8 Urban Areas

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Frequently Asked Questions

Executive Summary

Urban climate adaptation can build resilience and enable sustainable development. {8.1, 8.2, 8.3}

Action in urban centers is essential to successful global climate change adaptation. Urban areas hold more than half the world's population and most of its built assets and economic activities. They also house a high proportion of the population and economic activities most at risk from climate change, and a high proportion of global greenhouse gas emissions are generated by urban-based activities and residents (*medium confidence*, based on *medium evidence*, *high agreement*). {8.1}

Much of key and emerging global climate risks are concentrated in urban areas. Rapid urbanization and rapid growth of large cities in low- and middle-income countries have been accompanied by the rapid growth of highly vulnerable urban communities living in informal settlements, many of which are on land at high risk from extreme weather (*medium confidence*, based on *medium evidence*, *high agreement*). {8.2, 8.3, Tables 8-2, 8-3}

Cities are composed of complex inter-dependent systems that can be leveraged to support climate change adaptation via effective city governments supported by cooperative multilevel governance. This can enable synergies with infrastructure investment and maintenance, land use management, livelihood creation, and ecosystem services protection (*medium confidence*, based on *limited evidence*, *medium agreement*). {8.3, 8.4}

Urban adaptation action that delivers mitigation co-benefits is a powerful, resource-efficient means to address climate change and to realize sustainable development goals (*medium confidence*, based on *medium evidence*, *high agreement*). {8.4}

Urban climate change risks, vulnerabilities, and impacts are increasing across the world in urban centers of all sizes, economic conditions, and site characteristics. {8.2}

Urban climate change-related risks are increasing (including rising sea levels and storm surges, heat stress, extreme precipitation, inland and coastal flooding, landslides, drought, increased aridity, water scarcity, and air pollution) with widespread negative impacts on people (and their health, livelihoods, and assets) and on local and national economies and ecosystems (*very high confidence*, based on *robust evidence*, *high agreement*). These risks are amplified for those who live in informal settlements and in hazardous areas and either lack essential infrastructure and services or where there is inadequate provision for adaptation. {8.2, Table 8-2}

Climate change will have profound impacts on a broad spectrum of infrastructure systems (water and energy supply, sanitation and drainage, transport and telecommunication), services (including health care and emergency services), the built environment, and ecosystem services. These interact with other social, economic, and environmental stressors exacerbating and compounding risks to individual and household well-being (*medium confidence*, based on *medium evidence*, *high agreement*). {8.2}

Cities and city regions are sufficiently dense and of a spatial scale that they influence their local micro-climate. Climate change will interact with these conditions in a variety of ways, some of which will exacerbate the level of climate risk (*high confidence*, based on *robust evidence*, *high agreement*). {8.2}

Urban climate adaptation provides opportunities for both incremental and transformative development. {8.3, 8.4}

Urban adaptation provides opportunities for incremental and transformative adjustments to development trajectories toward resilience and sustainable development via effective multilevel urban risk governance, alignment of policies and incentives, strengthened local government and community adaptation capacity, synergies with the private sector, and appropriate financing and institutional development. Opportunities to do so are high in many rapidly growing cities where institutions and infrastructure are being developed, though there is limited evidence of this being realized in practice (*medium confidence*, based on *limited evidence*, *high agreement*). {8.4}

Urban adaptation can enhance economic comparative advantage, reducing risks to enterprises and to households and communities (*medium confidence*, based on *medium evidence*, *high agreement*). {8.3}

City-based disaster risk management with a central focus on risk reduction is a strong foundation on which to address increasing exposure and vulnerability and thus to build adaptation. Closer integration of disaster risk management and climate change adaptation along with the incorporation of both into local, subnational, national, and international development policies can provide benefits at all scales (*high confidence*, based on *medium evidence*, *high agreement*). {8.3}

Ecosystem-based adaptation is a key contributor to urban resilience (*medium confidence*, based on *medium evidence*, *high agreement* (among practitioners)). {8. 3}

Effective urban food-security related adaptation measures (especially social safety nets but also including urban and peri-urban agriculture, local markets, and green roofs) can reduce climate vulnerability especially for low-income urban dwellers (*medium confidence*, based on *medium evidence*, *medium agreement*). {8.3}

Good quality, affordable, well-located housing provides a strong base for city-wide climate change adaptation minimizing current exposure and loss. Possibilities for building stock adaptation rest with owners and public, private, and civil society organizations (*high confidence*, based on *robust evidence*, *high agreement*). {8.3, 8.4}

Reducing basic service deficits and building resilient infrastructure systems (water supply, sanitation, storm and waste water drains, electricity, transport and telecommunications, health care, education, and emergency response) can significantly reduce hazard exposure and vulnerability to climate change, especially for those who are most at risk or vulnerable (*very high confidence*, based on *robust evidence*, *high agreement*). {8.3}

For most key climate change associated hazards in urban areas, risk levels increase from the present (with current adaptation) to the near term but high adaptation can reduce these risk levels significantly. It is less able to do so for the longer term, especially under a global mean temperature increase of 4°C. {Tables 8-3, 8-6}

Implementing effective urban adaptation is possible and can be accelerated. {8.4}

Urban governments are at the heart of successful urban climate adaptation because so much adaptation depends on local assessments and integrating adaptation into local investments, policies, and regulatory frameworks (*high confidence*). {8.4}

Well governed cities with universal provision of infrastructure and services have a strong base for building climate resilience if processes of planning, design, and allocation of human capital and material resources are responsive to emerging climate risks (*medium confidence*, based on *medium evidence*, *high agreement*). {8.4}

Building human and institutional capacity for adaptation in local governments, including scope for reflecting on incremental and transformative adaptation pathways, accelerates implementation and improves urban adaptation outcomes (*high confidence*, based on *medium evidence*, *high agreement*). {8.4}

Coordinated support from higher levels of governments, the private sector, and civil society and horizontal learning through networks of cities and practitioners benefits urban adaptation (*medium confidence*, based on *medium evidence*, *medium agreement*). {8.4}

Leadership within local governments and also across all scales is important in driving successful adaptation and in promoting and sustaining a broad base of support for the urban adaptation agenda (*medium confidence*, based on *medium evidence*, *high agreement*). {8.4}

Addressing political interests, mobilizing institutional support for climate adaptation, and ensuring voice and influence to those most at risk are important strategic adaptation concerns (*medium confidence*, based on *limited evidence*, *medium agreement*). {8.4}

Enabling the capacity of low-income groups and vulnerable communities, and their partnership with local governments, can be an effective urban adaptation strategy (*medium confidence*, based on *limited evidence*, *high agreement*). {8.3, 8.4}

Urban centers around the world face severe constraints to raising and allocating resources to implement adaptation. In most low- and middle-income country cities, infrastructure backlogs, lack of appropriate mandates, and lack of financial and human resources severely constrain adaptation action. Small urban centers often lack economies of scale for adaptation investments and local capacity to act, as they have relatively low national and international profiles (*medium confidence*, based on *medium evidence*, *high agreement*). {8.3, 8.4}

International financial institutions provide limited financial support for adaptation in urban areas. There is limited current commitment to finance urban adaptation from different levels of government and international agencies (*medium confidence*, based on *limited evidence*, *high agreement*). {8.4}

A scientific evidence base in each urban center is essential for effective adaptation action. This includes local risk and vulnerability assessments and information and data with which to consider current and future risk and adaptation and development options (*medium confidence*, based on *medium evidence*, *high agreement*). {8.4}

Dealing with the uncertainty associated with climate change projections and balancing them with actions to address current vulnerabilities and adaptation costs helps to assist implementation in urban areas (*medium confidence*, based on *medium evidence*, *medium agreement*). {8.2, 8.4}

8.1. Introduction

8.1.1. Key Issues

Adaptation to climate change depends centrally on what is done in urban centers, which now house more than half the world's population and concentrate most of its assets and economic activities (World Bank, 2008; UN DESA Population Division, 2012). As Section 8.4 emphasizes, this will require responses by all levels of government as well as individuals and communities, the private sector, and civil society. The serious impacts of extreme weather on many urban centers each year demonstrate some of the risks and vulnerabilities to be addressed (UNISDR, 2009; IFRC, 2010). Climate change will usually add to these and other risks and vulnerabilities. Urban policies also have major implications for mitigation, especially for future levels of greenhouse gas (GHG) emissions and for delivering co-benefits, as discussed in WGIII AR5. This chapter focuses on the possibilities for governments, enterprises, and populations to adapt urban centers to the direct and indirect impacts of climate change.

The level of funding needed for sound urban adaptation could exceed the capacities of local and national governments and international agencies (Parry et al., 2009; Brugmann, 2012). Much of the investment will have to come from individuals and households, communities, and firms through their decisions to address adaptation and resilience (Agrawala and Fankhauser, 2008; Fankhauser and Soare, 2013). This might suggest little role for governments, especially local governments. But whether these small-scale decisions by households, communities, and firms do contribute to adaptation depends in large part on what local governments do, encourage, support, and prevent—as well as their contribution to providing required infrastructure and services. An important part of this is the provision by local governments of appropriate regulatory frameworks and the application of building standards, to ensure that the choices made by individuals, households, and firms support adaptation and prevent maladaptation. For instance, land use planning and management have important roles in ensuring sufficient land for housing that avoids dangerous sites and protects key ecological services and systems (UN-HABITAT, 2011a).

In reviewing adaptation needs and options for urban areas, the documentation reviewed for this chapter points to two key conclusions. The first is how much the adaptive capacity of any city depends on the quality of provision and coverage of infrastructure and services; the capacities for investments and land use management; and the degree to which buildings and infrastructure meet health and safety standards. This capacity provides a foundation for city resilience on which adaptation can be built. There is little of this foundation in most urban centers in low-income and in many middle-income nations. The second conclusion is the importance of city and municipal governments acting now to incorporate climate change adaptation into their development plans and policies and infrastructure investments. This includes not only building that foundation of resilience (and its institutional, governance, and financial underpinnings) but also mobilizing new resources, adjusting building and land use regulations, and continuously developing the local capacity to respond. This is not to diminish the key roles of other actors. But it will fall to city and municipal government to provide the scaffolding and regulatory framework within which other stakeholders contribute and collaborate. Thus, adaptation in urban areas depends on the competence and capacity of local governments and a locally rooted iterative process of learning about changing risks and opportunities, identifying and evaluating options, making decisions, and revising strategies in collaboration with a range of actors.

8.1.2. Scope of the Chapter

This chapter focuses on what we know about the potential impact of climate change on urban centers and their populations and enterprises (Section 8.2), what measures are being taken to adapt to these changes (and protect vulnerable groups) (Section 8.3), and what institutional and governance changes can underpin adaptation (Section 8.4). Both this and Chapter 9 highlight the multiple linkages between rural and urban areas that have relevance for adaptation. This chapter also overlaps with Chapter 10, especially in regard to infrastructure, although this chapter focuses on urban infrastructure and in particular the infrastructure that comes within the responsibilities or jurisdiction of urban governments.

This chapter draws its urban statistics from the United Nations Population Division (UN DESA Population Division, 2012). Urban centers vary from those with a few thousand (or in some nations a few hundred) inhabitants to metropolitan areas with more than 20 million inhabitants. There is no international agreement—and considerable national variation—in how urban areas are defined (UN DESA Population Division, 2012). The main differences are in how settlements with a few hundred up to 20,000 inhabitants are classified; depending on the country, some, most, or all of these may be classified as urban or rural. There are also differences in how urban boundaries are set. In some places, they encompass the urban built up area or the central urban core; in others, they go well beyond the built up area and include large areas devoted to agriculture (Satterthwaite, 2007).

The issue here is whether provision for adaptation includes "rural" populations living around urban centers and within urban jurisdictions. In addition, it is common for part of the workforce in larger urban centers to live outside the urban center and to commute—and this may include many that live in settlements designated as rural. There is also no agreed definition for what constitutes a city—although the term city implies an urban center with some economic, political, or cultural importance and would not be applied to most small urban centers.

