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RANKING PORT CITIES WITH HIGH EXPOSURE AND VULNERABILITY TO CLIMATE EXTREMES

EXPOSURE ESTIMATES

ENVIRONMENT WORKING PAPERS No. 1

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ABSTRACT

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 assessment 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 study provides a much more comprehensive analysis than earlier assessments, focusing on the 136 port cities around the world that have more than one million inhabitants in 2005. 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.

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; 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 top 10 cities in terms of assets exposed 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. The total value of assets exposed in 2005 is across all cities considered here is estimated to be US$3,000 billion; corresponding to around 5% of global GDP in 2005 (both measured in international USD).

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 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 global GDP in this period. On a global-scale, for both types of exposure, population growth, socio-economic growth and urbanization are the most important drivers of the overall increase in exposure. Climate change and subsidence significantly exacerbate this effect although the relative importance of these factors varies by location. Exposure rises most rapidly in developing countries, as development moves increasingly into areas of high and rising flood risk.

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 higher protection levels than those in the developing world. Exposed population and assets remain dependent on protection that can fail. Hence, even assuming that protection levels will be very high everywhere in the future, the large exposure in terms of population and assets is likely to translate into regular city-scale disasters across the global scale. 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.

RÉSUMÉ

Cette étude globale propose une première estimation de l'exposition des grandes villes portuaires aux inondations côtières, dues aux marées de tempête, et aux vents forts. Elle s'intéresse en particulier aux effets du changement climatique sur l'exposition de chacune de ces villes à l'horizon des années 2070. Cette évaluation comprend les 136 villes côtières qui ont plus d'un million d'habitants dans le monde en 2005. Elle est donc beaucoup plus exhaustive que les estimations disponibles jusqu'à présent. Cette analyse montre que la population des villes portuaires exposée aux inondations côtières est déjà très importante. Dans les villes considérées par cette étude, environ 40 millions de personnes (soit 0.6% de la population mondiale et environ un habitant sur dix de ces villes) sont exposés à l'inondation centennale (celle dont la probabilité annuelle est de 1% et le temps de retour 100 ans).

Dans les conditions présentes (en 2005), les dix villes les plus exposées en termes de population sont Bombay, Canton, Shanghai, Miami, Ho Chi Minh Ville, Calcutta, l'agglomération New-yorkaise, Osaka-Kobe, Alexandrie et la Nouvelle Orléans. Ces villes sont également réparties entre pays développés et pays en développement. Quand on s'intéresse au patrimoine exposé, les pays développé deviennent beaucoup plus représentés, car le niveau de vie est alors un facteur essentiel. Les dix villes les plus exposées en terme de patrimoine sont Miami, l'agglomération New-yorkaise, la Nouvelle Orléans, Osaka-Kobe, Tokyo, Amsterdam, Rotterdam, Nagoya, Tampa-Saint-Petersbourg, et Virginia Beach. Ces villes représentent 60% de l'exposition totale, mais sont dans seulement trois pays riches : les USA, le Japon et la Hollande. La valeur totale du patrimoine exposé en 2005 est estimée à 3.000 milliards de dollars américains, ce qui correspond à environ 5% du PIB annuel mondial.

D'ici aux années 2070, la population exposée totale pourrait être multipliée par plus de trois, pour atteindre 150 millions de personnes, en raison de l'effet combiné du changement climatique (montée du niveau de la mer et intensification des tempêtes), de la subsidence, de l'augmentation de la population, et de l'urbanisation. Le patrimoine exposé pourrait augmenter de manière encore plus importante, pour atteindre 35.000 milliards de dollars américains, ce qui représente plus de 10 fois le niveau actuel et environ 9% du PIB annuel mondial projeté pour cette période. A l'échelle globale, la croissance de la population, la croissance économique et l'urbanisation sont les causes principales de l'augmentation de l'exposition des populations et du patrimoine. Le changement climatique et la subsidence amplifient toutefois de manière significative cette augmentation, même si l'importance relative des différents déterminants varie selon les villes. L'exposition augmente plus rapidement dans les pays en développement, en raison du développement de zones où le risque d'inondation est élevé et en augmentation.

Il est important de noter que l'exposition ne se transforme pas forcément en impact. Le lien entre l'exposition et le risque résiduel d'impact dépend des mesures de protections contre les inondations (et les vents forts). En général, les villes des pays riches ont un niveau de protection supérieur que celles des pays en développement. Toutes les populations et le patrimoine exposés restent toutefois dépendants de ces protections qui peuvent céder ou être submergées. Ainsi, même en supposant que les niveaux de protection seront partout très élevés dans le futur, le niveau d'exposition attendu en termes de population et de patrimoine se traduira probablement par des catastrophes régulières à l'échelle globale. Les implications politiques de ce rapport sont claires : les bénéfices des politiques climatique – d'atténuation comme d'adaptation locale à l'échelle des agglomérations – sont potentiellement importantes.

FOREWORD

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.

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.

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

TABLE OF CONTENTS

EXECUTIVE SUMMARY

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[1] 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 cites 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.[2]

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

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[1] 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).

[2] The UN database precedes the landfall of Hurricane Katrina.

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.

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.

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.

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.

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 extra-tropical 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, Shenzen and Miami. All except Shenzen 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 21st 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.

This analysis is an input to an ongoing OECD project on the benefits of climate policies at city-scale. Refinement and extension of this analysis and the global-local modelling tools developed here will be considered in the course of that project.

SCREENING STUDY: RANKING PORT CITIES WITH HIGH EXPOSURE AND VULNERABILITY TO CLIMATE EXTREMES

INTERIM ANALYSIS: EXPOSURE ESTIMATES

by

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1. Background

Port cities are a vital component of the global economy and are increasingly becoming important concentrations of population and asset value. Thirteen out of the twenty most populated cities in the world in 2005 are port cities. In addition, their economic importance in terms of international trade has grown markedly, particularly in developing countries, in line with globalisation and the rapid development of the newly industrialised countries. Globally, the volume of seaborne trade has more than doubled in the past 30 years and Hurricane Katrina recently demonstrated the effect of a major storm on an important port city (New Orleans). This storm created significant physical damage and long run disruption at a regional scale, but also had social and economic implications at national and global scales (GROSSI and MUIR-WOOD, 2006; NICHOLLS *et al.*, 2007a; WILBANKS *et al.*, 2007). In a world with fast growing coastal populations, an increasing volume of seaborne trade and a changing climate, the risk of climate extremes to port cities risks will inevitably increase.

Future sea level rise and the possibility of more intense storms are of particular concern. Many coastal cities, especially those in deltas, are also predisposed to natural subsidence. As shown in New Orleans, local subsidence can also be an important factor contributing to growing risk. This effect can be aggravated by human effects, such as drainage and groundwater pumping (DIXON *et al.*, 2006; NICHOLLS, 1995).

The goal of this screening exercise is to take a first global overview of coastal flood risks to world port cities and produce rankings based on physical exposure and socio-economic vulnerability to climate extremes (tropical and extra-tropical storms and associated storm surges); the effects of relative sea-level rise due to global climate change and local subsidence. The rankings are across two different types of exposure to flood risk -- population and assets[4]: six scenarios are examined covering both today and the 2070s across the combined pressures from climate change and socio-economic growth. In each case, calculated water levels are used with the population distributions as a function of elevation to estimate the population and assets below a 1 in 100 year extreme water level. The results indicate relative exposure across world port cities, thus broadly highlighting where further understanding is most urgently needed to effectively respond to coastal flood risk. This analysis builds on the analysis of NICHOLLS (1995), but

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[4] 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).

considers a much larger sample of cities –136 port cities with a population greater than one million people in 2005. A preliminary analysis to wind hazard for the same cities under present conditions is also included.

2. Methodology

The focus of this analysis is exposure rather than 'residual risk' (which includes defences and other adaptation). Flood protection is not included explicitly as it is difficult to ascertain accurate and comprehensive data on flood protection in many, if not most, of the cities under study. The methodology adopted was therefore based on determining the numbers of people who would be *exposed*[5] to extreme water levels (see Figure 1) which could then be related to the potential economic assets exposed within the city. Existing modelling approaches used to estimate flood protection often assume economically optimum standards of protection, and where we do have data, these methods appear to tend to overestimate protection standards in comparison to reality, especially in many poorer countries.

The metric of exposure to, for example a 1 in 100 year flood event, can reveal much about the risks faced in each city. Principally this is because people in the flood plain will be reliant on formal or informal flood defences, and thus will be at some level of risk even in the best defended of port cities. This risk could arise from a failure of existing flood defences due to breaching or overtopping[6]. In other words the exposure metric can be viewed as a worst case scenario, and exposure can translate into major losses and transformation during extreme events (e.g. New Orleans in 2005). This metric is particularly relevant when considering long timescales, as there is the added uncertainty around what appropriate defence levels will be required, if they will be available and, if available, whether they will be sufficiently maintained to be fully effective. In this study, the exposure metric is calculated for a 1 in 100 year coastal flood event. The possible role of protection is discussed later.

A range of climate and other change factors are considered:

- Population and economic growth;
- Natural subsidence/uplift;
- Global sea-level rise;
- More intense storms and higher storm surges;
- Potential human-induced subsidence.

Using these change factors, six main scenarios were investigated to understand changes in exposure given a 100 year return period extreme water level event. The scenarios are outlined in Table 1 and are as follows:

(i) Current city (C): (situation in 2005);

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[5] Exposure refers to the population and assets that are threatened, taking no account of any defences or other adaptation.

[6] Overtopping refers to seawater flowing over the defences without degrading the defence so as the flood levels diminish after the event, the ingress of water ceases. Breaching refers to the lowering of defences due to various failure mechanisms. This generally allows much larger volumes of water to flood the defended area (MUIR WOOD and BATEMAN 2005)

(ii) Future city, No environmental Change (FNC): (current environmental situation with the 2070's economy and population. scenario);

(iii) Current city, Climate Change (CCC) (Current socio-economic situation with the 2070's climate change and natural subsidence/uplift);

(iv) Current city, All Changes (CAC) (Current socio-economic situation with the 2070's climate change, natural subsidence/uplift and human-induced subsidence);

(v) Future city, Climate Change (FCC) (Future socio-economic situation with 2070's climate change and natural subsidence/uplift);

(vi) Future city, All Changes (FAC): (Future socio-economic situation with the 2070's climate change, natural subsidence/uplift and human-induced subsidence).;

Future exposure is evaluated for the 2070s (the decade 2070-2080). This timescale was chosen for two key reasons. Firstly, it is a long enough timescale that key environmental and socioeconomic factors are significantly different from today and therefore, provides a significant change in exposure. Secondly, this is a timescale relevant for planning adaptation measures. Many policy choices over land-use and defences, for example, are already locked in for the next few decades. The 2070s is a timescale for which current policy choices and debates can influence both exposure and risk.

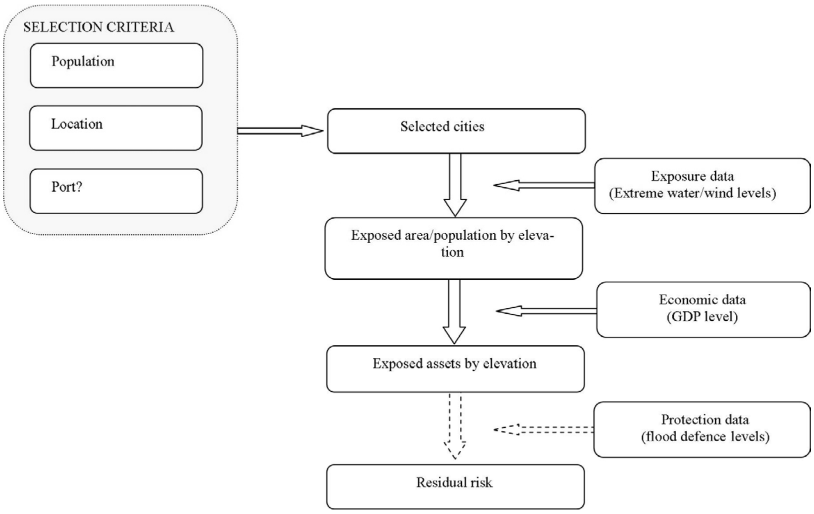

Figure 1. Methodology adopted to produce ranking of city vulnerability to coastal flooding.

To explore how the rankings might change, typically high-end projections which emphasise the potential for change were considered. Scenarios (iii) to (iv) consider the impacts of climate change, in terms of global sea-level rise and increased storm intensity (IPCC, 2007). Human-induced subsidence in (iv) and (vi) represents the potential effects of groundwater withdrawal and land drainage in those cities that are susceptible, mainly comprising cities in deltaic settings (cf. NICHOLLS, 1995). Socio-economic development in (v) and (vi) is drawn from a single economic baseline for the future (OECD, 2008 forthcoming). This baseline is derived from recent OECD environmental-economic analysis and has been extended from 2050 to the end of the century for this analysis. While this baseline portrays only one possible future, it is sufficient to illustrate the interaction between development and climate change in the 2070s timeframe explored here. To simplify presentation, the discussion here focuses most on rankings on the (i) – C, (ii) FNC and (vi) FAC scenarios. This allows a comparison between today's exposure levels and those that may emerge in the future due to a combination of socio-economic growth, high subsidence and climate change.

Scenario		Water levels				Population and Economy
		Climate		Subsidence		
Number and Name	Description	Global sea-level rise	Storm enhance-ment factor	Natural	Anthro-pogenic	
(i) C	Current city	X	X	X	X	CB
(ii) FNC	Future city	X	X	X	X	FB - 2070s
(iii) CCC	Current city with Climate Change	√	√	√	X	CB
(iv) CAC	Current City All Changes	√	√	√	√	CB
(v) FCC	Future City Climate Change	√	√	√	X	FB- 2070s
(vi) FAC	Future City All Changes	√	√	√	√	FB - 2070s

Table 1. Description of scenarios used to analyse the 100 year flood event; CB – or current baseline ; FB – future baseline, 2070s) (see Appendix 1 for water level calculation methods)

Also considered, in simplistic terms, is the present-day (2005) vulnerability of the selected port cities to wind damage due to tropical and extratropical storms[7]. A summary methodology is given below. A full description of the data and methodologies used is included in Appendix 1.

2.1 City Selection

The initial screening is limited to cities with populations greater than one million; these cities were identified using the 2005 population figures for cities from the United Nations (UN, 2005). In this report, city names refer to an urban agglomeration defined as the area comprising the city (or town proper) and also the suburban fringe or thickly settled territory lying outside of, but adjacent to, the city boundaries. The longitude and latitude of cities were then used to determine those with a coastal location and a known port. Ports were classified by type and size.

2.2 Exposure to Extreme Sea Levels

To demonstrate the land area and population exposed to inundation in extreme water level events, the investigation took the form of an elevation-based GIS (Geographical Information Systems) analysis, after MCGRANAHAN *et al.*, (2007) (see Appendix 1, section 1).

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[7] It should be noted that the sea level exposure analyses do assume an increase in storm surge height associated with future more intense storms. Given the uncertainties in future storminess this is simply treated. As described in Appendix 1, it is assumed that storm surge heights increase by a fixed percentage for cities affected by tropical cyclones, and by the same percentage for those cities, within a defined latitude band, affected by extratropical cyclones.

Current extreme water levels are taken from the DIVA database (Appendix 1). The water levels for each future scenario and each city were calculated as illustrated in Table 1, combining the appropriate relative sea-level rise (including natural subsidence/uplift), the 1:100 year return period extreme water level, a storm enhancement factor (reflecting the potential increase in extreme water levels due to more intense storms, which was developed as part of this study), natural and anthropogenic subsidence, where appropriate. Global sea-level rise assumed a 0.5 m rise; for tropical storms a 10% increase in extreme water levels was assumed, with no expansion in affected area; while for extratopical storms, a 10% increase in extreme water levels was assumed between 45^{o} and 70^{o} latitude. For anthropogenic subsidence, a uniform 0.5 m decline in land levels was assumed from 2005 to the 2070s in those cities which are susceptible (see Appendix 1). Thus the change in extreme water level is variable from roughly 0.5 m in cities only affected by global sea-level rise, to as much as 1.5 m for those cities affected by global sea-level rise, increased storminess and human-induced subsidence.

Across the scenarios, the calculated water levels were used with the population distributions to estimate the exposed population and the value of exposed infrastructure assets that are located at an elevation below the 1:100 year extreme water level. This is the population and assets that would be impacted by 1:100 year event in the absence of any flood defences – and indicates the scale of the impacts in a flood event when the defences fail. Also of interest is the population and magnitude of assets “at risk”, which measures the residual risk in terms of the average annual population and assets that may be flooded, taking into account an estimated protection level[8]. Protection is not treated comprehensively here. Rather we consider only a few cities where the protection standard is known, including degradation of the defences due to rising water levels, and look more generally at national wealth as an indicator of adaptive capacity and disaster response.

2.3 Cities in the 2070s with Economic and Population Growth

This analysis considers socio-economic futures based on the forthcoming baseline projections from the OECD ENV-Linkages model (OECD, 2008 forthcoming). City population projections are derived from global projections and from simple extrapolations to 2075 of the UN urbanization rate projection to 2030. The city projections assume that the population of all cities within a given country will grow at the same rate and that new inhabitants of cities in the future will have the same relative exposure to flood risk as current inhabitants. Using the OECD baseline projections to 2075, the analysis again assumes that the GDP for all cities within a given country grow at the same rate and urban GDP per capita is assumed to grow at the same rate as the relevant national (or regional) GDP per capita trends throughout the period 2005 to 2075 (see Appendices 1 and 2).

