Megacities and the Coast

Based on a major international study, this volume provides a synthesis of scientific knowledge on the urbanisation processes, environmental impacts, and policy response options, and disaster risk management challenges that are associated with coastal megacity development. It is the primary output of a major international scientific project sponsored by the International Geosphere Biosphere Programme, the Land-Ocean Interactions at the Coastal Zone programme of IHDP/IGBP and others. It brings together the work of over 60 contributing authors and an international review board.

This volume presents the international policy and academic community with an unbiased and high-quality assessment of social–ecological systems interaction in coastal megacities. One of its main messages is that while we know a great deal about megacities of more than ten million people and about urban processes, and about coasts and their physical and ecological processes (aquatic, physical and atmospheric), there is relatively little work that focuses primarily at points of intersection between these. The book responds to this gap by providing the first global synthesis of megacity and large urban region urbanisation on the coast. Its focus is on environmental and development challenges, climate change and disaster. It is interdisciplinary and brings together world-recognised scientists (including many IPCC lead authors) on urban climate and atmosphere, disaster risk management, demography and coastal environments.

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Megacities and the Coast

Risk, Resilience and Transformation

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Tables

Acronyms

ADB	Asian Development Bank
CBDP	community-based disaster preparedness
CCA	climate change adaptation
CCM	climate change mitigation
CCN	concentration of condensation nuclei
CCSM	Community Climate System Model
COAMPS	Coupled Ocean-Atmosphere Mesoscale Prediction System
DKI	Special Capital Territory of Jakarta
DRM	disaster risk management
DRR	disaster risk reduction
DTR	diurnal temperature range
EAC	Eko Atlantic City
ENSO	El Nino Southern Oscillation
ESS	ecosystem services
FAO	Food and Agriculture Organisation
GCM	global climate model
GDP	gross domestic product
GHG	greenhouse gas
GEC	global environmental change
GECAFS	Global Environmental Change and Food Systems
ICZM	integrated coastal zone management
IPC	integrated food security phase classification
IPCC	Intergovernmental Panel on Climate Change
LASG	Lagos State Government
LECZ	low elevation coastal zone
LLGHG	long-lived greenhouse gases
LOICZ	Land-Ocean Interactions on the Coastal Zone
MCGM	Municipal Corporation of Greater Mumbai
MM	Metro Manila
MSP	maritime spatial planning
MEA	Millennium Ecosystem Assessment
MENA	Middle East and North Africa
NCAR	National Center for Atmospheric Research
NPCC	New York City Panel on Climate Change
NYC	New York City

PM	particulate matter
RCP	representative concentration pathways
SLR	sea-level rise
SREX	IPCC Special Report for Managing the Risks of Events and Disasters to Advance Climate Change Adaptation
TOA	top of the atmosphere
UBL	urban boundary layer
UET	urban environmental transition
UHI	urban heat island
UN-DESA	United Nations Department for Economic and Social Affairs
UNCLOS	United Nations Law of the Sea
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNFPA	United Nations Population Fund
UN-HABITAT	United Nations Human Settlements Programme
UNISDR	International Secretariat for Disaster Reduction
WHO	World Health Organisation

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Executive summary

Mark Pelling and Sophie Blackburn

The coast represents a highly dynamic interface between land, sea and atmosphere, subjecting urban development in this zone to a unique set of pressures and opportunities. However, whilst offering many benefits, a coastal location is also exposed to varied sources of risk – many of which are being exacerbated in the context of the new and uncertain pressures associated with global environmental change. Such concerns are most salient in megacities – defined as having a population exceeding 10 million – where the concentration of human life and assets is greatest, and where consequences for failure as well as opportunities for innovative solutions remain high. Global trends in urban geography have acquired heightened significance as the majority of the world's population is now recognised as urban-dwelling. Simultaneously, megacity development itself exerts pressures on coastal ecosystems and geomorphology, with both short and long-term implications for ecological and human wellbeing and sustainability. The degree to which megacity residents, property and ecologies are exposed and vulnerable to environmental hazards is an outcome not only of technological and economic capacity, but – more importantly – of governance systems, dominant development priorities and values. How far current trajectories for environmental and social change are shifting the balance between opportunity and risk, and for whom, are thus important questions of our time.

Responding to this globally strategic concern and opportunity for sustainable development, this volume is the principle outcome of an international, interdisciplinary assessment of global scientific knowledge on the interaction of megacities and the coastal environment. It is the product of collaboration between the Land-Sea Interactions at the Coastal Zone (LOICZ) hotspot theme on Urbanization in Coastal Zones, and the International Geosphere Biosphere Programme (IGBP). It aims to begin the process of building an international community of researchers that can lead transdisciplinary expertise, and frame future research on megacities and urban regions on the coast. The completion of this volume in itself has brought together an international group of more than 60 scientists from a multitude of subject specialisms, from across North and South America, Asia, Africa, Europe and Australasia. Lead authors and a number of contributing authors were selected via the LOICZ Open Science Congress, Yantai, China, 2011, with additional opportunities for inputs from the international scientific community encouraged through sessions at the IHDP Open Science Meeting, London, 2012, and the 2nd US Coastal City Summit, St Petersburg, Florida, 2012. The review process has been coordinated with advice from a senior steering and review committee including members of LOICZ and IGBP.

Context

Megacities are large and highly dynamic systems, and represent concentrated sites of human life and assets as well as of pollution and ecological stress. Due to this combination, as neighbourhoods and cities grow in size and resource capacity, transformations in social-environmental relations are also observed. Over time, local environmental hazards associated with inadequate sanitation and services tend to be replaced by risks that accrue at the city scale and globally, as cities progress through industrial and post-industrial stages. Furthermore the increasingly inter-connected nature of urban places at a global scale alters the nature and rate of urban change. Accountability for this can be difficult to trace, since the sites of risk production and impact are often far removed. For example, there are clear justice consequences for globalised megacities that are important nodes in the production of pollution and greenhouse emissions which have negative impacts on distant ecologies and populations at regional and global scales. Historically, coastal megacities have recorded some of the highest human and economic losses to disaster events, however this is not a trend which need necessarily continue into the future: simultaneous with being sites of extreme risk, megacities are also centres of capacity, ingenuity and resource.

The complexity and reach of urbanisation processes is matched by those of coastal environmental systems, which are amongst the most diverse ecological systems worldwide. Beyond their intrinsic value, these are systems that offer significant ecosystem services ranging widely from coastal protection to fisheries and recreation. Management of hazards, vulnerability and environmental management in megacities is inherently complex, and governance responses require attention to multiple scales of impact, and negotiation between many competing interests.

The Aim: an integrated agenda for research and policy on large coastal, urban systems

The scientific community understands a good deal of the drivers and constraints acting in megacity systems and coastal systems, and work from social and natural sciences and integrated and trans-disciplinary programmes of research have made substantial recent advances. However, there is one over-riding and critical gap: the lack of integration between urban and coastal research. As yet, we know much less about the interaction of coastal and large urban systems than we do of the constituent parts. Knowledge of the dynamic two-way interactions between megacities and the coast is, we argue, a large and dangerous gap in our collective knowledge.

This global review seeks to address this gap, adopting an interdisciplinary approach that is unique in drawing on both the physical and social sciences to explore the causes, impacts and management of environmental degradation, human vulnerability, and feedbacks between the two. In an attempt to delineate the contours of the relationship between mega-urbanisation and coasts that is explored in detail in the rest of the volume, this Executive Summary highlights seven key messages arising from this synthesis review project.

Key Message 1

Fragmentation, agglomeration and disproportionately rapid expansion in less wealthy countries are major global trends in coastal megacity development

Megacities present important lessons on planning and risk management at scale. There are currently 23 worldwide, 16 of which are in the coastal zone – defined here as the area within 100km and 50m elevation from the coast. Of these, ten are in Asia (Tokyo, Mumbai, Shanghai, Guangzhou, Shenzhen, Kolkata, Karachi, Manila, Osaka-Kobe, Jakarta), two each in Latin America (Buenos Aires, Rio de Janeiro) and North America (New York City, Los Angeles), and one each in Africa (Lagos) and Europe (Istanbul). However there are many problems inherent in defining the above list. Most significant among these are: 1) the use of multiple conflicting parameters in defining the boundary between 'urban' and 'rural', a dichotomy which is increasingly rejected in favour of a 'continuum' concept; 2) ambiguity over uses of the term 'urbanisation', which range from demographic to structural interpretations; and 3) the intuitive difficulty of excluding rapidly growing cities lying below the 10 million threshold, and those lying slightly outside the 'coastal' limits but whose growth nonetheless has relied heavily on the features of a coastal or estuarine location (for example Cairo, London and Sao Paulo).