8.1.3. Context: An Urbanizing World

In 2008, for the first time, more than half the world's population was living in urban centers and the proportion continues to grow (UN DESA Population Division, 2012). Three-quarters of the world's urban population and most of its largest cities are now in low- and middle-income nations. A comparison of Figures 8-1 and 8-2 highlights the increase in the number of large cities from 1950 to what is projected for 2025. UN projections suggest that almost all the increase in the world's population up to 2050 will be in urban centers in what are currently low- and middle-income nations (see Table 8-1). Most of the gross domestic product (GDP) of most nations and globally is generated in urban centers and most new investments have concentrated there (World Bank, 2008; Satterthwaite et al., 2010). Clearly, just in terms of the population, economic activities, assets, and climate risk they increasingly concentrate, adapting urban areas to climate change requires serious attention.

Most urbanization is underpinned by an economic logic. All wealthy nations are predominantly urbanized and rapid urbanization in low- and middle-income nations is usually associated with rapid economic growth (World Bank, 2008; Satterthwaite et al., 2010). Most of the world's largest cities are in its largest economies (World Bank, 2008;

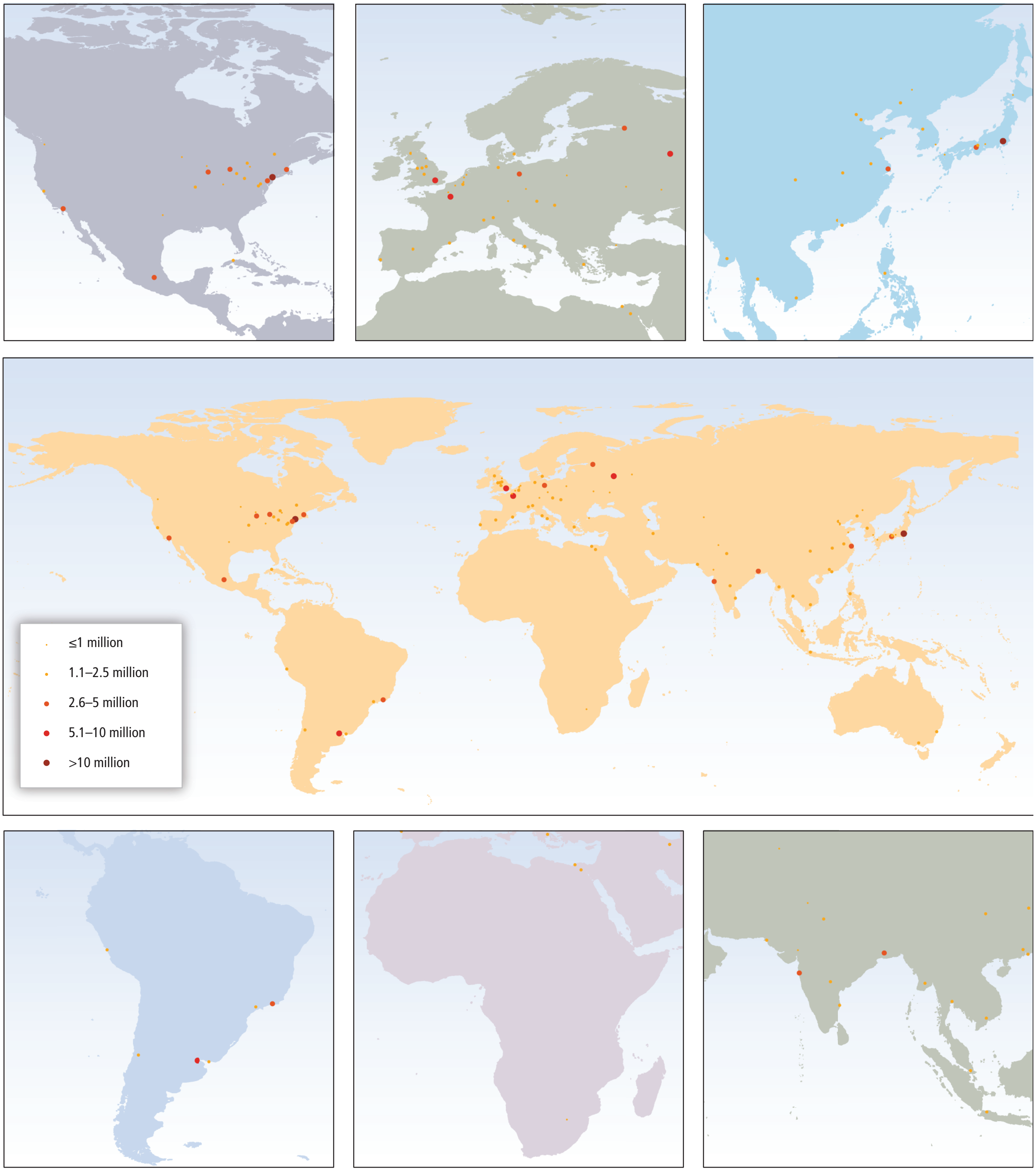


Figure 8-1 | Global and regional maps showing the location of urban agglomerations with 750,000-plus inhabitants in 1950 (derived from statistics in UN DESA Population Division, 2012).

Satterthwaite et al., 2010). If rapid urbanization and rapid city population growth are associated with economic success, it suggests that more resources should be available there to support adaptation. But, as discussed in Section 8.3, this is rarely the case. In most urban centers in low- and middle-income nations including many successful cities, local governments have been unable to manage their economic and physical expansion and there are large deficits in provision for infrastructure and services that are relevant to climate change adaptation. About one in seven people in the world live in poor quality, overcrowded accommodation in urban areas with inadequate provision (or none) for basic infrastructure

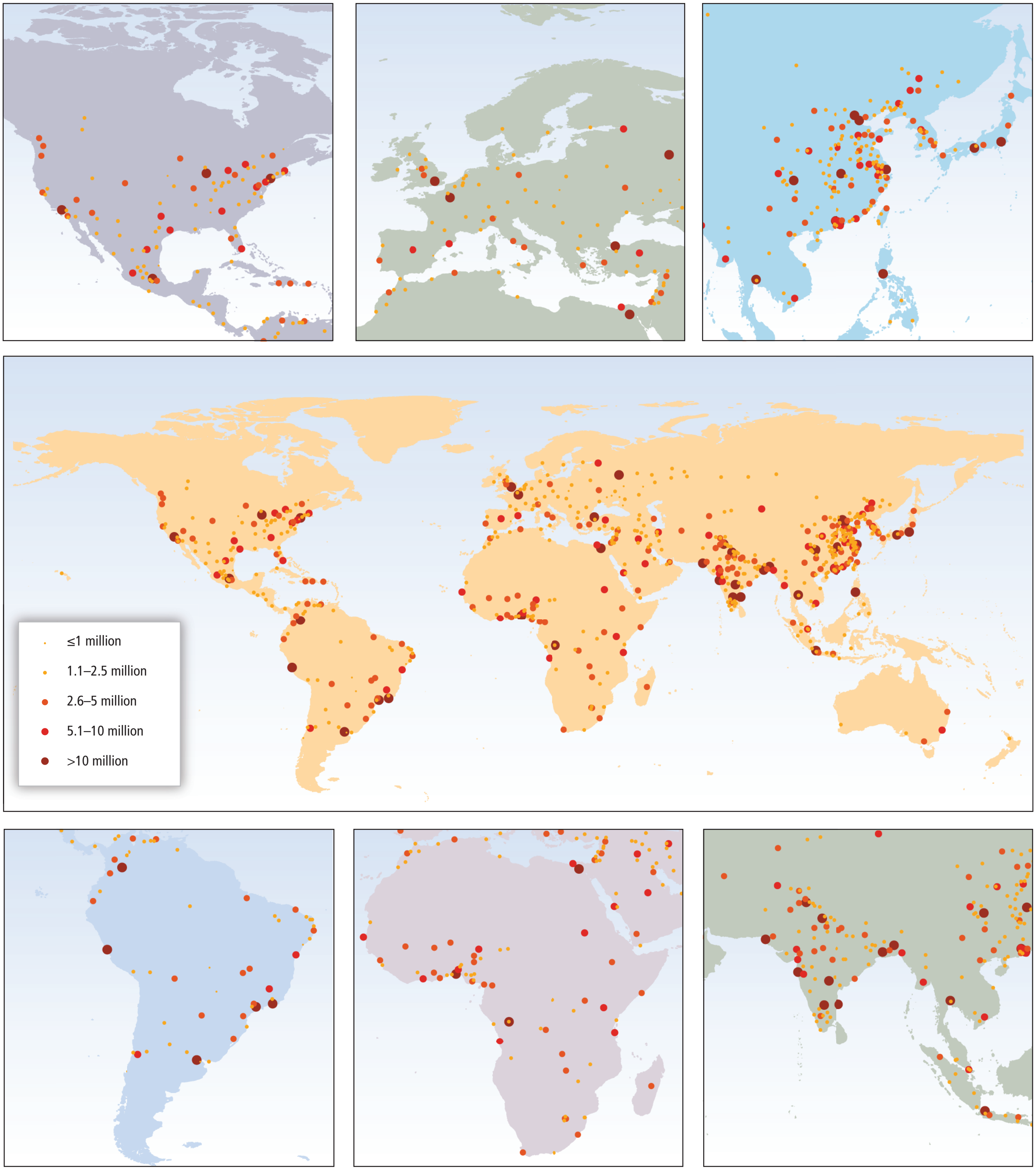


Figure 8-2 | Global and regional maps showing the location of urban agglomerations with 750,000-plus inhabitants projected for 2025 (derived from statistics in UN DESA Population Division, 2012).

Table 8-1 | Distribution of the world's urban population by region, 1950–2010 with projections to 2030 and 2050. Source: Derived from statistics in United Nations (2012).

	Major area, region, or country	1950	1970	1990	2010	Projected for 2030	Projected for 2050
Urban population (millions of inhabitants)	**World**	745	1352	2281	3559	4984	6252
	More developed regions	442	671	827	957	1064	1127
	Less developed regions	304	682	1454	2601	3920	5125
	Least developed countries	15	41	107	234	477	860
	Sub-Saharan Africa	20	56	139	298	596	1069
	Northern Africa	13	31	64	102	149	196
	Asia	245	506	1032	1848	2703	3310
	China	65	142	303	660	958	1002
	India	63	109	223	379	606	875
	Europe	281	412	503	537	573	591
	Latin America and the Caribbean[a]	69	163	312	465	585	650
	Northern America	110	171	212	282	344	396
	Oceania	8	14	19	26	34	40
Percent of the population in urban areas	**World**	29.4	36.6	43.0	51.6	59.9	67.2
	More developed regions	54.5	66.6	72.3	77.5	82.1	85.9
	Less developed regions	17.6	25.3	34.9	46.0	55.8	64.1
	Least developed countries	7.4	13.0	21.0	28.1	38.0	49.8
	Sub-Saharan Africa	11.2	19.5	28.2	36.3	45.7	56.5
	Northern Africa	25.8	37.2	45.6	51.2	57.5	65.3
	Asia	17.5	23.7	32.3	44.4	55.5	64.4
	China	11.8	17.4	26.4	49.2	68.7	77.3
	India	17.0	19.8	25.5	30.9	39.8	51.7
	Europe	51.3	62.8	69.8	72.7	77.4	82.2
	Latin America and the Caribbean	41.4	57.1	70.3	78.8	83.4	86.6
	Northern America	63.9	73.8	75.4	82.0	85.8	88.6
	Oceania	62.4	71.2	70.7	70.7	71.4	73.0
Percent of the world's urban population	**World**	100.0	100.0	100.0	100.0	100.0	100.0
	More developed regions	59.3	49.6	36.3	26.9	21.4	18.0
	Less developed regions	40.7	50.4	63.7	73.1	78.6	82.0
	Least developed countries	2.0	3.0	4.7	6.6	9.6	13.8
	Sub-Saharan Africa	2.7	4.1	6.1	8.4	11.9	17.1
	Northern Africa	1.7	2.3	2.8	2.9	3.0	3.1
	Asia	32.9	37.4	45.2	51.9	54.2	52.9
	China	8.7	10.5	13.3	18.6	19.2	16.0
	India	8.5	8.1	9.8	10.6	12.2	14.0
	Europe	37.6	30.5	22.0	15.1	11.5	9.5
	Latin America and the Caribbean	9.3	12.1	13.7	13.1	11.7	10.4
	Northern America	14.7	12.6	9.3	7.9	6.9	6.3
	Oceania	1.1	1.0	0.8	0.7	0.7	0.6

[a]Chapter 26 on North America includes Mexico; in the above statistics, Mexico is included in Latin America and the Caribbean.

and services, mostly in informal settlements (UN-HABITAT, 2003a; Mitlin and Satterthwaite, 2013). Much of the health risk and vulnerability to climate change is concentrated in these settlements (Mitlin and Satterthwaite, 2013). So this chapter is concerned not only with an adaptation deficit for, but also with a development deficit that is relevant to, this risk and vulnerability.

