



# RANKING OF THE WORLD'S CITIES MOST EXPOSED TO COASTAL FLOODING TODAY AND IN THE FUTURE

## *Executive Summary*



## AUTHORS

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## FOREWORD

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This report is part of an OECD project on Cities and Climate Change. A priority of this project is to explore the city-scale risks of climate change and the benefits of both (local) adaptation policies and, to the extent possible, (global) mitigation strategies. The current study is one of the first products to emerge from the project, focusing initially on global port cities to examine the exposure to coastal flooding, today and in the 2070s. The goal is to pinpoint which cities are most reliant on adequate flood defences, and thus where relevant adaptation is most crucial. Refinement and extension of this analysis, and the global-local modelling tools developed here, will be considered in the course of this project, including investigation of the residual risk from coastal inundation with defences and a wider range of climate scenarios. A companion OECD report – a literature review on cities and climate change -- is being issued in December 2007 and additional reports are planned in 2008, including in depth city case studies.

This study represents a collaborative effort involving a number of international experts in climate modelling, risk management, policy and economics. Authors are from Southampton University/Tyndall Centre, Risk Management Solutions, and CIREN/Meteo-France and the OECD. The OECD is an intergovernmental organisation, representing 30 Member countries, all of whom are committed to common principles to support economic development, including among others, protection of environment and social protection. Working through the OECD committee process, national governments are providing guidance and inputs to the work as it develops. However the views and opinions expressed here are the responsibility of the authors and may not reflect those of the OECD or its member governments.

The full report, produced as part of the OECD project on Cities and Climate Change, is published on line as an OECD Environment Working Paper "Screening Study: Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Interim Analysis: Exposure Estimates", OECD 2007. The full report can be accessed from: [www.oecd.org/env/workingpapers](http://www.oecd.org/env/workingpapers).

Funding for the project was provided by the OECD as well as extra-budgetary contributions to the OECD from the Governments of Denmark, Italy, Finland, and the United States.

For more information about this OECD work, please contact the project leader: Jan Corfee-Morlot (email [jan.corfee-morlot@oecd.org](mailto:jan.corfee-morlot@oecd.org)).

## EXECUTIVE SUMMARY

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This global screening study makes a first estimate of the exposure of the world's large port cities to coastal flooding due to storm surge and damage due to high winds. This study also investigates how climate change is likely to impact each port city's exposure to coastal flooding by the 2070s, alongside subsidence and population growth and urbanisation. The assessment provides a much more comprehensive analysis than earlier studies, focussing on the 136 port cities around the world that have more than one million inhabitants.

Most of these largest port cities are found in Asia (38%), and many of them (27%) are located in deltaic settings, again mainly in Asia. Cities in deltaic locations tend to have higher coastal flood risk as a result of their tendency to be at lower elevations and experience significant (natural and anthropogenic) subsidence.

The analysis focuses on the exposure of population and assets<sup>1</sup> to a 1 in 100 year surge-induced flood event (assuming no defences), rather than the 'risk' of coastal flooding. This is, firstly, because knowledge about flood protection across the spectrum of cities is limited and can give misleading results for risk analysis. Secondly, flood protection does not eliminate risk as protection measures can fail and it is important to consider the implications of this residual risk. Exposure is a particularly useful metric for this type of comparative study. The potential for protection to influence risk is considered briefly based on known examples and relative wealth as an indicator of protection standard. Hence, global, continental and national results on exposure are provided, as well as the city rankings which indicate those cities most worthy of further more detailed investigation.

The analysis demonstrates that a large number of people are already exposed to coastal flooding in large port cities. Across all cities, about 40 million people (0.6% of the global population or roughly 1 in 10 of the total port city population in the cities considered here) are exposed to a 1 in 100 year coastal flood event. The exposure is concentrated in a few of the cities: the ten cities with highest population exposure contain roughly half the total exposure and the top 30 cities about 80 percent of the global exposure. Of these thirty cities, nineteen are located in deltas. For present-day conditions (2005) the top ten cities in terms of exposed population are estimated to be Mumbai, Guangzhou, Shanghai, Miami, Ho Chi Minh City, Kolkata, Greater New York, Osaka-Kobe, Alexandria and New Orleans.<sup>2</sup>

The ten cities with highest population exposure today are almost equally split between developed and developing countries. When assets are considered, the current distribution becomes more heavily weighted towards developed countries, as the wealth of the cities becomes important. The total value of assets exposed in 2005 is estimated to be US\$3,000 billion; corresponding to around 5% of global GDP in 2005 (both measured in international USD). The top 10 cities in this ranking are Miami, Greater New York, New Orleans, Osaka-Kobe, Tokyo, Amsterdam, Rotterdam, Nagoya, Tampa-St Petersburg and Virginia Beach. These cities contain 60% of the total exposure, but are from only three (wealthy) countries: USA, Japan and the Netherlands.