Further complicating megacity identification are global trends of urban sprawl, fragmentation, and agglomeration, which serve to blur city boundaries. Recent reports highlight the growing importance of peri-urban areas in regional economies, which are expanding largely as a result of urban sprawl. In order to incorporate such 'grey areas' – which nonetheless are a key feature of contemporary megacities – a joint focus on megacities and 'urban regions' is preferred in this volume. This also seeks to take account of 'mega-regions', where several megacities have agglomerated through urban expansion, or where large urban areas have developed with multiple foci rather than a single epicentre. Currently the largest of such agglomerations is the Hong Kong-Shenhzen-Guangzhou region in China, which has a total population of approximately 120 million.

Set against these trends is the relatively static growth of megacities in Europe, the Americas and East Asia, relative to the very rapid urban growth observed in Central Asia and Africa. Rapid urbanisation is especially consequential in Africa where demography, economies and environments are set to be transformed in the next decade. The implications for international trade networks and distributions of global capital is still a young field, and is an important area for future inquiry that should focus on the politics of internal trade-offs between economic development, human well-being and environmental sustainability. The importance of this research agenda is magnified by the risks to trade associated with a coastal location and additional pressures from global environmental change anticipated to have a disproportionately significant impact on low- and middle-income countries.

Key Message 2

Large-scale urbanisation in the coastal zone causes transformations in the geosphere, biosphere, atmosphere and hydrosphere, which can be damaging to the environment over both short and long timescales

The environmental impacts of coastal megacity growth are complex and intersecting, with many feedbacks between spheres which can exacerbate or ameliorate outcomes. Environmental impacts are largely an outcome of urban processes of structural development, waste and pollution, and resource consumption, and on such a large scale, these are greatly magnified. Furthermore, due to the complex and delicate nature of coastal ecosystems, the environmental impacts of coastal megacities can also be disproportionate compared to non-coastal cities.

The most significant impacts of megacities and urban regions on the geosphere include: subsidence due to excessive building load and groundwater extraction, pollution of soils and groundwater reserves, and resource extraction. Pollution and habitat disturbance are the most damaging bi-products of megacity development on the coastal biosphere, causing changes in species composition, population and resilience. Coral reefs and wetlands including temperate salt-marsh and tropical mangrove are particularly vulnerable ecosystems, due to their ecological and structural sensitivity. Degradation of wetlands also has important feedback implications for human vulnerability, as both provide a buffer against storm surge and tsunami. Given the range of ecosystem services on which cities depend, seeking to reduce these negative impacts by improving sustainability is therefore a vital consideration for megacity development.

Aside from aquatic pollution reducing marine and estuarine water quality, the hydrosphere is affected through structural changes to estuaries and the coastal strip. This can alter regimes of erosion and sedimentation in such a way that disturbs ecosystems and damages existing structures. Ecosystems can also be damaged as a result of extractive industries, for example along the Jakarta coastline, coral has been mined for use in cement. Finally, megacities impact on the atmosphere as a result of polluting industries and their intense concentration of motor vehicles, and the creation of an urban microclimate is common (for example, the 'heat island effect'). However interaction between land and coastal air can ameliorate local pollution and temperature extremes. A more sophisticated analysis is required to track the impacts of megacity consumption on local, regional and global environments.

The movement not only of goods but of the energy (ie carbon footprint), resource and water embedded within them brings new responsibilities for consumers. As yet science has only a limited view on the pathways and dynamics through which benefits for some bring risk to others and the ways in which such distributions are moderated – some would say distorted – by the action of the global economy, and financial speculation (for example) on commodity prices. New ways of conceptualising these relationships and of tracking flows as a precursor to a more nuanced allocation of responsibilities and rights in the global social contract is well overdue. These are questions that go beyond coastal megacities and represent where some focussed research effort can generate wider benefit.

Key Message 3

Climate change is affecting both the sources of environmental hazard and their impacts on coastal megacities, although the scale and nature of these changes is highly uncertain

Evidence from the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX 2011) sheds new light on existing predictions of how tropical cyclones will be affected by global environmental change. Whilst previous studies suggested that both the frequency and intensity of storms were increasing and would continue to do so in the future, SREX indicates that cyclone frequency is in fact stable. The proportion of these which are at the high end of the intensity spectrum (level 4 or 5) is, however, increasing. This has key implications for how megacities and urban regions can best prepare for cyclone events, and the preparations made in New York City in anticipation of Hurricanes Irene in 2011 and Sandy in 2012, thus serve as useful simulations.

Whilst the rate and magnitude of mean sea level rise is also debated, there is consensus about the negative implications of rising sea levels for marine hazards such as increased wave height, storm surge and coastal flooding. Additional hazards of concern to coastal megacities are heat wave, tsunami, monsoonal rains and landslide. These hazards threaten human life and livelihoods both directly – i.e. causing deaths, structural damage and interruption to baseline economic activity – or indirectly, through hazards reducing the productivity or availability of ecosystem services (e.g. damage to reefs) which support particular livelihoods (e.g. fisheries). The anticipated threat to Tokyo from the Fukushima nuclear plant following the 2011 Japanese tsunami is another apt illustration of indirect hazard. In order to pinpoint more specifically the social-ecological and socio-economic impacts likely to affect coastal megacities in the future, further research is needed to narrow the margins of error surrounding estimates of projected shifts in climate-forced hazards.

Key Message 4

Coastal megacities have direct and indirect impacts on the atmospheric composition, climate, hydrology and ecology, however current models are inadequate in simulating these dynamics

Observations and numerical modelling are just starting to yield the first insights into the dynamic processes by which coastal megacities impact the environment at a variety of scales. These impacts are largely the product of megacities' high concentration of industrial activity and emissions, coinciding with proximity to the sensitive of hydrological and ecological systems associated with a coastal location. Data also indicate that megacities can play a very significant role in reducing global emissions of greenhouse gases and pollutants.

This report also finds that to date, atmospheric (aerosol/chemical) and meteorological models have tended to treat different environmental impacts in isolation from one another, failing to acknowledge and therefore fully understand the complex interactions and feedbacks between them. The report therefore calls for the development of coupled models addressing the non-linear interactions between urban environmental phenomena. This will improve understanding of urban-environmental interactions at a variety of scales, assisting in the simulation of outcomes – particularly in understanding the scaled-up 'macro' impacts of coastal megacities. A step change in understanding may be possible with the further integration across natural and social science modelling. In particular analysis that can demonstrate feedback between natural and social systems is important for identifying the processes of social amplification that can take on considerable scale effects in megacities, but where, as yet, there is a limited analytical and methodological base.

Key Message 5

The politics of environmental risk management in megacities is complex due to the high number of stakeholders and interest groups. There is increasing pressure and good opportunity to mainstream risk management into other core functions of urban governance

Joined up adaptation approaches that bring together engineering and institutional projects of reform or transformation are the underpinning resources for sustainable cities, however integration requires concerted effort and new skills. The multilevel characteristics of megacities where local, city region, city and wider scale initiatives need coordination make for a particular challenge. This is especially so where different ways of understanding vulnerability, hazard and its drivers are influenced by specific cultural viewpoints fed through political agendas.

Contemporary approaches to risk management acknowledge the need for soft risk reduction measures such as education, good governance, and risk communication, being applied in conjunction with hard (i.e. technocratic) engineering solutions such as sea walls, groynes and levees seeking to protect the coastline. However applying these principles in megacities is challenging, requiring collaboration between a multitude of stakeholders. These include actors operating at all scales from the international (in the case of large land-owning corporations and supranational donor organisations funding climate change mitigation measures) to the individual (public consultation is now a standard component of the majority of urban development projects). Good governance is key to risk management, but there is much debate over precisely what this entails and its limitations.