Many aspects of urban change in recent decades have been so rapid that they have overwhelmed government capacity to manage them. Among the 611 cities with more than 750,000 inhabitants in 2010, 47 had populations that had grown more than 20-fold since 1960; in 120, the growth was more than 10-fold (statistics in this paragraph are drawn from data in UN DESA Population Division, 2012). The increasing concentration of the world's urban population and its largest cities outside the highest income nations represents an important change. Over the 19th and 20th centuries, most of the world's urban population and most of its largest cities were in its most prosperous nations. Now, urban areas in low- and middle-income nations have close to two-fifths of the world's total population, close to three-quarters of its urban population, and most of its large cities. In 2011, of the 23 "mega-cities" (with populations over 10 million), only 5 were in high-income nations (two in Japan, two in the USA, one in France). Of the remaining 18, 4 were in China, 3 in India, and 2 in Brazil. But more than three-fifths of the world's urban population is in urban centers with fewer than 1 million inhabitants and it is here that much of the growth in urban population is occurring.

Underlying these population statistics are large and complex economic, social, political, and demographic changes, including the multiplication in the size of the world's economy and the shift in economic activities and employment structures from agriculture to industry and services (and within services to information production and exchange) (Satterthwaite, 2007). One of the most significant changes has been the growth in the size and importance of cities whose economies increased and changed as a result of globalization (Sassen, 2012). Another is the number of large cities that are now centers of large extended metropolitan regions.

One of the challenges for this chapter is to convey the very large differences in adaptive capacity between urban centers. There are tens of thousands of urban centers worldwide with very large and measurable differences in population, area, economic output, human development, quality, and coverage of infrastructure and services, ecological footprint, and GHG emissions. The differences in adaptive capacity are far less easy to quantify. Table 8-2 illustrates differences in adaptive capacity and factors that influence it. It indicates how each urban center falls within a spectrum in at least four key factors that influence adaptation: local government capacity; the proportion of residents served with risk-reducing infrastructure and services; the proportion living in housing built to appropriate health and safety standards; and the levels of risk from climate change's direct and indirect impacts. This chapter and Table 8-2 also draw on detailed case studies to illustrate this diversity—New York (Solecki, 2012), Durban (Roberts and O'Donoghue, 2013), and Dar es Salaam (Kiunsi, 2013). Section 8.5 provides tables of current and indicative future climate risks for Dar es Salaam, Durban, London, and New York.

Many attributes of urban centers can be measured and compared. As noted above, populations vary from a few hundred to more than 20 million. Areas vary from less than one to thousands of square kilometers. Average life expectancy at birth varies from more than 80 years to less than 40 years, and under-five mortality rates vary by a factor of 20 or more (Mitlin and Satterthwaite, 2013). Average per capita incomes vary by a factor of at least 300; so too does the funding available to local governments per person (UCLG, 2010). GHG emissions per person (in tonnes of carbon dioxide equivalent) vary by more than 100 (Dodman, 2009; Hoornweg et al., 2011).

There are large differences between urban centers in the extent to which their economies are dependent on climate-sensitive resources (including commercial agriculture, water, and tourism).There are also large variations in the scale and nature of impacts from extreme weather. As Table 8-2 suggests, there are urban indicators relevant for assessing the resilience to climate change impacts that urban areas have acquired (including the proportion of the population with water piped to their homes, sewers, drains, health care, and emergency services); it is more of a challenge to find indicators for the climate change related risks and for the quality and capacity of government.

Recent analyses of disaster impacts show that a high proportion of the world's population most affected by extreme weather events is concentrated in urban centers (UNISDR, 2009, 2011; IFRC, 2010). As shown in Table 8-2, a high proportion of these urban centers lack both local governments with the capacity to reduce disaster risk, and much of the necessary infrastructure. Their low-income households may require particular assistance because of greater exposure to hazards, lower adaptive capacity, more limited access to infrastructure or insurance, and fewer possibilities to relocate to safer accommodation, compared to wealthier residents.

All successful urban centers have had to adapt to environmental conditions and available resources, although local resource constraints have often been overcome by drawing on resources and using sinks from "distant elsewhere" (Rees, 1992; McGranahan, 2007); this includes importing goods that are resource intensive and whose fabrication involves large GHG emissions. The growth of urban population over the last century has also caused a very large anthropogenic transformation of terrestrial biomes. Urban centers cover only a small proportion of the world's land surface—according to Schneider et al. (2009) only 0.51% of the total land area; only in Western Europe do they cover more than 1%. However, their physical and ecological footprints are much larger. The net ecological impact of urban centers includes the decline in the share of wild and semi-natural areas from about 70% to less than 50% of land area, largely to accommodate crop and pastoral land to support human consumption (Ellis et al., 2010). It has led not only to a decrease in biodiversity but to fragmentation in much of the remaining natural areas and a threat to the ecological services that support both rural and urban areas. Future projections (Seto et al., 2012) suggest that, if current trends continue, urban land cover will increase by 1.2 million km^2 by 2030, nearly tripling global urban land area between 2000 and 2030. This would mean a "considerable loss of habitats in key biodiversity hotspots," destroying the green infrastructure that is key in helping areas adapt to climate change impacts (Seto et al., 2012, p. 16083) as well as increasing the exposure of population and assets to higher risk levels.

Many of the challenges and opportunities for urban adaptation relate to the central features of city life—the concentration of people, buildings, economic activities, and social and cultural institutions (Romero-Lankao and Dodman, 2011). Agglomeration economies are usually discussed in relation to the advantages for enterprises locating in a particular city. But the concentrations of people, enterprises, and institutions in urban areas also provide potential agglomeration economies in lower unit costs for piped water, sewers, drains, and a range of services (solid waste collection, schools, health care, emergency services, policing) and in the greater capacity for people, communities, and institutions to respond collectively (Hardoy et al., 2001). At the same time, the advantages that come with these concentrations of people and activities are also accompanied by particular challenges—for instance, the management of storm and surface runoff and measures to reduce heat islands. Large cities concentrate demand and the need for ecological services and natural resources (water, food, and biomass), energy, and electricity, and many city enterprises rely on lifeline infrastructure and supply chains that can be disrupted by climate change (UNISDR, 2013; see also Section 8.3.3).

Table 8-2 | The large spectrum in the capacity of urban centers to adapt to climate change. One of the challenges for this chapter is to convey the very large differences in adaptive capacity between urban centers. This table seeks to illustrate differences in adaptive capacity and the factors that influence it. For a more detailed assessment of adaptation potentials and challenges for specific cities (Dar es Salaam, Durban, London, and New York), see Table 8-6. Sources: This table was constructed to provide a synthesis of key issues, so it draws on all the sources cited in this chapter. However, it draws in particular on Solecki (2012), Kiunsi (2013), and Roberts and O'Donoghue (2013).

Indicator clusters	Very little adaptive capacity or resilience/ "bounce-back" capacity	Some adaptive capacity and resilience/"bounce-back" capacity	Adequate capacity for adaptation and resilience/"bounce-back" capacity, but not yet acted on	Climate resilience and capacity to bounce forward	Transformative adaptation
The proportion of the population served with risk-reducing infrastructure (paved roads, storm and surface drainage, piped water…) and services relevant to resilience (including health care, emergency services, policing/rule of law) and the institutions needed for such provision	0–30% of the urban center's population served; most of those unserved or inadequately served living in informal settlements.	30–80% of the urban center's population served; most of those unserved or inadequately served living in informal settlements.	80–100% of the urban center's population served; most of those unserved or inadequately served living in informal settlements.	Most/all of the urban center's population with these and with an active adaptation policy identifying current and probable future risks and with an institutional structure to encourage and support action by all sectors and agencies. In many cities, also upgrade aging infrastructure.	Urban centers that have integrated their development and adaptation policies and investments within an understanding of the need for mitigation and sustainable ecological footprints.
The proportion of the population living in legal housing built with permanent materials (meeting health and safety standards)				Active program to improve conditions, infrastructure, and services to informal settlements and low-income areas. Identify and act on areas with higher/ increasing risks. Revise building standards.	Land use planning and management successfully providing safe land for housing, avoiding areas at risk and taking account of mitigation.
Proportion of urban centers covered	Most urban centers in low-income and many in middle-income nations.	Many urban centers in many low-income nations; most urban centers in most middle-income nations.	Virtually all urban centers in high-income nations, many in middle-income nations.	A small proportion of cities in high-income and upper-middle-income nations.	Some innovative city governments thinking of this and taking some initial steps.
Estimated number of people living in such urban centers	1 billion	1.5 billion	1 billion	Very small	
Infrastructure deficit	Much of the built up area lacking infrastructure				Most or all the built up area with infrastructure (paved roads, covered drains, piped water…)
Local government investment capacity	Very little or no local investment capacity				Substantial local investment capacity
Occurrence of disasters from extreme weather[a]	Very common				Uncommon (mostly due to risk-reducing infrastructure, services, and good quality buildings available to almost all the population)
Examples	Dar es Salaam, Dhaka	Nairobi, Mumbai	Most cities in high-income nations	Cities such as New York; London, Durban, and Manizales with some progress	
Implications for climate change adaptation	Very limited capacity to adapt. Very large deficits in infrastructure and in institutional capacity. Very large numbers exposed to risk if these are also in locations with high levels of risk from climate change.	Some capacity to adapt, especially if this can be combined with development, but difficult to get city governments to act. Particular problems for those urban centers in locations with high levels of risk from climate change.	Strong basis for adaptation, but needs to be acted on and to influence city government and many of its sectoral agencies.	City government that is managing land use changes as well as having adaptation integrated into all sectors.	City government with capacity to influence and work with neighboring local government units. Also with land use changes managed to protect eco-system services and support mitigation.

Notes: For cities that are made up of different local government areas, it would be possible to apply the above at an intra-city or intra-metropolitan scale. For instance, for many large Latin American, Asian and African cities, there are local government areas that would fit in each of the first three categories.

[a]See text in regard to disasters and extensive risk (United Nations, 2011).

The increasing concentration of the world's population in urban centers means greater opportunities for adaptation but more concentrated risk if they are not acted on. Many urban governments lack the capacity to do so, especially those in low- and lower-middle-income nations. The result is large deficiencies in infrastructure and services. Urban centers in high-income nations, although much better served, may also face particular challenges—for instance, aging infrastructure and the need to adapt energy systems, building stock, infrastructure, and services to the altered risk set that climate change will bring (see Zimmerman and Faris (2010) and Solecki (2012) for discussions of this for New York). Many studies have shown that working with a range of government and civil society institutions at local and supra-local levels increases the effectiveness of urban adaptation efforts; support and enabling frameworks from higher levels of government were also found to be helpful (see Section 8.4 and many of the studies listed in Box 8-1).