By the 2070s, total population exposed could grow more than threefold to around 150 million people due to the combined effects of climate change (sea-level rise and increased storminess), subsidence, population growth and urbanisation. The total asset exposure could grow even more dramatically, reaching US \$35,000 billion by the 2070s; more than ten times current levels and rising to roughly 9% of projected annual GDP in this period.

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<sup>1</sup> The term "assets" is generally used here to refer to economic assets in cities in the form of buildings, transport infrastructure, utility infrastructure and other long-lived assets. The common unit for monetary amounts in the study is international 2001 US dollars (USD) using purchasing power parities (PPP).

<sup>2</sup> The UN database precedes the landfall of Hurricane Katrina.

| Rank | Country       | Urban Agglomeration | Exposed Population Current | Exposed Population Future |
|------|---------------|---------------------|----------------------------|---------------------------|
| 1    | INDIA         | Kolkata (Calcutta)  | 1,929,000                  | 14,014,000                |
| 2    | INDIA         | Mumbai (Bombay)     | 2,787,000                  | 11,418,000                |
| 3    | BANGLADESH    | Dhaka               | 844,000                    | 11,135,000                |
| 4    | CHINA         | Guangzhou           | 2,718,000                  | 10,333,000                |
| 5    | VIETNAM       | Ho Chi Minh City    | 1,931,000                  | 9,216,000                 |
| 6    | CHINA         | Shanghai            | 2,353,000                  | 5,451,000                 |
| 7    | THAILAND      | Bangkok             | 907,000                    | 5,138,000                 |
| 8    | MYANMAR       | Rangoon             | 510,000                    | 4,965,000                 |
| 9    | USA           | Miami               | 2,003,000                  | 4,795,000                 |
| 10   | VIETNAM       | Hai Phòng           | 794,000                    | 4,711,000                 |
| 11   | EGYPT         | Alexandria          | 1,330,000                  | 4,375,000                 |
| 12   | CHINA         | Tianjin             | 956,000                    | 3,790,000                 |
| 13   | BANGLADESH    | Khulna              | 441,000                    | 3,641,000                 |
| 14   | CHINA         | Ningbo              | 299,000                    | 3,305,000                 |
| 15   | NIGERIA       | Lagos               | 357,000                    | 3,229,000                 |
| 16   | CÔTE D'IVOIRE | Abidjan             | 519,000                    | 3,110,000                 |
| 17   | USA           | New York-Newark     | 1,540,000                  | 2,931,000                 |
| 18   | BANGLADESH    | Chittagong          | 255,000                    | 2,866,000                 |
| 19   | JAPAN         | Tokyo               | 1,110,000                  | 2,521,000                 |
| 20   | INDONESIA     | Jakarta             | 513,000                    | 2,248,000                 |

Table 1: Top 20 cities ranked in terms of population exposed to coastal flooding in the 2070s (including both climate change and socioeconomic change) and showing present-day exposure (Source: Nicholls et al (2007), OECD, Paris)