2.4 Exposure to Wind Damage

The relative exposure to wind damage of the port cities was calculated by weighting the present-day wind damage hazard, for tropical and extratropical cyclones, by the total city population (see Appendix 1, section 2 for details).

2.5 Limitations

As with any study, it is important to recognise and understand limitations in the methodology. The city data is derived from global datasets and these are subject to large uncertainties inherent in such sources (e.g. SMALL and NICHOLLS, 2003; VAFEIDIS *et al.*, 2007). One data limitation arises from the limited resolution of the elevation data, and future work could improve this analysis through the use of a more precise dataset. In terms of methods, the flooding analysis is based on elevation data only, with no modelling of water propagation and dynamics. It is well known that damages depend on water dynamics

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[8] Average annual damages are a standard metric for reporting damages from local to global scales.

(e.g. water velocity) and flood duration. Since we focus on exposure, however, this limitation remains acceptable.

Thus, the city impacts are indicative in magnitude -- identification of a high impact potential in this study indicates the need for more detailed investigation of the possible impacts with more detailed data. As the uncertainties are unbiased, the aggregated national, continental and global results are increasingly robust (cf. HOOZEMANS *et al.*, 1993). Any future work should include a better analysis of all these uncertainties as far as possible.

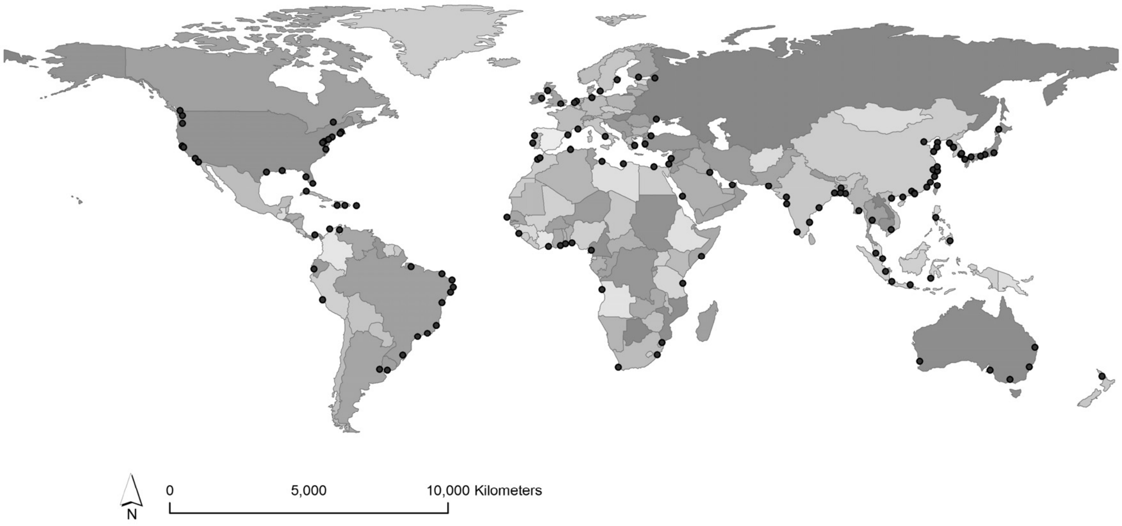

Figure 2. The location of the 136 port cities analysed in this study

3. Results

A total of 136 cities were found to comply with the selection criteria. Some of these had more than one associated port due to the size of the city. For example, Tokyo includes the ports of Tokyo, Chiba and Yokohama. The cities cover a diversity of port settings. Thirty-seven of the port cities were either entirely or partially in deltaic locations. Of the remaining port cities, some are located in open coast settings, such as Miami, while others are located on estuaries, such as the Thames.

The global distribution of these port cities (see Figure 2) is concentrated in Asia (52 ports or 38%), with the USA (17 ports or 13%), China (14 ports or 10%) and Brazil (10 ports or 7%) the dominant individual countries. They include seaports and river ports (in the coastal zone), with the majority of ports being seaports/harbours (119 port cities), including sixteen deepwater ports and two oil terminals. Additionally, there are 17 coastal cities with river ports, varying in size from small (e.g., Hai Phong and Thành Pho Ho Chi Minh in Vietnam) to very large (e.g., Philadelphia and New Orleans in the USA). All the coastal cities with river ports are at elevations and locations where they are affected by storm surges today, and will also be affected by sea-level rise: important examples include Dhaka and Kolkata (cf. MUNICH RE, 2004).

Note that some large and growing cities within the coastal zone such as Hanoi are not currently classified as having a port (Hanoi's port city Hai Phong is included in the analysis). Other large near-coastal cities such as Caracas and Sao Paulo do not include ports, and are also at elevations where coastal flooding is not significant: in the case of Sao Paulo, its port city of Santos is included in the analysis. Lastly, some cities could be amalgamated for analysis purposes as they are adjacent, such as Hong Kong and Guangzhou (cf. MUNICH RE, 2004). However, the report follows the definitions in the UN (2005) city data throughout.

In what follows, results are given at global, continental and national levels, as well as the individual city rankings. When discussing the city ranking, the main focus is the Top 20 ranked cities for the different vulnerability measures are given in the following tables. The full list of port cities with all vulnerability data is given in Appendix 3.

3.1 Global Exposure to Extreme Sea Levels

Exposure to extreme water levels was calculated relative to the baseline as represented by current exposure to a 1 in 100 year event. The total number of people currently exposed across the globe in the 136 cities is approximately 38.5 million and the distribution of this exposed population across the continents is shown in Figure 3. Asia has a significantly higher number of people living under an elevation corresponding to the 1:100 water level, with 65% of the global exposed population, whilst South America and Australasia have relatively low exposure: 3% and <1% of the global total, respectively. This reflects both the high numbers of cities in Asia, and high exposure per city in Asia, when compared to other continents.

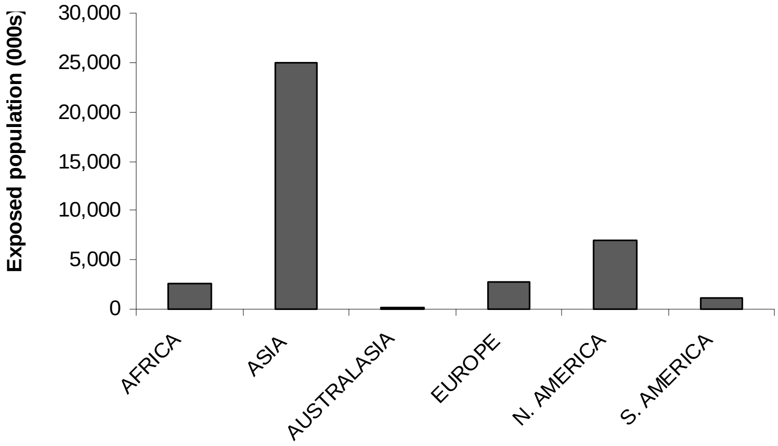

Figure 3. Distribution of population currently exposed to extreme water levels (scenario C, situation in 2005).

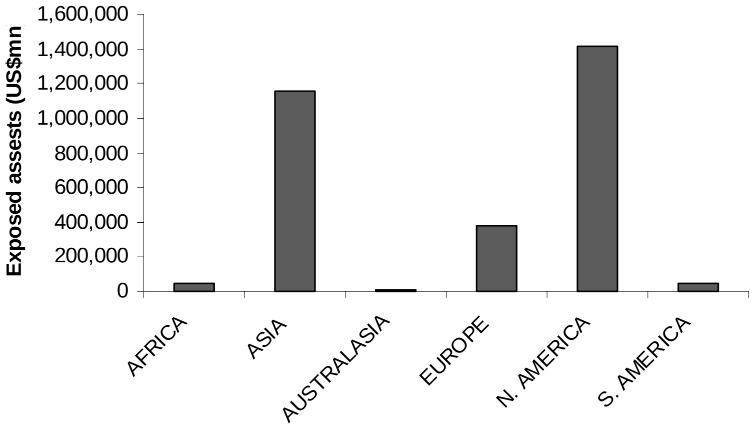

Figure 4. Total assets currently exposed to extreme water levels by continent (scenario C, situation in 2005)

This distribution changes when lookng at the total assets within each city exposed to extreme water levels (Figure 4). North America has the largest monetary value within the areas susceptible to an extreme event, because the per capita GDP (PPP) rate is substantially higher than that of nearly all the Asian countries. Asia is a close second – most of the current assets at risk in Asia are located in Japan.

Climate change, subsidence and population growth all increase the population exposed, with population growth/urbanisation being the dominant factor driving increased flood exposure (Figure 5). Overall, environmental changes (including natural subsidence, increased storminess and sea level rise), increase exposure by around 35%, with the largest contribution being from sea-level rise (24%). Human-induced subsidence increases overall exposure by around 14%. Population growth/urbanisation has by far the largest effect, more than doubling population exposure by itself. The relative contributions of these drivers of exposure growth differ at the city level. In general, exposure changes in developing country cities is more strongly driven by socioeconomic changes, while developed country cities see a more significant effect from climate change. For a few cities in the developed world, for example Hamburg, population is projected to decline by the 2070s, giving a negative contribution to exposure. Cities that experience natural subsidence or are exposed to storms will see larger contributions from these factors. Lastly, cities susceptible to human-induced subsidence (mainly, developing county cities in deltaic regions with rapidly growing populations) could see significant increases in exposure due to human-induced subsidence as shown historically in several Asian cities (NICHOLLS, 1995). It is important to note that the potential impact of human-induced subsidence on the exposure and risk of these cities is of similar magnitude to storm enhancement and slightly less than sea-level rise. Thus, human actions, such as groundwater extraction and drainage, could significantly aggravate the impact of climate change. This demonstrates that effective long-term water management strategies to limit human-induced subsidence can provide significant advantages in terms of risk management for the future.

If all the influences on extreme water level by the 2070s are combined with today’s (2005) population, the exposed population grows to 59 million by the 2070s: an increase of about 50 percent. Incorporating population growth projections increases this figure dramatically to 147 million (an increase of about 150 percent) representing a three-fold increase in exposure by the 2070s. If the environmental or socio-economic changes were smaller than assumed here, the exposure would be reduced, but the underlying trends would remain.

To compare to Figure 5, Figure 6 shows the asset values as a function of the socio-economic scenarios and the different climate- and subsidence-driven components of rising extreme water levels. The much larger differences due to the socio-economic scenario are the most striking difference with the population results: without any increase in water levels, asset exposure could grow eightfold. However, water levels do contribute to additional asset exposure, and under the FAC scenario (which corresponds to All Factors in Figures 5 and 6), they are collectively responsible for about one third of the growth in asset exposure.

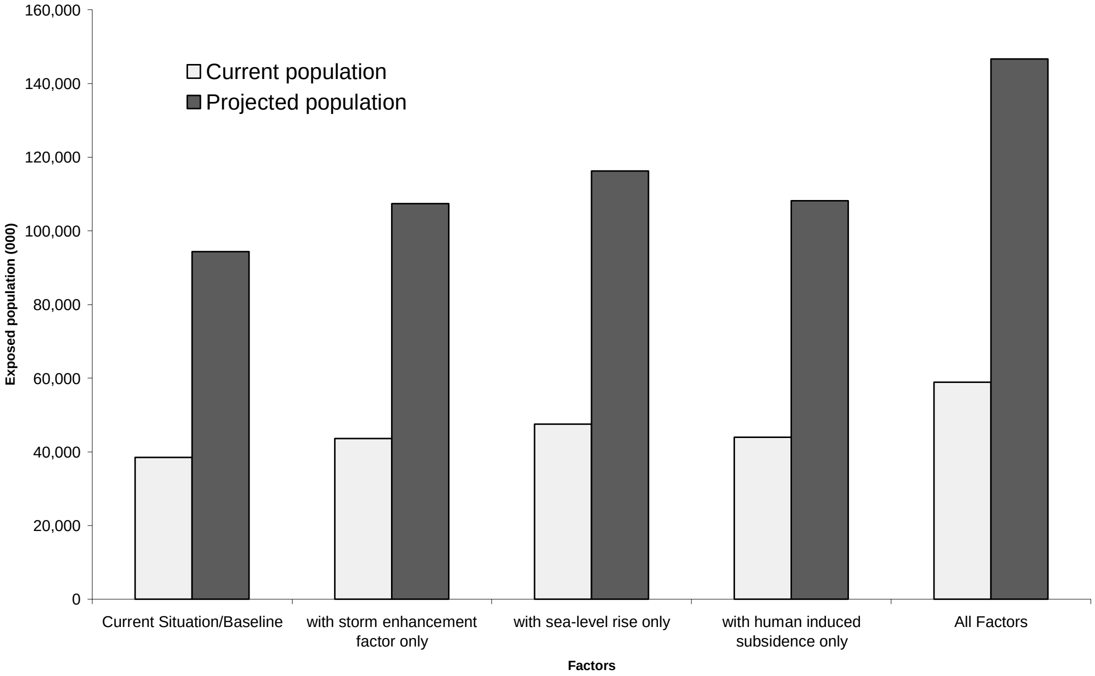

Figure 5. Comparison of the impacts of individual and combined water level factors on global population exposure, based on present and future population scenarios.

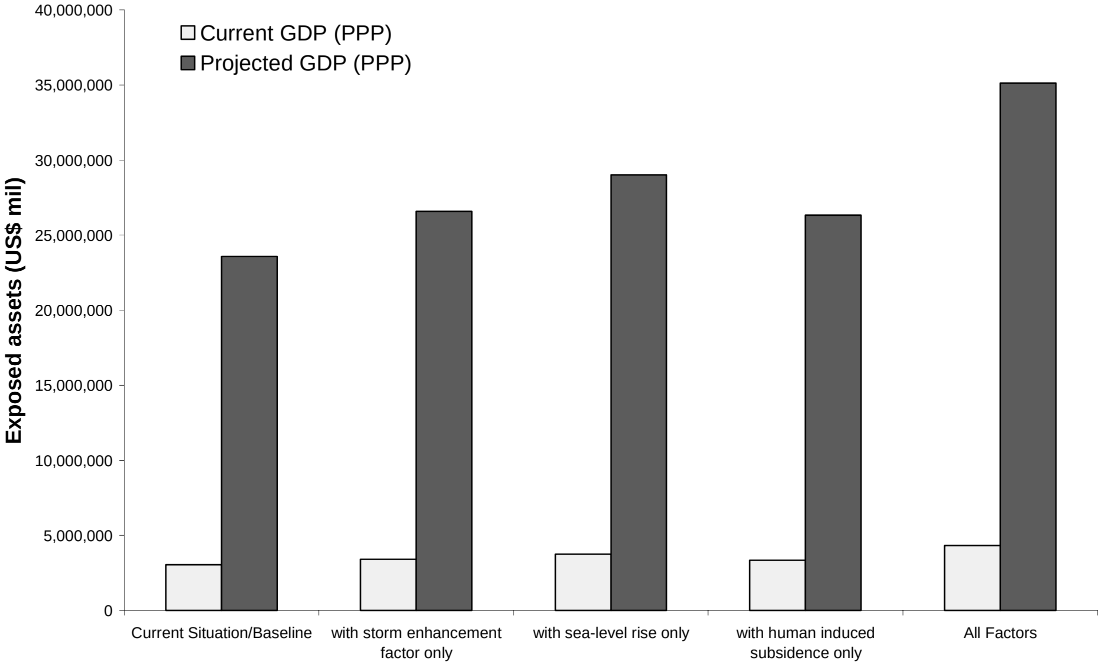

Figure 6. Comparison of the impacts of individual and combined water level factors on global asset exposure, based on present and future asset value scenarios.

3.2 Ranking exposure by country

On a national scale, the exposure analysis reveals that 90% of the total estimated 2070s asset exposure in large, world port cities (i.e. across the 136 cities studied here) is concentrated in only eight nations (China, USA, India, Japan, Netherlands, Thailand, Vietnam and Bangladesh) (see Figure 7). For population, 90% of the exposure is contained in eleven countries (again, China, USA, India, Japan, Thailand, Vietnam and Bangladesh as well as Myanmar, Egypt, Nigeria and Indonesia), (see Figure 8).

The concentration of future exposure in rapidly growing cities in developing countries in Asia and Africa, as noted above, urgently underscores the need to integrate 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 their trade hub role in national economies, failure to develop effective adaptation strategies could have large national economic consequences.

Working in partnership, local and national decision-makers will bring greater resources and expertise to bear on the adaptation problem; policies will be needed to establish incentives for public and private investors (OECD 2003). National governments are uniquely well-placed to assist port city adaptation efforts by bringing available research to bear on specific locations to better understand the nature of the risks in local contexts and the costs and benefits of adaptation, and to facilitate the development of risk sharing approaches and insurance markets. Local governments on the other hand will need to work closely to local stakeholders and decision-makers to assess and choose amongst available adaptation options to reflect and balance the interests of those most directly affected.

Interactions between national and city-level decision-makers, public and private, as well as national and often international policymakers (i.e. where relevant official development assistance) inevitably shape the way cities and city infrastructure develops (OECD 2006). Figures 9 and 10 show that these decisions on how and where cities develop will make a difference to the exposure of cities to coastal flood risk. Climate change will exacerbate the pressures of population and economic exposure in port cities, including expanding into high risk areas. Broad engagement across scales of governance and different types of actor will be necessary to protect against and to manage coastal flood risk.