8.1.4. Vulnerability and Resilience

For each of the direct and indirect impacts of climate change, there are groups of urban dwellers that face higher risks (illness, injury, mortality, damage to or loss of homes and assets, disruption to incomes) (Hardoy and Pandiella, 2009; Mitlin and Satterthwaite, 2013). Age may be a factor (for instance infants and elderly people are more sensitive to particular hazards such as heat stress) or health status (those with particular diseases, injuries, or disabilities may be more sensitive to these impacts). Or it may be that they live in buildings or in locations facing greater risks—for instance on coasts or by rivers with increased flood risks—or that they lack coping capacities. Women may face higher risks in their work and constraints on adaptation if they face discrimination in access to labor markets, resources, finance, services, and influence (see Box CC-GC). These are often termed vulnerable groups—although, to state the obvious, they are vulnerable to direct climate change impacts only to the extent that the hazard actually poses a risk. Remove people's exposure to the hazard (e.g., provide drains that prevent flooding) and there is limited or no impact. Infants may face serious health risks when water supplies are contaminated by flooding, but rapid and effective treatment for diarrhea and quickly re-establishing availability of drinking quality water greatly reduces impacts (Bartlett, 2008). Adaptations by individuals, households, communities, private enterprises, or government service providers can all reduce risks.

Adaptation in a particular area or settlement may have clear benefits for the inhabitants there, but can also have knock-on effects on the well-being of inhabitants in other areas. Diverting a river course or building an embankment to protect new development may prevent flooding in one location, but may cause or increase flooding somewhere else (see Revi, 2005, for Mumbai; Alam and Rabbani, 2007, for Dhaka).

Assessments of vulnerability to climate change draws on assessments in other contexts—including the vulnerability of low-income groups to stresses and shocks (e.g., Chambers, 1989; Pryer, 2003) and to disasters (Cannon, 1994; Manyena, 2006). The term is generally used in relation to an inability to cope with external changes including avoiding harm when exposed to a hazard. This includes people's inability to avoid the hazard (exposure), anticipate it, and take measures to avoid it or limit its impact; cope with it; and recover from it (Hardoy and Pandiella, 2009). Vulnerable groups may be identified on the basis of any of these four factors. The definition of resilience used in the WGII AR5 when applied to urban centers means the ability of urban centers (and their populations, enterprises, and governments) and the systems on which they depend to anticipate, reduce, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner (see the Glossary).

The term vulnerability is also applied to sectors, including food processing, tourism, water, energy, and mobility infrastructure and their cross-linkages, for instance, the dependency of perishable commodities on efficient transport. Much tourism is sensitive to climate change, which can damage key tourist assets such as coral reefs and beaches or make particular locations less attractive to tourists because of more extreme weather. The term is also applied to natural systems/ecosystems (e.g., mangroves, coastal wetlands, urban tree canopy). If the adaptive capacity of these systems is increased, they can also provide natural protection from the impacts of climate change in urban areas (see, e.g., Sections 8.2.4.5, 8.3.3.7 for more details).

8.1.4.1. Differentials in Risk and Vulnerability within and between Urban Centers

In urban centers where virtually all buildings meet health and safety standards, where land use planning prevents developments on sites at risk, and where there is universal provision for infrastructure and basic services, the exposure differentials between high- and low-income groups to climate-related risk are quite low. Having low income and few assets in such urban centers does not necessarily imply greater vulnerability to climate change (Mitlin and Satterthwaite, 2013). But typically, the larger the deficit in infrastructure and service provision, the larger the differentials in exposure to most climate change impacts between income groups. Low-income groups in low- and middle-income nations are often disproportionately vulnerable because of poor quality and insecure housing; inadequate infrastructure; and lack of provision for health care, emergency services, and disaster risk reduction (UNISDR, 2009; IFRC, 2010; UN-HABITAT, 2011a; IPCC, 2012; Mitlin and Satterthwaite, 2013). Most deaths from disasters are concentrated in low- and middle-income countries—including more than 95% of deaths from natural disasters between 1970 and 2008 (IPCC, 2012). More than 95% of the deaths from storms and floods registered on the EM-DAT from 2000 to September 2013 were in low- and middle-income nations.[1]

An analysis of annual fatalities from tropical cyclones showed these to be heavily concentrated in low-income nations even though there was high exposure in many upper-middle- and high-income nations (and these nations had larger economic losses; UNISDR, 2009). These analyses do not separate rural and urban populations—but there is a growing body of evidence that most urban deaths from extreme weather events are in low-income and lower-middle-income countries (UNISDR, 2009; IFRC, 2010). Analyses of risks across many cities usually show the cities at highest risk from extreme weather or particular kinds of such weather

[1] These are drawn from data in the The International Disaster Database EM-DAT accessed on September 16, 2013.

(e.g., floods) to be primarily in high-income countries (Munich Re, 2004; Hallegatte et al., 2013). But this is because these analyses are based on estimates of economic costs or economic losses. If they were based instead on deaths and injuries, the ranking would change fundamentally (see also Balica et al., 2012). The official statistics on disaster deaths are also known to considerably understate total deaths, in part because many deaths go unrecorded, in part because of the criteria that a disaster event has to meet to be included (one of the following criteria must be fulfilled: ten or more people reported killed; 100 or more people reported affected; declaration of a state of emergency; or call for international assistance) (UNISDR, 2009).

There are dramatic examples of extreme weather events in high-income countries with very large impacts, including high mortality. But the analyses in UNISDR (2009) and IFRC (2010), and the reports of deaths from extreme weather in many of the case studies listed in Box 8-1, suggest that most extreme weather disaster deaths in urban centers are in low- and lower-middle-income nations, and that risks are concentrated in informal settlements. As noted by IPCC (2012), the occupants of these settlements are typically more exposed to climate events with limited or no hazard-reducing infrastructure, low-quality housing, and limited capacity to cope.

Where provision for adequate housing, infrastructure, and services is most lacking, the capacity of individuals, households, and community organizations to anticipate, cope, and recover from the direct and indirect losses and impact of disasters (of which climate-related events are a subset) becomes increasingly important (see Section 8.4). The effectiveness of early warning systems, the speed of response, and the effectiveness of post-disaster response is especially important to those who are more sensitive and have less coping capacity. The effectiveness of such responses depends on an understanding of the specific vulnerabilities, needs, and priorities of different income groups, age groups, and groups that face discrimination, including that faced by women and by particular social or ethnic groups (UN-HABITAT, 2011a).

8.1.4.2. Understanding Resilience for Urban Centers in Relation to Climate Change

In relation to disasters, resilience is usually considered to be the opposite of vulnerability, but vulnerability is often discussed in relation to particular population groups while resilience is more often discussed in relation to the systemic capacity to protect them and reduce the impact of particular hazards through infrastructure or climate-risk sensitive land use management. In recent years, a literature has emerged discussing resilience to climate change for urban centers and what contributes to it (Muller, 2007; Leichenko, 2011; Moench et al., 2011; Pelling, 2011a; Brown et al., 2012; da Silva et al., 2012). Addressing resilience for cities is more than identifying and acting on specific climate change impacts. It looks at the performance of each city's complex and interconnected infrastructure and institutional systems including interdependence between multiple sectors, levels, and risks in a dynamic physical, economic, institutional, and socio-political environment (Kirshen et al., 2008; Gasper et al., 2011). When resilience is considered for cities, certain systemic characteristics are highlighted—for instance flexibility, redundancy, responsiveness, capacity to learn, and safe failure (Tyler et al., 2010; Moench et al., 2011; Brown et al., 2012; da Silva et al., 2012), as well as take account of the multiple interdependencies between different sectors (see Section 8.2).

When a specific city is being considered, the level and forms of resilience are often related to specific local factors, services, and institutions—for instance, for each district in a city, will the storm and surface drains cope with the next heavy rainfall? During hot days, will measures to help those at risk from heat stress reach all high-risk groups (see Box CC-HS for more detail)? Here, resilience is not only the ability to recover from the impact but also the ability to avoid or minimize the need to recover and the capacity to withstand unexpected or unpredicted changes (UNISDR, 2011). An important aspect of resilience is the functioning of institutions to make this possible and the necessary knowledge base (da Silva et al., 2012).The emerging literature on the resilience of cities to climate change also highlights the need to focus on resource availabilities and sinks beyond the urban boundaries. It may also require coordinated actions by institutions in other jurisdictions or higher levels of government, for example, watershed management upstream of a city to reduce flood risks (Ramachandraiah, 2011; Brown et al., 2012). There are also the slow onset impacts that pose particular challenges and that may also be outside the jurisdiction of urban governments—for instance, the impact of drought on agriculture, which can raise food prices and reduce rural incomes and demand for urban services.

Resilience to extreme weather for urban dwellers is strongly influenced by factors already mentioned—the quality of buildings, the effectiveness of land use planning, and the quality and coverage of key infrastructure and services. It is also influenced by the effectiveness of early warning systems and public response measures (IFRC, 2010; UN-HABITAT, 2011a) and by the proportion of households with savings and insurance and able to afford safe, healthy homes. Safety nets for those with insufficient incomes are also important, along with the administrative capacity to ensure these reach those in need. Urban governments have importance for most of this, although their capacity to provide usually depends on the revenue raising powers and legislative and financial support from higher levels of government. These in turn are driven in part by political pressure from urban dwellers and innovation by city governments. Private companies or non-profit institutions may provide some of these but the framework for provision and quality control is provided by local government or local offices or national or provincial government.

Cities in high-income nations and many in middle-income nations have become more resilient to extreme weather (and other possible catalysts for disasters) through a range of measures responding to risks and to the political processes that demand such responses (IFRC, 2010; UN-HABITAT, 2011a; Satterthwaite, 2013). The universal provision of piped water, sewers, drains, health care and emergency services, and standards set and enforced on housing quality and infrastructure were not a response to climate change but what was built over the last 100 to 150 years in response to the needs and demands of residents. This has produced what can be termed accumulated resilience in the built environment to extreme weather and built the capacity of local governments to act on risk reduction (e.g., Hardoy and Ruete, 2013, on Rosario, Argentina). In addition, it helped build the institutions, finances, and governance systems that can support climate change adaptation (Satterthwaite, 2013). Building and infrastructure standards can be adjusted as required (if there is infrastructure in place that can be adjusted, e.g., by increasing capacity for storm and surface water drainage systems). Existing levels of service provision can be modified to take into account new risks or risk levels, as can city planning and land use management (e.g., by keeping city expansion away from areas facing higher risk levels). Private sector investments can support these kinds of adjustments (e.g., changing insurance premiums and coverage) (IFRC, 2010; UN-HABITAT, 2011a; UNISDR, 2013). All of these provide the foundation on which to build adaptive capacity to withstand climate change-related direct and indirect impacts.

Whether this will happen depends on willingness of urban governments to take this on, the demands of local inhabitants and their capacity to organize and press for change, and the capacity for learning and cooperation within local institutions. Obviously, it also depends on global agreements that slow and stop the increases in risk from GHG emissions and other drivers of climate change. Many cities with accumulated resilience may still not be equipped to respond to the changed hazards and risks associated with climate change (IPCC, 2012). The issue here becomes whether the institutions and political pressures that built the accumulated resilience are able to shift to resilience building as a directed process—and to respond dynamically and effectively to evolving and changing climate-related risks (and the evolving and changing knowledge bases that supports this).

For urban centers with little accumulated resilience, resilience as a process is also important, both to help reduce over time the (often very large) deficiencies in most or all the infrastructure, services, and regulatory frameworks that provide resilience in high-income nations and to build resilience to climate change impacts (see Table 8-2). For around a third of the world's urban population, this has to be done in a context of limited incomes and assets and poor living conditions and little current coping capacity to stresses or shocks (UNISDR, 2009; IPCC, 2012). Just an increase in the price of food staples, a drop in income, or a new cost, such as medicine for a sick family member, can quickly mean inadequate food, hunger, and reduced capacity to work (Mitlin and Satterthwaite, 2013).

This implies the need for a specific perspective on how climate change adaptation must be supported. It highlights the intimate relationship between resilience to climate change impacts and the quality of governance, especially local governance. The government's capacity and willingness to listen to, work with, support, and serve those who lack resilience is fundamental (IPCC, 2012). This is demonstrated by the many successful partnerships between local government and grassroots organizations formed by residents of informal settlements that have built or improved homes and neighborhoods (see Section 8.4).