| Rank | Country     | Urban Agglomeration | Exposed Assets Current (\$Billion) | Exposed Assets Future (\$Billion) |
|------|-------------|---------------------|------------------------------------|-----------------------------------|
| 1    | USA         | Miami               | 416.29                             | 3,513.04                          |
| 2    | CHINA       | Guangzhou           | 84.17                              | 3,357.72                          |
| 3    | USA         | New York-Newark     | 320.20                             | 2,147.35                          |
| 4    | INDIA       | Kolkata (Calcutta)  | 31.99                              | 1,961.44                          |
| 5    | CHINA       | Shanghai            | 72.86                              | 1,771.17                          |
| 6    | INDIA       | Mumbai              | 46.20                              | 1,598.05                          |
| 7    | CHINA       | Tianjin             | 29.62                              | 1,231.48                          |
| 8    | JAPAN       | Tokyo               | 174.29                             | 1,207.07                          |
| 9    | CHINA,      | Hong Kong           | 35.94                              | 1,163.89                          |
| 10   | THAILAND    | Bangkok             | 38.72                              | 1,117.54                          |
| 11   | CHINA       | Ningbo              | 9.26                               | 1,073.93                          |
| 12   | USA         | New Orleans         | 233.69                             | 1,013.45                          |
| 13   | JAPAN       | Osaka-Kobe          | 215.62                             | 968.96                            |
| 14   | NETHERLANDS | Amsterdam           | 128.33                             | 843.70                            |
| 15   | NETHERLANDS | Rotterdam           | 114.89                             | 825.68                            |
| 16   | VIETNAM     | Ho Chi Minh City    | 26.86                              | 652.82                            |
| 17   | JAPAN       | Nagoya              | 109.22                             | 623.42                            |
| 18   | CHINA       | Qingdao             | 2.72                               | 601.59                            |
| 19   | USA         | Virginia Beach      | 84.64                              | 581.69                            |
| 20   | EGYPT       | Alexandria          | 28.46                              | 563.28                            |

Table 2: Top 20 cities ranked in terms of assets exposed to coastal flooding in the 2070s (including both climate change and socioeconomic change) and showing present-day exposure (Source: Nicholls et al (2007), OECD, Paris)

By better understanding the drivers of increased exposure, more effective adaptation plans can be put into place. For both population and asset exposure, socioeconomic development (including population growth, economic growth and urbanization) is proportionately more important in developing regions and environmental factors are more important for developed regions, where population and economic growth are expected to be smaller. The relative influence of the different factors is dependent on the individual city's conditions. For example, the influence of human-induced subsidence due to shallow ground-water extraction and drainage is especially important in deltaic cities that are rapidly developing such as Shanghai and Ho Chi Minh City. Collectively, climate change and subsidence contribute about one third of the increase in exposure for people and assets under the scenarios considered here, with the balance coming from socio-economic change.