The International Council for Local Environmental Initiatives (ICLEI) 2011 White Paper argues convincingly that the above challenges would be more easily overcome if resilience was treated as a mainstream concern in urban planning. This is based on the observation that resources are often wasted where urban problems are addressed with an isolated agenda in mind. For example, road surfaces ought to be maintained routinely with an in-built consideration of flood risk. ICLEI argue that therefore, climate change adaptation finance should be demand rather than supply-driven because this is less prescriptive and more responsive to community needs. Further research is needed to examine the logistical, financial and political implications of such an approach.

Key Message 6

There are many aspects of disaster risk reduction (DRR) and climate change adaptation (CCA) which overlap, whilst also having distinct and conflicting implications for urban economic development and human well-being

Whilst CCA shares DRR concerns about reducing human vulnerability to extreme events, it also goes beyond this to include managing the incremental stresses to everyday livelihoods and shifting 'baseline' conditions that are associated with climate change. It also places additional emphasis on forward-looking assessments of risk and the ability of risk actors to reorganise entitlements and resources.

Both CCA and DRR have direct implications for economic development, because both extreme events and incremental livelihood pressures – particularly for the urban poor – are known to slow or even 'reverse' development. However, in practice the introduction of proactive adaptive strategies at the level of individuals, organisations and governments is difficult because initial outlay costs tend to exceed tangible benefits in the short-term. Decision-makers face a very significant challenge in negotiating these various pressures. Further work is needed on the progress of existing practical attempts to mainstream DRR and CCA into the sustainable development agenda for coastal megacities.

Key Message 7

Global trends in urban development and environmental change are permanently altering the ways in which coastal megacities interact with the environment, necessitating policy and research agendas that are innovative and forward-thinking

The material in this synthesis report paints a picture of contemporary mega-urbanisation on the coast. It highlights both new and existing sources of risk as they relate to populations, urban infrastructure, and the environment, outlining in each case their construction, impact and changing nature. Amongst the most significant trends contributing to new sources of risk on the coast are:

- the increasing inter-connectedness between urban centres, which simultaneously exposes cities to new 'domino-effect' global cascades of risk whilst also offering fresh opportunities for collaborative and complementary adaptation responses;
- the disproportionately rapid growth of megacities in low- and middle-income country contexts, accompanied by rising urban inequality in richer and poorer countries;
- poor understanding of complex feedback mechanisms between various environmental processes and urban development – including coastal realignment, subsidence, environmental health – which are mutually constitutive and culminate in the construction of 'feedback hazards' which tend to be inadequately addressed in planning policy

Whilst representing a 'knowledge-capture' of existing published and peer review evidence on these subjects, this report also seeks to identify gaps and areas of weakness or contradiction in received wisdoms. Centrally the process of developing this book has been successful in building a community of practice surrounding the most pressing questions for better understanding the interface between megacities and the coastal zone, by stimulating fresh enquiry and debate in this vitally important area of research.

Conclusion

The reach of coastal megacities is global. As hubs of global trade, centres for technological innovation and political leadership, and sites of consumption and social reproduction, large cities occupy a pivotal position in struggles towards global sustainability. Recent trends in the urbanisation of poverty and inequality, local and global environmental degradation and disaster risk and loss suggest that mega-urbanisation not only makes the ambition of sustainable development increasingly remote, but that these characteristics of dominant 'development' pathways are compounding risk and loss in large urban systems, and through them to the global.

As a first international effort in synthesising scientific knowledge on megacities and the coast, this report highlights the great capacity for resilience inherent in large cities, but also the barriers that have tended to deny this possibility – certainly for the majority of urban residents in low and middle income countries and for ecological systems. Some have observed an urban environmental transition in large cities, one where economic growth allows for the exporting of environmental externalities. This can be seen in the transition in the nature of urban environmental risks from sanitation to local air quality and finally global environmental impacts. Is this dominant approach to environment-development relationships sustainable? Reflexivity in social-ecological systems experienced in coastal megacities suggests not. Feedback mechanisms are now impacting on the urban through increased hazard, and exacerbated by high levels of exposure and susceptibility. Vulnerability is expressed at the household level through poverty and the occupation of low-lying, hazard prone locations, but also systemically as critical infrastructure systems (energy, water, transport, communication and security) in large cities become increasingly interdependent, opening scope for compound crisis. Storm Sandy in New York is the most recent indicator of this threat with damage to transport and energy systems arguably generating greater loss than direct storm impacts.

Hard decisions lie ahead for megacities – and other areas of the urbanised coast – as aspirations for resilient and sustainable development are tested by growing economic inequality and environmental risk. Continuing failure in climate change mitigation, and the spectre of 2° Celsius warming, requires planning decisions to be made now and in the next decade in anticipation of a planet living with the consequences of dangerous climate change by mid-century. Cities have already transformed their local environments. Adapting to live with climate change will likely usher in a new era of environmental and social transformation, as the desires for growth and security are rebalanced. Understanding better the interactions between ecological, physical, socio-economic and political processes is a starting point for making transformations that can be deliberate – rather than forced – and through this process for enhancing informed and transparent decision-making.

Chapter 1

Mega-urbanisation on the coast

Global context and key trends in the twenty-first century

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1 Introduction

The aim of this book is to explore the dynamic interactions that exist between urban and environmental systems in coastal megacities. This interaction is highly significant because of the coinciding concentrations of biophysical risk, ecological sensitivity, and human life and assets that exist in these areas. In the context of the global increase in the number and size of coastal megacities worldwide, the negative impact of intense urban expansion and population pressures on sensitive coastal environments, and the expectation of new and uncertain hazards associated with the onset of climate change, improving our understanding of the dynamic pressures at work on the coast has never been more important. This chapter sets the scene for the in-depth exploration of these interactions throughout this volume, outlining some of the key trends, shifts and concerns facing coastal megacities in the twenty-first century.

The coastal zone is characterized by high biological diversity and richness, and highly dynamic geomorphology. The coast offers a range of opportunities for industry, including access to valuable geological resources (particularly oil and gas reserves), national and international trade routes, and opportunities for tourism. These qualities provide coastal settlements a plethora of advantages, based on the coast's economic, ecological, aesthetic and scientific values. As a result, it is estimated that in more than half of the world's coastal countries, at least 80 per cent of the national population lives within 100 kilometres of the coastline (Martínez *et al*. 2007). The largest coastal settlements are coastal megacities – defined as cities with ten million or more inhabitants – which are the focus of this report.

This intensity of urban development along the coastal strip – which has accelerated markedly in low- and middle-income countries over the last half-century (UN-HABITAT 2008) – is understood to be strongly influenced by increased openness to trading opportunities (Henderson and Wang 2007). Urbanisation is a critical driver of environmental transformation on the coast, and the manner in which urban centres evolve is a core determinant of coastal environmental sustainability in the immediate and long-term (Klein *et al.* 2003). Urbanisation on the coast also leads to increased exposure of human life and assets to a wide range of hazards associated with a coastal location – including coastal flooding, cyclones and tsunami – and environmental health concerns. In the context of global environmental change, this interaction between human and geo-ecological spheres is heightened due to the added pressures faced by both the environment and society. These include resource pressures, sea level rise and changes in hazard behaviour and impact.

In seeking to explore these various dynamics, this volume fills a vital gap in existing literature surrounding dynamic two-way interactions on the coast between human and natural systems. It draws on a very wide range of literatures including urban geography, global environmental change, natural hazards, environmental science, ecology and development studies. The breadth of knowledge captured in this volume thus provides a vital resource for academics and decision makers associated with urban and environmental planning on the coast.

This chapter provides an introduction to the rest of the book, by outlining a number of key themes to contextualize the ensuing discussion of specific aspects of coastal megacities. This chapter will focus on the following questions: what is a coastal megacity, and where are they found? How do we define a coastal megacity and what are the challenges inherent in this? What are the key global trends in coastal megacity development worldwide? What are the risks and opportunities for resilience to be found in coastal megacities? And finally, what significance does the growth of coastal megacities have on the global economy and human well-being of megacity dwellers?

