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High Rise - Costing climate change

Hydrolink

HIGH RISE: COSTING

AS SEA LEVELS RISE WE WILL NEED TO INCREASE PROTE

SALLY BROWN AND ROBERT J. NICHOLLS

Media reports indicate almost daily how potentially devastating the effects of climate change and associated sea-level rise could be. A simple Google News search for 'sea-level rise' illustrates the diversity of impacts, from migratory birds to energy supplies to soil salinisation to flooding. These impacts could have a significant impact on the environment and the people who reside there – typically the coastal zone is about three times more densely populated as further inland (Small and Nicholls, 2003). As engineers, we have the ability to protect those who are vulnerable, such as through building hard defences such as sea walls or dikes. But in order to do this – particularly over the long-term - we need to understand how much sea levels might rise and how much it might cost so that the financial commitment can be assessed into the future. This is especially true when poorer countries may seek financial assistance to support such adaptations. In 2010, the World Bank published its 'Economic of Coastal Zone Adaptation to Climate Change' report (Nicholls et al., 2010) to answer these questions, which was part of a larger 'Economics of Adaptation to Climate Change' project which looked at a number of sectors (World Bank, 2010).

Rising sea levels

Sea levels have been naturally varying for thousands of years, but it is only over the last century or so that man is believed to influence the rate of sea level change. From 1900 to 2009 sea levels rose 1.7±0.2 mm/yr, partly due to a warming atmosphere (Church and White, 2011). Sea levels are expected to continue to rise, particularly as temperatures continue to increase due to human-induced global warming. However the magnitude of future sea-level rise is uncertain for a range of reasons including the unknown rate of ice melt from small glaciers and ice caps, and the large ice sheets of Greenland and Antarctica. Consequently, the World Bank study analysed a range of global mean sea-level rise scenarios (or plausible futures) of 16 cm to 38 cm by 2050 with respect to 1990 levels.

Modelling protection against sea-level rise

Rising sea levels have many consequences for those residing or living in the coastal zone, including flooding and erosion of land. This will almost certainly trigger adaptation to reduce impacts. Traditionally one or more of three main approaches may be taken (Figure 1, also see Linham and Nicholls, 2010):

- To retreat, and move away from the coast;
- To remain in place, but accommodate for physical changes, by altering one's day-to-day actions, homes or economy in order to cope (e.g. raising buildings, changing crop type etc)
- To remain in place and continue on with 'business as normal' and protect valuable assets (e.g. building dikes, nourishing beaches etc).

In the study, the option of protecting against sea-level rise was investigated for 143 low income to upper middle income countries, where gross national income per capita is $12,475 or less (hereafter known as World Bank countries). Protection and costs were calculated by the Dynamic Interactive Vulnerability Assessment (or more simply DIVA), an impacts model used to assess physical, social and economic change in coastal zones (Hinkel and Klein, 2009; Vafeidis et al. 2008). DIVA breaks down the world's coastal zone into over 12,000 segments (average length 85 km) and associates each segment with a range of geophysical, ecology, economic and demographic information. Together with climate change, a scenario of population change and economic growth were considered, where economic growth is regionally orientated and population growth is high over the 21st century, increasing from 6 billion in 2000 to over 9 billion by 2050.

The global mean sea level scenarios were downscaled to local segment level and were combined with land level change using estimates of glacial isostatic adjustment and delta compaction. Other factors such as human-induced subsidence were not considered due to lack of data. For each segment, the local rates of sea-level rise were added to the exceedance curves – which calculate the return period of an extreme sea flood event, such that as sea levels rise, it would be expected that an extreme water level today would happen more often. It assumes that present storm surge characteristics are simply linearly displaced as relative sea levels rise. Cyclones may intensity with climate change, thus further rising extreme sea levels during storm conditions. Thus, an arbitrary 10 % increase in 100-year extreme water levels, combined with the highest sea-level rise was evaluated. From these high water levels, DIVA estimates the amount of land loss due to erosion and damage due to flooding.

Impacts also depend on the level of coastal protection. In the absence of a global dataset detailing protection levels, the baseline protection (for 1995) was estimated using a 'demand for safety' function. Given the socio-economic conditions, DIVA includes two types of protection; dikes (protecting from the open sea and the coastal part of river estuaries) and beach nourishment (to preserve protective beaches). As sea levels rise and/or as population and economies grow (represented by gross national product per capita), defences will increase. As hard defences need to be efficient, cost-effective and have a long design lifetimes, it was assumed that the defences were built anticipating climate and sea level conditions fifty years into the future i.e. in 2050 assuming the sea levels could potentially rise up to 1.26 m by 2100 (for the high scenario). Beach nourishment costs only considered the conditions in the timeframe measured as the beneficial effects of nourishment are felt immediately, so as in engineering practice, periodic top-ups are required. All financial results are given in 2005 US dollars, with no discounting.