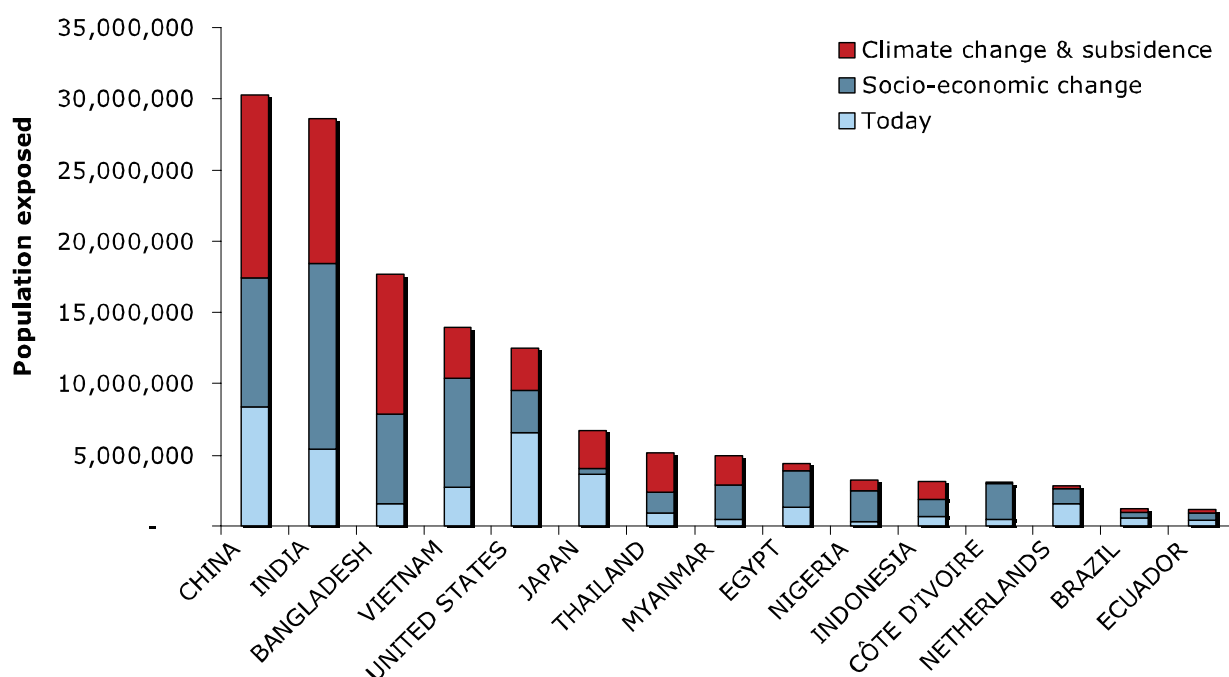


Figure 1: Top 15 countries by population exposed today and in the 2070s, showing the influence of future climate change vs. socioeconomic change (Source: Nicholls et al (2007), OECD, Paris)

By the 2070s, the Top 10 cities in terms of population exposure (including all environmental and socioeconomic factors), are Kolkata, Mumbai, Dhaka, Guangzhou, Ho Chi Minh City, Shanghai, Bangkok, Rangoon, Miami and Hai Phòng. All the cities, except Miami, are in Asian developing countries. The top 10 cities in terms of assets exposed are Miami, Guangdong, Greater New York, Kolkata, Shanghai, Mumbai, Tianjin, Tokyo, Hong Kong, and Bangkok. Hence, cities in Asia, particularly those in China, India and Thailand, become even more dominant in terms of population and asset exposure, as a result of the rapid urbanisation and economic growth expected in these countries.

Many smaller cities (both in terms of population and wealth) also experience very rapid increases in population and asset exposure. These include, for example, Mogadishu in Somalia and Luanda in Angola. While the absolute exposure of these cities is relatively low, the rapid increase expected by 2070s will nonetheless pose significant challenges for local communities.

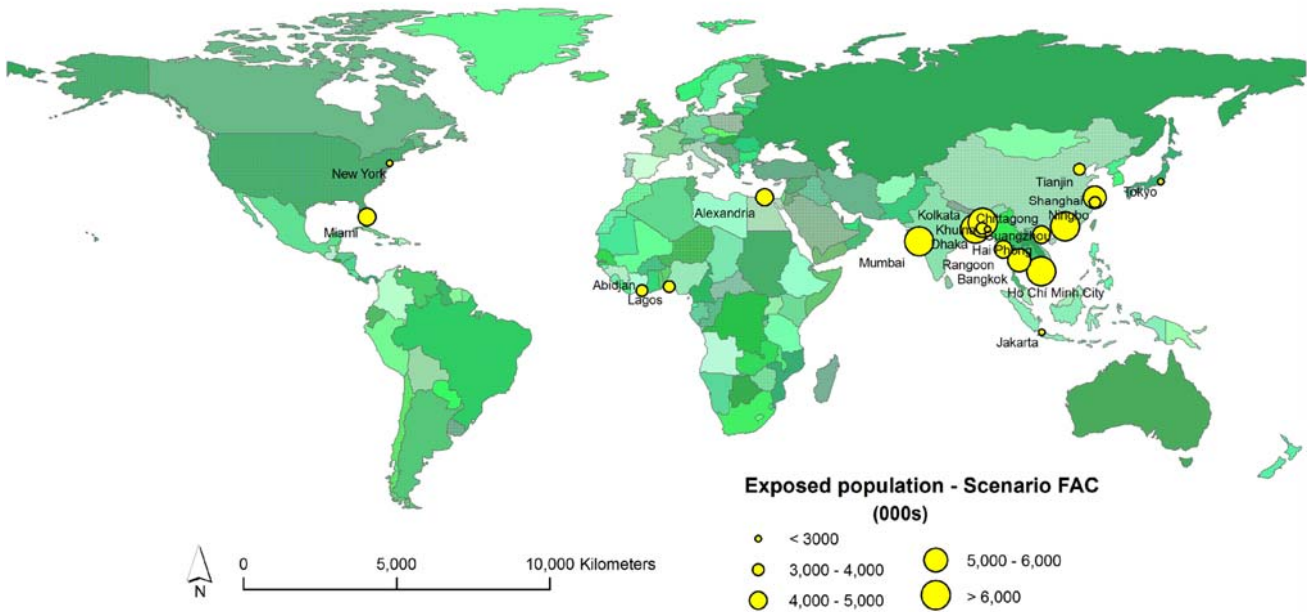


Figure 2: Map showing the Top 20 cities for exposed population under the future climate change and socioeconomic change scenario (Source: Nicholls et al (2007), OECD, Paris)