2 Locating coastal megacities

It is estimated that in 2010 the global population became predominantly urban (UN-HABITAT 2010), with an estimated 360 million residing in megacities in 2011 (UN-DESA 2012a). Unless otherwise stated, all other population statistics in the remainder of this chapter are drawn from UN-DESA (2012b) *World Urbanization Prospects 2011*, including Table 1.1.

This volume adopts the UN-DESA (2012a) definition of megacities as those with more than ten million inhabitants. However, our definition is expanded to include ‘urban regions’, defined as city-regions of comparable magnitude (i.e. aggregate population of at least ten million) but where some parts lie outside of administratively designated urban zones. This includes areas with multiple overlapping jurisdictions (i.e. municipal, city or local governments) and areas dominated by a high number of small, intervening settlements linked by semi-rural or peri-urban areas that, individually, would escape the megacity characterization. Our inclusion of urban regions seeks to take account of the economic and infrastructural significance of these inter-connected areas. We define the coast as the area within a 50-metre elevation and a 100-kilometre distance of mean high water, after UNEP (2005).

Whilst half the world’s population is urban, only 2.8 per cent of global land cover is urbanized (McGranahan *et al.* 2006). This intense concentration of population is most acute on the coast: two-thirds of cities with a population exceeding five million are located at least partially within 0–10 metres above sea level (McGranahan *et al.* 2007).

Table 1.1 Population and geographical characteristics of coastal megacities in 2011

City	*Distance from coast (km)*	*Significant portions below 20 m above mean sea level?*	*Population of urban agglomerations (millions)*	*Coastal type*
Tokyo	0	Yes	37.2	Coastal plain, some hills
New York-Newark	0	Yes	20.4	Island and coastal plain
Shanghai	0	Yes	20.2	Delta
Mumbai	0	Yes	19.7	Islands, delta, coastal plain
Kolkata	78	Yes	14.4	Delta
Karachi	0	Yes	13.9	Coastal plain, delta
Buenos Aires	0	Yes	13.5	Coastal plain, part delta
Los Angeles-Long Beach-Santa Ana	0	Yes	13.4	Coastal plain
Rio de Janeiro coastal plain	0	Yes	12.0	Mountainous, narrow
Manila	0	Yes	11.9	Coastal plain
Osaka-Kobe	0	Yes	11.5	Coastal plain, mountainous
Lagos	0	Yes	11.2	Low-lying coastal plain
Istanbul	0	Yes	11.3	Mountainous
Guangzhou	59	Yes	10.9	Delta
Shenzhen	22	Yes	10.6	Delta, coastal plain, islands
Jakarta*	0	Yes	9.8	Coastal plain

Population statistics sourced from UN-DESA (2012b) World Urbanisation Prospects 2011 table on the 30 largest urban agglomerations; typology of major coastal cities sourced from UN-DESA (2009) World Urbanization Prospects 2009; distance from coast calculated using *SEDAC TerraViva! Viewer*, by drawing a straight line from the centre of each urban agglomeration (as defined by CIESIN *et al.* 2011) to the coast; portions below 20 metres sea level were estimated using *SEDAC TerraViva! Viewer* Sea Level Rise data set based on Shuttle Radar Topography Mission (McGranahan *et al.* 2007).

*Whilst these official population statistics for Jakarta place it at just under ten million, Jakarta is included here to reflect the cumulative population of the Greater Jakarta Metropolitan Area and the uncertainty of the city boundaries. The city is also understood to have a greatly inflated daytime population of up to 12 million (*The Jakarta Post* 2011).

Table 1.1 identifies 16 coastal megacities in 2011, out of a total 23 worldwide. Geographically, ten coastal megacities are in Asia; two each in Latin America and North America; and one each in Africa and Europe. These 16 cities have a combined population of 242 million out of a total global population of seven billion – thus almost 3.5 percent of the world's population lives in coastal megacities. It must be noted that the list presented in this table is subject to many contradictions and uncertainties, and is therefore subject to significant debate as well as rapid change. For example, this list based on 2011 data already has two additional Chinese megacities than that presented in von Glasow *et al.* (2012), which was based on 2010 data (see also Section 4.1 of the present chapter). Section 2 explores the difficulties of attempting to compile definitive megacity data in some detail.

Table 1.1 identifies a range of environmental contexts where coastal megacities have emerged, highlighting significant diversity in physical form, geology (geomorphology) and climate. These differences determine, amongst other things, the range of biophysical hazards the city is affected by – outlined in greater detail in Section 4. Large urban areas have tended to be constructed near the mouths of major rivers, where locational and transportation advantages emerge through the linking of interior hinterlands with global trade through shipping (de Sherbinin *et al.* 2007). Of the cities outlined in Table 1.1, five (Guangzhou, Shenzhen, Shanghai, Kolkata and Lagos) are found in delta areas, which have significant land areas under 20 metres above mean sea level. Being low-lying, these are particularly prone to subsidence owing to sediment compaction (Vörösmarty *et al.* 2009). Other coastal urban types identified in Table 1.1 include those situated on steeply rising inland topography or even mountainous zones, such as characterizes many cities along the Mediterranean (Istanbul) and along the Brazilian coast (Rio de Janeiro). For some of these cities, there is a narrow coastal shelf that is densely populated, while in others the elevation rises abruptly from the coastline.

3 Defining coastal megacities

It is vital to acknowledge that any list of coastal megacities (including that presented in Table 1.1) is not definitive but open for discussion. This is for several reasons associated with the reliability, comparability and accuracy of the data sets, because the timing, methodology and quality of data collection vary widely between cities. For example, many data sources (including the UN-DESA data) distinguish between 'urban proper' (i.e. city centre) and 'urban agglomeration' (i.e. the wider or 'greater' city area), but others do not, which can cause inappropriate comparisons to be drawn. Satterthwaite (2010) outlines in detail the weaknesses of population data sets, including those associated with delineating city boundaries. A significant methodological challenge is identifying the limits within which the population data is included. Official city- or national-level urban data tend to be based on administrative boundaries and may exclude the significant number of people who migrate into the city for work, those who live in the suburbs and populations living in informal or 'slum' settlements who may be excluded from city population data but make substantial contributions to the city economy. Thus depending on methodology, there may be significant over- or underestimates of megacity populations (Cohen 2006, Satterthwaite 2010).

An additional barrier to definitively identifying coastal megacities is lack of definitional clarity. The challenges inherent in defining our two most significant parameters – what constitutes a city, and what constitutes the coast – are outlined below.

3.1 Definitional Challenge 1: urban, rural and beyond

The seemingly most obvious way in which to define a city is relative to what it is not: intuitively, cities are not rural. However, the flaws of a simplified rural–urban dichotomy, and the challenges associated with defining both terms, are now well-established (see for example Uzzell 1979, Pumain and Robic 1996, Beguin 1996). This stems from the rejection of assumptions about essential cultural differences between urban and rural societies (Uzzell 1979), recognition of the complexity of rural capital accumulation systems, and acknowledging that the tendency to define rural simply as 'not urban' denies its agency and uniqueness (Halfacree 1993). As a result the treatment of 'rural' and 'urban' as two extremes of a continuum rather than discrete categories is now widely preferred (Champion and Hugo 2004). Thus settlement classifications now tend to be based on relative, measurable parameters including population size and density, diversity of economic activity, level of 'built-up-ness' (related to either density of construction or average building height), and level of capital generation – which are all generally (but not always) higher in urban areas.