	Time	
	2050	2100
Sea-level rise above 1990 levels (cm)		
Low	16	40
Medium	29	88
High	28	126

Table 1. Climate-induced sea-level rise scenarios used in the Nicholls et al. (2010) study

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Costs of protection

The costs of protection were projected in 2050 for a low, medium and high sea level rise (see Table 1), with the latter also computing a 10% increase in surge height due to the intensification of surge activity. Additionally, a hypothetical scenario of no sea-level rise (i.e. accounting for land movement only) was undertaken to evaluate residual effects. Results for the total adaptation (protection) costs from dike building and nourishing beaches are shown in Figure 2. The results indicate a wide range of costs based across the scenarios, and that the magnitude of sea-level rise is more important than timing. Hence we are already committed to many of these costs as some sea-level rise is inevitable.

It was observed that:

1) There are baseline costs even if climate-induced sea-level rise is zero.

Land subsidence, increasing population and a growing economy will lead for a demand for higher defences in many places, independent of climate change. Globally, these protection costs could be up to $10 billion per year over the coming decades (less than 0.01 % of global GDP). These costs are included in the estimates below.

2) World Bank regions account for at least 55 % of the total adaptation costs.

Under low to high sea-level rise scenarios, global protection costs range from $21-$60 billion per year over the coming decades. World Bank regions with the highest cost include Latin America and the Caribbean, followed by East Asia and the Pacific Region. The regions with the lowest cost are the Middle East and North Africa. Dikes are responsible for around four fifths of the total capital cost of defences.

3) Increases in cyclone intensity only had a relatively small influence on the cost of protecting the coast.

Globally, costs were increased only by 8-9 % compared with the equivalent scenario without cyclones. Even in World Bank regions where cyclones are prevalent, such as East Asia and Pacific and South Asia, dike costs only rise by 13 % in the 2040s.

4) Protection costs are likely to increase over time as dikes must be maintained to remain effective.

Sea and river dike maintenance costs (not reported in Figure 2, but estimated at 1% and 0.5% of capital costs respectively following reported practise) increase approximately linearly throughout the study period, with costs increasing 4.2 times from the 2010s to 2040s to $7.9 billion per year. This can represent significant increased expenditure, and should be considered in long-term planning, including beyond the time period analysed here as sea levels will continue to rise beyond 2050. The cost estimate is a minimum as we did not consider the maintenance of the dikes built prior to our 1995 model baseline, which will have significant additional maintenance costs

Maximising benefits and appropriate adaptation options

From a strategic planning perspective, protecting the coast often happens where it is cost efficient to do so: That is, where overall damage costs via protection are greater than the expense of adapting to any residual damage. On a global scale, the benefit to cost ratio suggests that adaptation is a worthwhile investment: It not only protects the coastal zone, but also benefits infrastructure networks that are linked to it.

This study only investigated capital costs of dike building and nourishing beaches, plus associated dike maintenance costs, but other forms of protection and adaptation are available. These methods may be more cost effective or appropriate depending on the local situation, but are difficult to model at global scales. Thus engineers have a wider range of options to consider, integrating into wider coastal zone management and coastal change. These need to be evaluated at a small scale or by a case-by-case basis to determine cost-effective adaptation measures that are affordable, plus socially and ecologically appropriate for different settings. For instance, Dutch engineers operate a 'Building with Nature' approach creating integrated and flexible protection solutions, that help boost the

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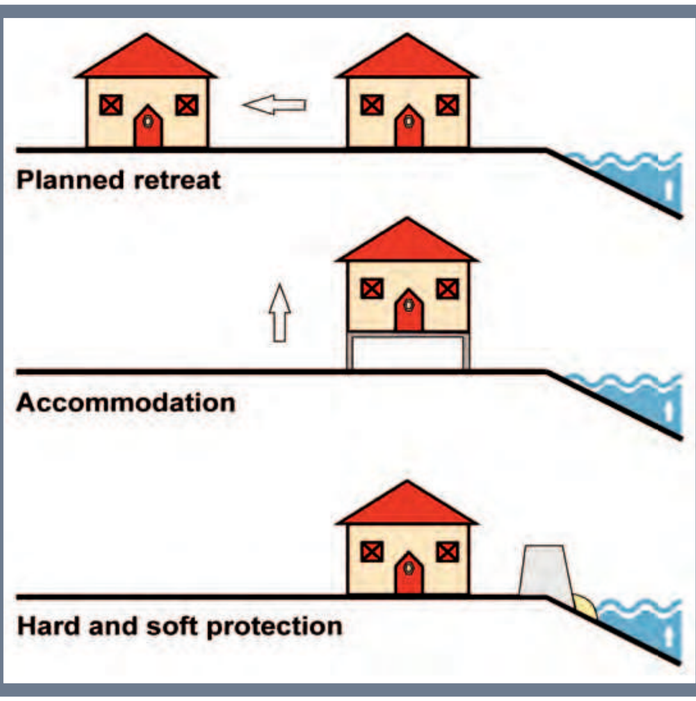