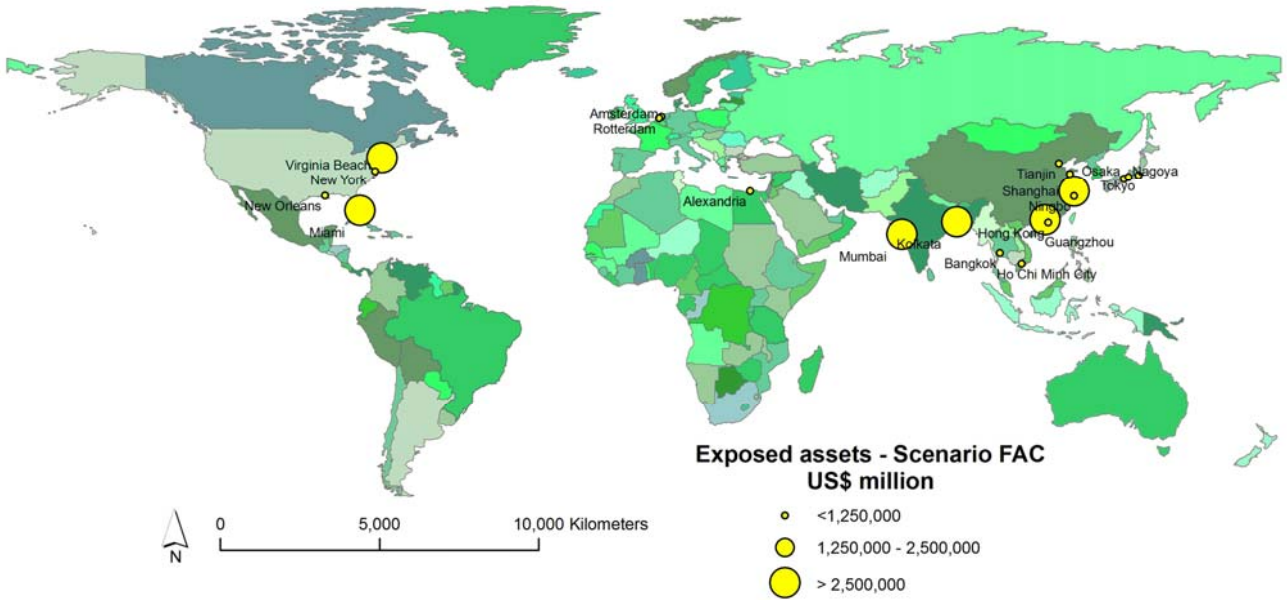


Figure 3: Map showing the Top 20 cities for exposed assets under the future climate change and socioeconomic change scenario (Source: Nicholls et al (2007), OECD, Paris)

The study also provides interesting insights into future vulnerability on a national scale. The analysis reveals that 90% of the total estimated 2070s asset exposure in large port cities is concentrated in only eight nations (China, US, India, Japan, Netherlands, Thailand, Vietnam and Bangladesh). For population, 90% of the exposure in the 2070s is contained in eleven countries (again, China, USA, India, Japan, Thailand, Vietnam and Bangladesh as well as Myanmar, Egypt, Nigeria and Indonesia). The concentration of future exposure to sea level rise and storm surge in rapidly growing cities in developing countries in Asia, Africa and to a lesser extent Latin America, urgently underscores the need to integrate the consideration of climate change into both national coastal flood risk management and urban development strategies. Given the heavy concentration of people and assets in port city locations, and the importance in global trade, failure to develop effective adaptation strategies would inevitably have not just local but also national or even wider economic consequences.