Thus, resilience can be considered in relation to individuals/households, communities, and urban centers. In each of these, it includes the capacity to undertake anticipatory adaptation—action that avoids or reduces a climate change impact, for instance, by living in a safe location, having a safe house, or having risk-reducing infrastructure. It also includes reactive adaptation to cope with the impact of an event, to "bounce back" to the previous state (Shaw and Theobald, 2011). For urban centers, "bouncing back" includes the government capacity to rapidly restore key services and repair infrastructure. Ideally, for climate change adaptation, responses by urban populations, enterprises, and governments should allow "bounce forward" to a more resilient state. This is discussed in disaster risk reduction and is termed "building-back better" (Lyons, 2009). This is part of the shift from resilience to transformative adaptation shown in Table 8-2 where urban centers have integrated their development, disaster risk reduction, and adaptation policies and investments within an understanding of the need for mitigation and sustainable ecological footprints (see also Pelling and Dill, 2010; Manyena et al., 2011; Shaw and Theobald, 2011).

8.1.5. Conclusions from the Fourth Assessment Report (AR4) and New Issues Raised by this Chapter

AR4's chapter on Industries, Settlements, and Human Society (Wilbanks et al., 2007) notes that variability in environmental conditions has always been a given, but that when change is more extreme, persistent, or rapid than has been experienced in the past, especially if it is not foreseen and capacities for adaptation are limited, the risks will increase (WGII AR4 Section 7.1.1). The chapter also noted that, except for abrupt extreme events, climate change impacts are not currently dominant issues for urban centers (WGII AR4 Section 7.1.3). Their importance lies in their interaction with other stressors, which may include rapid population growth, political instability, poverty and inequality, ineffective local governments, jurisdictional fragmentation, and aging or inadequate infrastructure (WGII AR4 Section 7.2). Key challenges identified for turning attention to adaptation include the difficulties of estimating and projecting the magnitudes of climate risk in particular places and sectors with precision and a weak knowledge base on the costs of adaptation (issues that are still challenges today).

Wilbanks et al. (2007) describe how the interactions between urbanization and climate change have led to concentrations of urban populations in low-income nations with weak adaptive capacity. They also describe the interactions between climate change and a globalized economy with long supply chains, resulting in impacts spreading from directly affected areas and sectors to other areas and sectors through complex linkages (WGII AR4 Section 7.2). Many impacts will be unanticipated and overall effects are poorly estimated when only direct impacts are considered. Key global vulnerabilities include interregional trade and migration patterns. This chapter also describes how climate change impacts and most vulnerabilities are influenced by local contexts, including geographic location, the climate sensitivity of enterprises located there, development pathways, and population groups unable to avoid dangerous sites and homes (WGII AR4 Sections 7.3, 7.4.3). Key risks are most often related to climate phenomena that exceed thresholds for adaptation (e.g., extreme weather or abrupt changes) and limited resources or institutional capacities to reduce risk and cope (e.g., with increased demands on water and energy supplies and often on health care and emergency response systems).

Individual adaptation may not produce systemic adaptation. In addition, adaptation of systems may not benefit all individuals or households, because of the different vulnerability of particular groups and places (WGII AR4 Section 7.6.6). Adaptation will be well served by a greater awareness of threats and alternatives beyond historical experience and current access to finance. Technological innovation for climate adaptation comes largely from industry and services that are motivated by market signals, which may not be well matched with adaptation needs and residual uncertainties. Many are incremental adjustments to current business activities.

For the types of infrastructure most at risk—including most transport, drainage, and electricity transmission systems and many water supply abstraction and treatment works—reserve margins can be increased and back-up capacity developed (WGII AR4 Section 7.6.4). Adaptation of infrastructure and building stock often depends on changes in the institutions and governance framework, for example, in planning regulations and building codes. Climate change has become one of many changes to be understood and planned for by local managers and decision makers (WGII AR4 Section 7.6.7). For instance, planning guidance and risk management by insurers will have roles in locational choice for industry.

Since AR4, a much larger and more diverse literature has accrued on current and potential climate change risks for urban populations and centers (see Section 8.2). The literature on urban "adaptation" and on building resilience at city and regional scales has also expanded (see Sections 8.3, 8.4) including work on urban centers in low- and middle-income nations (see Box 8-1). Far more city governments have published documents on adaptation. There is more engagement with urban adaptation by some professions, including architects, engineers, urban planners, and disaster risk reduction specialists (Engineers Canada, 2008; UNISDR, 2009; Engineering the Future, 2011; UN-HABITAT, 2011a; da Silva, 2012). There are also assessments and books that focus specifically in climate change and cities with a strong focus on adaptation (Bicknell et al., 2009; Rosenzweig et al., 2011; UN-HABITAT, 2011a; Cartwright et al., 2012; Willems et al., 2012; Bulkeley, 2013).

This makes a concise and comprehensive summary more difficult. But it has also allowed for more clarity on what contributes to resilience in urban centers and systems. Specifically, there is now:

- A more detailed understanding of key urban climate processes, including drivers of climate change, and improved analytical and down-scaled integrated assessment models at regional and city scale
- A more detailed understanding on the governance of adaptation in urban centers and the adaptation responses being considered or taken; this includes a large and important gray literature produced by or for city governments and some international agencies and, in many high-income and some middle-income nations, support for this from higher levels of government
- More nuanced understanding of the many ways in which poverty and discrimination exacerbates vulnerability to climate impacts (see also Chapter 13)
- More detailed studies on particular built environment responses to promote adaptation (see, e.g., the growth in the literature on green and white roofs)
- More case studies of community-based adaptation and its potential contributions and limitations
- More consideration of the role of ecosystem services and of green (land) and blue (water) infrastructure in adaptation
- More consideration of the financing, enabling, and supporting of adaptation for households and enterprises
- More on learning from innovation in disaster risk reduction
- A greater appreciation of the interdependencies between different infrastructure networks and of the importance of "hard" infrastructure and of the institutions that plan and manage it
- More examples of city governments and their networks contributing to national and global discussions of climate change adaptation (and mitigation), including establishing voluntary commitments (see, e.g., the Durban Adaptation Charter for local governments) and engaging with the Conference of Parties.

A range of key uncertainties and research priorities emerge from the literature reviewed in this chapter:

- The limits to understanding and predicting impacts of climate change at a fine-grained geographic and sectoral scale
- Inadequate knowledge on the vulnerabilities of urban citizens and enterprises to the direct impacts of climate change, to second- and third-order impacts, and to the interdependence between systems
- Inadequate knowledge on the vulnerability of the built environment, buildings, building components, building materials, and the construction industry to the direct and indirect impacts of climate change and of the most effective responses for new-build and for retrofitting
- Inadequate knowledge on the adaptation potentials for each urban center (and its government) and their costs, and on the limits on what adaptation can achieve (informed by a new literature on loss and damage)
- Serious limitations on geophysical, biological, and socioeconomic data needed for adaptation at all geographic scales, including data on nature-society links and local (fine-scale) contexts (see WMO, 2008) and hazards
- Uncertainties about trends in societal, economic, and technological change with or without climate change, including the social and political underpinnings of effective adaptation
- Understanding the different impacts and adaptation responses for rapid and slow-onset disasters
- Developing the metrics for measuring and monitoring success in adaptation in each urban center:
  - Human deaths and injuries from extreme weather
  - Number of permanently or temporarily displaced people and others directly and indirectly affected
  - Impacts on properties, measured in terms of numbers of buildings damaged or destroyed
  - Impacts on infrastructure, services, and lifelines
  - Impacts on ecosystem services
  - Impacts on crops and agricultural systems and on disease vectors
  - Impacts on psychological well-being and sense of security
  - Financial or economic loss (including insurance loss)
  - Impacts on individual, household, and community coping capacities and need for external assistance.

8.2. Urbanization Processes, Climate Change Risks, and Impacts

8.2.1. Introduction

This section assesses the connections between urbanization and climate change in relation to patterns and conditions of climate risk, impact, and vulnerability. The focus is on urbanization's local, regional, and global environmental consequences and the processes that may lead to increased risk exposure, constrain people in high-risk livelihoods and residences, and generate vulnerabilities in critical infrastructure and services. Understanding urbanization and associated risk and vulnerability distributions is critical for an effective response to climate change threats and their impacts (Vale and Campanella, 2005; Bicknell et al., 2009; Solnit, 2009; Bulkeley, 2010; Romero-Lankao and Qin, 2011). It is also critical for the promotion of sustainable urban habitats and the transition to increased urban resilience. There is a particular interest here in the ability of cities to respond to environmental crises, and the resilience and sustainability of cities (Solecki et al., 2011; Solecki, 2012).

The section assesses the direct impacts of climate change on urban populations and urban systems. Together, with shifts in urbanization, these direct impacts change the profile of societal risk and vulnerability. Both can alter transition pathways that lead toward greater resilience and sustainable practices and the basis of how such practices are managed within a community. Understanding and acting on the connections between climate change and urbanization are also crucial because changes in one can affect the other. We investigate a range of direct impacts including those on physical and ecological systems, social and economic systems, and coupled human-natural systems. Where relevant to understanding, cascading impacts (where systems are tightly coupled) and secondary (indirect) impacts also are noted.

8.2.2. Urbanization: Conditions, Processes, and Systems within Cities

8.2.2.1. Magnitude and Connections to Climate Change

The spatial, temporal, and sustainability-related qualities of urbanization are important for understanding the shifting, complex interactions between climate change and urban growth. Given the significant and usually rising levels of urbanization (Section 8.1.3), a growing proportion of the world's population will be exposed to the direct impacts of climate change in urban areas (de Sherbinin et al., 2007; Revi, 2008; UN-HABITAT, 2011a). Urban centers in Africa, Asia, and Latin America with fewer than a million inhabitants are where most population growth is expected (UN DESA Population Division, 2012), but these smaller centers are "often institutionally weak and unable to promote effective mitigation and adaptation actions" (Romero-Lankao and Dodman, 2011, p. 114).

Urbanization alters local environments via a series of physical phenomena that can result in local environmental stresses. These include urban heat islands (higher temperatures, particularly at night, in comparison to outlying rural locations) and local flooding that can be exacerbated by climate change. It is critical to understand the interplay among the urbanization process, current local environmental change, and accelerating climate change. For example, in the past, long-term trends in surface air temperature in urban centers have been found to be associated with the intensity of urbanization (Kalnay et al., 2006; He et al., 2007; Ren et al., 2007; Stone, 2007; Fujibe, 2008, 2011; Jung, 2008; Rim, 2009; Sajjad et al., 2009; Santos and Leite, 2009; Tayanç et al., 2009; Kolokotroni et al., 2010; Chen et al., 2011; Iqbal and Quamar, 2011). Climate change can influence these microclimate and localized regional climate dynamics. For example, urbanization (micro scale to meso scale) can strengthen and/or increase the range of the local urban heat island (UHI) altering small-scale processes, such as a land-sea breeze effect, katabatic winds, etc., and modifying synoptic scale meteorology (e.g., changes in the position of high pressure systems in relation to UHI events). Climate modeling exercises indicate an "urban effect" that leads locally to higher temperatures. Building material properties are influential in creating different urban climate temperature regimes, which can alter energy demand for climate control systems in buildings (Jackson et al., 2010).

The dense nature of many large cities has a pronounced influence on anthropogenic heat emissions and surface roughness, linked to the level of wealth, energy consumption, and micro and regional climate conditions. Anthropogenic heat fluxes across large cities can average within a range of approximately 10 to 150 W m^{-2} but over small areas of the city can be three to four times these values or even more (Flanner, 2009; Allen et al., 2011). In London, an annual mean anthropogenic heat flux of 10.9 has been observed (Iamarino et al., 2012) with higher values in small areas of the city exceeding 100 (Allen et al., 2011) with a similar range found in Singapore (13 W m^{-2} in low-density residential areas and 113 W m^{-2} in high density commercial areas (Quah and Roth, 2012). Values locally greater than 1000 W m^{-2} have been calculated in Tokyo (Ichinose et al., 1999). Strong seasonal, diurnal, and meteorological variability in temperature also influence the level of significance of urbanization-related changes on specific cities.

