COASTAL ADAPTATION

Rising seas and subsiding cities

Coastal adaptation aims to reduce impacts of relative sea-level rise from climate-induced sea-level rise and land elevation changes. Now, a global projection of relative sea-level rise to 2050 suggests the critical role of managing land subsidence for coastal cities on sinking deltas.

Nobuo Mimura

Climate-induced sea-level rise (SLR) brings about serious threats to coastal societies by intensifying the damages of inundation, storm surges, high waves and erosion[1]. Land subsidence of coastal areas also causes similar problems. For example, Tokyo suffered from intensive subsidence up to 4.5 m due to heavy withdrawal of natural gases and groundwater, especially during Japan's high economic growth period in the 1960s[2]. This led the eastern part of Tokyo to become a 'zero-metre area', which is below the mean sea level. On account of strong regulations for withdrawal, the groundwater table in the area recovered. However, this process caused other problems, such as instability of building foundations due to buoyancy effects and vulnerability to liquefaction caused by earthquakes[3]. This story illustrates that assessment of coastal impacts and adaptation needs to target the combination of climate-induced SLR and land movements, which is called relative sea-level rise (RSLR). Furthermore, careful planning needs to consider multiple aspects that will likely be unique for each location. Therefore, it is important to draw a global picture of the RSLR to develop adequate adaptation strategies reflecting spatial characteristics of RSLR, as opposed to only climate-induced SLR. Writing in this issue of *Nature Climate Change*, Robert Nicholls and colleagues[4] do just this in work that presents the current global distribution of RSLR and its future projection to 2050.

Geological factors causing land movements include glacial-isostatic adjustment[5] (GIA; rebound of the Earth's crust associated with melting of thick ice sheets that covered the land in the last glacial age) and land subsidence of deltas, particularly the large cities located on them. Studies of these land movements have found that some deltas are sinking many times faster than climate-induced SLR because of human activities, such as withdrawal of groundwater, oil and gas, and construction of heavy buildings[6]. Therefore, the vertical land movements vary between locations with different rates and at different timescales, as does RSLR.

Fig. 1 | Strengthening protection of subsiding coastal areas in Jakarta. The northern part of Jakarta experiences frequent overflows of sea water over seawalls during the spring tide, which deteriorates the living conditions of residents. Seawalls were raised repeatedly as land subsidence proceeded. Photograph reproduced with permission from Japan International Cooperation Agency (JICA).

In their study, Nicholls et al.[4] integrated three components of RSLR: (1) climate-induced sea-level change (1993 to 2015), (2) GIA and (3) land subsidence. Land subsidence was further classified into two components: total deltaic subsidence mainly due to natural compaction of young sediments and human-induced accelerated compaction in coastal cities on deltas and alluvial plains.

Based on this analysis, Nicholls et al.[4] present a global perspective of the current distribution of RSRL. Some areas such as North America experience sea-level fall due to GIA uplift. While the uplifting coasts occupy 12.5% of the global coastline, only 2.3 million people live in these areas. On the other hand, although the coasts where the rate of RSLR is over 10 mm yr^{-1} (three times larger than the mean climate-induced SLR) are only 0.7–0.8% of the global coastline in terms of length, the people living in these areas amount to 147 to 171 million, which comprise 19.1–22.3% of the world's coastal population below 10-m elevation. This uneven distribution of population is attributed to the fact that deltaic cities have been attracting large populations and active urban development, which, in turn, resulted in much faster land subsidence. Such areas are located particularly in South, South East and East Asia, including megacities such as Jakarta, Bangkok, Manila, Ho Chi Minh City and Tianjin. Parts of these cities have already faced severe inundation and frequent flooding, and need seawalls to prevent inundation. For example, North Jakarta experienced large subsidence with a typical rate of 3–10 cm yr^{-1} during the 1990s[7]. As a result, even under usual conditions, sea water flows over seawalls and river dikes during high tides, causing inundation of low-lying areas (Fig. 1).

According to the Nicholls et al.[4] projections, the global coastal population at risk would increase from the current 250 million to 280 million by 2050, even without changes in RSLR. It would increase further to 305–320 million and 330–350 million if land subsidence and climate-induced SLR combined with subsidence are included. This result indicates that the contributions of land subsidence and climate-induced SLR to the additional population at risk are similar in magnitude, ranging from 20 to 40 million people. If these cities can reduce the rate of subsidence to 5 mm yr^{-1}, this would lead to the reduction of 20–35 million people at risk in the deltaic cities. Based on these results, Nicholls et al.[4] suggest that, due to its coincidence with major population centres, subsidence has global social and economic implications. As the influence of subsidence is comparable to climate-induced SRL in the next few decades, subsidence should be better recognized in regional and global assessments of relative sea-level rise impacts, and not simply restricted to local assessments.

However, subsidence may not be dominant on the rest of the world's coasts. For these coasts, climate-induced SLR will be a major driver imposing a variety of impacts such as inundation of coastal lowlands, flooding, erosion and sea-water intrusion to coastal aquifers and rivers. These effects will be intensified by other phenomena of climate change such as stronger hurricanes, heavy rains and droughts, and increased water temperature. Adaptation to RSLR also has a close relationship with other development challenges such as disaster risk management, management of water resources and natural environment, and urban planning, and should therefore be integrated in the wider context of sustainable development so that adaptation to RSLR will be a part of the climate-resilient development of society[8].

In this context, Nicholls et al.[4] shed light on the importance of controlling subsidence of large cities on deltas. In the coming decades, the world population will grow further, and the increased population will be concentrated in coastal cities[9]. Therefore, it should be recognized as an important strategy to maintain the land elevation of coastal cities while ensuring water resources and other development needs in order to guarantee the safety and security of large populations against rising seas and disasters intensified by climate change, particularly in the developing world. ❐

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Published online: 8 March 2021
https://doi.org/10.1038/s41558-021-01009-6

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Competing interests

The author declares no competing interests.

CONSERVATION PRIORITIES

Cold-water species need warm water too

Climate change vulnerability assessments of cold-water species have focused on protecting cold summer habitats in high-elevation streams. Now, a study shows that seasonally warm rivers can provide the majority of growth potential for cold-water fishes, unveiling a notable blind spot in freshwater climate research and planning.

Clint C. Muhlfeld

Climate change is warming up the planet's lands, rivers and seas, putting many species at risk as temperatures exceed thermal limits[1]. In response, resource managers are increasingly challenged with identifying and prioritizing 'climate refugia': habitats that will best allow for species persistence[2]. In attempting to do so, complex ecological processes are typically distilled into simple maps that may not account for temporal dynamics of species' movements and habitat use across landscapes. In this issue of *Nature Climate Change*, Armstrong and colleagues[3] show that such approaches may be insufficient to conserve species in a warming world. They demonstrate that growth opportunities for migratory cold-water fishes seasonally propagate up and down river networks, and that downstream habitats that are warm in the summer provide the majority of growth potential during the spring and autumn. These findings uncover a synergy between cold and warm habitats supporting productive cold-water fisheries that is currently overlooked in climate adaptation planning.

Highly mobile animals such as butterflies, ungulates, birds and fishes have evolved an ability to migrate long distances to exploit diverse habitats to grow, survive and reproduce across a mosaic of dynamic environments. Salmonids — a group of fishes (trout, salmon, char) of enormous ecological and socioeconomic value — have used these behavioural strategies to persist