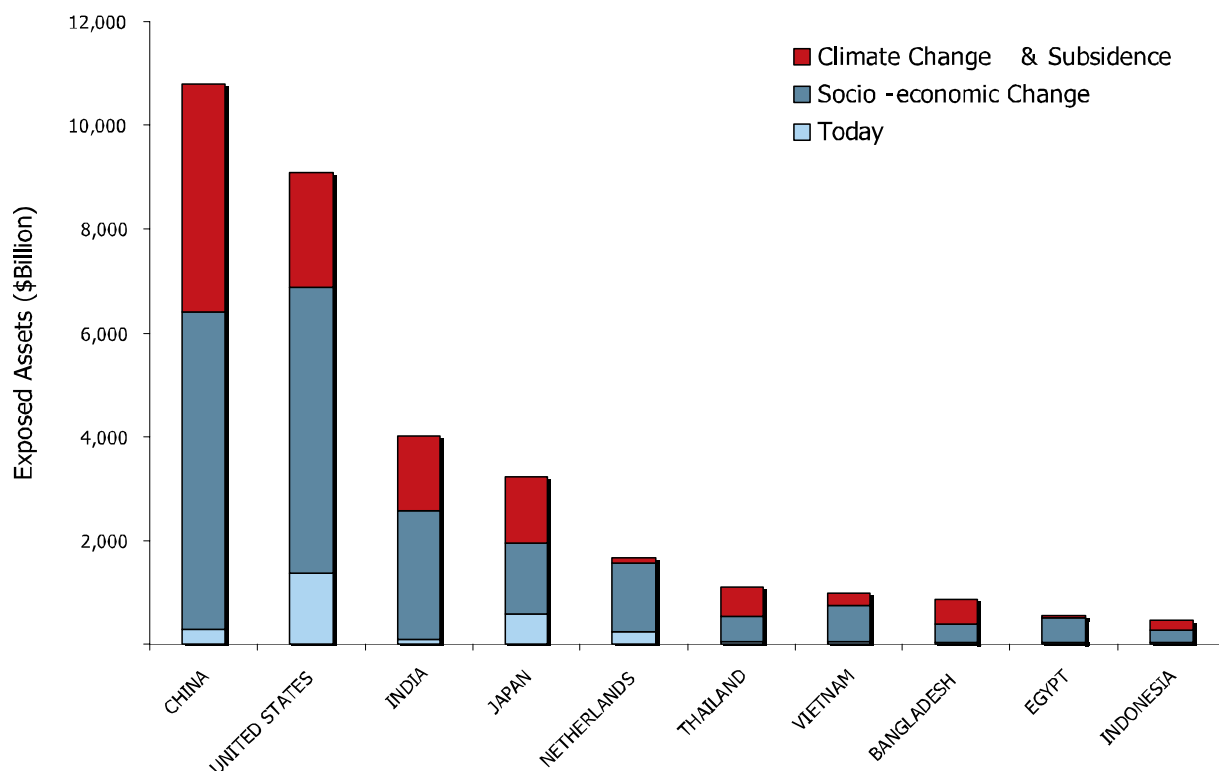


Figure 4: Top 10 countries by assets exposed today and in the 2070s, showing the influence of future climate change vs. socioeconomic change (Source: Nicholls et al (2007), OECD, Paris)

It must also be noted that those cities with greatest population exposure to extreme sea levels also tend to be those with greatest exposure to wind damage from tropical and extratropical cyclones. For example, the ten cities with highest exposure to wind damage are also among the Top 20 cities exposed to present-day extreme sea levels. These include Tokyo, New York, Shanghai, Kolkata, Dhaka, Osaka, Mumbai, Guangzhou, Shenzhen and Miami. All except Shenzhen have also been identified as having high (Top 20) exposure to coastal flood risk in the 2070s. To an extent, this is to be expected, given the role of high winds in driving extreme sea levels. A main conclusion is that these cities may experience combined perils of growing storm surges and more intense winds, and therefore must incorporate both perils into their adaptation and risk management strategies.

Considering responses to flooding, it must be emphasised that exposure does not necessarily translate into impact. The linkage between exposure and the residual risk of impact depends upon flood (and wind) protection measures. In general, cities in richer countries have (and are more likely to have in the future) much better protection levels than those in the developed world. For example, cities like London, Tokyo and Amsterdam are protected to better than the 1 in 1000 year standard, while many developing countries have far lower standards, if formal flood defences exist at all. This is because the high exposed value of wealthy city infrastructures – many billions of dollars for a single city like Hamburg, or even hundreds of billions of



dollars for Osaka – justifies a higher protection level. Also important is the higher risk aversion tendency of richer populations that push local and national authorities to reduce environmental or natural hazard risks.