The large spatial extent and significant amount of built environment of megacities (10 million or more inhabitants) can have significant impacts on the local and regional energy balance and associated weather, climate, and related environmental qualities such as air quality. Grimmond (2011) found increasing evidence that cities can influence weather (e.g., rainfall, lightning) through complex urban land use-weather-climate directional feedbacks (see also Ohashi and Kida, 2002). Spatially massive urban centers also can affect downwind locations by raising temperature and negatively impacting air quality (Bohnenstengel et al., 2011). Megacity impact on air flows has been modeled for New York and Tokyo (Holt and Pullen, 2007; Thompson et al., 2007; Holt et al., 2009). Megacity-coastal interactions may impact the hydrological cycle and pollutant removal processes through the development of fog, clouds, and precipitation in cities and adjoining coastal areas (Ohashi and Kida, 2002; Shepherd et al., 2002). Other modeling efforts define building density and design and the scale of urban development as important local determinants of the influence of urbanization on local temperature shifts (Trusilova et al., 2008; Oleson, 2012).

8.2.2.2. Spatiality and Temporal Dimensions

Spatial settlement patterns are a critical factor in the interactions among urbanization, climate-related risks, and vulnerability. One aspect is density, ranging from concentrated to dispersed, with most planned urban settlements decreasing in population density with distance from the core (Solecki and Leichenko, 2006; Seto et al., 2012). In cities with large fringe and unplanned settlements, this pattern can be reversed. In both cases, urban growth is experienced through horizontal expansion and sprawl (UN DESA Population Division, 2012), fostering extensive networks of critical infrastructure, which are frequently vulnerable to climate change (Rosenzweig et al., 2011; Solecki et al., 2011). Rapid urban population growth in the last decade also has been increasingly marked by growth in vertical density (high-rise living, and working), especially in Asia. Higher density living offers opportunities for resource conservation but also challenges for planning and urban management (Section 8.3.3).

Urbanization is associated with changing dimensions of migration and materials flows into and out of cities and also within them (Grimm et al., 2008). The level of increase (or in some cases decrease) of these conditions creates a dynamic quality of risk in cities. Rapidly changing cities must try to manage this growth through housing and infrastructure development while simultaneously understanding the relative impact of climate change. For example, in sub-Saharan Africa, the combination of relatively high population growth rates and increasing levels of urbanization brings a rise in exposure to climate change impacts (Parnell and Walawege, 2011). The conflation of local environmental change resulting from urbanization with climate change shifts makes the identification and implementation of effective adaptation strategies more difficult. Water shortages, for instance, already a chronic concern for many cities in low- and middle-income nations, typically worsen as the population and demand continue to grow (Muller, 2007). Climate change-related reductions or uncertainties in supply combine with this existing instability to create the conditions for greater management and governance crises (Milly et al., 2008; Gober, 2010).

8.2.2.3. Urbanization and Ecological Sustainability

The urbanization-climate change connection has important implications for ecological sustainability. Climate change can accelerate ecological pressures in cities, as well as interact with existing urban environmental, economic, and political stresses (Wilbanks and Kates, 2010; Leichenko, 2011). This is an especially important in a world where transgressions of key planetary boundaries such as climate change and biodiversity may take humanity out of the globe's "safe operating" space (Rockström et al., 2009, p. 1) into an unsafe and unpredictable future. A study by Trusilova et al. (2008) analyzes the urbanization-induced disturbances of the carbon cycle in Europe through land use change, local climate modification, and atmospheric pollution. This study shows that urban effects spread far beyond the city's boundaries and trigger complex feedback/responses in the biosphere (Trusilova et al., 2008). Urbanization changes land use cover, generally reduces the amount of ecologically intact land, and causes fragmentation of the remaining land, which reduces habitat value for species and increases the likelihood of further ecological degradation.

The linkage between urbanization, ecological sustainability, and climate change is well illustrated by the example of New Orleans. This city's geophysical vulnerability is shaped by its low-lying location, accelerating subsidence, rising sea levels, and heightened intensity and frequency of hurricanes—a combination of natural phenomena exacerbated by settlement decisions, canal development, loss of barrier wetlands, extraction of oil and natural gas, and the design, construction, and failure of protective structures and rainfall storage" (Wilbanks and Kates, 2010, p. 726; see also Ernstson et al., 2010). For cities in arid regions, already struggling with water shortages often in the context of rising demand, climate change may further reduce water availability because of shifts in precipitation and/or evaporation (Gober, 2010).

8.2.2.4. Regional Differences and Context-Specific Risks

Case studies and regional reviews assessing urban vulnerabilities to climate change have revealed diverse physical and societal challenges and large differences in levels of adaptive capacity (Hunt and Watkiss, 2011; Rosenzweig et al., 2011). Research on African cities (Simon, 2010; Kithiia, 2011; Castán Broto et al., 2013) has highlighted the lack of capacity and awareness of climate change, and often extremely high levels of vulnerability among the continent's large and rapidly growing urban poor populations. Other reviews have considered cities in Latin America (Hardoy and Romero-Lankao, 2011; Luque et al., 2013), North America (Zimmerman and Faris, 2011), Europe (Carter, 2011), and Asia (Alam and Rabbani, 2007; Kovats and Akhtar, 2008; Revi, 2008; Birkmann et al., 2010; Liu and Deng, 2011). The global distribution of urban risks is highly context specific, dynamic, and uneven among and within regions. Absolute exposure to extreme events over the next few decades will be concentrated in large cities and countries with urban populations in low-lying coastal areas, as in many Asian nations (McGranahan et al., 2007). Settlements located in river flood plains also are prone to flooding during extreme or persistent precipitation/severe storm conditions.

Many cities include dangerous sites, such as steep slopes, low lands adjacent to unprotected riverbanks, and ocean shorelines, and have structures that do not meet building codes (Hardoy et al., 2001; Pelling, 2003). Context-specific risks and associated vulnerability also relates to the socioeconomic status of residents. Women, children, health-compromised people, and the elderly in informal settlements are generally most vulnerable to climate change impacts. Poor access to infrastructure and transport, low incomes, limited assets, and dangerous locations can combine to put them at high risk from disasters (Moser and Satterthwaite, 2009).

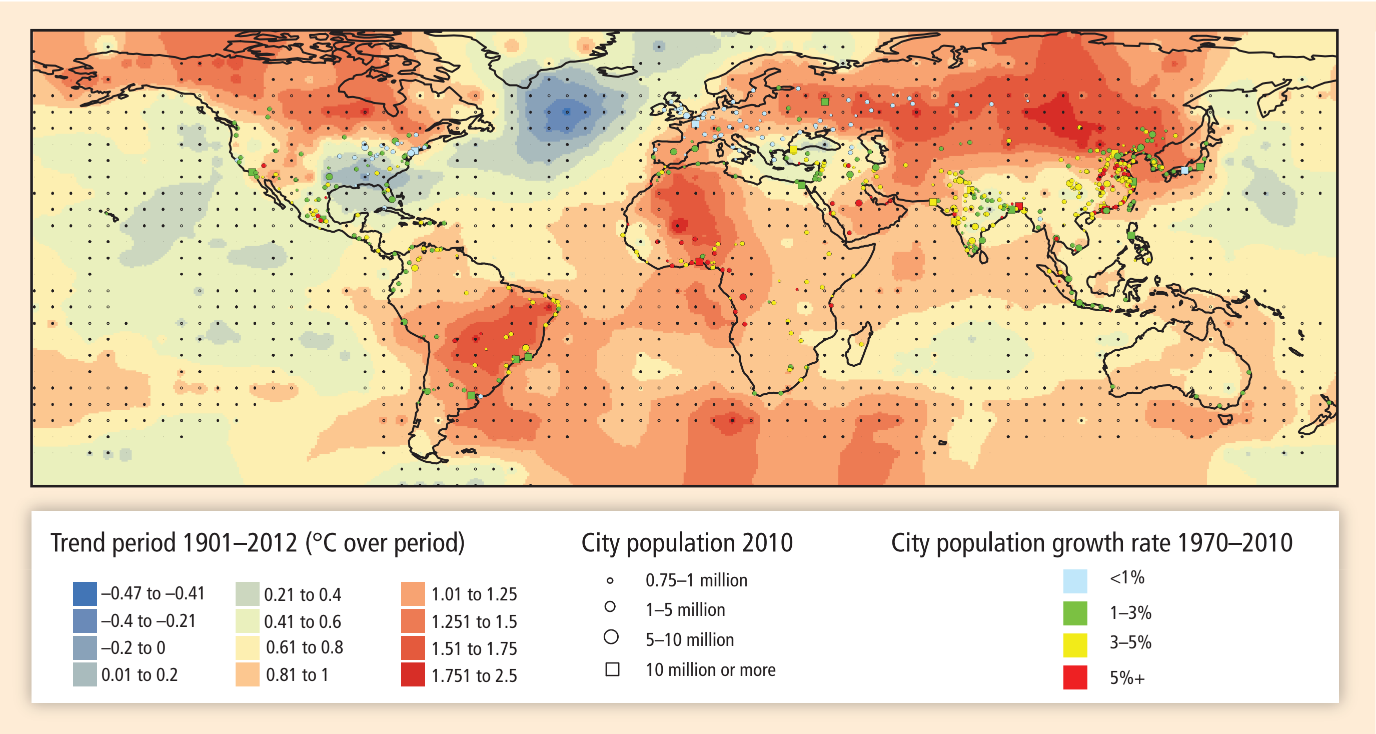
8.2.3. Climate Change and Variability Impacts: Primary (Direct) and Secondary (Indirect) Impacts

Climate change will lead to increased frequency, intensity, and/or duration of extreme weather events such as heavy rainfall, warm spells and heat events, drought, intense storm surges, and associated sea level rise (IPCC, 2007, 2012; Hunt and Watkiss, 2011; Romero-Lankao and Dodman, 2011; Rosenzweig et al., 2011). Several urban aspects of these changes are described below.

8.2.3.1. Urban Temperature Variation: Means and Extremes

The three maps in Figure 8-3 show where the world's largest urban agglomerations are concentrated in relation to changes in observed and projected temperature. Figure 8-3a shows the location of the largest urban agglomerations in 2010 against the backdrop of the observed history of climate-induced temperature rise (1901–2012). The dot for each urban agglomeration is color-coded according to its population

(a) Large urban agglomerations 2010 with observed climate change, trend period 1901–2012



(b) Large urban agglomerations 2025 with projected climate change for the mid-21st century using RCP2.6