Application of the continuum concept in land-use classifications in practice varies in complexity, and can incorporate multiple dimensions of urban measurement. For example in Indonesia, each sub-community is ranked according to three parameters (population density, percentage of population engaged in agriculture and number of 'urban' facilities present) and the sum total determines its categorization as rural or urban (Champion and Hugo 2004, p. 14). However, the persistent essentialism of such systems, incorporating multiple parameters but continuing to culminate in either/or categorizations (i.e. urban *or* rural), has attracted criticism. As a result, over time more elaborate conceptualizations of interconnections of the urban/ rural interconnections have emerged. Partly due to the rapidity of suburban expansion and urban sprawl, what was previously considered 'rural' is now interspersed with partially built-up areas that link together adjacent cities. This makes the demarcation of individual cities more difficult and strengthens arguments about the inadequacy of the rural–urban dichotomy (Cohen 2006). Research into the nature of and transitions within this 'peri-urban interface' has burgeoned as a result (see for example Allen 2003). Simultaneously there has been growing appreciation of the validity of ecological research in urban centres (a field formerly reserved for rural areas, within which 'nature' was assumed to be bounded), stimulating the growing field of urban ecology (Pickett *et al.* 2001).

Challenges also arise when attempting to define 'urbanisation' empirically, because it too relies on being able to clearly capture what it means to be urban. Put simply, urbanisation refers to the process of becoming increasingly urban. Thus a population can be said to be urbanising if the share that is urban is increasing, while an area is urbanising if the share of its land that is urban is increasing. In practice, however, urbanisation is often used to refer to different processes, which do not necessarily coincide, and indeed are becoming increasingly distinct. Thus, whereas once the urbanisation of population, space and culture could legitimately be treated as different aspects of the same transformation, this is now no longer the case. To ensure continuity and clarity in this volume, three alternative definitions of urbanisation are summarized below:

Demographic urbanisation

This is the 'standard' definition of urbanisation that will serve as the default in this synthesis report. Demographic urbanisation refers to an increasing proportion of the population living in urban areas, accompanied by a relative decline in rural populations and enterprise. Thus urban population growth is the sum of natural increase plus the rate of urbanisation.

Urbanisation as urban expansion

Here urbanisation is equated to the spatial expansion of built-up areas, or of land administratively designated as such, and the commensurate loss of rural land. This can be useful in evaluating environmental impacts. However, current trends of declining urban density and fragmentation mean that urban expansion often takes place without demographic urbanisation, and involves a process of declining settlement density. It is misleading to refer to this declining settlement density as urbanisation, since demographic urbanisation refers to a process of increasing settlement density, and this has historically been seen as one of the key features of urbanisation.

Urbanisation as process of socio-economic transition

This definition refers to a transition from the social, economic, cultural and political systems assumed to be characteristic of rural areas, to those associated with urban centres. This definition is now contested due to the aforementioned debate over definitions of rural and urban 'characteristics' that are now viewed as overly simplistic.

It is due to these complexities that this report includes 'urban regions' in addition to megacities, to avoid excluding 'borderline' cities that escape classification as megacities as a result of administrative (rather than qualitative) boundaries. It is for this reason that Jakarta, for example, has been included in the report as an 'urban region', to reflect its uncertain urban boundaries, very large peripheral population and rapid growth trajectory. This approach reflects the intention to engage primarily in analysis of urban–marine interactions, rather than rural–urban. As Champion and Hugo (2004) argue, the key in any study of urban phenomena is to be clear, and to avoid definitive statistics in the absence of clear qualification as to their meaning.

3.2 Definitional Challenge 2: urbanisation on the coast

As with urban areas, there is no single definition of the coastal zone and use of this term varies significantly across disciplines and between locations. Generally, the coastal zone is classified as an interface between land and sea, and contains unique ecological, geologic and biologic domains, vital for the maintenance of a multitude of life forms (Beatley, Brower and Schwab 2002). As stated, this volume adopts a simple definition of the area located within a 50-metre elevation and a 100-kilometre distance from mean high water. However, once again, the diversity of definitions in circulation leads to a degree of subjectivity in the designation of coastal zones (Klein *et al*. 2003).

Kay and Alder (2005) identify four typologies of coastal definitions in the policy realm: fixed distance definitions, variable distance definitions, definition according to use and hybrids of these (p. 4). Others still have defined it in terms of elevation in proximity to the coast (McGranahan *et al*. 2007), or combined distance and elevation criteria (Klein *et al*. 2003, UNEP 2005). Such measures are useful, but fail to capture the changing spatiality of land–ocean interactions. They also fail to delineate the inclusion of three-dimensional dynamics such as atmospheric flows and exchanges, which have fundamental implications at ground level (e.g. controlling the hydrological cycle). Furthermore, strict use of the elevation-based definitions excludes some cities from the 'coastal megacity' bracket that would intuitively be included – for example São Paulo (Brazil), which lies only 50 kilometres from the coast but 800 metres above sea level (Nicholls 1995) and is included by von Glasow *et al.* (2012).

Rather than attempting to come up with a more rigorous definition of the coastal zone (i.e. one based on a complex set of quantitative parameters), it is also possible to identify coastal megacities according to certain typical or exclusively coastal geomorphic and economic qualities – more in line with Kay and Alder's third typology: (definition according to use). For example, typical coastal landscapes include tidal, deltaic and estuarine features, which often coincide with economic reliance on large-scale fishing or freight industries (Klein *et al.* 2003). Use of a more qualitative definition based on the presence of such features would include Cairo (11.17 million, 119 kilometres from coast) and Dhaka (15.39 million, 140 kilometres from coast), which interact strongly with the coast despite being located more than 100 kilometres from the shoreline (see Plate 3). Von Glasow *et al.* (2012) acknowledge and address the difficulty of delineating between 'coastal' and 'not coastal', by identifying both 'coastal agglomerations' and 'those with coastal influence'. Such a 'third way' could arguably also include Greater London (although von Glasow *et al.* do not). Furthermore the Thames – which historically and currently has been a hugely significant source of both economic opportunity and environmental hazard in London – is highly tidal, necessitating flood defence structures such as the Thames Barrier. These arguments also support the inclusion of those parts of urban regions that lie beyond the coastal plain (in places such as Los Angeles, Seoul and Istanbul) in accounts of coastal urbanisation.

4 Global trends in megacity development

The purpose of this section is to highlight some of the most significant trends in coastal megacity development, which have bearing on the nature of risk and opportunity in these areas. Note that due to the large degree of contradiction and debate which surrounds megacity growth statistics, what is presented here is an overview of key narratives. It should also be noted that many of the issues identified are not limited to the spatial fixidity of coastal megacities – that is, they are more to do with cities than with the coast and also apply in non-coastal contexts – however, they are of particular significance in coastal megacities due to the concentration of risk, assets and environmental sensitivity in these areas as previously outlined. Given the difficulties outlined above, a broad definition of megacities and urban regions is adopted.

4.1 The 'new' megacities: growth in low- and middle-income countries

Between 1975 and 2000, the number of megacities in low- and middle-income countries rose from two to 13, with the global megacity population increasing more than seven-fold to 165 million (more if wider agglomeration boundaries are drawn) (Cohen 2006). Looking at Plate 1, of the seven new megacities anticipated by UN-HABITAT to emerge by 2025, all are in low- or middle-income countries with only four remaining in developed countries. Even more significantly, by 2011 three of these projections have already become reality, with Lagos, Shenzhen and Guangzhou already having passed ten million in population – and Jakarta is not far behind (UN-DESA 2012b). That two Chinese cities have done this reflects the 'staggeringly high' growth rates being experienced in China, which exceeded 10 per cent in 2008 (UN-HABITAT 2008).

These data indicate that generally, urban growth rates are higher in Asia, Africa and Latin America compared to the 'older' megacities in Europe, North America and Japan. Nevertheless despite the rapid growth of these 'new' megacities, recent reports are keen to dispel popular visions of a future led by 'explosive' urbanisation – a myth largely driven by megacities' high visibility and the media (Satterthwaite 2010). Whilst it is true that megacities have grown in size and number in the last few decades, this growth has been much slower than expected – particularly in high-income nations (Angel *et al.* 2011). Currently, 63 per cent of urban populations in developed countries reside in intermediate and small-sized cities, compared to 9 per cent being located in megacities (UN-HABITAT 2009). Some observations indicate trends of counter-urbanisation in large cities in Europe and North America since the 1970s, and the rate of growth of some low-income-country cities also slowed during the 1980s (McDonald 2000). Satterthwaite (2005) also observes that in many cities, movement outwards exceeds migration inwards, and few have reached anything close to the size that was predicted for them in the 1970s. However it is difficult to say the extent to which these trends are the product of the boundaries within which population data is collected, or changes to census methodologies. Furthermore, data suggesting declining urban growth rates in high-income countries may also reflect demographic factors such as the reduction of urban and rural fertility, and a game of diminishing returns in calculating net population change relative to a very large and increasing total.