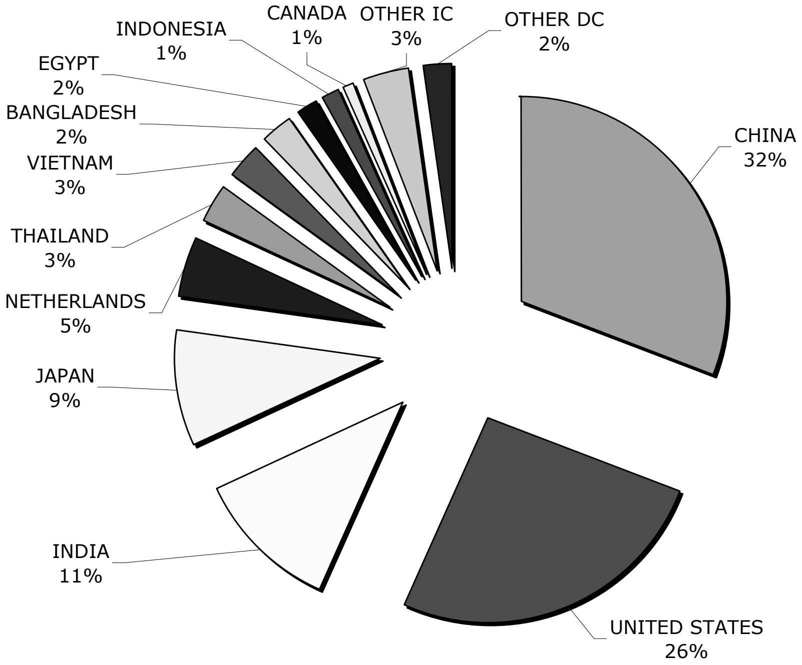

Figure 7. Assets exposed to sea-level rise, storm surge and subsidence by country (for scenario FAC). Total estimated exposure is $US 35,000 billion.

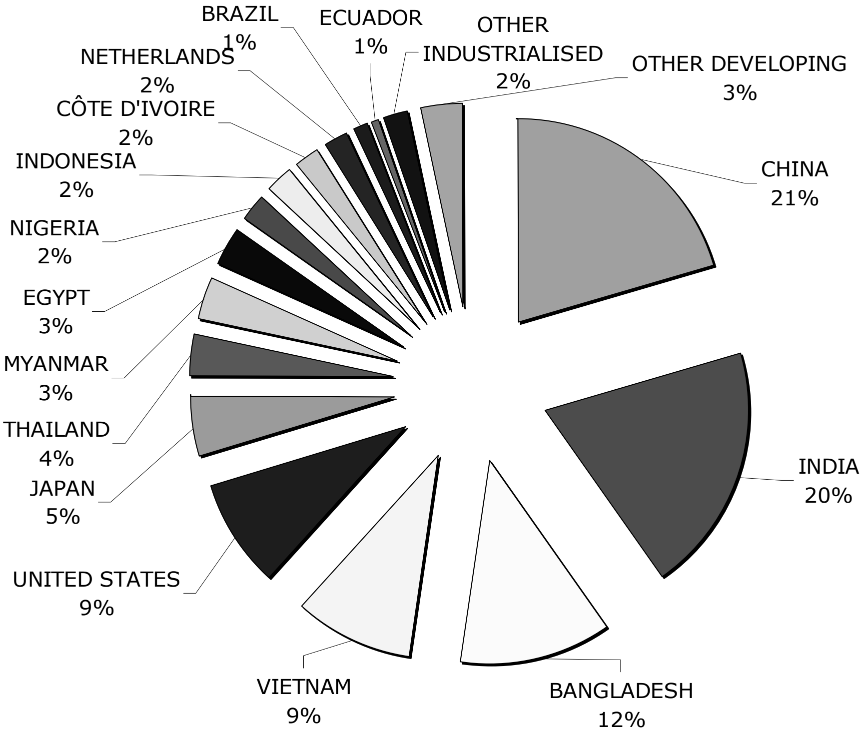

Figure 8. Population exposed to sea-level rise, storm surge and subsidence by country (for scenario FAC). Total estimated exposure is 147 million people.

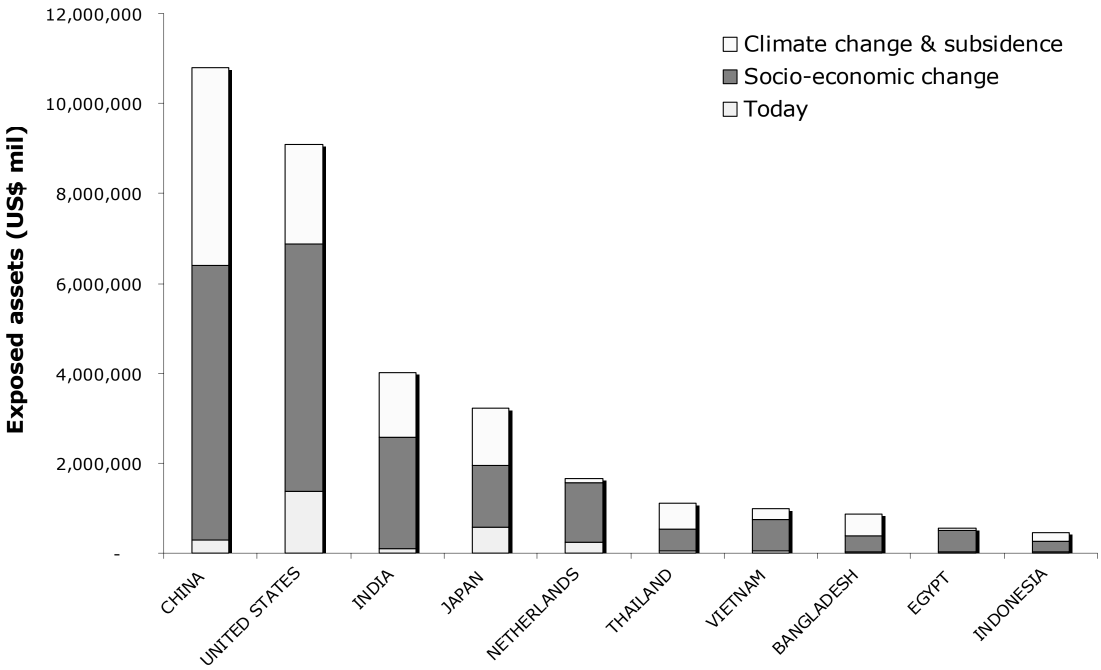

Figure 9. Top 10 countries by assets exposed today and in the 2070s (for scenario FAC).

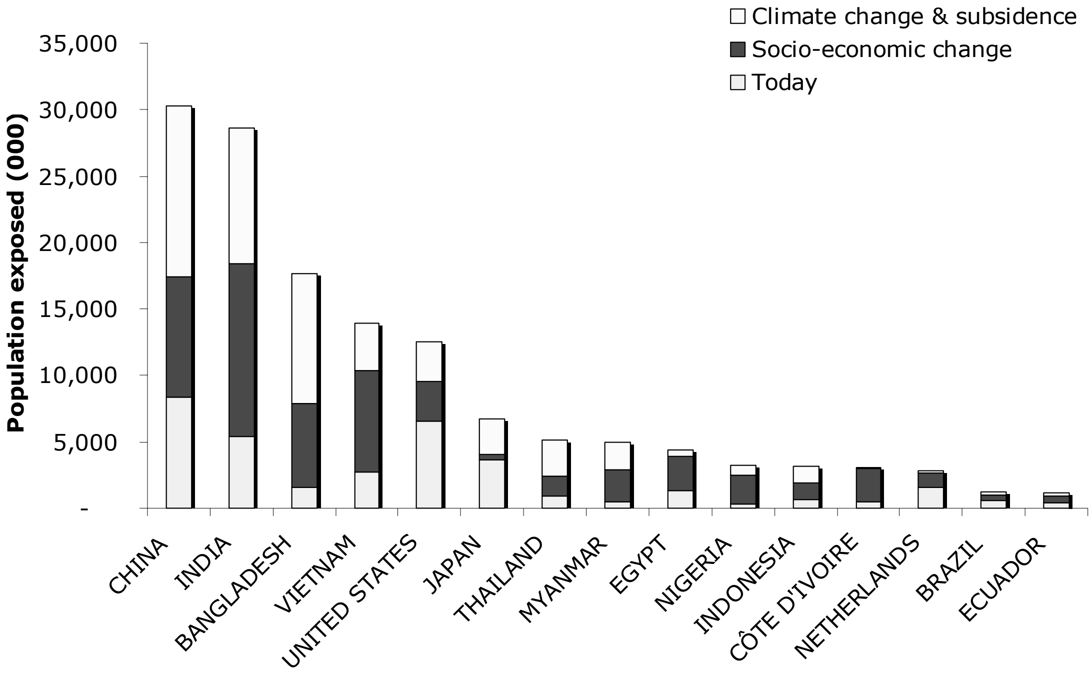

Figure 10. Top 15 countries by population exposed today and in the 2070s (for scenario FAC)

3.3 Ranking exposure by city

A few cities contain most of the exposed population and assets. As over 50% of the exposed population and assets are found in the top ranked 10 (the 7th percentile in Figure 11), and more than 70% in the Top 20 (the 14th percentile in Figure 11) of the 136 port cities, this discussion focuses mainly on the Top 20 cities. Widening the consideration to the Top 50 cities encompasses more than 95% of the population and asset exposure. For the scenarios defined in Table 1, Tables 2-5 show the Top 20 cities under the current and future baseline scenarios (C, FNC) and the future cities, future subsidence and climate change scenario FAC in terms of population and assets exposed, respectively. The following discussion looks across these Tables.

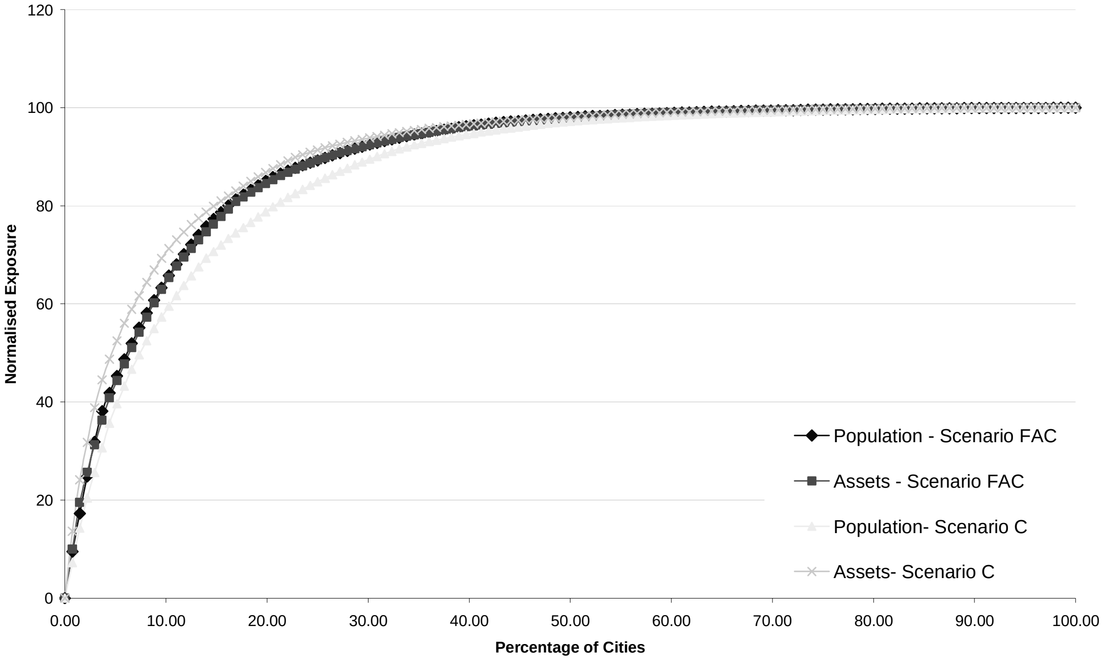

Figure 11. Cumulative distribution of total exposure for the current baseline and 2070s (scenarios C and FAC) Ranking by exposed population

The Top 20 cities for population exposure are disproportionately located in deltas with 13 to 17 deltaic cities being found in the Top 20 rankings in Tables 2-5 (indicated by a [D]). Asia contains a high proportion (≥65%) of the Top 20 cities (Figure 12). Nonetheless, the Top 20 include cities in both developed and developing countries (Tables 2-5, column 1). Climate change and human-induced subsidence (Tables 4 and 5) increase the absolute size of the exposed population, but many of the same cities remain in the Top 20 rankings irrespective of the changes (although with different order). Top 20 cities in all the rankings include Mumbai, Guangzhou, Shanghai, Miami, Ho Chi Minh City, Kolkata, New York, Osaka-Kobe, Alexandria, New Orleans, Tokyo, Tianjin, Bangkok, Dhaka and Hai Phong. This reinforces the importance of Asia in this analysis. It is notable that the Top 20 cities include both river and sea ports. For cities with river ports (e.g. Hai Phòng and Thành-Pho-Ho-Chí-Minh in Vietnam), their location and low elevation still often leaves them vulnerable to climate change in absolute terms.

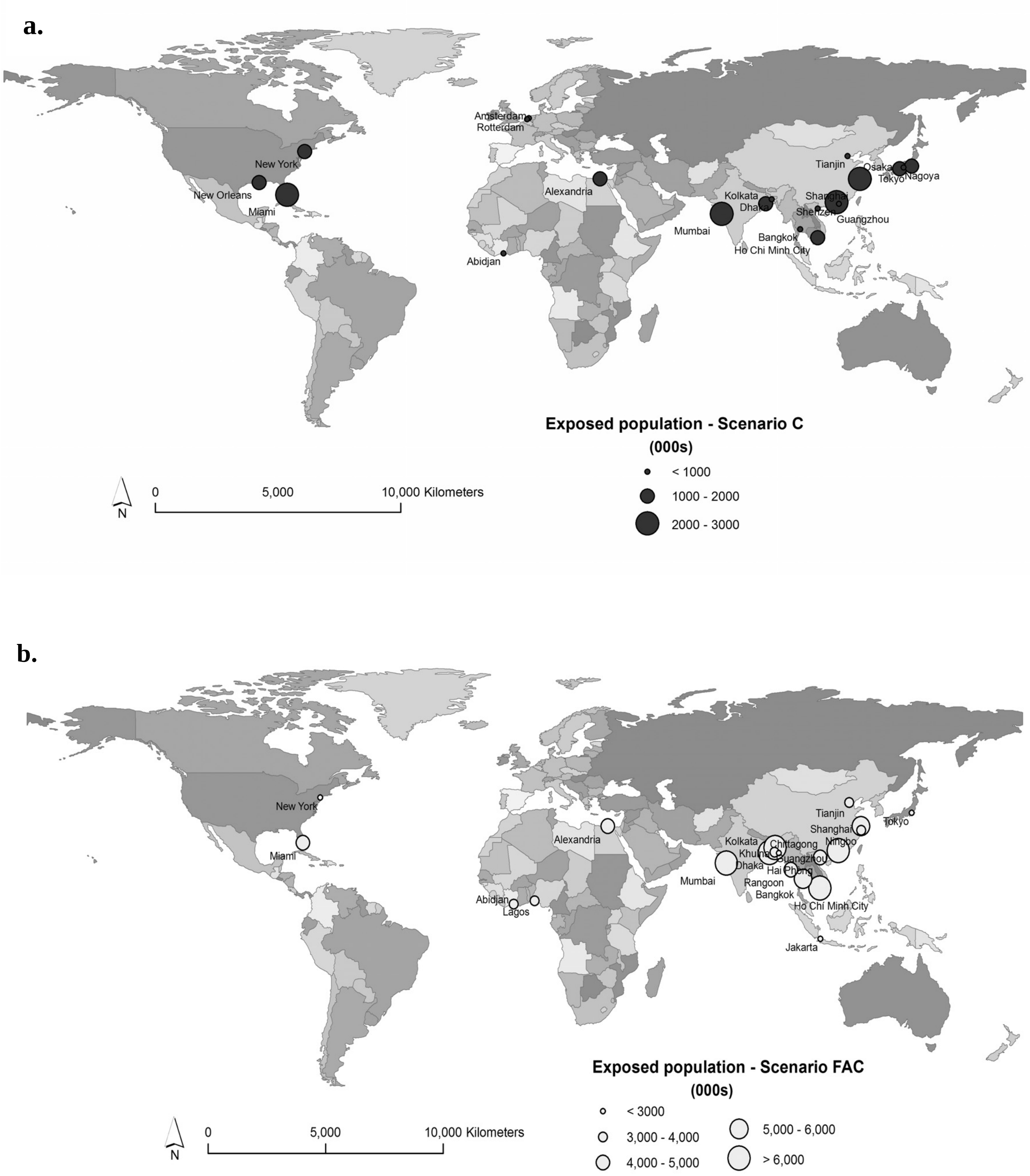

Figure 12. Maps showing the Top 20 cities for exposed population under (a) scenario C (situation in 2005) and (b) scenario FAC (scenario for the 2070's). Note the different scales in the key.