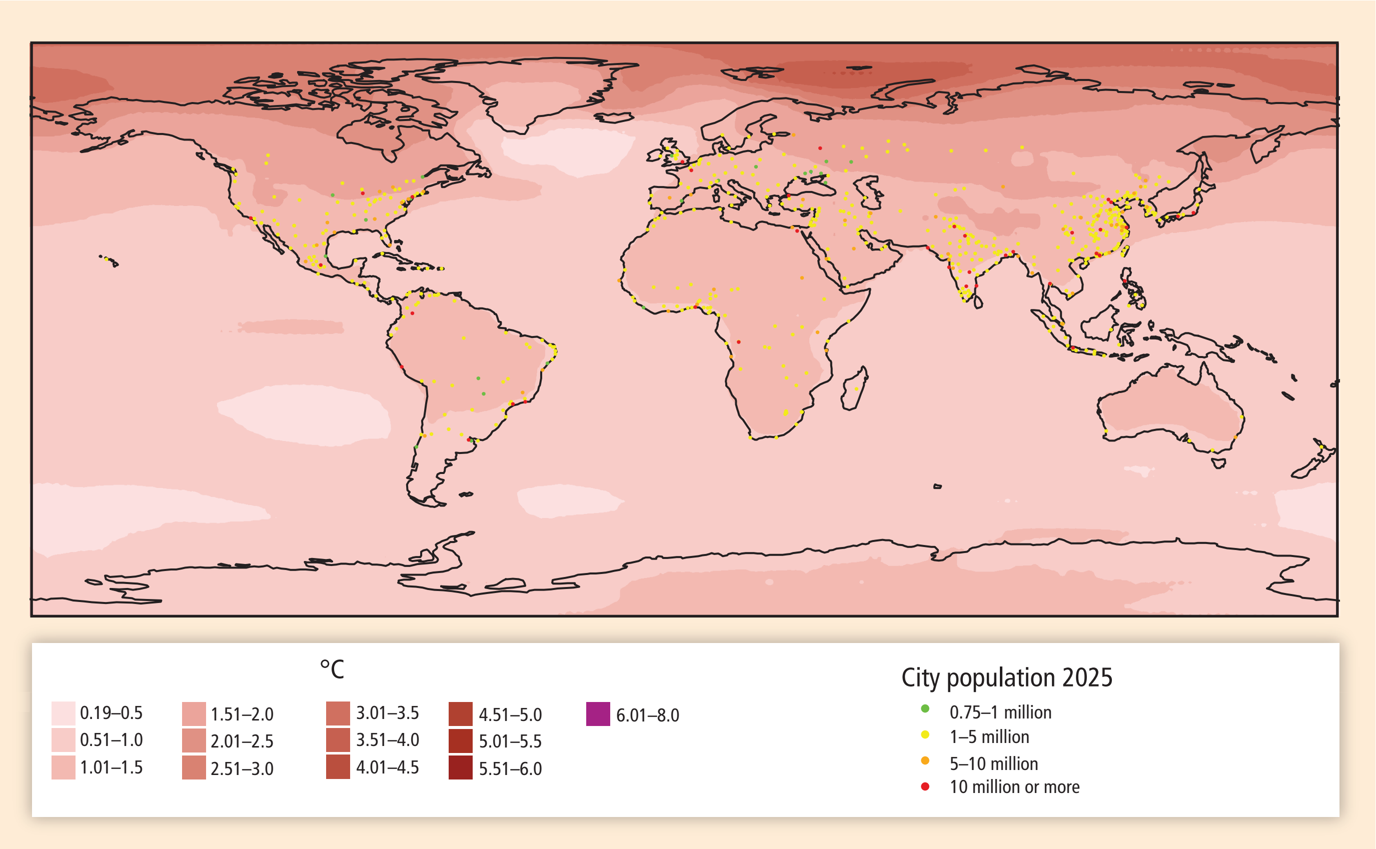
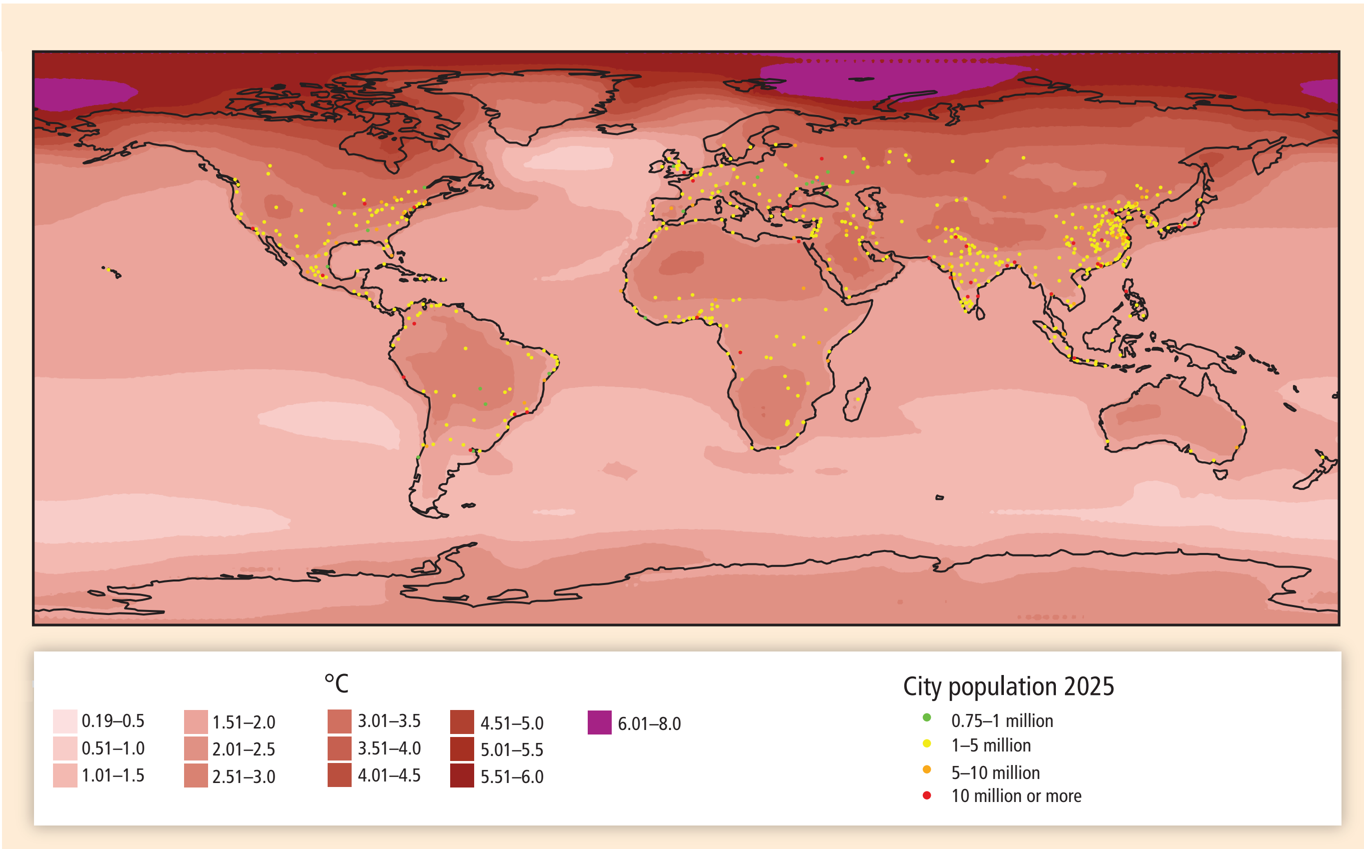


Figure 8-3 | Large urban agglomerations and temperature change (maps drawn from IPCC, 2013; urban agglomeration population and population growth data from UN DESA Population Division, 2012).

Continued next page →

Figure 8-3 (continued)

(c) Large urban agglomerations 2025 with projected climate change for the mid-21st century using RCP8.5



growth rate between 1970 and 2010. Those that had the most rapid population growth rates for these 4 decades are strongly clustered in Asia (especially in China and India) and in Latin America and sub-Saharan Africa (with many on the coast). This map highlights the temperature rise of greater than 1°C in areas in north and central Asia, western Africa, South America, and parts of North America, indicating the potential differential exposure of large cities to climate risk.

Figure 8-3b shows the location of the largest urban agglomerations according to projected populations for 2025 within the world map showing projected temperature changes for the mid-21st century, using Representative Concentration Pathway 2.6 (RCP2.6). This is a scenario with strong mitigation. Projected populations for urban agglomerations were not made up to 2050 because there is no reliable basis for making these. Each urban agglomeration's future population is much influenced by its economic performance and by social, demographic, economic, and political changes that cannot be predicted so far into the future. Assuming that almost all the large urban agglomerations in 2025 will still be large urban agglomerations in 2050, Figure 8-3b suggests that a number of large urban agglomerations in almost all continents, will be exposed to a temperature rise of greater than 1.5°C (over preindustrial levels) by mid-century, using the RCP2.6 scenario (IPCC, 2013).

Figure 8-3c shows a similar map showing projected temperature changes for the mid-21st century but using the RCP8.5 scenario. This scenario, based on unchanged current GHG emission trends by mid-century, shows that the bulk of the world's population living in the largest urban agglomerations (based on their 2025 populations) will be exposed to a minimum 2°C temperature rise over preindustrial levels, excluding urban heat island effects. By late-century, under the RCP2.6 scenario, a number of the urban agglomerations that were among the largest in 2025 will be exposed to temperature rise of up to 2.5°C over preindustrial levels (excluding urban heat island effects), especially in the high latitudes. This implies that mean temperature rise in some cities could be greater than 4°C. The RCP8.5 scenario by late century (with unchanged current GHG emission trends) shows that the bulk of the world's population living in large urban agglomerations will be exposed to a minimum 2.5°C temperature rise. Some cities in high latitudes experience a mean 3.5°C rise, or greater than 5°C when combined with UHI effects. Peak seasonal temperatures could be even higher. Temperature increases of 6°C to 8°C in the Arctic and temperature rise in Antarctica would contribute to sea level rise that would impact coastal cities across the world.

Increased frequency of hot days and warm spells will exacerbate urban heat island effects, causing heat-related health problems (Hajat et al., 2010) and, possibly, increased air pollution (Campbell-Lendrum and Corvalan, 2007; Blake et al., 2011), as well as an increase in energy demand for warm season cooling (Lemonsu et al., 2013). Conversely, widespread reduction in periods of very cold weather will mean a decline in heating demands (Mideksa and Kallbekken, 2010) and potential reduction in mortality from cold waves.

Climate change will modify UHIs in cities. Recent studies with physically based models (McCarthy et al., 2010; Früh et al., 2011; Oleson, 2012) show mixed signals, with reductions in UHI in many areas of the world and increases in some in response to climate change simulations. London's annual number of nights with heat islands stronger than 4ºC has increased by 4 days per decade since the late 1950s; meanwhile, the average nocturnal heat island intensity rose by approximately 0.1°C per decade over the same period (Wilby, 2007). Projections suggest that by 2050, London's nocturnal UHI in August could rise another 0.5°C, representing a 40% increase in the number of nights with intense UHI episodes (Wilby, 2007). However, McCarthy et al. (2011), looking specifically at London and Manchester, found 0.1ºC or less (T_{min}) increase in expected UHI by the 2050s. Future projections of UHI under global warming conditions were also conducted for Tokyo, where a potential increase of the UHI intensity of 0.5ºC was defined (Adachi et al., 2012). Adachi et al. (2012) model an increase in UHI from 1.0ºC to 1.5ºC by the 2070s. In addition to the greater UHI intensity, air temperature in August is projected to increase about 2ºC by the 2070s according to an average of five Global Climate Models (GCMs) under the *Special Report on Emissions Scenarios* (SRES) A1B scenario (the range of uncertainty in GCMs is about 2ºC).

Climate change in New York City is expected to increase extended heat waves, thus exacerbating existing UHI conditions (Rosenzweig et al., 2009). Increased nighttime minimum temperatures are associated with increased cooling demand and health-related stresses. For cities in India, the implications of future climate for connections between urbanization and the development of UHI have been defined (Mohan et al., 2011a,b, 2012). Overall, the current trend of increasingly frequent extreme events is expected to increase with climate change (Manton, 2010). Comparison of the annual mean minimum temperatures of two stations in Delhi (Safdarjung and Palam) since the 1970s shows night temperature trends synchronizing with the city's pace of expansion (Mohan et al., 2011a).

8.2.3.2. Drought and Water Scarcity: Means and Extremes

Drought can have many effects in urban areas, including increases in water shortages, electricity shortages (where hydropower is a source), water-related diseases (through use of contaminated water), and food prices and food insecurity from reduced supplies. These may all contribute to negative economic impacts and increased rural to urban migration (Vairavamoorthy et al., 2008; Herrfahrdt-Pähle, 2010; Farley et al., 2011). An estimated 150 million people currently live in cities with perennial water shortage, defined as less than 100 liters per person per day of sustainable surface and groundwater flow within their urban extent. Averages across all climate change scenarios, noting the role of demographic growth, suggest a large increase in this number, possibly up to 1 billion by 2050 (McDonald et al., 2011).