Figure 1. Retreat-accommodate-protect adaptation options as sea levels rise

economy, are environmentally friendly and sustainable, whilst making the country a safe place to live (De Vriend and Van Koningsveld 2010). Whilst the Dutch are frequently exhibited as a model of good practice and robustness in protecting the coast, other nations may not want to or be able to afford to protect. It is these nations that remain vulnerable and alternative, innovative forms of adaptation to sea-level rise may need to be considered. Simultaneously, the natural environment is also important to consider and preserve, as noted in Europe through various EU directives. Indeed, in many developing countries it is the natural environment (e.g. mangroves) that is the first line of defence against extreme water levels.

Finally, climate change and sea-level rise are often blamed, not just by the general public, but also within science as the main cause of future coastal disasters. Disasters from extreme water levels have occurred well before climate change was mainstream. Today, in our increasingly urbanised lifestyle, it is the combination of increased infrastructure, investment and people living on the coast that make the coastal region vulnerable (e.g. Kron 2012). Thus man's direct management and influence on the coast is as important as any local sea level rise.

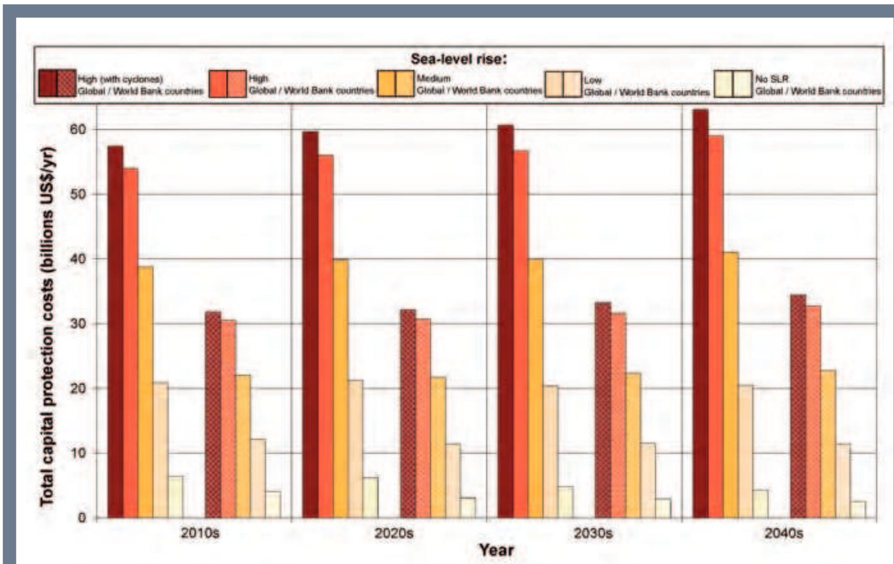

Figure 2. Total protection costs from dike building and nourishing beaches, globally and for World Bank countries to protect against sea-level rise.

Next steps

What are the next steps to understanding and and strategically planning for damage caused by climate change and sea-level rise, and associated adaptation costs? For developing nations, there is funding for adaptation, protection and resilience against climate change which was initialised under the auspices of the Kyoto protocol. One such programme is the Pilot Program for Climate Resilience aiming to integrate climate risk with development planning and its implementation shifting away from a 'business-as-usual' approach to broad-based country-level strategies of climate resilience. For instance, funding has recently been granted to improve coastal embankments, coastal resilient infrastructure and promote climate resilient agriculture and food security and in Bangladesh. These projects often have dual benefits (e.g. reduce flood risk and improve food security), whilst providing a long-term investment in country's future.

Conclusions

With relative sea levels continuing to rise, and expected to accelerate, we will hear increasing reports of how extreme water levels effect livelihoods. Engineers have the opportunity to do something about this, and the results from the World Bank study by Nicholls et al. (2010) suggest that the financial costs of adapting are going to remain high. However, building defences in not the only answer, and engineers can work with communities to determine the optimum way to increase resilience and to adapt, potentially via protection, to rising sea levels and other coastal change over long time-scales. One such project undertaking this in Bangladesh and the Ganges-Brahmaputra delta is the ESPA Deltas programme , and this research project is discussed in the next article.

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