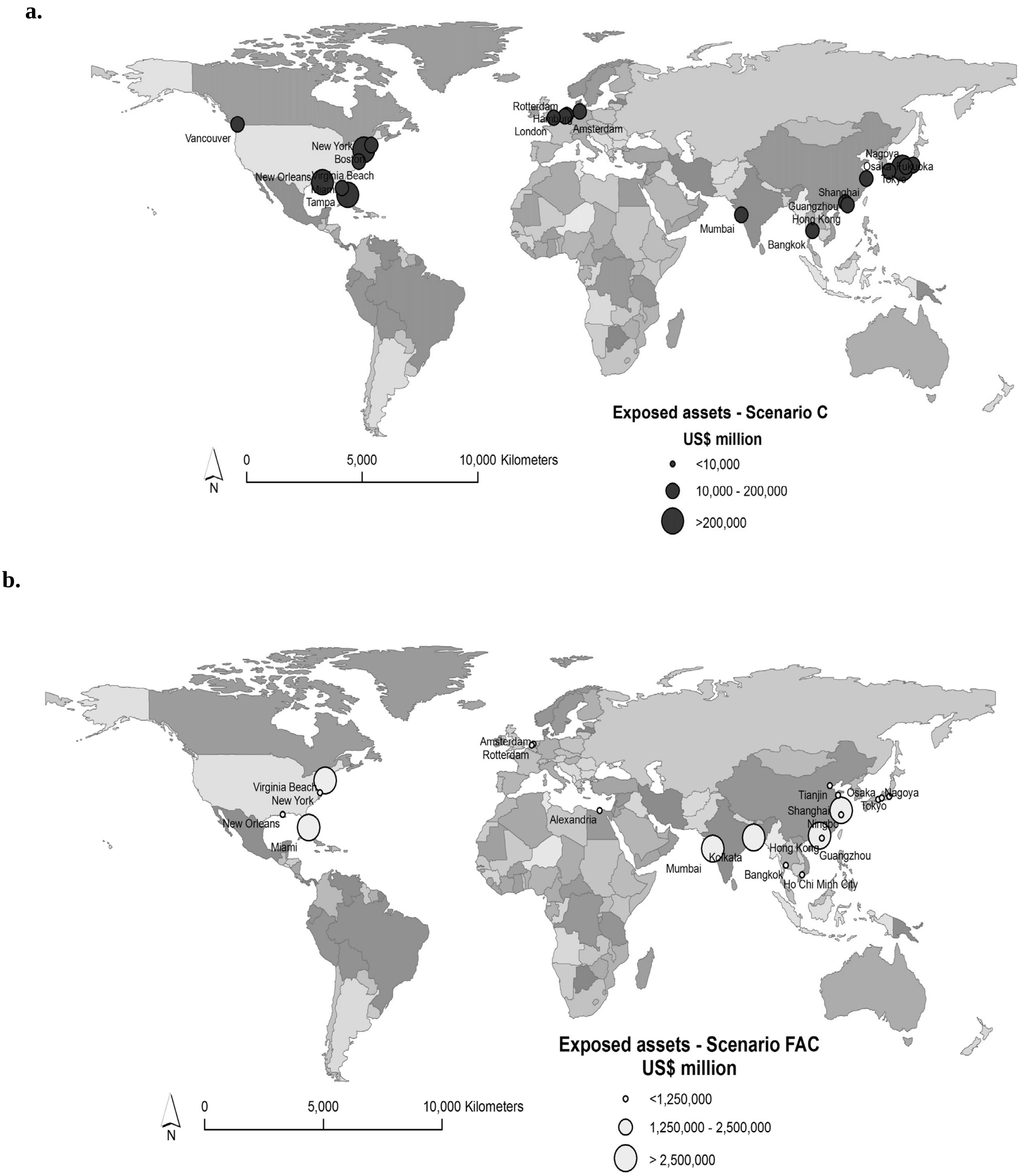

Figure 13. Maps showing the Top 20 cities for exposed assets under (a) scenario C (situation in 2005) and (b) scenario FAC (scenario for the 2070's). Note the different scales in the key.

Figure 14 shows the twenty cities with the greatest increase in population exposed out of the top fifty cities most exposed to present-day extreme sea levels. The top three cities, Dhaka and Chittagong (both in Bangladesh), and Ningbo (China), are all projected to see a ten-fold increase in population exposed. Each of the top twenty are projected to see more than a 200% increase in exposure. These twenty cities are all in developing regions, with 17 being in Asia (four being Capitals), and three being in Africa (two being Capitals). The rapid increase in exposure in these cities reflects the effect of the strong population growth and urbanisation expected throughout Asia.

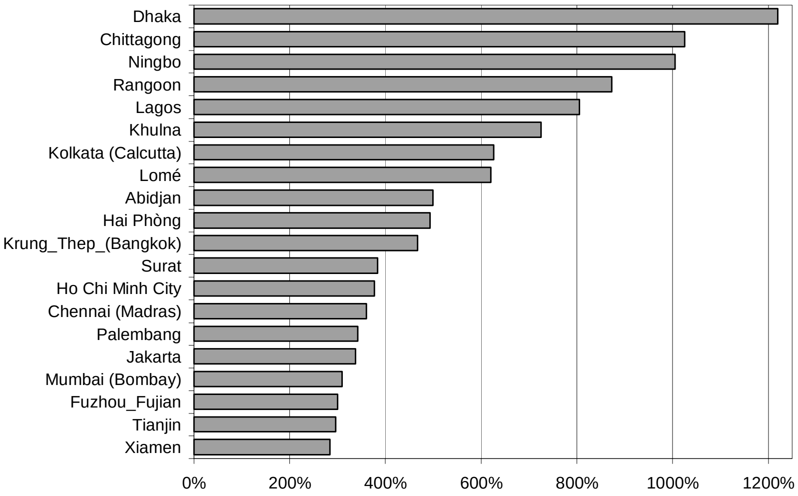

Figure 14. Top 20 cities with the highest proportional increase in exposed population by the 2070s under the FAC scenario (2070's) relative to the C scenario (2005). Cities were selected from the Top 50 cities with the highest exposure in 2005.

A number of other cities, not present in the top fifty for current population exposure, see significant proportional increases in exposure. These include many African cities, such as Mogadishu in Somalia and Luanda in Angola. While these cities are not expected to experience the highest absolute increases in exposure, their significant proportional increase could lead to flood management challenges within the city nonetheless. The highest relative increase is seen in Qingdao in China, which is projected to experience a 2000% increase in exposure (although its absolute exposure is below the Top 20 at 1.8m people).

3.4 Ranking by exposed assets

Exposed assets are also substantial (Figure 9) and increase over time in line with the projected rise in population and GDP. However the cities appearing at the top of the rankings show a different pattern to population exposure. The more wealthy countries (as represented by the GDP (PPP)) currently dominate the rankings. When looking at the assets currently exposed to extreme water levels (scenario C), the Top 10 are all located in the USA, Netherlands or Japan and represent over 60% of the top 50 cities' vulnerable assets. The cities of the Asian developing countries, become more important by the 2070s (Figure 13). Mumbai and Kolkata, which appear at the top of the population rankings, rank much lower for assets, falling just inside the Top 20.

In terms of the percentage increase in assets exposed (Figure 15), all but one of the top twenty cities is an Asian city. The exception is Miami at rank 20. The increases in assets exposed are in round terms an order of magnitude larger than the increases in population exposed. Each of the top ten cities is projected to experience a more than thirty-fold increase in assets exposed. The top three cities, Ningbo (China), Dhaka (Bangladesh) and Kolkata (India), are projected to see a more than sixty-fold increase in exposure. This striking increase in asset exposure is driven by the large increases in wealth and population projected in Asian cities.

As with population exposure, there are a number of cities that experience high proportional increases in assets exposed, while their absolute value of assets exposed is relatively low. Again, this includes a number of African cities, as well as smaller Asian cities. Qingdao is projected to see the largest proportional increase in assets exposed. Unlike population exposure, no cities are expected to see a decrease in assets at risk as wealth increase is projected everywhere.

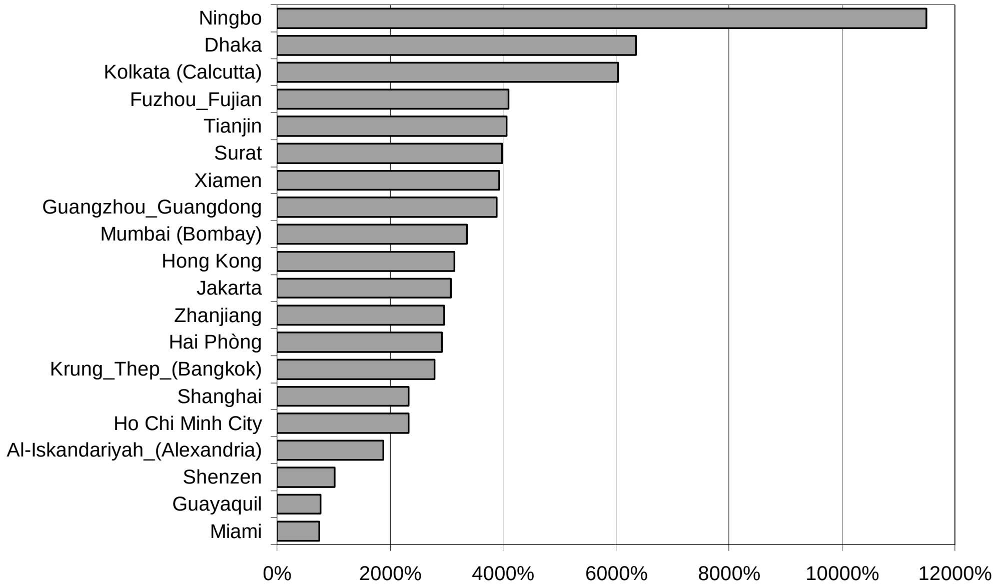

Figure 15. Top 20 cities with the highest proportional increase in exposed assets by the 2070s under the FAC scenario (2070's) relative to the the current situation - C (2005). Cities were selected from the Top 50 cities with the highest exposure in 2005.

				CURRENT CLIMATE CURRENT POPULATION/ASSETS			CURRENT CLIMATE FUTURE POPULATION/ASSET		FUTURE CLIMATE + ANTH SUB FUTURE POPULATION/ASSETS	
				Scenario C			Scenario FNC		Scenario FAC	
Country	Urban Agglomeration	Delta	Pop 2005	Wind Damage Index	Exposed Population (000)	Exposed Assets (US$bil)	Exposed Population (000)	Exposed Assets (US$bil)	Exposed Population (000)	Exposed Assets (US$bil)
INDIA	Mumbai (Bombay)		18196	26	2,787	46.20	9,193	1286.63	11,418	1598.05
CHINA	Guangzhou Guangdong	[D]	8425	24	2,718	84.17	6,391	2076.56	10,333	3357.72
CHINA	Shanghai	[D]	14503	41	2,353	72.86	2,744	891.72	5,451	1771.17
USA	Miami		12298	0	2,003	416.29	3,194	2340.32	4,795	3513.04
VIETNAM	Ho Chi Minh City	[D]	5065	7	1,931	26.86	7,151	506.52	9,216	652.82
INDIA	Kolkata (Calcutta)	[D]	14277	41	1,929	31.99	6,903	966.15	14,014	1961.44
USA	New York-Newark		1010	3	1,540	320.20	2,374	1739.24	2,931	2147.35
JAPAN	Osaka-Kobe	[D]	11268	32	1,373	215.62	1,199	574.26	2,023	968.96
EGYPT	Alexandria	[D]	3770	0	1,330	28.46	3,939	507.20	4,375	563.28
USA	New Orleans	[D]	5434	15	1,124	233.69	1,316	963.98	1,383	1013.45
JAPAN	Tokyo	[D]	35197	100	1,110	174.29	1,283	614.31	2,521	1207.07
CHINA	Tianjin	[D]	7040	0	956	29.62	2,312	751.25	3,790	1231.48
THAILAND	Bangkok	[D]	6593	9	907	38.72	2,392	520.23	5,138	1117.54
BANGLADESH	Dhaka	[D]	12430	35	844	8.43	4,012	195.99	11,135	544.00
NETHERLANDS	Amsterdam	[D]	1147	3	839	128.33	1,361	800.54	1,435	843.70
VIETNAM	Hai Phòng	[D]	1873	5	794	11.04	3,222	228.23	4,711	333.70
NETHERLANDS	Rotterdam	[D]	1101	3	752	114.89	1,313	771.95	1,404	825.68
CHINA	Shenzen		7233	21	701	21.70	651	211.45	749	243.29
JAPAN	Nagoya	[D]	3179	9	696	109.22	1,049	502.39	1,302	623.42
CÔTE D'IVOIRE	Abidjan		3577	0	519	3.87	2,970	135.58	3,110	141.98

Table 2. Top 20 world port cities ranked by population exposure under the current situation (C) and compared to scenarios FNC and FAC (Coloured numbers indicate presence in the Top 20 under relative scenario).

				CURRENT CLIMATE CURRENT POPULATION/ASSETS			CURRENT CLIMATE FUTURE POPULATION/ASSET		FUTURE CLIMATE + ANTH SUB FUTURE POPULATION/ASSETS	
				Scenario C			Scenario FNC		Scenario FAC	
Country	Urban Agglomeration	Delta	Pop 2005	Wind Damage Index	Exposed Population (000)	Exposed Assets (US$bil)	Exposed Population (000)	Exposed Assets (US$bil)	Exposed Population (000)	Exposed Assets (US$bil)
INDIA	Kolkata (Calcutta)	[D]	14277	41	1,929	31.99	6,903	966.15	14,014	1961.44
INDIA	Mumbai (Bombay)		18196	26	2,787	46.20	9,193	1286.63	11,418	1598.05
BANGLADESH	Dhaka	[D]	12430	35	844	8.43	4,012	195.99	11,135	544.00
CHINA	Guangzhou Guangdong		8425	24	2,718	84.17	6,391	2076.56	10,333	3357.72
VIETNAM	Ho Chi Minh City	[D]	5065	7	1,931	26.86	7,151	506.52	9,216	652.82
CHINA	Shanghai	[D]	14503	41	2,353	72.86	2,744	891.72	5,451	1771.17
THAILAND	Bangkok	[D]	6593	9	907	38.72	2,392	520.23	5,138	1117.54
MYANMAR	Rangoon		4107	12	510	3.62	2,894	100.28	4,965	172.02
USA	Miami	[D]	12298	0	2,003	416.29	3,194	2340.32	4,795	3513.04
VIETNAM	Hai Phòng	[D]	1873	5	794	11.04	3,222	228.23	4,711	333.70
EGYPT	Alexandria	[D]	3770	0	1,330	28.46	3,939	507.20	4,375	563.28
CHINA	Tianjin	[D]	7040	0	956	29.62	2,312	751.25	3,790	1231.48
BANGLADESH	Khulna	[D]	1494	4	441	4.41	2,477	121.03	3,641	177.86
CHINA	Ningbo	[D]	1810	5	299	9.26	1,007	327.21	3,305	1073.93
NIGERIA	Lagos	[D]	10886	0	357	2.12	2,488	90.39	3,229	117.32
CÔTE D'IVOIRE	Abidjan	[D]	3577	0	519	3.87	2,970	135.58	3,110	141.98
USA	New York-Newark		1010	3	1,540	320.20	2,374	1739.24	2,931	2147.35
BANGLADESH	Chittagong	[D]	4114	12	255	2.54	1,411	68.93	2,866	140.01
JAPAN	Tokyo	[D]	35197	100	1,110	174.29	1,283	614.31	2,521	1207.07
INDONESIA	Jakarta	[D]	13215	0	513	10.11	1,383	197.60	2,248	321.24

Table 3. Top 20 world port cities in the 2070s ranked by population exposure under scenario FAC and compared to scenarios FNC and current conditions (C) (Coloured numbers indicate presence in the Top 20 under relative scenario).

				CURRENT CLIMATE CURRENT POPULATION/ASSETS Scenario C			CURRENT CLIMATE FUTURE POPULATION/ASSETS Scenario FNC		FUTURE CLIMATE + ANTH SUB FUTURE POPULATION/ASSETS Scenario FAC	
Country	Urban Agglomeration	Delta	Pop 2005	Wind Damage Index	Exposed Population (000)	Exposed Assets (US$bil)	Exposed Population (000)	Exposed Assets (US$bil)	Exposed Population (000)	Exposed Assets (US$bil)
USA	Miami		12298	0	2,003	416.29	3,194	2340.32	4,795	3513.04
USA	New York-Newark		1010	3	1,540	320.20	2,374	1739.24	2,931	2147.35
USA	New Orleans	[D]	5434	15	1,124	233.69	1,316	963.98	1,383	1013.45
JAPAN	Osaka-Kobe	[D]	11268	32	1,373	215.62	1,199	574.26	2,023	968.96
JAPAN	Tokyo	[D]	35197	100	1,110	174.29	1,283	614.31	2,521	1207.07
NETHERLANDS	Amsterdam	[D]	1147	3	839	128.33	1,361	800.54	1,435	843.70
NETHERLANDS	Rotterdam	[D]	1101	3	752	114.89	1,313	771.95	1,404	825.68
JAPAN	Nagoya	[D]	3179	9	696	109.22	1,049	502.39	1,302	623.42
USA	Tampa-St Petersburg		2989	8	415	86.26	579	424.59	730	534.92
USA	Virginia Beach		2252	6	407	84.64	572	419.08	794	581.69
CHINA	Guangzhou Guangdong	[D]	8425	24	2,718	84.17	6,391	2076.56	10,333	3357.72
USA	Boston		2205	3	370	76.81	557	408.16	720	527.70
CHINA	Shanghai	[D]	14503	41	2,353	72.86	2,744	891.72	5,451	1771.17
UK	London		1330	0	397	60.14	129	65.09	174	88.06
CANADA	Vancouver	[D]	2188	6	320	55.25	522	270.91	584	303.04
JAPAN	Fukuoka-Kitakyushu	[D]	2800	8	307	48.26	329	157.37	478	228.88
INDIA	Mumbai (Bombay)		18196	26	2,787	46.20	9,193	1286.63	11,418	1598.05
GERMANY	Hamburg		1740	5	261	39.39	221	109.95	255	127.27
THAILAND	Bangkok	[D]	6593	9	907	38.72	2,392	520.23	5,138	1117.54
CHINA, HONG KONG SAR	Hong Kong		7041	20	223	35.94	531	899.58	687	1163.89

Table 4. Top 20 world port cities ranked by asset exposure for current conditions (C) compared to scenarios FNC and FAC (Coloured numbers indicate presence in the Top 20 under relative scenario).