Despite these complexities, overall it is clear that urban growth rates are much larger in less developed regions than in more developed regions. Plate 2 illustrates this, showing the fastest urban growth rates lie in low- and middle-income countries compared to low or even negative growth rates in high-income countries, where urban growth rates have been declining since 1950 (Montgomery 2008).

The most likely drivers of high rates of urbanisation in low- and middle-income countries are public perceptions about enhanced employment opportunities and better provision of basic services in cities. However, in many cases such assumptions about elevated living conditions in urban centres are highly inaccurate, and levels of urban poverty, inequality and social exclusion are very high in many megacities (Tacoli *et al.* 2008). Extreme urban poverty is fuelled by population growth and in-migration, stimulating rapid expansion of informal settlements in the absence of necessary improvements to public services and infrastructure (Cohen 2006). For example in Lagos, Nigeria, 40 per cent of the population live in over-crowded housing with low access to sanitation whilst the city continues to expand (UN-HABITAT 2010). Recent reports estimate urban densities in low-income countries to be twice as high as those in Europe and Japan (Angel *et al.* 2011) – high density combined with poverty and inadequate waste management and sanitation infrastructure can culminate in severe environmental health problems (see McGranahan *et al.* 1996, McMichael 2000). Aggressive gentrification policies, seeking to 'clean up' the city to make way for high-value developments by bulldozing informal settlements, are widespread, and have caused massive dislocation of the population, for example in Mumbai and Lagos (UN-HABITAT 2010). Unfortunately, attempts to curb megacity growth through the exclusion or neglect of migrants are just as likely to reinforce rather than counter these issues of inequality (Tacoli *et al.* 2008).

4.2 Declining urban densities

Arguably more significant than the apparent demographic slow-down in higher income nations is Angel *et al.*'s (2011) observation that urban *expansion* is occurring at a rate twice as fast as urban population growth, meaning the density of built-up areas must be declining. Angel *et al.* estimate that urban densities have decreased by 2 per cent every year between 1990 and 2000 and that if current rates continue global urban population will double within 43 years, whilst urban land cover will take only 19. 'Urban sprawl' is the most commonly used term to describe low-density urban expansion, and is a well-recognized phenomenon in cities literature (see for example Harvey and Clark 1965, and the more recent Yu and Ng 2007). UN-HABITAT (2009) state that urbanisation beyond metropolitan boundaries is a particularly significant trend in Asia. Sprawl is attributed with causing fragmentation of the open space surrounding urban centres, and there is a wide literature on its associated negative environmental impacts (Hasse and Lathrop 2003, UN-DESA 2011. In many low-income regions, sprawl is dominated by informal or 'slum' settlements, which grow on city outskirts where the land is often cheaper as a product of increased distance from the economic centre, lower quality land and higher exposure to risk. For example, in Rio de Janeiro, Brazil, favela settlements at the city edges extend up very steep slopes on highly unstable terrain (Ojima and Hogan 2009).

As cities expand through urban sprawl (in combination with other processes such as 'leap-frogging' (Korff and Rothfu 2009) and incorporation of outlying settlements), scale makes it difficult for megacities to perform as an organic whole. This can force a multiplication of loci for economic activity, industry, educational excellence, places of poverty, etc., creating pressures for geographical, social, administrative and political fragmentation and leading to a transition from uni-polarity to multi-polarity (Laquian 2011). Fragmentation may also arise where areas of new and old growth are not closely connected, either in terms of governance or transportation links. This mechanism of fragmentation may be particularly visible in low-income country megacities, where loose systems of urban governance can detract from planning that is informed by a holistic vision of the city as an organic whole. Nevertheless, fragmentation need not necessarily lead to decreased efficiency of the city en masse, as in many high-income countries (especially in the US and Australia) high motorization increases connectivity between outlying areas of the city (Huang and Sellers 2007). However, it can be problematic for these multiple centres to interact in planned ways that can benefit from scale economies at the city level.

Closely related to sprawl is peri-urbanisation, which refers to the semi-urban development of previously rural land. Peri-urbanisation is an ambiguous term (Allen 2003), defined by Martine (2011) as "the non-contiguous and patchwork form of urban expansion and leapfrog development which springs from land speculation, changing production modalities, and the spread of automobile transportation" (p. 13).

Allen (2003) argues that current planning systems and regulation are inadequate to deal with the unique development and environmental challenges of the peri-urban interface. These include increased need for transportation links, job creation, sanitation, and education and healthcare facilities, which are often lacking in peri-urban areas that have grown very rapidly (da Gama Torres 2011). Peri-urban areas almost always straddle more than one administrative jurisdiction, adding to the complexity of peri-urban governance. Allen (2003) notes the growing literature on peri-urbanisation as a legitimate land use, and calls for the development of planning regulations that consider the environmental, social and economic specificity of peri-urban areas.

4.3 The growth of megaregions, urban corridors and city regions

As stated by UN-HABITAT's 'State of the world's cities: 2010/11' report (2010), the growth of mega-regions is a key trend in global urban development. This has been particularly significant along the coast, linked to the locational advantages of coastal areas for industry and trade. Megaregions form through the overlapping sprawl of multiple urban centres as agglomerations spread away from the coastal strip, facilitated by technological advances (Aguilar *et al.* 2003). Megaregions tend, therefore, to be polycentric. They may continue to draw on coast-based industries as a source of (amongst other things) trade, employment and energy, but as the model shifts from core-periphery to multi-core, economic dependency on the coast may become weaker or more indirect. Castells (1998) emphasizes that megaregions are a distinct entity from 'megacities', which may form part of a megaregion. In practice, however, the strong degree of interaction and interdependency between megacities and adjoining agglomerations can make them difficult to distinguish. Examples of coastal megaregions include the area extending from Accra, Ghana, to Lagos in Nigeria (through four countries), Osaka-Nagoya-Tokyo in Japan, and – the largest of all with 120 million people – the Hong Kong-Shenhzen-Guangzhou region in southern China (UN-HABITAT 2010).

As megacities and urban regions often result from the agglomeration of previously distinct urban (and rural) entities, different political and administrative institutions may begin to share authority. Megaregions may therefore retain much of the heterogeneity between its poly-centres that pre-existed their integration. However, this adds significantly to the challenge of cohesive urban governance, and may hinder attempts at coordinated development and environmental management, including adaptation to climate change and the management of other emerging pressures and risks, throughout the megaregion (Laquian 2011).

The growth of megaregions has implications at both regional and global scales. Cities in clusters, corridors and megaregions are described by UN-HABITAT as 'becoming the new engines of both global and regional economies' (2010 p. ix), by improving interconnectivity between cities and nations. Florida *et al.* (2008) identify 40 megaregions with a combined economy that exceeds $100 billion per annum – estimated to represent 66 per cent of global economic output and 85 per cent of innovation. However, the report also warns that megaregions represent both a symptom and a cause of the perpetuation of asymmetrical development, strengthening existing patterns of economic dependency rather than supporting 'diffused spatial development'. Reinforcement of 'status quo' patterns of economic development is of little benefit to populations living outside these economic 'powerhouses', a concern that is particularly salient to rural populations in low-income countries. This poses a significant challenge to development planners in national and local governments (UN-HABITAT 2010).

5 Risk, vulnerability and resilience in coastal megacities

The growth in the number and size of coastal megacities worldwide, particularly those in low- and middle-income countries, is simultaneously resulting in increasing pressures on the natural environment and changing the way that environmental risk is constructed and experienced. These goalposts are shifting further as a result of global environmental change, which is anticipated to bring changes in the behaviour and frequency of extreme climate events and cause additional stress to human and environmental systems. These systems are best viewed as being coupled, because disturbances in one can cause and reinforce disturbances in another, through complex feedback mechanisms. For example, urban expansion along the coast often results in concrete reinforcement of the coastline, which interrupts natural erosion cycles and tidal movements, which increases flood risk; also urban expansion leads to pollution and exploitation of resources, which harm ecosystems and ultimately reduce the availability and quality of ecosystem services and resources on which the urban population depends, with negative implications for human health, economies and well-being. In both cases, greater attention to finding sustainable forms of urban growth, in which human and environmental systems can co-exist in a balanced and symbiotic way, is necessary.

