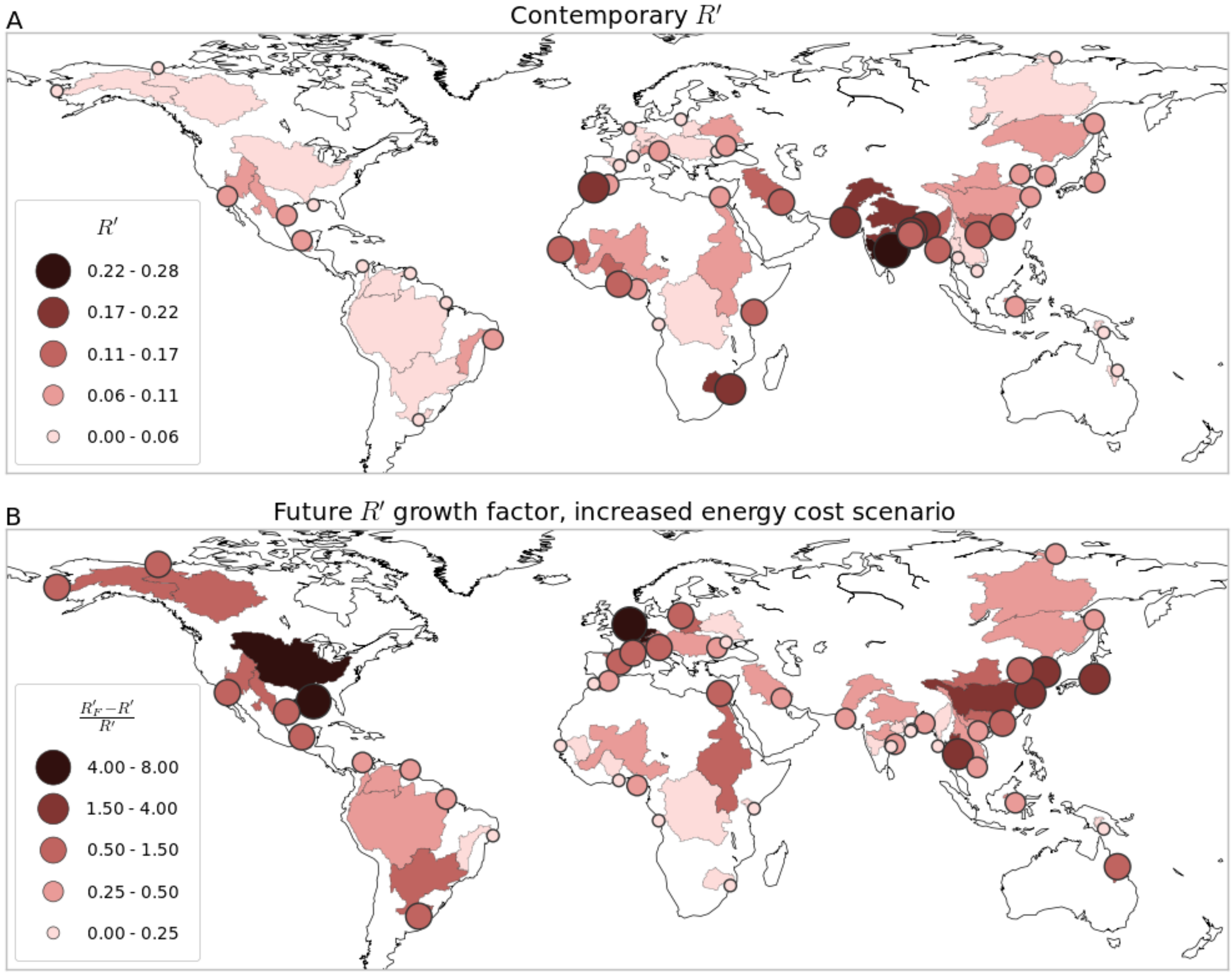

Fig. 4: Contemporary and future risk trend growth. (**A**) High contemporary values of R' are distributed globally: the highly populated deltas of Southeast Asia, and deltas in developing parts of Africa and the Middle East. (**B**) Estimated 50-year growth in future risk trend, R'_F, relative to current R'. Highest relative growth in future R'_F are in the Rhine, Mississippi, Han, Tone, and Chao Phraya, all systems where current risk is reduced through investments enabled by high GDP and affordable energy costs, relative to the future scenario.