				CURRENT CLIMATE CURRENT POPULATION/ASSETS			CURRENT CLIMATE FUTURE POPULATION/ASSETS		FUTURE CLIMATE + ANTH SUB FUTURE POPULATION/ASSETS	
				Scenario C			Scenario FNC		Scenario FAC	
Country	Urban Agglomeration	Delta	Pop 2005	Wind Damage Index	Exposed Population (000)	Exposed Assets (US$bil)	Exposed Population (000)	Exposed Assets (US$bil)	Exposed Population (000)	Exposed Assets (US$bil)
USA	Miami		12298	0	2,003	416.29	3,194	2340.32	4,795	3513.04
CHINA	Guangzhou Guangdong	[D]	8425	24	2,718	84.17	6,391	2076.56	10,333	3357.72
USA	New York-Newark		1010	3	1,540	320.20	2,374	1739.24	2,931	2147.35
INDIA	Kolkata (Calcutta)	[D]	14277	41	1,929	31.99	6,903	966.15	14,014	1961.44
CHINA	Shanghai	[D]	14503	41	2,353	72.86	2,744	891.72	5,451	1771.17
INDIA	Mumbai (Bombay)		18196	26	2,787	46.20	9,193	1286.63	11,418	1598.05
CHINA	Tianjin	[D]	7040	0	956	29.62	2,312	751.25	3,790	1231.48
JAPAN	Tokyo	[D]	35197	100	1,110	174.29	1,283	614.31	2,521	1207.07
CHINA, HONG KONG SAR	Hong Kong		7041	20	223	35.94	531	899.58	687	1163.89
THAILAND	Bangkok	[D]	6593	9	907	38.72	2,392	520.23	5,138	1117.54
CHINA	Ningbo	[D]	1810	5	299	9.26	1,007	327.21	3,305	1073.93
USA	New Orleans	[D]	5434	15	1,124	233.69	1,316	963.98	1,383	1013.45
JAPAN	Osaka-Kobe	[D]	11268	32	1,373	215.62	1,199	574.26	2,023	968.96
NETHERLANDS	Amsterdam	[D]	1147	3	839	128.33	1,361	800.54	1,435	843.70
NETHERLANDS	Rotterdam	[D]	1101	3	752	114.89	1,313	771.95	1,404	825.68
VIETNAM	Ho Chi Minh City	[D]	5065	7	1,931	26.86	7,151	506.52	9,216	652.82
JAPAN	Nagoya	[D]	3179	9	696	109.22	1,049	502.39	1,302	623.42
CHINA	Qingdao		2817	4	88	2.72	1,232	400.38	1,851	601.59
USA	Virginia Beach		2252	6	407	84.64	572	419.08	794	581.69
EGYPT	Alexandria	[D]	3770	0	1,330	28.46	3,939	507.20	4,375	563.28

Table 5. Top 20 world port cities in the 2070s ranked by asset exposure under scenario FAC compared to scenarios C and FNC. (Coloured numbers indicate presence in the Top 20 under relative scenario)

3.5 *The potential role of coastal protection*

So far, we have focussed on exposure which ignores the potential benefits of protection in reducing the risks of flooding. Many coastal cities have extensive natural or artificial defences, such as sand dunes or marshes, or dikes or storm surge barriers (e.g. Figure 16). In many low-lying areas within cities, water management and pumped drainage is also essential. While cities often emerge in the lee of natural defences or on relatively high ground, as they grow in size and wealth, there is a trend towards building in more hazardous locations and a growing dependence on artificial defences over time. These defences greatly reduce the risk of flooding, but as already noted, residual risk always remains. Hence, exposure does not automatically translate into risk, and it is important to consider the protection and adaptation strategies which are available for each city. Currently, individual cities such as Amsterdam, Rotterdam, London and Tokyo are known to be protected to better than a 1 in 1,000 year event and the change in exposure numbers for these is shown in Table 6. The standard metric in these cases is the average annual risk of damage, measured in terms of people affected, or assets damage or affected – here we consider affected populations and assets per year. As the defences improve, so the damage in an event is distributed over a longer period, and the average annual damages are reduced substantially as shown in Table 6. It is noteworthy that the risks are relatively high in New York, especially in terms of assets at risk, reflecting the relatively low flood defences. When the increase in water levels due to climate change and subsidence are taken into account for the cities in Table 6, it is estimated that the average annual risks increase dramatically (Table 7).

Figure 16. Thames Barrier, London (Photograph courtesy of the Environment Agency)

The increase in average annual risks reflects estimates of the extreme flood levels in each city from the DIVA database (Appendix 1). Without adaptation, the analysis suggests a massive increase in flood risk in all the cities in Table 6: the change varies from city to city depending on local conditions. Detailed case studies in London (DAWSON *et al*., 2005) and New York (ROSENZWEIG and SOLECKI, 2001) demonstrate that these types of changes are realistic. If defence standards are maintained, flood risk will still rise, but only in proportion to the socio-economic scenarios. Hence to maintain risk at the levels in 2005 requires more than maintenance of defence standards – rather the standard has to also be raised.

City	Current Exposure		Approximate Protection Standard (Return period in years)	Annual Average Risk (Residual Risk)	
	Population (000)	Assets (US$ bil)		Population (000/yr)	Assets (US$ bil/yr)
London	397	60	1:1000	0.3	0.06
Shanghai	2,353	73	1:1000	2	0.07
Osaka	1,373	216	1:300	4.6	0.7
New York	1,540	320	1:100	15	3.2
Tokyo	1,110	174	1:1000	1	0.174
Amsterdam	839	128	1:10000	0.08	0.013
Rotterdam	752	115	1:10000	0.08	0.011
New Orleans	1124	234	1:200[9]	5.1	1.168.4

Table 6. Examples of present estimated average annual risks for selected cities with a known protection standard (Scenario C).

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[9] Following Katrina, it is recognised that the standard of defence that was actually provided was lower.

City	Scenario CAC		Scenario FAC		Scenario FAC (maintain the flooding probability through the improvement of existing defences)	
	Annual Average Risk (Residual Risk)		Annual Average Risk (Residual Risk)		Annual Average Risk (Residual Risk)	
	Population (000/yr)	Assets (US$ bil/yr)	Population (000/yr)	Assets (US$ bil/yr)	Population (000/yr)	Assets (US$ bil/yr)
London	397	60	448	226	0.45	0.23
Shanghai	2353	73	5451	1771	5.45	1.77
Osaka	1373	216	2023	969	6.74	3.23
New York	114	24	216	159	29.31	21.47
Tokyo	1110	174	2521	1207	2.52	1.21
Amsterdam	46	7	79	46	1.44	0.84
Rotterdam	752	115	1404	826	1.40	0.83

Table 7. Examples of average annual risks for selected cities if current defences are not upgraded (Scenarios CAC and FAC), and if current defence standards are maintained relative to rising water levels (with Scenario FAC). (see Appendix 1 for methods)

It is worth noting that the average annual risk can be misleading as the average annual risk will be realised infrequently in well defended areas – and the impacts per flood event will be much higher than the average annual values. Even with high levels of protection today, and assuming no change in risks, the exposed population and assets will be largely flooded if and when the defences fail, especially if the failure mechanism is breaching. In 100 years, there is a 63.4% chance of experiencing a single 1 in 100 year event, a 9.5 % chance of experiencing a single 1 in 1000 year event, and a 1 % chance of a 1 in 10000 year event. Moreover, in a non-stationary world of increasing risks, as we expect through the 21st century, the likelihood of extreme events is rising.

Per capita GDP (PPP) US$	Income classification	Presumed protection standard
>15,000	High	High
15,000 - 3,500	Medium	Medium
>3,500	Low	Limited, ad hoc approach

Table 8. Protection criteria

The detailed information on protection standards in Table 6 is not widely available and we know that many developing countries have much lower defences, if they have formal defences systems at all. A simple qualitative classification, based on the 2005 per capita GDP (PPP), can be used to assess the current ability of the country to adapt its exposed cities against the potential impact of extreme events and recover from disastrous events (following HOOZEMANS et al., 1993; NICHOLLS, 2004). Classification criteria are shown in Table 8 and are broadly in line with the OECD DAC classification (DAC, 2006) of country income. It was then assumed that each income level could provide a given potential protection level for its coastal cities (Table 8).

Number of cities	Exposed population (000s)	Country	GDP CLASS
15	8,154	CHINA	MEDIUM
17	6,538	UNITED STATES OF AMERICA	HIGH
6	5,412	INDIA	LOW
6	3,683	JAPAN	HIGH
2	2,725	VIETNAM	LOW
2	1,591	NETHERLANDS	HIGH
3	1,540	BANGLADESH	LOW
1	1,330	EGYPT	MEDIUM
1	907	THAILAND	MEDIUM
4	700	INDONESIA	MEDIUM

Table 9. Top 10 countries by population currently exposed to a 1:100 extreme event compared to potential to protect

Based on the link between wealth and protection standards, cities in rich countries have much better protection levels than cities in the developing world, and there is significant variation between developing countries. This can be explained by the large cost of protection infrastructures – up to billions of dollars for a single city like London – that make them unaffordable for poor countries, and by the larger value of assets at risk in rich countries that justifies a higher protection level. Also important is the higher risk aversion of richer populations that push local and national authorities to reduce natural hazard risks. It can be expected, therefore, that the economic growth scenario considered here will allow a general improvement in protection levels and a corresponding decrease in flooding risks in coastal cities around the globe (NICHOLLS, 2004; NICHOLLS *et al.*, 2007a).

Compared with the number of currently exposed people (Table 9), the GDP classification indicates that of the Top 10 countries, the USA and the Netherlands are the only ones considered capable of providing high protection against an extreme event. By comparison India, Vietnam and Bangladesh are only likely to be able to provide limited protection for their population, and disaster recovery would be especially challenging and probably depend on donor support. In total, across the full set of port cities, 26 cities with a total exposed population of 11.4 million people (Scenario C) are located in countries classified as ‘low income’. These are shown in Table 10 – 14 in Asia, 11 in Africa and one in the Caribbean. While these cities have a low asset exposure and sometimes a low population exposure, there is concern about the human impacts of flooding, including the threat to life.

Country	Agglomeration	Per capita GDP (PPP)	GDP Class	Exposed Population (000s) (Scenario C)
INDIA	Chennai	3,316	LOW	1
	Kochi	3,316	LOW	255
	Kolkata	3,316	LOW	844
	Mumbai	3,316	LOW	441
	Surat	3,316	LOW	11
	Visakhapatnam	3,316	LOW	519
ANGOLA	Luanda	2,829	LOW	22
VIETNAM	Hai Phòng	2,782	LOW	14
	Ho Chi Minh City	2,782	LOW	41
GHANA	Accra	2,601	LOW	1
PAKISTAN	Karachi	2,549	LOW	159
CAMEROON	Douala	2,284	LOW	94
BANGLADESH	Chittagong	1,998	LOW	1,929
	Dhaka	1,998	LOW	2,787
	Khulna	1,998	LOW	418
GUINEA	Conakry	1,986	LOW	25
SENEGAL	Dakar	1,914	LOW	61
DEM Republic of Korea	N'ampo	1,800	LOW	510
HAITI	Port-au-Prince	1,688	LOW	357
TOGO	Lomé	1,600	LOW	49
CÔTE D'IVOIRE	Abidjan	1,493	LOW	18
MYANMAR	Rangoon	1,417	LOW	9
MOZAMBIQUE	Maputo	1,335	LOW	119
NIGERIA	Lagos	1,188	LOW	36
UNITED REPUBLIC OF TANZANIA	Dar-es-Salaam	720	LOW	794
SOMALIA	Muqdisho_(Mogadishu)	600	LOW	1,931

Table 10. Cities in countries classified as having a limited capacity to protect based on GDP class

Note that the relationship between wealth and protection is not automatic. Even though rich countries have a larger capacity to protect their cities, they may or may not choose to do so. For instance, Amsterdam, Rotterdam, London and Tokyo, cities where GDP per capita is between $30,000 and $38,000, are protected to better than a 1 in 1,000 year event (Table 6). But Greater New York, in spite of a higher national GDP per capita in the U.S. ($42,000), is protected to a lower standard of about 1 in 100. Shanghai, with the lower Chinese national GDP (PPP) per capita ($6,193), has a better protection level than New York, with defences similar to London. However, in New York the capacity for disaster recovery is large compared to poorer cities. These examples highlight that protection levels depend not only on wealth, but also cultural, political and historic factors making projecting protection levels up to the 2070s problematic. It can be argued that protection levels are likely to be improved at the global scale, but no prediction for a particular city can be easily proposed, especially given the lack of comprehensive data on past investments in coastal flood protection. This is an important issue for further research.

3.6 Risk Management Strategies

The available risk management strategies include a combination of:

(i) Upgraded protection;

(ii) Managing subsidence (in susceptible cities);

(iii) Land use planning, focusing new development away from the floodplain;

(iv) Selective relocation away from existing city areas; and

(v) Flood warning and evacuation.

Relocation seems unlikely for valuable city infrastructure, and a portfolio of the other approaches could act to manage and reduce risks to acceptable levels. Generally, a combination of spatial planning and enhanced defences is required in all coastal cities. Improved protection infrastructures and flood defences would reduce risks, because they would avoid impacts during the most frequent events, whose intensity is below the defence protection level. It has to be mentioned, however, that defences do not reduce the consequences of an event with an intensity which is significantly larger than the defence protection level: defences reduce probability of flooding but do not reduce losses in case of overtopping and breaching. Also, as shown by Katrina in New Orleans, when defences fail, the event can be catastrophic and trigger permanent city decline. For instance, after Hurricane Hazel in the 1960s, New Orleans never recovered its population and Hurricane Katrina in 2005 may continue this trend (GROSSI and MUIR-WOOD, 2006). Finally, even if upgraded protection investments maintain the probability of flooding (e.g. 1 in 1,000 year event), the losses caused by an event exceeding this design level will tend to increase with sea-level rise and subsidence as flood depths rise. Flood warnings and evacuation plans are one strategy to minimise risks to human life in this situation, but will do little to change risks to assets.

So, in addition to directly defending cities, the issue of the management of residual risk needs to be considered and a proactive strategic approach will be necessary to minimise the exposure to coastal disasters[10]. A factor for reducing exposure in many locations, but especially in cities built on deltas, is the minimisation of human-induced subsidence. Enforced policies to minimise future subsidence, such as the reduction of ground water extraction, as already found in the Netherlands, Shanghai and major cities in Japan (NICHOLLS, 1995), could reduce future exposure and risk sea level rise and storm surge. This is particularly important in Asia, with its concentration of deltaic cities.

3.7 Exposure to Wind Damage

Table 11 gives the Top 20 cities ranked in terms of their present-day exposure to wind damage. The table shows the tropical and extratropical cyclone hazard for each city, along with a simple wind damage index that captures the effect of hazard and population exposed. Nine of the Top 20 cities exposed to high wind hazards are in developed countries including Japan, the USA, Australia and the UK. Tokyo has by far the greatest exposure to wind damage, due to a combination of its high tropical cyclone hazard and its high population. Five of the Top 20 are situated in the USA, all of which are exposed to tropical cyclone hazard. Only three of the Top 20 cities enter the rankings due to their extratropical cyclone hazard alone.

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[10] It should be noted that risks can only be minimised and can never be totally eliminated, except by relocation of the city and its inhabitants out of the risk zone.

EXPOSURE TO PRESENT-DAY WIND DAMAGE				
Rank	**City**	**Tropical Cyclone Hazard**	**Extratropical Cyclone Hazard**	**Wind Damage Index**
1	Tokyo	2	0	100
2	New York-Newark	1	1	53
3	Shanghai	2	0	41
4	Kolkata (Calcutta)	2	0	41
5	Dhaka	2	0	35
6	Osaka-Kobe	2	0	32
7	Manila	2	0	30
8	Mumbai (Bombay)	1	0	26
9	London	0	2	24
10	Guangzhou_Guangdong	2	0	24
11	Shenzen	2	0	21
12	Hong Kong	2	0	20
13	Chennai (Madras)	2	0	20
14	Buenos Aires	0	1	18
15	Karachi	1	0	16
16	Miami	2	0	15
17	Philadelphia	1	1	15
18	Boston	1	1	12
19	Sydney	0	2	12
20	Houston	2	0	12

Table 11. **The Top 20 world port cities in terms of population exposed to present-day wind damage (measured by a wind damage index). Shaded in light grey are those cities that also appear in the Top 20 in terms of population exposed to present-day extreme sea levels. Each of these cities (with the exception of Shenzen) also appear in the Top 20 rankings for future population exposure.**

Each of these cities, except Sydney and Buenos Aires, are assumed to experience an increase in storm surge height driven by increased storm intensity in the future sea level exposure analyses. Based on recent scientific literature, storm surge heights in Sydney and Buenos Aires are here assumed to remain unchanged (in the exposure analyses) due to the competing effects of the increase in storm intensity and reduced frequency associated with the poleward movement of storm tracks (Appendix 1).

Ten of the cities in the Top 20 are also among the Top 20 cities exposed to present-day extreme sea levels, including Tokyo, New York, Shanghai, Kolkata, Dhaka, Osaka, Mumbai, Guangzhou, Shenzen and Miami. This is to be expected given the relationship between local storm surge heights and storminess, but nonetheless highlights the additional risks facing these cities. All except Shenzen have also been identified as having high (Top 20) exposure to future extreme sea levels.