Vulnerability to hazards is defined as human sensitivity to hazard impacts and is the product of a wide range of factors (Wisner *et al.* 2004). Resilience, simply put, is the ability to withstand hazard impact, such that the system affected is able to continue to function, as well as learn from and adapt to new and unanticipated sources of hazard (Cutter *et al.* 2008). Whilst urban resilience is, in part, a product of a city's specific vulnerabilities and it's actions taken to mitigate these (Pelling 2011b). The most significant factors affecting vulnerabilities and resilience in coastal megacities are addressed in this section.

5.1 Drivers of risk in coastal megacities

The hazards affecting any given megacity depend upon the geographical location and physical characteristics of the city in question. Flood risk, for example, is greatest in cities that are either in close proximity to major rivers or are susceptible to storm surges – and even more so if these coincide (Prasad *et al.* 2009, Dasgupta *et al.* 2009). Elevation is another strong predicator of coastal flood risk, and coastal plains may or may not be sufficiently raised above sea level to mitigate exposure to coastal flooding as well as near- or medium-term projections for sea level rise due to climate change. Deltaic settings tend to be particularly vulnerable for this reason also, although Manila and Mumbai are examples of non-deltaic but nonetheless very low-lying exposed cities. Some additional factors that contribute to heightened exposure to current and future risks in coastal megacities are outlined in Box 1.1.

Box 1.1 Geographical characteristics increasing hazard exposure in coastal megacities

Low elevation deltas – Coastal cities tend to be highly exposed to coastal flooding, whether due to changes in sea level, tidal waves or the effects of cyclones or frontal systems. Moreover, many coastal cities are also located by rivers as this provides a source of fresh water and, historically, access points to interior lands. Given how floods propagate downstream through catchments, this also makes coastal cities vulnerable to flooding from upstream (for example the flooding of the Mississippi which affected New Orleans in May 2011).

Topography – Depending on their tectonic setting, coastal cities may be surrounded by mountains/topographic barriers that serve to enhance local precipitation as onshore, saturated winds are forced to rise. Weather systems, be these cyclones, frontal systems or simply air flowing on-land from features such as persistent trade winds, interact with these physical barriers resulting in heavy rainfall rates and runoff. Even in the absence of significant topography, changes in surface roughness can affect the movement of onshore storm systems.

Land use – Many large coastal cities are also ports and industrial processing areas, for example Shanghai is amongst the world's busiest ports. Some of the associated industrial activities, for example oil refineries, result in huge emissions with significant implications for local and regional air quality. The ratio of green space versus impermeable surface in a coastal megacity also has significant implications for flood risk, as it affects the infiltration rate of the land area.

Sea/land breezes – The proximity of water and land, and the differential heating of these two surfaces over the course of the day, generates day-time sea breezes (onshore flows of air) and land breezes (offshore flows of air). In summer, sea breezes are important in coastal cities in mitigating heat stress, though in some urban settings the density of buildings impedes the penetration of the sea breeze, reducing ventilation, with implications for thermal stress and air quality. Tokyo, for instance, is considering removing buildings to allow the sea breeze to penetrate and aerate the city. Other cities are also considering the orientation of the buildings in order to affect the inflow of sea air (e.g. Hong Kong, Singapore). This needs to take into account both wind flow and solar gain (e.g. Ng *et al.* 2011). Sea/land breezes also serve to concentrate and re-circulate pollutants across coastal cities with important implications, particularly at night when the urban boundary layer (and thus atmospheric mixing) is diminished.

Population density and heat island effect – Coastal megacities tend to be denser than megacities in other geographical settings, in part because of competing land uses and topography, and as a result some 13 of the 20 densest cities worldwide are in the coastal zone (McGranahan *et al.* 2007). Thus coastal cities tend to have a high proportion of impervious cover, which is a key determinant of energy flux partitioning – latent heat fluxes (evapotranspiration rates) are suppressed, while sensible and storage heat fluxes are enhanced. This results in greater heating of the air and substrate, culminating in the 'heat island effect'. High population densities (which often coincide with high poverty levels) experience heightened exposure to concentrated pollution, which exacerbates environmental health problems and enhances greenhouse gas emissions – contributing further to urban warming effects.

Source: Grimmond (2011)

The full range of hazards that coastal megacities are exposed to is outlined in detail in Chapter 3 of this volume. A selection of these are summarized in Plate 3.

The construction of risk, however, is more than simply exposure to hazard; risk is also the product of vulnerability (Wisner *et al*. 2004). Pelling (2011a) observes seven features of coastal megacities that influence their vulnerability to natural hazards, relative to other types of human settlement in other locations: (1) the concentration of physical assets, industries, energy installations and exposed populations; (2) a significant migrant population and cultural and socio-economic diversity; (3) their reach and dependency on coastal and interior networks of infrastructure; (4) the layering of coastal hazards – subsidence, salinization, liquefaction, sea-level rise, etc., which makes risk management more complex and raises the likelihood of risk-reduction policies with regards to one risk having adverse effects on vulnerability to another; (5) a capacity to trigger economic contagion at different scales through their strategic importance as finance and trade centres; (6) the possibilities of hotspot growth for new ecological assemblages as a result of degradation and interruption of ecosystems; (7) an extensive source of intervention in biophysical systems through extractive industry, water and air pollution, and others, implicated in the creation and reinforcement of urban hazards by reducing the sustainability and environmental quality of the city.

These features highlight that it is the unique juxtaposition between large-scale settlement and environmental processes that exists in coastal megacities that culminates in heightened risk in coastal megacities. It is where these systems interact that the potential for hazard arises. However, it is also in this space of overlap that the potential for adaptation and resilience arises, depending on cities' responses to the source of environmental pressure.

5.1 Possibilities for resilience and transformation

Despite the sources of hazard and vulnerability outlined above, some studies have highlighted the increased resilience of large urban regions compared to small towns and rural areas, due to greater capacity to respond and prepare for hazard impact (Cross 2001, Cutter *et al*. 2010). Megacities in particular may have advantages in scale and concentration of assets that can help find solutions to hazard and vulnerability driven by competition over land and social diversity (Pelling 2011a). They have the locational advantage of being able to benefit from coast-dependent industries, and access to international trade links. Furthermore, as hotbeds of economic prosperity, magnets for highly skilled migrants and having close connections with other centres of innovation, coastal megacities are uniquely placed for the development of innovative solutions to risk management and adaptation. This is facilitated through the emergence of formalized networks such as C40, or the UNISDR's global 'Making Cities Resilient' campaign (2010–2015).

A similar view is put forward by Klein *et al.* (2003), Parker (1995) and Handmer (1995) who argue that megacities in particular have more power, resources and the built-in complexities of economic, physical and social form and function that can confer capacity to adapt to hazards and reduce risk from mitigating climate change to air pollution control, and to lead such innovations that might then also benefit smaller cities and their hinterlands. Satterthwaite *et al.* (2009) argue that it is 'easy' to envisage a future where urban planning and development have embedded adaptation to natural hazard risks into their normal functions. They see this as an achievable goal so long as long-term policies are in place to ensure that the costs of adaptation are spread over time. Such measures could include directing urban growth away from high-risk areas, prioritizing risk-resistant infrastructure, or adjustments being made to building codes and standards. Klein *et al.* (2004) similarly observe that the survival of some cities through history (such as Istanbul, Baghdad and Cairo), whilst others have failed or been abandoned, indicates that there are some qualities that enable certain urban areas to resist and recover from external (and internal) shocks and continue to thrive.