There are exceptions to the general relationship between wealth and protection. For example, Greater New York, despite having a larger GDP than London, Tokyo and Amsterdam, is currently only protected to a standard of roughly a 1 in 100 year flood. Shanghai, a developing country city with a lower GDP than New York and European cities, has nevertheless a protection level similar to London. These examples highlight that protection levels are also strongly influenced by cultural, political and historical issues. This dependency means that projecting protection levels in the long-term is difficult, and we have not attempted to develop individual city estimates of protection standard. However, at a global level, it can be expected that economic growth will allow a general improvement in protection levels in coastal cities around the globe. The cost-effectiveness and institutional challenges of implementing such protection, however, requires further attention. Of more immediate concern are 11 million people living in port cities today in low income countries that are exposed to coastal flooding. These people have limited protection and often no formal warning systems, and the human consequences of flooding could be significant.

It is also important to note that, even if all cities are well protected against extreme events, large-scale city flooding may remain a frequent event at the global scale because so many cities are threatened and because protection is not fail-safe. For instance, assuming that flooding events are independent, there is a 74% chance of having one or more of the 136 cities affected by a 100-year event every year, and a 99.9% chance of having at least one city being affected by such an event over a 5-year period. Even considering 1000-year events, the probability of having one of the 136 cities affected is as large as 12% over one year and 49% over 5-year periods. So, at the global scale, 100-year and 1000-year events will affect individual port cities frequently. As a consequence, even assuming that protection levels will be high in the future, the large exposure in terms of population and assets is likely to translate into regular city-scale disasters at global scale. This makes it essential to consider both adaptation as well as what happens when adaptation and especially defences fail. There is a need to consider warnings and disaster response, as well as recovery and reconstruction strategies, including foreign aid, in order to minimize as much as possible the long-term consequences of disasters.

The policy implications of this report are clear: the benefits of climate change policies – both global mitigation and local adaptation at the city-scale are potentially great. As reported in the IPCC Fourth Assessment Report, global mitigation can slow and limit the exacerbating effects of climate change on coastal flood risk, at a minimum buying precious time for cities to put adaptation measures in place. As cities are also responsible for the majority of greenhouse gas emissions they are also key actors in the design and implementation of mitigation strategies. In parallel, effective adaptation is essential for managing risks against the background of developing cities and the changing climate. Coastal cities will face great challenges in managing the significant growth in exposure that will come about from both human and environmental influences, including climate change. The size and concentration of population and economic development in many of the world's largest port cities, combined with climate change, highlights the strong two-way linkage between development and climate change and the need for more effective governance for climate change adaptation at the city-scale. Effective adaptation strategies will require multilevel governance approaches to assist port cities to understand and to pro-actively manage current and future flood risk. The large amount of future port city asset exposure on its own (as much as US\$35,000 billion in the 2070s) argues for proactive adaptation which will require a much more focused effort across scales of governance (global–local and public-private) to advance adaptation measures to manage these risks in port cities.

To effectively manage each of the key drivers of risk, adaptation strategies must encompass a range of policy options, including, as relevant, a combination of (1) upgraded protection, (2) managing subsidence (in susceptible cities), (3) land use planning, focusing new development away from the floodplain, (4) selective relocation away from existing city areas, and (5) flood warning and evacuation, particularly as an immediate response in poorer countries. Relocation seems unlikely for valuable city infrastructure, and a portfolio of the other approaches could act to manage and reduce risks to acceptable levels. Cities in locations prone to human-induced subsidence could reduce future exposure and risk by having enforced policies to minimise future human-induced subsidence, as is already the case in the Netherlands, and major cities in Japan and in China. All port cities require a combination of spatial planning and enhanced defences to manage the rising risk of sea level rise and storm surge with climate change.

For cities with large areas at or below mean sea level, flooding can be catastrophic as they can be permanently flooded as illustrated in New Orleans in 2005: only defence repair and pumping can remove the flood water. Where cities remain in these areas, the residual risk needs to be carefully evaluated and defence and drainage systems carefully reviewed; this issue is likely to grow in importance through the 21<sup>st</sup> Century.

However, putting into place effective disaster management strategies, land use practices and protection investments will take time. Previous defence projects (e.g., the Thames Barrier) have shown that implementing coastal protection infrastructure typically has a lead-time of 30 years or more. The inertia of the socio-economic response suggests that action must begin today to protect port cities and to manage flood risk for impacts expected by the middle of this century. The concentration of these risks in a few of the world's cities and nations underscores the urgent need for leadership and attention in these locations. Such action could inform effective management responses, a knowledge base that could help to advance action in many other locations in the coming decades.

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