The MUNICH RE (2004) study highlights Dhaka and Kolkata as also having 'high' risk associated with inland flooding, and Shanghai, Osaka and Mumbai has having 'medium' risk. These risks are not investigated here, but must be considered when evaluating the full vulnerability of cities to future climate change and developing effective risk management strategies. These cities exposed to a combination of natural perils are potentially extremely susceptible to climate change.

4. Discussion and concluding thoughts

This global screening study has made a first estimate of the exposure of the world's 136 large port cities to coastal flooding due to storm surge and damage due to high winds. As such, it has achieved its goal of identifying broad-scale patterns of population and asset exposure in port cities and how they might change to the 2070s as economies and urban populations grow and the climate changes. It also provides a basis for targeting further more detailed city-scale investigations in key locations. In particular, this study investigates how climate change is likely to impact each port city's exposure to coastal flooding, alongside natural and anthropogenic subsidence, population and economic growth, and urbanisation.

Through assessing a larger number of cities than previous analyses (e.g. MUNICH RE, 2004; NICHOLLS, 1995), this study recognises the risks to cities with large areas in the floodplain, but also, importantly, risks facing the emerging large cities of the 2070s. Nonetheless, it should be recognised that these are preliminary results and much work remains to extend our understanding. Future work will need to target improving city data, where possible, as well as assessment of risk management strategies, most notably of the cost and effectiveness of adaptation options, including protection, and of residual risk to population and assets in port cities.

A key result of the study is that socio-economic changes are the most important driver of the overall increase in both population and asset exposure and that climate change and subsidence have the potential to significantly exacerbate this effect. This is consistent with earlier analyses (e.g. NICHOLLS, 2002; e.g. NICHOLLS *et al.*, 1999). However, at the individual city scale, the relative influence of the different change factors is dependent on the individual city's situation. In general, socioeconomic changes are proportionately more important in developing regions, whereas environmental factors are proportionately more important for developed countries (where population and economic growth are expected to be smaller). The influence of human-induced subsidence due to shallow ground-water extraction and drainage can also be important, especially in cities that are rapidly developing in deltaic settings, such as Shanghai and Ho Chi Minh City among many coastal cities in Asia. By understanding the drivers of increases in exposure in a city, more effective adaptation plans can be put in place.

This study also underlines the vulnerability of several of the rapidly developing cities to future sea level rise. 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. Katrina and New Orleans demonstrates how significant these consequences might be – 1,500 deaths, evacuation of 700,000 people, with hundreds of thousands still displaced two years on, massive flood damage from which recovery is still ongoing, and the global shock to the oil price (GROSSI and MUIR-WOOD, 2006; HALLEGATTE, 2006; NICHOLLS *et al.*, 2007b; WILBANKS *et al.*, 2007). New Orleans may never fully recover and another major hurricane landfall could trigger further decline or even total abandonment. Given the large and growing concentration of people and assets in port city locations, and the importance of global trade, failure to develop effective adaptation strategies would inevitably have not just local but also large national and even wider economic consequences.

Considering adaptation to flooding, it must be emphasised that exposure does not automatically translate into impact. The linkage between exposure and the risk of impact depends upon flood protection measures. In broad terms, cities in richer countries have better protection levels than those in the developed world, and they also have access to greater resources for disaster recovery (although the asset losses may be much higher). For example, wealthy cities with high asset values like London, Tokyo and Amsterdam are already 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 reflects both benefit-cost rationale and the higher risk aversion of richer populations that push local and national authorities to reduce natural risks. However, there are exceptions and New York has rather low defences for such a rich city, while Shanghai has defences comparable with London. These examples highlight that protection levels depend not just upon wealth but also upon cultural, political and historical issues. This makes projecting protection levels in the long-term difficult, and hence we have not attempted to develop individual city estimates of protection standard in this preliminary assessment. 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, if this is recognised as a priority. Of immediate concern are the 26 port cities in low income countries with a combined exposed population of approximately 11 million people.

It is important to note that, even if all cities are well protected against extreme events, large-scale city flooding may remain frequent at the global scale because so many cities are threatened. 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 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 large port cities frequently. As a consequence, even assuming that protection levels will be very high everywhere in the future, the large exposure in terms of population and assets is likely to translate into regular city-scale disasters across the global scale. This fact 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.

While the results are preliminary, the policy implications of this report are clear: the benefits of climate change policies at city-scale are potentially great, with policies necessarily including both global mitigation and local adaptation. As reported in the IPCC Fourth Assessment Report, global mitigation will slow and limit the exacerbating effects of climate change on coastal flood risk, at a minimum buying precious time for cities to put adaptation strategies in place (NICHOLLS *et al.*, 2007b). Cities are also responsible for the majority of greenhouse gas emissions and are thus key actors in the design and implementation of mitigation strategies. The results of this study provide a useful vehicle to communicate with decision-makers about the interactions of climate change with future development in the coastal regions of the world.

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 potential port city asset exposure on its own (i.e. up to US$35,000 billion in 2070s, in PPP, 2001USD) argues for a much more focused effort across all scales of governance -- from global to local and public to private -- to advance portfolios of adaptations to manage these risks in port cities (cf. EVANS *et al.*, 2004; THORNE *et al.*, 2007).

This report highlights that a strategic approach will be necessary to minimise the likelihood of coastal disasters[11]. Aside from global mitigation, adaptation to reduce risks is an obvious strategy. While there are many available coastal adaptation options (KLEIN *et al.*, 2001), the most effective adaptation policy options include a combination of (1) upgraded protection, (2) managing subsidence (in susceptible cities), (3) land use planning, focusing new development away from the floodplain, and (4) selective relocation away from existing city areas. For human-induced subsidence the increased risk could be mitigated to some degree by avoiding the processes that lead to shallow subsidence, such as groundwater withdrawal, alongside urban water demand management. Several Asian cities appear to have successfully implemented such policies including Tokyo, Osaka-Kobe and Shanghai (NICHOLLS, 1995). Relocation seems unlikely for valuable city infrastructure, however a portfolio of the other approaches could act to manage and reduce risks to acceptable levels. Flood warning and evacuation also may have an important role.

For cities with large areas at or below mean sea level, flooding can be catastrophic as they need to be pumped dry after a flood, as illustrated in New Orleans in 2005. If cities remain in these areas, the residual risk needs to be carefully evaluated and defences and drainage carefully reviewed: two cities where this issue is relevant today is Guangzhou and Alexandria, but the issue is likely to become more widespread through the 21st century.

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. The 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. In deltaic port cities in particular, changes to river flooding could be an important additional contribution to growing risk.

However, putting into place effective disaster management strategies, safer land use choices, more resistant infrastructure, and protection investments will take time. Building and other urban infrastructure lifetimes range from 30 to 150 years. Previous coastal defence projects (e.g., the Thames Barrier) have shown that implementing coastal protection infrastructure typically has a lead-time of 30 years or more (e.g. GILBERT and HORNER, 1984). The inertia of the socio-economic responses suggests that action must begin today to protect port cities and to manage flood risk for impacts expected by the middle of this century.

All 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. Proactive adaptation will require strengthening adaptive management and governance capacity to manage increasing risks in port cities. This must include more effective partnerships with national governments and other stakeholders to facilitate the transition towards safe urban development in large port cities and to eventual disaster management in the event of flooding.

The concentration of the majority of exposure in a few of the world’s cities and nations there is an urgent need for leadership and attention in these locations. Such action could inform effective management responses and create a knowledge base that could help to advance action in many other locations in the coming decades.[12]

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[11] It should be noted that risks can only be minimised and can never be totally eliminated, except by relocation of the city and its inhabitants out of the risk zone.

[12] A good example is the Thames Estuary 2100 (TE2100) Project which has been planning London’s response to flooding through the 21st Century since about 2000 (LAVERY and DONOVAN, 2005; RAMSBOTTOM and LAVERY, 2007). The goal is to deliver improved defences and other management by 2030 when the protection from the Thames Barrier is expected to fall design standard of 1 in 1000.

5. Next steps

These rankings can be used to select case studies for more detailed analysis. They can also be developed to provide more detailed rankings of vulnerability to a wider range of scenarios and drivers. Key steps could be as follows:

- Better quantify the risk at regional scale of climate change in the form of sea level risk and storm surge taking into account a fuller range of possible climate change outcomes, i.e. to include lower levels of climate change consistent with an aggressive global mitigation of greenhouse gas emissions and to higher levels of climate change due to a higher emissions scenario.

- Develop a better understanding of the impact of future socio-economic development pathways including urbanisation, rising populations, increasing asset values and changes in water supply and use patterns (which affects subsidence and effective sea level rise in any location) their relative effect on risks from climate change and these port city rankings. For example, assuming that investments in flood defence increase with wealth, implies that rapid economic development could reduce vulnerability in many countries, especially the poorest. Hence, the future vulnerability to extreme climate events may be strongly dependent on the socio-economic scenario of the future. A sensitivity analysis would be particularly interesting to assess how protection levels may change with socio-economic development and evaluate how this would affect risks.

- Develop a better understanding of adaptation responses to these hazards, especially the cost and effectiveness of protection, adaptive capacity including behavioural and institutional barriers to cost-effective adaptation. This would provide a stronger empirical basis for analysis of protection;

- Develop rankings for other climate extremes that might affect these cities such as flash floods, river floods, heat wave, wind and storm damage), and ultimately an aggregate index.

APPENDIX 1 – DATA AND DETAILED METHODOLOGIES FOR EXPOSURE ANALYSIS

City selection and port definition

City selection was undertaken using the population figures from the UN World Urbanization Prospects (UN, 2005). The longitude and latitude of cities were then used to determine those with both a coastal location and a known port. Ports were classified by type and size.

The characteristics of each port were defined from a number of data sources. Some data on container traffic was obtained from the Institute of Shipping Statistics Shipping year books, but this did not have universal coverage and noted that cargo comparisons should be made with caution since tonnage and Tonnage Equivalent Units (TEUs) measures are not directly comparable and cannot be converted to a single, standardised unit. Information on the type and size of port associated with each city was therefore obtained from www.worldportsource.com. Contact with the creator of the database confirmed that this information was qualitative but the classifications of port type and size were still considered useful for this project. From these classifications, all cities selected by population were found to be port cities of one type or another.

Defining the city population

The UN city data was not used directly for the population exposure calculations[13]. Instead, population data for the selected cities were taken from Landscan 2002 and constrained using city extents from post code data. Postcodes were largely taken from RMS geocoding data and, in the USA, Metropolitan Statistical Areas (MSAs) from Census. Where postcode data were unavailable, internet-based city maps were used. The 1km resolution Landscan 2002 data was resampled to 100m for all cities, with the exception of those in the USA and UK, which were resampled to 30m.

To establish whether the postcode data captured the extent envisaged by the UN data, the two data sets were compared. This analysis indicated that the derived population figures for the cities are largely within +/- 10% of the UN 2005 figures. The notable exceptions are Luanda (Angola), Lima (Peru), Benghazi (Libya) where Landscan values were smaller, and Kuala Lumpur (Malaysia) where Landscan values were higher. These differences are presumed to be related to the spatial extent of the UN urban agglomeration and the fact that city boundaries and populations may alter over time. As these cities do not appear to be especially vulnerable, this is not considered to be of great concern.

Calculation of population distribution by elevation

For most countries, the analysis used 90m resolution topographic data from the Shuttle Radar Topography Mission (SRTM). However, for the USA, 30m SRTM data and for the UK, a 10m Digital Elevation Model (DEM) (provided by Infoterra) was available.

For each of the port cities, the population distribution within the postcode-defined areas were mapped onto the relevant Digital Terrain Model (DTM), giving a horizontal map of geographical cells with defined population and elevation. From this, the total populations within 1m vertical bands were extracted.

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[13] In addition to the intrinsic limitations of the UN (UN, 2005) population data, a major limitation of this data is the lack of spatial information on the extent of the identified agglomeration. For example, while for some areas, the data relates to entire administrative divisions composed of a populated centre and adjoining territory, others may include separate urban localities with variable population density which is important to capture in an analysis of this type. Hence, alternative GIS data had to be sourced.

Exposure to Wind Damage

Tropical cyclone (TC) hazard

Cities are given a TC hazard between zero and two according to their present-day hazard (Table A.1). The rating is based on historical activity (based on economic loss data[14] and storm track records[15]) and the present-day hazard based on Munich Re[16] data.

Tropical Cyclone Rating	Hazard Level	Description
0	None	Zero/negligible historical TC activity and no TC hazard
1	Moderate	History of TC activity and/or level 1 100-yr probable maximum intensity based on Saffir-Simpson scale.
2	High	History of TC activity, level 2 or above 100-yr probable maximum intensity based on Saffir-Simpson scale, and storm surge hazard

Table A.1: Rating system for TC hazard

Extratropical cyclone (ETC) hazard

Cities are given a rating for ETC hazard between zero and two (Table A.2). The rating represents the present-day hazard, based on Munich Re data.

Extratropical Cyclone Rating	Hazard Level	Description
0	None	No ETC hazard
1	Moderate	“Medium-high” extratropical storm intensity
2	High	“High – very high” extratropical storm intensity

Table A.2: Rating system for ETC hazard

Wind damage index

A ranking for wind damage was created to give an indication of the relative exposure of a city to TC and ETC hazards. The ranking is the sum of the ETC and TC ratings for a city weighted by its total population, and normalised to give a value between zero and a hundred.

Exposure to Extreme Sea Levels

Data Sources

Data and estimates on present-day extreme sea levels, coast protection standards and other coastal characteristics data were obtained mainly from the database of the DIVA (Dynamic Interactive Vulnerability Assessment) model (DINAS-COAST CONSORTIUM, 2006) available at http://www.civil.soton.ac.uk/diva/. This is a global analytical database which is based on a vector model of linear coastal segments determined by variations in population density, administration boundaries, geomorphic structure of the coast, and expected coastal morphological change given sea-level rise (MCFADDEN *et al.*, 2007). The database contains about 100 parameters on 12,148 segments around the

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[14] Center for Hazards and Risk Research (CHRR), Columbia University; Center for International Earth Science Information Network (CIESIN), Columbia University; International Bank for Reconstruction and Development/The World Bank; United Nations Environment Programme Global Resource Information Database Geneva (UNEP/GRID-Geneva), 2005, Global Cyclone Hazard Frequency and Distribution, http://www.ldeo.columbia.edu/chrr/research/hotspots/

[15] Storm tracks based on data from the US National Hurricane Centre and Joint Typhoon Warning Centre: http://commons.wikimedia.org/wiki/Image:Global_tropical_cyclone_tracks-edit2.jpg

[16] Munich Re, Natural Hazards Assessment Network, http://mrnathan.munichre.com/

worlds coasts, including storm surge, tidal range and natural subsidence attached to each segment (VAFEIDIS *et al.*, 2005; 2007). A single coastal segment was used to represent each port location. As a port extent may comprise multiple segments (e.g. Vancouver), the most representative segment was selected.

***Calculation of future water level*s**

Water levels for the three sea-level scenarios (see Table 1) were calculated as shown below. The factors introduced into the calculation are described below. Note that all factors, with the exception of $SLR_{2070s,}$ are dependent on the city.

Scenario (i): $WL = S100$ (Eq 1)

Scenario (ii): $WL = SLR_{2070s} + (x \times S100) + SUB_{NATURAL}$ (Eq 2)

Scenario (iii): $WL = SLR_{2070s} + (x \times S100) + SUB_{NATURAL} + SUB_{ANTHROPOGENIC}$ (Eq 3)

Where:

WL = Water level

$S100$ = 1 in 100 year extreme water level

x = "storm enhancement factor"

SLR_{2070s} = Global mean sea level rise in 2070s (relative to current levels)

SUB_{NATURAL} = Total natural subsidence in 2070s(relative to current levels)

$SUB_{\text{ANTHROPOGENIC}}$ = Total human-induced subsidence in 2070s(relative to current levels)

Tidal range and storm surge (inc. S100) values

For each segment, tidal range (classified as micro/meso/macro or hyper) and extreme water level data for both one (S1) and a hundred (S100) return periods were recorded from the DIVA database.

Future "storm enhancement factor" (x)

For the future exposure scenarios, S100 was scaled to illustrate the effect of potential changes in tropical and extratropical storm intensity and frequency under climate change in different regions. Future changes in storm characteristics remain highly uncertain and therefore, these scenarios should be treated as an indicative sensitivity test on future exposure, based on current scientific understanding.

The scaling factor, or "storm enhancement factor", was prescribed based on the individual tropical and extratropical cyclone ratings for each city.

For cities exposed to present-day tropical cyclone hazard (only), S100 is assumed to increase by 10% (i.e. $x = 1.1$). This scale factor was defined based on current scientific understanding of the influence of climate change on tropical cyclones. The Working Group I contribution to the IPCC Fourth Assessment Report (AR4) (SOLOMON *et al.*, 2007), concluded that "based on a range of models, it is *likely* [i.e. greater than two-thirds chance] that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation". The scale of intensity increases is more uncertain. Higher resolution models, as used by KNUTSON and TULEYA (2004) and OOUCHI *et al*. (2006), suggest that peak wind speeds could increase by 6% and 14%, respectively, towards the end of the century (under similar medium emissions scenarios). Estimates of future changes in the frequency of tropical cyclones are less consistent and vary greatly between regions. As a sensitivity test, in this study, an intensity increase of 10% is assumed, consistent with intensity projections given by KNUTSON and TULEYA (2004). Since no reliable information is available for changes in frequency and geographical location of tropical cyclones, these are assumed to remain unchanged.