Nevertheless, at the global scale, while urbanisation is rising in importance as an area for social and physical research and policy innovation, there remain important strategic gaps in understanding and knowledge. The lack of shared definitions for different types of human settlements and variation in the quality of national-level data that are relied upon for global assessment and modelling continues to be a concern – both for researchers and policy makers. This is a weakness not only of basic demographic data but also of data on populations exposed to or impacted by environmental, technological and disaster risk. Moreover, information on the depth and social distribution of poverty in cities is variable and often underestimated (Pelling 2003). The greater reliance on money economies and the absence of entrenched moral economies in urban places are two factors that make survival post-disaster and on the margins of the economy more difficult in urban places compared to rural. However, the erosion of social cohesion and continued incursion of the global economy in many rural areas are reducing this distinction, which is becoming associated more with governance than geography, demography or geology.

Goals such as urban sustainability and resilience of urban systems require a cohesive and responsive system of governance, with clear flows of information between research, policy and practice. Achieving these goals first requires improvements to the collection, management and collation of observations, modelling approaches and tools, as well as promoting knowledge exchange and understanding in tandem (see Table 1.2, Grimmond *et al.* 2010, NAS 2010).

Given that meteorological hazards occur at both ends of the frequency spectrum (i.e. high/low frequency/magnitude) to predict and inform those who are vulnerable requires a multi-agency approach (e.g. Tang 2006) and one that is embedded within systems of practice – including government, civil society and private sector actors.

Table 1.2 High-priority recommendations from the World Climate Conference 3- Need for more sustainable cities: information for improved management and planning of cities

Observations

- Need for more operational *urban measurement station and networks*; this will require stations within the urban area and upwind. Station should to be sited and equipment exposed in conformity with WMO Urban Guidelines. Stations are especially needed in *rapidly developing cities in hot climates* and in their surroundings. Both simple and complex topographical settings should be represented.
- Where possible *vertical profiles* of physical and chemical variables should be sampled.
- *Long-term measurement stations* should be preserved or established in cities with different urban morphologies to determine universal flow and flux characteristics.

Data

- Need to establish an *international data archive* to aid translation of research findings into design tools and guidelines for different climate zones and urban land use. The archive should consist of high-quality data of use to a broad range of practitioners.
- The importance of fully documenting *urban station metadata* (e.g. description of instruments, site, data quality assurance and control, protocol) should be stressed.

Understanding

- Need to develop methods and frameworks to *analyse atmospheric data* measured above complex urban surfaces.
- Proposed actions to make cities sustainable need to be assessed to determine at what scale interventions are needed and are possible.
- Need methods to distinguish between signals attributable to urban climate change and those to regional and global change.

Modelling

- Need to improve short-range, high-resolution numerical prediction of weather, air quality and chemical dispersion in the urban areas through improved modelling of the biogeophysical features of the urban land surface and consequent exchange of heat, moisture, momentum and radiation with the atmospheric urban boundary layer.
- Need to improve or incorporate data assimilation from meteorological and biogeophysical observations from improved observing networks.

Tools

- Need to develop tools to allow models to be able to accommodate the wide differences in data availability (e.g. routine versus research intensive data) depending on the application from research to operational situation.
- Need to develop tools that allow probable impacts of proposed sustainable design measures to be assessed and ranked, including any unintended consequences of the proposed changes.

Knowledge exchange

- Need to ensure widespread education of the meteorological community (including National Meteorological and Hydrological Services, NMHS) in urban meteorology.
- Assist NMHS to appreciate the role of meteorology and hydrology in urban planning and management of more sustainable cities of all sizes.
- *Communication* across scientific disciplines and spatial and temporal scales must be encouraged.

Source: Grimmond *et al.* (2011), NAS (2010)

6 Discussion: Urban transitions, urban futures

At a global scale, the urban transition – a shift from a predominantly rural population to a predominantly urban population – has been accompanied by a demographic transition – a shift from high birth and death rates, to low birth and death rates (de Sherbinin and Martine 2007). Although the reasons for this are contested, this is thought to be due in part to improved employment opportunities for women and the elevated cost of living in the city, which both reduce fertility, and improved access (typically, although not always) to medical services, which reduces mortality and improves access to family planning (Caldwell 2005, de Sherbinin and Martine 2007). Also at the global scale, this urban metamorphosis has accompanied a transformation of society, culture, politics, economics and environmental management (de Sherbinin and Martine 2007). However, as outlined below, these associations are neither inherent nor universal.

The literature on the connection between urbanisation and economic development is wide, complex and contradictory. There is evidence for symbiotic relationships between various aspects of modern development, two facets of which are indeed economics and urbanisation (Tacoli *et al.* 2008). However, identifying which is the prime driving force is problematic. For example, UN-HABITAT identifies positive links between urbanisation and improvements to democratic governance and female empowerment, which are both viewed as characteristics of developed societies (UN-HABITAT 2008), and observes that "no country has ever achieved sustained economic growth or rapid social development without urbanising [sic]" (UN-HABITAT 2010). Henderson and Wang (2007) provide empirical evidence to suggest that urbanisation is an outcome of development, attributing urban growth to (1) technological advances and (2) democratization. Both, they argue, promote demographic urbanisation and urban expansion, but they affect differently sized cities in different ways. They find that whilst technology facilitates scale economies and management systems, and promotes growth in very large cities, increased democratization has the greatest growth impact on smaller cities because decentralized politics increases local autonomy.

However, this argument in itself accounts for neither the persistence of intensely asymmetrical rural–urban divides (Montgomery 2008) nor the high rates of urban poverty that exist in low-income countries (Tacoli *et al.* 2008). To understand these inequalities it is useful to distinguish different types of 'development', particularly human development and economic development. Human development is defined by the UNDP Human Development Reports as "enlarging people's choices . . . by expanding human capabilities and functionings", the prerequisites of which are 'for people to lead long and healthy lives, to be knowledgeable and to have a decent standard of living' (UNDP n.d.). Insofar as democracy can be understood as a means to express free choice, it is therefore a key facet of human development. It could therefore be posited that the growth of megacities with high poverty levels have succeeded in generating sufficient agglomeration of industry and labour to achieve economic development, but have failed to improve human development equitably. Ranis *et al.* (2000) argue that in the long-term it is preferable to promote human development in the first instance, because this can generate a virtuous cycle of mutual reinforcement between human and economic development, driven by a healthy and well-educated workforce. In making such a choice, governance is clearly central.

This logic supports the well-developed argument that urban governance is key to vulnerability and poverty reduction, and that 'good governance' is necessary to ensure that both human and economic development accompany urbanisation (Pelling 2003, Wisner *et al.* 2004, UN-HABITAT 2008, UN-HABITAT 2010). Good governance means having an accountable, responsive and well-structured governance system with well-designed policies and effective enforcement power. This is also key in maintaining a functioning land market, capable of revealing the value put on land by residents, developers and profit-making enterprises (a context that is important to good planning, and making interventions in the interest of environment, equity and public interests generally), and to ensure the benefits of urban growth reach the poor as well as the elite (Martine *et al.* 2008). However, there are strong forces preventing human development from being given priority over economic growth, and this view contrasts strongly with the claim that inequality is an almost inevitable consequence of development (World Bank 2009).

The impact of the urban transition on the environment varies according to many factors (see Chapter 2). Factors that affect the sustainability potential of megacities include the spatial extent, type of land, form of occupancy and ecological condition of urban residence (de Sherbinin and Martine 2007). The failure or damage of ecosystem services such as clean water, inadequate access to them, or disproportionate demand for available resources, are attributed to environmental health concerns in coastal megacities (McGranahan *et al.* 2006). Literature on the urban environmental transition states that the majority of environmental health problems are actually associated with large-scale poverty rather than urbanisation per se, and that increased wealth is associated with negative environmental impacts being located increasingly remotely from the point of consumption (McGranahan and Songsore 1994). In terms of future development, therefore, it seems certain that the management of urban growth in low-income megacities will dictate the proportion of the city that lives in poverty and has environmental health problems (Martine *et al.* 2008).

The following chapters develop in more detail the impacts of coastal megacities and city regions on the environment, and in turn the hazards and vulnerabilities experienced by these cities. The trade-offs and synergies between management options will be analyzed, outlining potential adaptive strategies now and in the future.

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