The 100-year extreme water height is assumed to scale linearly with tropical cyclone intensity. A number of studies have attempted to estimate future changes in storm surge heights from projections of changes to cyclone characteristics (e.g. see Box 11.5 of IPCC 2007). The most relevant here is WALSH and RYAN (2000), which examines the effect on storm surge height of changes in tropical cyclone intensity (with no change in frequency or location) for North East Australian. They find that a 10% increase in tropical cyclone intensity leads to a roughly 10% increase in 100-year storm surge height. Our assumption is in line with this result.

For cities exposed to present-day extratropical cyclone hazard, we introduce a geographic dependence on the scaling factor, again based on current scientific understanding. Estimates of future changes in extratropical cyclones remain uncertain and projections vary greatly between regions. A consistent result is that the mid-latitude storm tracks are expected to shift poleward by several degrees in a warmer climate (IPCC 2007). Modelling studies presented by BENGTSSON *et al.* (2006) and YIN (2005) suggest an increase in extratropical cyclone activity in the range 45° - 70° (with longitudinal variability) and decrease outside of that range. While some studies suggest little other change in extratropical cyclone characteristics, many indicate individual regions experiencing an increase in the number of intense storms and a decrease in the overall number of storms (similar to tropical cyclones), but few consistent estimates exist. The poleward shift in extratropical storm tracks and increase in cyclone intensity is roughly consistent with modelling by WANG *et al*. (2004), WANG and SWAIL (2006A; 2006B) and CAIRES *et al.* (2006) which suggest an increase in extreme sea level height in many mid-latitude regions. In addition, studies of future storm surge heights indicate a strong longitudinal variability in changes (e.g. CAIRES *et al.*, 2006; LOWE and GREGORY, 2005), however, a consistent picture of longitudinal changes is still unavailable.

To represent the poleward shift in storm tracks and potential increase in extratropical cyclone intensity, the 100-year storm surge height is assumed to increase by the same magnitude as for tropical storms (i.e. 10%) for cities within the latitude band 45° - 70° and with non-zero extratropical cyclone hazard. This magnitude of change is roughly in line with the scales projected by modelling studies (e.g. CAIRES *et al.*, 2006; LOWE and GREGORY, 2005). Cities outside of that latitude band are assumed to experience no change in 100-year storm surge height, which aims to represent the competing influences of an increase in intensity and reduction in frequency.

Global mean sea level rise in 2070s (SLR_{2070s})

The mean sea level rise in the 2070s is uniform across all cities and assumed to be 0.5m (above present-day levels). This assumption is based on RAHMSTORF (2007), which uses a semi-empirical model to project future global mean sea levels based on the past relationship between temperature and sea level changes. On medium assumptions, Rahmstorf projects that global sea levels will rise by around 0.5m (above the 1990s level) by the 2070s. Based on his study, our 0.5m level could also be considered an upper bound estimate for the 2050s and a lower bound estimate for the 2090s.

We note that Rahmstorf's sea level rise estimates are higher than those reported by IPCC (2007), which are based on climate models and do not include estimates of future contributions from the major ice sheets. Based on IPCC (2007), a scenario of 0.5 m would be a medium-high estimate for the 2090s. Note that the scenario used here is within the range reported by the IPCC Third Assessment Report (CHURCH *et al.*, 2001) and is not inconsistent with IPCC (2007) if all the uncertainties are considered (CHURCH *et al.*, 2007). Hence, estimates based on RAHMSTORF (2007) were used as these implicitly take into account the contributions from ice sheets that have proved important over recent decades (e.g. IPCC 2007, Table SPM-1).

Subsidence ($SUB_{NATURAL}$ and $SUB_{ANTHROPOGENIC}$)

The annual rate of natural subsidence/uplift was taken directly from the DIVA database and is based on a combination of glacial-isostatic adjustment from Peltier (2000) with an adjustment for natural subsidence in deltaic areas (Vafeidis *et al.*, 2005). These values were used to calculate a total amount of subsidence/uplift for the 2070's and then transform the uniform global sea-level rise scenario to a spatially variable, relative sea-level rise scenario, including these natural changes.

The potential for anthropogenic subsidence is not included within the DIVA database and an alternative global source was not available. Supported by information from published sources on anthropogenically-induced subsidence (e.g. Chatterjee *et al.*, 2006; Ericson *et al.*, 2006; Hu *et al.*, 2004; Kooi, 2000; Nicholls, 1995; Rodolfo and Siringan, 2006), an approach based on the geology/morphology of the area was therefore adopted. Deltaic settings are the areas where significant surface subsidence is most likely due to groundwater extraction and/or drainage. For the 37 cities in this situation, a fixed uniform amount of potential subsidence of 0.5 m over the seventy years was applied across the entire city, as a scenario of major human-induced subsidence. (It should be noted that in historic cases during the 20th Century, subsidence has been spatially variable with a maximum subsidence of up to 5 m in Tokyo, and 3 m in Shanghai and Osaka (Nicholls, 1995) – a uniform 0.5 m rise is a reasonable first order approximation to the amount of possible change. In a few non-deltaic areas (e.g., Houston, Texas), significant subsidence is known to be possible and a uniform 0.25 m rise was applied, which is half the deltaic rate of subsidence.

Calculation of population exposed and population at risk

Using the population distribution by elevation, the population 'exposed' below the contour defined by the extreme water level was estimated. This corresponded to the 100 year event for each scenario. As appropriate, the population below the 0.5 m elevation relative to mean sea-level rie was also estimated to look at the population most threatened if defences fail.

The population 'at risk' considers the likelihood of flooding based on the estimated protection standard. In future scenarios, to determine effect of a change in extreme water level on the protection standard, assuming no improvements/upgrades to the defences, the following equation was used:

$$\text{Reduced protection standard} = 10^{R}$$

$$\text{Where R} = \log\left(P_s\right) - 2\left(\Delta WL \middle/ S100 - S1\right)$$

P_s = Original protection standard (Eq 4)

ΔWL = Increase in extreme water level

$S100$ = 1 in 100 year storm surge height

$S1$ = 1 in 1 year storm surge height

The population at risk for each city was calculated using the equation below:

$$\text{Population at risk} = E_p \times {}^{1}\!/_{P_s}$$

Where; (Eq 5)

E_p = Exposed population

P_s = Protection standard

Calculation of assets exposed

National per capita GDP Purchasing Power Parity (PPP) values for 2005 were obtained from the International Monetary Fund database (available online at www.imf.org). PPP values were used as this is a standardised value and is recognised as a good indicator for economic comparison. Per capita GDP is assumed to be equal throughout the country thus urban GDP per capita equals rural GDP per capita in a given year. For future cities, the relationship is also assumed to hold (see below).

The assets exposed and at risk were calculated directly from the population measures using a simple relationship between exposed population, GDP per capita and exposed assets (Equation 6).

$$E_a = E_p \times GDP_{percapita(PPP)} \times 5 \qquad \text{(Eq 6)}$$

Where;

E_a = Exposed assets

E_p = Exposed population

The factor of five translates per capita GDP, i.e. the annual production of the economy divided by population, to the per capita value of assets. This value can be derived from simple analyses, and from previous experience. First, annual investments usually represent, on average, about 25 percent of GDP. Since economic assets in cities include buildings, transport infrastructures, utility infrastructures, and other long-lived assets, assuming a lifetime of 40 years for these investments is acceptable. Assuming that per capita asset value in the city is growing by 3 percent a year, a rapid calculation suggests that the value of these assets is between 4 and 5 times per capita GDP. Consistent with this calculation, previous experience of RMS (i.e. studies of historical losses from flooding events), shows that, in general, losses from flood events are around five times greater than the GDP of the affected population. This factor of five, however, does not take into account the greater GDP contribution and assets at risk in cities (compared to other areas) and therefore, may underestimate the assets at risk particularly for less developed regions, where there is a greater inequality between cities and rural areas.

Future cities: population, urbanisation and GDP

Population and GDP projections

To consider the exposure and vulnerability to climate change of cities in a 2070s "future world", the investigation uses projections drawing on recent baseline projections from the OECD ENV-Linkages model (OECD, 2008 forthcoming).

The population projections are based upon UN "medium variant" projections to 2050 (UN, 2004). In this variant, the global population stabilises around 9 billion by mid-century, which is about 50 percent higher than the current population. Between 2050 and 2080 the population growth rates trends are extrapolated forward with the exception of a few regions. In Japan, Russia and in countries within eastern European region, the UN projects rapidly rates of decline in population to 2050. For these regions, the OECD baseline projection assumes that the rates of decline slow significantly in the last half of the century. For these aggregate regions, the OECD baseline is is generally consistent with population projections found in post-SRES medium scenario outcomes (FISHER *et al.*, 2007). Annual average growth rates in population by region for the projection period from the OECD baseline are shown in Appendix 2, Table 2.1.

With respect to national and regional GDP growth over the long term, the primary determinants of future economic activity are labour productivity and population growth. The OECD economic baseline reflects movement towards convergence in labour productivity growth rates across regions. In the long-term, productivity growth per hour worked is conjectured to grow at 1¾% per annum. Countries slowly converge to that rate closing the growth rate gap by 2% per year from 2015 to 2050. After 2050 the rate of convergence is faster: full convergence in labour productivity is assumed in 2070, while full convergence in labour productivity growth rates occurs before the end of the century in about 2080. Overall global average GDP growth in the 2005 to 2080 period is estimated to be 2.3% per year. Annual average growth rates of GDP from the OECD baseline, by region and by decade, are shown in Appendix 2, Table 2.2.

Projection of city population in 2070s

The population in the cities in 2070s depends on three factors: (1) the projection of regional population; (2) change in urbanization rate; (3) specific properties of the city. This analysis uses population projections for each OECD region, taken from the OECD baseline scenario in 2075. The UN provides a projection of urbanization rates for all countries up to 2030. The 2005-2030 trend in urbanization rate has been used to estimate urbanization rate in 2075, assuming that the urbanization rate will saturate at 90 percent, except where it is already larger than this value (special cases like Hong Kong). Considering that this is a simple ranking exercise, it was not within the project scope to investigate specific properties of all cities individually. Instead it was assumed that all cities of a country have the same growth rate. The equations are:

For the urbanization rate in country C:

$$u^{C}_{2075} = \mathrm{Min}\left[\, u^{C}_{2005} + (u^{C}_{2030} - u^{C}_{2005})/25 * (2075 - 2005)\ ;\ Max(u^{C}_{2005};\ 90\%) \,\right] \qquad \text{(Eq 7)}$$

Where;
u^{C}_{2075} = urbanization rate projection for 2075 in country C
u_{2005} = the observed urbanization rate in 2005
u_{2030} = the UN projection for 2030 in this country

For the population of a city A, which is located in the country C, and the OECD region R:

$$Pop^{A}_{2075} = Pop^{A}_{2005} * u^{C}_{2075}/u^{C}_{2005} * PopRegion^{R}_{2075}/PopRegion^{R}_{2005} \qquad \text{(Eq 8)}$$

Where;
$Pop_{2075/2005}$ = population of city in 2075 or 2005
u^{C}_{2075} = urbanization rate projection for 2075 in country C
u_{2005} = the observed urbanization rate in 2005
$PopRegion_{2075/2005}$ = population of region in 2075or 2005

Future GDP at city-scale

GDP at city-scale is assumed to track developments in GDP at national and regional scale, as noted above. The analysis uses the OECD baseline projections to 2075. Urban GDP per capita is assumed to grow at the same rate as national (or regional) GDP throughout the period 2005 to 2075; urban GDP per capita is assumed to be equivalent to rural GDP per capita. Total GDP for each city is therefore the product of projected urban population and per capita GDP in 2075 for a given region or nation.

APPENDIX 2. BACKGROUND DATA TO SOCIO-ECONOMIC SCENARIOS

Table 2.1 : **Population, Annual Average Growth Rates, by Region, to 2080 of the OECD Baseline (ENV-Linkages)**

	2005-10	**2010-20**	**2020-30**	**2030-40**	**2040-50**	**2050-60**	**2060-70**	**2070-80**	**2005-50**	**2050-80**
OECD	**0.56**	**0.44**	**0.29**	**0.15**	**0.04**	**-0.02**	**-0.06**	**-0.10**	**0.27**	**-0.06**
North America	0.97	0.85	0.65	0.47	0.32	0.19	0.04	-0.09	0.62	0.05
USA & Canada	*0.92*	*0.81*	*0.65*	*0.51*	*0.40*	*0.27*	*0.08*	*-0.08*	*0.63*	*0.09*
Mexico	*1.14*	*0.96*	*0.67*	*0.36*	*0.06*	*-0.08*	*-0.09*	*-0.10*	*0.58*	*-0.09*
Europe	0.33	0.22	0.11	-0.01	-0.11	-0.13	-0.11	-0.10	0.08	-0.12
Pacific	0.23	0.07	-0.11	-0.26	-0.36	-0.33	-0.21	-0.11	-0.12	-0.22
Oceania	*0.97*	*0.90*	*0.74*	*0.52*	*0.40*	*0.28*	*0.08*	*-0.08*	*0.67*	*0.09*
Asia	*0.13*	*-0.05*	*-0.25*	*-0.40*	*-0.51*	*-0.46*	*-0.27*	*-0.12*	*-0.25*	*-0.28*
Transition Economies	**-0.20**	**-0.22**	**-0.36**	**-0.42**	**-0.49**	**-0.46**	**-0.27**	**-0.12**	**-0.35**	**-0.28**
Russia	-0.45	-0.51	-0.60	-0.57	-0.57	-0.50	-0.30	-0.12	-0.55	-0.31
Other EECCA	-0.23	-0.31	-0.44	-0.54	-0.62	-0.54	-0.31	-0.12	-0.45	-0.33
Other Transition Economies	0.08	0.12	-0.09	-0.23	-0.37	-0.38	-0.24	-0.11	-0.12	-0.24
Developing countries	**1.36**	**1.22**	**0.94**	**0.72**	**0.52**	**0.32**	**0.13**	**-0.05**	**0.91**	**0.13**
East & SE Asia, Oceania	0.77	0.65	0.34	0.10	-0.10	-0.18	-0.14	-0.10	0.30	-0.14
China	*0.58*	*0.50*	*0.16*	*-0.09*	*-0.29*	*-0.34*	*-0.22*	*-0.11*	*0.13*	*-0.22*
Indonesia	*1.14*	*0.82*	*0.57*	*0.38*	*0.12*	*0.00*	*-0.05*	*-0.10*	*0.55*	*-0.05*
Other East Asia	*1.19*	*1.02*	*0.74*	*0.48*	*0.27*	*0.12*	*0.01*	*-0.09*	*0.69*	*0.01*
South Asia	1.57	1.36	1.03	0.76	0.55	0.31	0.10	-0.08	1.00	0.11
India	1.41	1.19	0.85	0.57	0.37	0.18	0.04	-0.09	0.82	0.04
other south asia	2.02	1.82	1.51	1.22	0.94	0.61	0.24	-0.06	1.45	0.26
Middle East	2.07	1.90	1.46	1.16	0.89	0.56	0.22	-0.07	1.43	0.24
Middle East	2.07	1.90	1.46	1.16	0.89	0.56	0.22	-0.07	1.43	0.24
Africa	2.12	1.99	1.76	1.52	1.27	0.90	0.43	0.03	1.69	0.46
Northern Africa	*1.65*	*1.43*	*1.07*	*0.78*	*0.52*	*0.29*	*0.09*	*-0.08*	*1.03*	*0.10*
Republic of South Africa	*0.16*	*0.06*	*0.06*	*0.01*	*0.04*	*0.04*	*-0.03*	*-0.09*	*0.06*	*-0.03*
Other sub-Saharan Africa	*2.35*	*2.22*	*1.96*	*1.71*	*1.43*	*1.02*	*0.49*	*0.05*	*1.89*	*0.52*
Latin America	1.34	1.11	0.83	0.56	0.33	0.16	0.03	-0.09	0.78	0.03
Brazil	*1.26*	*1.00*	*0.72*	*0.47*	*0.25*	*0.10*	*0.00*	*-0.09*	*0.68*	*0.00*
Other Latin America	*1.37*	*1.18*	*0.89*	*0.61*	*0.37*	*0.19*	*0.04*	*-0.08*	*0.83*	*0.05*
Central & Caribbean	*1.43*	*1.23*	*0.94*	*0.65*	*0.39*	*0.20*	*0.05*	*-0.08*	*0.87*	*0.05*
World	**1.14**	**1.02**	**0.78**	**0.59**	**0.42**	**0.25**	**0.09**	**-0.06**	**0.75**	**0.09**

Table 2.2. **GDP Annual Average growth rates, by Region to 2080, of the OECD Baseline (ENV-Linkages)**

	2005-10	**2010-20**	**2020-30**	**2030-40**	**2040-50**	**2050-60**	**2060-70**	**2070-80**	**2005-50**	**2050-80**
OECD	**2.79**	**2.24**	**1.98**	**2.06**	**1.93**	**1.86**	**1.77**	**1.71**	**2.14**	**1.78**
North America	3.54	2.49	2.32	2.37	2.20	2.06	1.87	1.72	2.48	1.89
USA & Canada	*3.43*	*2.41*	*2.26*	*2.36*	*2.22*	*2.08*	*1.88*	*1.72*	*2.44*	*1.90*
Mexico	*5.33*	*3.63*	*3.06*	*2.40*	*1.99*	*1.79*	*1.75*	*1.71*	*3.05*	*1.75*
Europe	2.45	2.12	1.79	1.85	1.72	1.68	1.68	1.70	1.94	1.68
Pacific	1.56	1.81	1.34	1.52	1.40	1.46	1.57	1.68	1.52	1.57
Oceania	*3.47*	*2.48*	*2.24*	*2.45*	*2.24*	*2.06*	*1.87*	*1.72*	*2.47*	*1.88*
Asia	*1.37*	*1.74*	*1.23*	*1.40*	*1.28*	*1.36*	*1.52*	*1.68*	*1.41*	*1.52*
Transition Economies	**4.73**	**3.68**	**3.44**	**2.93**	**2.48**	**2.21**	**1.78**	**1.68**	**3.31**	**1.89**
Russia	4.66	3.86	3.64	3.03	2.60	2.32	1.82	1.68	3.43	1.94
Other EECCA	4.42	3.46	3.14	2.78	2.37	2.08	1.73	1.67	3.10	1.83
Other Transition Economies	5.34	3.47	3.23	2.81	2.26	2.01	1.74	1.68	3.21	1.81
Developing countries	**5.55**	**4.21**	**3.88**	**3.46**	**2.97**	**2.54**	**2.02**	**1.72**	**3.84**	**2.09**
East & SE Asia, Oceania	6.45	4.66	3.97	3.44	2.85	2.40	1.89	1.69	4.03	1.99
China	*7.16*	*4.85*	*4.11*	*3.52*	*2.82*	*2.37*	*1.85*	*1.68*	*4.19*	*1.97*
Indonesia	*5.74*	*4.52*	*3.88*	*3.29*	*2.84*	*2.38*	*1.92*	*1.70*	*3.86*	*2.00*
Other East Asia	*5.17*	*4.28*	*3.67*	*3.30*	*2.91*	*2.48*	*1.98*	*1.71*	*3.72*	*2.06*
South Asia	6.54	5.09	4.48	3.92	3.33	2.75	2.11	1.72	4.46	2.19
India	6.55	5.18	4.50	3.89	3.25	2.68	2.06	1.72	4.46	2.15
other south asia	6.53	4.81	4.42	4.03	3.58	2.98	2.25	1.75	4.46	2.32
Middle East	4.63	3.63	3.87	3.47	3.03	2.63	2.16	1.75	3.63	2.18
Middle East	4.63	3.63	3.87	3.47	3.03	2.63	2.16	1.75	3.63	2.18
Africa	5.36	4.22	4.44	4.14	3.85	3.27	2.43	1.80	4.29	2.50
Northern Africa	*5.39*	*4.34*	*4.15*	*3.48*	*3.04*	*2.60*	*2.10*	*1.73*	*3.93*	*2.15*
Republic of South Africa	*3.23*	*2.15*	*2.44*	*2.49*	*2.48*	*2.28*	*1.95*	*1.72*	*2.49*	*1.98*
Other sub-Saharan Africa	*6.34*	*4.89*	*5.29*	*5.07*	*4.67*	*3.83*	*2.68*	*1.85*	*5.13*	*2.78*
Latin America	3.75	2.90	2.81	2.59	2.26	2.02	1.85	1.72	2.76	1.86
Brazil	*3.40*	*2.75*	*2.52*	*2.26*	*1.97*	*1.81*	*1.77*	*1.71*	*2.49*	*1.76*
Other Latin America	*4.20*	*3.07*	*3.06*	*2.84*	*2.47*	*2.16*	*1.91*	*1.72*	*3.01*	*1.93*
Central & Caribbean	*3.18*	*2.69*	*2.64*	*2.46*	*2.15*	*1.95*	*1.85*	*1.72*	*2.56*	*1.84*
World	**3.40**	**2.73**	**2.52**	**2.50**	**2.28**	**2.10**	**1.86**	**1.71**	**2.61**	**1.89**

APPENDIX 3 – CITY DATA AND RANKINGS

Full listings of world port city data (alphabetically by country) for scenarios C, FNC and FAC. The pink and red shading indicate cities with medium and high, respectively, tropical/extratropical cyclone hazard in the present-climate. The green shaded data indicate that the city is in the Top 20 ranking for that particular measure.

					SCENARIO C		SCENARIO FNC		SCENARIO FAC	
Country	Urban Agglomeration	Delta	Pop 2005	Wind Damage Index	Exposed Population (000)	Exposed Assets (US$bil)	Exposed Population (000)	Exposed Assets (US$bil)	Exposed Population (000)	Exposed Assets (US$bil)
ALGERIA	**El Djazaïr (Algiers)**		3200	0	21	0.75	51	10.94	67	14.36
ANGOLA	**Luanda**		2766	0	1	0.02	15	0.91	18	1.07
ARGENTINA	**Buenos Aires**		12550	18	68	4.46	93	18.74	117	23.47
AUSTRALIA	**Adelaide**		1134	3	4	0.69	7	3.52	9	4.79
AUSTRALIA	**Brisbane**		1758	5	23	3.55	38	20.46	63	34.23
AUSTRALIA	**Melbourne**		3626	10	15	2.32	61	33.07	75	40.29
AUSTRALIA	**Perth**		1474	2	32	5.00	18	9.90	26	14.00
AUSTRALIA	**Sydney**		4331	12	4	0.64	8	4.46	11	5.98
BANGLADESH	**Chittagong**		4114	12	255	2.54	1,411	68.93	2,866	140.01
BANGLADESH	**Dhaka**	D	12430	35	844	8.43	4,012	195.99	11,135	544.00
BANGLADESH	**Khulna**	D	1494	4	441	4.41	2,477	121.03	3,641	177.86
BRAZIL	**Baixada Santista (Santos)**		1638	0	18	0.76	31	4.46	46	6.70
BRAZIL	**Belém**	D	2043	0	40	1.69	65	9.42	95	13.80
BRAZIL	**Fortaleza**		3237	0	12	0.51	20	2.91	23	3.29
BRAZIL	**Grande Vitória**		1613	0	320	13.52	528	76.74	607	88.27
BRAZIL	**Maceió**		1116	0	13	0.57	26	3.77	30	4.31
BRAZIL	**Natal**		1035	0	16	0.70	25	3.66	30	4.32
BRAZIL	**Porto Alegre**		3795	0	31	1.30	42	6.17	79	11.54
BRAZIL	**Recife**		3527	0	27	1.12	52	7.54	71	10.30
BRAZIL	**Rio de Janeiro**		11469	0	98	4.13	165	24.02	268	38.94
BRAZIL	**Salvador**		3331	0	9	0.38	16	2.30	24	3.50
CAMEROON	**Douala**	D	1761	0	11	0.13	60	4.18	101	7.07
CANADA	**Montréal**		3640	5	25	4.34	38	19.86	67	34.73

CANADA	**Vancouver**	D	2188	6	320	55.25	522	270.91	584	303.04
CHINA	**Dalian**		3073	4	96	2.97	248	80.55	368	119.43
CHINA	**Fuzhou Fujian**	D	2453	7	214	6.64	520	168.97	857	278.48
CHINA	**Guangzhou Guangdong**	D	8425	24	2,718	84.17	6,391	2076.56	10,333	3357.72
CHINA	**Hangzhou**	D	2831	8	17	0.53	26	8.31	36	11.62
CHINA	**Ningbo**	D	1810	5	299	9.26	1,007	327.21	3,305	1073.93
CHINA	**Qingdao**		2817	4	88	2.72	1,232	400.38	1,851	601.59
CHINA	**Shanghai**	D	14503	41	2,353	72.86	2,744	891.72	5,451	1771.17
CHINA	**Shenzen**		7233	21	701	21.70	651	211.45	749	243.29
CHINA	**Taipei**	D	2606	7	122	3.77	270	87.64	429	139.55
CHINA	**Tianjin**	D	7040	0	956	29.62	2,312	751.25	3,790	1231.48
CHINA	**Wenzhou**	D	2212	6	82	2.55	214	69.55	700	227.37
CHINA	**Xiamen**	D	2371	3	269	8.33	665	216.12	1,034	335.99
CHINA	**Yantai**		1991	0	8	0.25	23	7.36	39	12.61
CHINA	**Zhanjiang**		1514	4	230	7.13	624	202.82	670	217.75
CHINA, HONG KONG SAR	**Hong Kong**		7041	20	223	35.94	531	899.58	687	1163.89
COLOMBIA	**Barranquilla**	D	1857	0	3	0.09	5	0.59	15	1.71
CÔTE D'IVOIRE	**Abidjan**		3577	0	519	3.87	2,970	135.58	3,110	141.98
CUBA	**La Habana (Havana)**		2189	6	1	0.03	3	0.16	3	0.21
DEM Republic of Korea	**N'ampo**		1102	2	22	0.20	29	0.79	181	4.96
DENMARK	**København (Copenhagen)**		1088	3	25	4.42	26	17.22	47	31.48
DOMINICAN REPUBLIC	**Santo Domingo**		2022	6	11	0.40	21	2.25	36	3.79
ECUADOR	**Guayaquil**		2387	0	412	8.86	937	60.44	1,196	77.18
EGYPT	**Al-Iskandariyah (Alexandria)**	D	3770	0	1,330	28.46	3,939	507.20	4,375	563.28
FINLAND	**Helsinki**		1091	2	6	1.00	9	5.38	13	7.74
FRANCE	**Marseille-Aix-en-Provence**		1382	2	14	2.04	17	7.90	21	9.89
GERMANY	**Hamburg**		1740	5	261	39.39	221	109.95	255	127.27
GHANA	**Accra**		1981	0	14	0.18	42	3.37	51	4.03
GREECE	**Athínai (Athens)**		3230	0	3	0.28	4	1.59	5	2.19
GUINEA	**Conakry**		1425	0	41	0.40	386	23.42	496	30.14
HAITI	**Port-au-Prince**		2129	6	1	0.01	5	0.13	8	0.21
INDIA	**Chennai (Madras)**		6916	20	159	2.63	521	72.93	730	102.16

INDIA	**Kochi (Cochin)**		1463	2	94	1.56	247	34.62	360	50.44
INDIA	**Kolkata (Calcutta)**	D	14277	41	1,929	31.99	6,903	966.15	14,014	1961.44
INDIA	**Mumbai (Bombay)**		18196	26	2,787	46.20	9,193	1286.63	11,418	1598.05
INDIA	**Surat**		3557	5	418	6.93	1,459	204.21	2,020	282.80
INDIA	**Visakhapatnam**		1465	4	25	0.42	72	10.13	99	13.79
INDONESIA	**Jakarta**	D	13215	0	513	10.11	1,383	197.60	2,248	321.24
INDONESIA	**Palembang**		1733	0	127	2.50	341	48.74	561	80.08
INDONESIA	**Surabaya**		2992	0	53	1.04	146	20.91	327	46.67
INDONESIA	**Ujung Pandang**		1284	0	7	0.13	19	2.75	34	4.80
IRELAND	**Dublin**		1037	3	16	3.26	24	18.66	43	33.38
ISRAEL	**Tel Aviv-Yafo (Tel Aviv-Jaffa)**		3012	0	0	0.02	0	0.16	1	0.57
ITALY	**Napoli (Naples)**		2245	0	2	0.33	2	1.12	5	2.49
JAPAN	**Fukuoka-Kitakyushu**	D	2800	8	307	48.26	329	157.37	478	228.88
JAPAN	**Hiroshima**		2044	6	192	30.18	222	106.25	381	182.64
JAPAN	**Nagoya**	D	3179	9	696	109.22	1,049	502.39	1,302	623.42
JAPAN	**Osaka-Kobe**	D	11268	32	1,373	215.62	1,199	574.26	2,023	968.96
JAPAN	**Sapporo**	D	2530	4	5	0.72	7	3.12	13	6.01
JAPAN	**Tokyo**	D	35197	100	1,110	174.29	1,283	614.31	2,521	1207.07
KUWAIT	**Al Kuwayt (Kuwait City)**		1810	0	14	1.16	35	12.12	45	15.50
LEBANON	**Bayrut (Beirut)**		1777	0	5	0.16	15	2.00	33	4.32
LIBYAN ARAB JAMAHIRIYA	**Banghazi**		1114	0	37	2.10	101	34.58	143	48.83
LIBYAN ARAB JAMAHIRIYA	**Tarabulus (Tripoli)**		2098	0	3	0.19	7	2.50	10	3.32
MALAYSIA	**Kuala Lumpur**		1405	2	270	15.06	0.2	162	0.3	84
MOROCCO	**Dar-el-Beida (Casablanca)**		3138	0	33	0.76	71	9.81	88	12.08
MOROCCO	**Rabat**		1647	0	10	0.23	27	3.67	35	4.88
MOZAMBIQUE	**Maputo**		1320	0	61	0.40	347	9.68	384	10.70
MYANMAR	**Rangoon**	D	4107	12	510	3.62	2,894	100.28	4,965	172.02
NETHERLANDS	**Amsterdam**	D	1147	3	839	128.33	1,361	800.54	1,435	843.70
NETHERLANDS	**Rotterdam**	D	1101	3	752	114.89	1,313	771.95	1,404	825.68
NEW ZEALAND	**Auckland**		1148	3	7	0.90	12	5.01	18	7.86
NIGERIA	**Lagos**		10886	0	357	2.12	2,488	90.39	3,229	117.32

PAKISTAN	**Karachi**	D	11608	16	49	0.63	245	15.24	473	29.48
PANAMA	**Ciudad de Panama (Panama City)**		1216	0	15	0.53	33	3.51	43	4.55
PERU	**Lima**		7186	0	2	0.06	7	0.61	11	0.98
PHILIPPINES	**Davao**		1327	2	3	0.06	5	0.63	11	1.29
PHILIPPINES	**Manila**	D	10686	30	113	2.69	261	31.73	545	66.21
PORTUGAL	**Lisboa (Lisbon)**		2761	0	40	3.88	74	27.59	90	33.43
PORTUGAL	**Porto**		1309	2	14	1.33	19	7.12	22	8.17
PUERTO RICO	**San Juan**		2605	7	68	6.53	115	33.41	173	50.29
REPUBLIC OF KOREA	**Inchon**		2620	4	210	23.78	196	67.77	267	92.27
REPUBLIC OF KOREA	**Pusan**		3554	10	77	8.74	67	23.27	98	33.80
REPUBLIC OF KOREA	**Ulsan**		1056	3	7	0.81	8	2.68	12	4.08
RUSSIAN FEDERATION	**Sankt Peterburg (St. Petersburg)**		5312	8	189	10.60	151	35.24	358	83.87
SAUDI ARABIA	**Jiddah**		2860	0	15	1.13	28	8.57	42	13.07
SENEGAL	**Dakar**		2159	0	18	0.17	99	5.82	131	7.66
SINGAPORE	**Singapore**		4326	0	16	2.30	23	16.44	29	20.54
SOMALIA	**Muqdisho (Mogadishu)**		1320	0	9	0.03	97	1.77	115	2.11
SOUTH AFRICA	**Cape Town**		3083	9	10	0.57	17	4.58	25	6.80
SOUTH AFRICA	**Durban**		2631	4	15	0.86	34	9.48	42	11.56
SPAIN	**Barcelona**		4795	0	11	1.41	13	6.86	20	10.38
SWEDEN	**Stockholm**		1708	2	3	0.39	3	1.65	8	4.58
THAILAND	**Krung_Thep (Bangkok)**	D	6593	9	907	38.72	2,392	520.23	5,138	1117.54
TOGO	**Lomé**		1337	0	119	0.95	771	37.71	858	41.95
TURKEY	**Istanbul**		9712	0	70	2.80	131	37.05	166	46.84
TURKEY	**Izmir**		2487	0	27	1.07	49	13.83	86	24.23
UKRAINE	**Odessa**		1159	3	75	2.68	76	39.29	85	44.33
UNITED ARAB EMIRATES	**Dubayy (Dubai)**		8505	24	260	30.82	657	341.41	793	411.81
UK	**Glasgow**		1010	1	17	2.64	19	4.99	26	6.93
UK	**London**		1330	0	397	60.14	448	226.17	606	306
UNI. REP. OF TANZANIA	**Dar-es-Salaam**		2676	0	36	0.13	279	4.20	351	5.28

USA	**Baltimore**		1264	2	117	24.32	152	22.25	177	25.92
USA	**Boston**		2205	3	370	76.81	557	408.16	720	527.70
USA	**Houston**		4361	12	59	12.21	78	56.87	139	101.95
USA	**Los Angeles-Long Beach-Sanata Ana**		4320	12	77	16.11	115	84.01	165	120.78
USA	**Miami**		12298	0	2,003	416.29	3,194	2340.32	4,795	3513.04
USA	**New Orleans**	D	5434	15	1,124	233.69	1,316	963.98	1,383	1013.45
USA	**New York-Newark**		1010	3	1,540	320.20	2,374	1739.24	2,931	2147.35
USA	**Philadelphia**		18718	53	158	32.79	225	165.20	284	208.01
USA	**Portland**		5392	15	13	2.64	17	12.71	23	16.92
USA	**Providence**		1810	3	69	14.40	84	61.25	99	72.20
USA	**San Diego**		1248	5	4	0.84	6	4.55	7	5.45
USA	**San Francisco - Oakland**		2852	0	118	24.51	148	108.16	189	138.75
USA	**San Jose**		3385	0	4	0.93	6	4.70	14	10.02
USA	**Seattle**		1631	0	27	5.59	39	28.80	50	36.68
USA	**Tampa-St Petersburg**		2989	8	415	86.26	579	424.59	730	534.92
USA	**Virginia Beach**		2252	6	407	84.64	572	419.08	794	581.69
USA	**Washington, D C**		1460	2	32	6.68	41	30.29	57	41.95
URUGUAY	**Montevideo**		4238	6	16	0.79	19	14.12	25	18.57
VENEZUELA	**Maracaibo**		2255	0	24	0.70	46	4.04	65	5.74
VIETNAM	**Hai Phòng**	D	1873	5	794	11.04	3,222	228.23	4,711	333.70
VIETNAM	**Ho Chi Minh City**	D	5065	7	1,931	26.86	7,151	506.52	9,216	652.82

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