8.2.3.3. Coastal Flooding, Sea Level Rise, and Storm Surge

Sea level rise represents one of the primary shifts in urban climate change risks, given the increasing concentration of urban populations in coastal locations and within low-elevation zones (McGranahan et al., 2007). The new IPCC estimates for global mean sea level rise are for between 26 and 98 cm by 2100; this is higher than the 18 to 59 cm projected in AR4 (IPCC, 2013). Rising sea levels, the associated coastal and riverbank erosion, or flooding in conjunction with storm surge could have widespread effects on populations, property, and coastal vegetation and ecosystems, and present threats to commerce, business, and livelihoods (Nicholls, 2004; Dossou and Gléhouenou-Dossou, 2007; Zanchettin et al., 2007; El Banna and Frihy, 2009; Carbognin et al., 2010; Pavri, 2010; Hanson et al., 2011). This is well illustrated by several large-scale recent disasters including Hurricane Sandy in the New York metropolitan region. Lowland areas in coastal cities such as Lagos, Mombasa, or Mumbai are usually more at risk of flooding, especially where there is less provision for drainage (Awuor et al., 2008; Revi, 2008; Adelekan, 2010). Structures on infilled soils in the lowlands of Lagos and Mumbai are more exposed to risks of flood hazards than similar structures built on consolidated materials (Awuor et al., 2008; Revi, 2008; Adelekan, 2010). Many near coastal cities such as Dhaka have sites at risk from both riverine and coastal storm surge (Mehrotra et al., 2011a).

Cities with extensive port facilities and large-scale petro-chemical and energy-related industries are especially vulnerable to risks from increased flooding (Hallegatte et al., 2013). Hanson et al. (2011) estimate the change in flooding by the 2070s in the exposure of large port cities to coastal flooding with scenarios of socioeconomic growth, sea level rise and heightened storm surge, and subsidence. They find that with a 0.5 m rise in sea level, the population at risk could more than triple while asset exposure is expected to increase more than 10-fold. The "top 20" cities identified for both population and asset exposure to coastal flooding in both the current and 2070 rankings are spread across low-, middle-, and high-income nations, but are concentrated in Asian deltaic cities. They include: Mumbai, Guangzhou, Shanghai, Miami, Ho Chi Minh City, Kolkata, New York, Osaka-Kobe, Alexandria, Tokyo, Tianjin, Bangkok, Dhaka, and Hai Phong. Using asset exposure as the metric, cities in high-income nations and in China figure prominently: Miami, New York City, Tokyo, and New Orleans as well as Guangzhou, Shanghai, and Tianjin. Detailed site specific studies can define the local level of sea level rise and other local factors such as harbor development, dredging and erosion, groundwater withdrawal, and subsidence and other factors.

8.2.3.4. Inland Flooding, Hydrological and Geo-Hydrological Hazards at Urban Scale

Exposure to climate related hazards will vary with differences in the geomorphologic characteristics of cities (Luino and Castaldini, 2011). Heavy rainfall and storm surges would impact urban areas through flooding, which in turn can lead to the destruction of properties and public infrastructure, contamination of water sources, water logging, loss of business and livelihood options, and increase in water-borne and water-related diseases, as noted in wide range of studies (de Sherbinin et al., 2007; Dossou and Gléhouenou-Dossou, 2007; Douglas et al., 2008; Kovats and Akhtar, 2008; Revi, 2008; Roberts, 2008; Hardoy and Pandiella, 2009; Nie et al., 2009; Adelekan, 2010; Sharma and Tomar, 2010; Shepherd et al., 2011). Case studies of inland cities have considered the elevated risk of flooding due to climate change, as in Kampala (Lwasa, 2010) and travel disruptions in Portland (Chang et al., 2010). There have been significant research attempts to improve modelling of the frequency and condition of extreme precipitation events and resulting flooding (Nelson et al., 2008; Olsson et al., 2009; Onof and Arnbjerg-Nielsen, 2009; Sen, 2009; Ranger et al., 2011).

The review on the world-wide impacts of climate change on rainfall extremes and urban drainage by Willems et al. (2012) has shown that typical increases in rainfall intensity at small urban hydrology scales range from 10% to 60% from control periods in the recent past (typically 1961–1990) up to 2100. These changes in extreme short-duration rainfall events may have significant impacts for urban drainage systems and pluvial flooding. Results so far indicate more problems with sewer sub-charging, sewer flooding, and more frequent combined sewer overflow (CSO) spills. Extreme rainfall changes in the range of 10 to 60% may lead to changes in flood and CSO frequencies and volumes in the range 0 to 400% depending on system characteristics. This is because floods and overflows, when runoff or sewer flow thresholds are exceeded, can react to rainfall (changes) in a highly nonlinear way (Willems and Vrac, 2011; Willems et al., 2012; Arnbjerg-Nielsen et al., 2013; Willems, 2013).

8.2.3.5. Emerging Human Health, Disease, and Epidemiology Issues in Cities

WHO and WMO (2012) and Barata et al. (2011) note that climate change may affect the future social and environmental determinants of health, including clean air, safe drinking water, sufficient food, and secure shelter. There is good evidence that temperature extremes (heat and cold) affect health, particularly mortality rates (see Section 11.2.2). Increased warming and physiological stress on human comfort level is predicted in a variety of cities in subtropical, semiarid, and temperate sites (Thorsson et al., 2011; Blazejczyk et al., 2012); see also Figure 8-3. For more discussion on cities and impacts of increased warming in specific regions, see the regional chapters (Chapters 21 to 30).

Recent studies have illustrated the impact of heat stress on urban populations in low- and middle-income countries (see, e.g., Burkart et al., 2011, for Bangladesh and Egondi et al., 2012, for children in Nairobi's informal settlements). Hot days are known to have significant impacts on health that can be exacerbated by both drought conditions and high humidity. Studies in high-income countries show the elderly more vulnerable to heat-related mortality (see Oudin Åström et al., 2011, for a review of this). In urban settings where child mortality is high, extreme temperatures have been shown to have an impact on mortality (e.g., Egondi et al., 2012). People in some occupations are more at risk, as they are exposed to higher temperatures for long durations (see Hoa et al., 2013) and low-income households are more at risk when heat waves disrupt or limit income-earning opportunities (Kovats and Akhtar, 2008, see also Section 11.2.7 for more detailed discussion of occupational heat stress).

Climate change has implications for urban air quality (Athanassiadou et al., 2010), air pollution, and health policy (WGI AR5 Chapter 11). The impacts on urban air quality in particular urban areas are highly uncertain and may include increases and decreases of certain pollutants (Jacob and Winner, 2009; Weaver et al., 2009). Urban air quality in most cities already is compromised by localized air pollution from transport and industry, and often commercial and residential sources. Emerging literature shows strong evidence that climate change will generally increase ozone in the USA and Europe, but that the pattern of that change is not clear, with some areas increasing and some decreasing (Katragkou et al., 2011; Lam et al., 2011). The effects on particulate matter (PM) are also unclear, as are the effects on ozone and PM outside of the USA and Europe (Dawson et al., 2013).

The incidence of asthma exacerbation may be affected by climate change-related increases in ground level ozone exposures (Kinney, 2008; Gamble et al., 2009; O'Neill and Ebi, 2009; Reid et al., 2009; Barata et al., 2011); other pollutants may also be affected, particularly in cities with PM10 and ozone levels far above WHO guidelines (WHO, 2011). Climate change may change the distribution, quantity, and quality of pollen in urban areas, as well as the timing and duration of pollen seasons. WHO and WMO (2012) notes that diarrheal diseases, malnutrition, malaria, and dengue are climate sensitive and, in the absence of appropriate adaptation, could be adversely affected by climate change (see Chapter 11).

8.2.4. Urban Sectors: Exposure and Sensitivity

This section assesses how the observed and forecast direct impacts of climate change influence the exposure of city residents, buildings, infrastructure, and systems to risk. It considers key affected sectors and populations and possible interrelations. Direct impacts include all costs and losses attributed to the impact of hazard events, but exclude systemic impacts, for example, on urban economies through price fluctuations following a disaster or the impact of disaster losses on production chains (UN ECLAC, 1991). Both the temporal and spatial scales of the shifts in climate risk across cities and urbanizing sites in the next few decades are considered. In addition, we analyze the change in the scale and character of risks in cities, as climate extremes, means, and long-term trends (e.g., sea level rise) change.

Climate change will have profound impacts on a broad spectrum of city functions, infrastructure, and services and will interact with and may exacerbate many existing stresses. These impacts can occur both *in situ* and through long-distance connections with other cities and rural sites of resource production and extraction (Wackernagel et al., 2006; Seto et al., 2012). The interaction between climate change and existing environmental stresses can lead to a range of synergies, challenges, and opportunities for adaptation with complex interlinkages and often highly uncertain or nonlinear processes (Ernstson et al., 2010). For example, the 2007 floods in the city of Villahermosa, which covered two-thirds of Tabasco State in Mexico, had serious consequences for the city's economic base, with damages and losses equivalent to 30% of the state's annual GDP (CEPAL, 2008). The flood that struck the Chao Phraya River in 2011 caused a high loss of life and damages to many companies and several industrial estates in Bangkok (estimated local damage and loss was 3.5 trillion yen), but it also disrupted global scale industrial supply chains (Komori et al., 2012). Urban centers serving prosperous agricultural regions are particularly sensitive to climate change if water supply or particular crops are at risk. In Naivasha, Kenya, drought threatens high-value export-oriented horticulture (Simon, 2010). Urban centers that serve as major tourism destinations may suffer when the weather becomes stormy or excessively hot and leads to a loss of revenue. Recent assessments have projected the rising population and asset exposure in large port cities (Munich Re, 2004; Hanson et al., 2011; see also Section 8.2.3.3), alongside case studies in Copenhagen (Hallegatte et al., 2011b) and Mumbai (Ranger et al., 2011). By 2070, the exposed assets in cities such as Ningbo (China), Dhaka (Bangladesh), and Kolkata (India) may increase by more than 60-fold (Hanson et al., 2011).

Infrastructure will similarly be affected by systemic and cascading climate risks (Hunt and Watkiss, 2011). Climate stresses, particularly extreme events, will have effects across interconnected urban systems, within and across multiple sectors (Gasper et al., 2011). The cascading effects are especially evident in the water, sanitation, energy, transport, and communications sectors, owing to the often tightly coupled character of urban infrastructure systems (see Rosenzweig and Solecki, 2010, for a discussion of this for New York City). The U.S. National Climate Assessment effort has looked at the impacts of climate change on infrastructure, considering the water, land, and energy nexus, as well as on a large number of industries (Skaggs et al., 2012; Wilbanks et al., 2012). These systemic cascades can have both direct and indirect economic impacts (Hallegatte et al., 2011b; Ranger et al., 2011), which can extend from the built environment to urban public health (Frumkin et al., 2008; Keim, 2008). A critical element is the impact for infrastructure investments with long operational lives, in some cases 100 years or more (Hallegatte et al., 2011a). In low- and most middle-income cities, very large additional investment is needed to address deficits in infrastructure and services; without this investment, making the short- to long-term trade-off to improve resilience is difficult (Dodman and Satterthwaite, 2009). This is an opportunity for "climate smart" infrastructure planning that considers how to combine pro-poor development and climate change adaptation and mitigation. This is a more difficult task for cities such as New York with dense aging infrastructure and materials that "may not be able to withstand the projected strains and stresses from a changing climate" (Zimmerman and Faris, 2010, p. 63). These cities also have the opportunity, when replacing aging infrastructure, to integrate climate considerations into the new infrastructure decision-making processes.

8.2.4.1. Water Supply, Wastewater, and Sanitation

Water and sanitation systems affect household well-being and health, as well as influencing urban economic activities, energy demands, and the rural-urban water balance (Gober, 2010). Climate change will impact residential water demand and supply and its management (O'Hara and Georgakakos, 2008). Among the projected impacts are altered precipitation and runoff patterns in cities, sea level rise and resulting saline ingress, constraints in water availability and quality, and heightened uncertainty in long-term planning and investment in water and waste water systems (Muller, 2007; Fane and Turner, 2010; Major et al., 2011). Local government departments and utilities responsible for water supply and waste water management must confront these new climatic patterns and major uncertainties in availabilities and learn to respond to dynamic and evolving sets of constraints (Milly et al., 2008).

Climate change will increase the risk and vulnerability of urban populations to reductions in groundwater and aquifer quality (e.g., Praskievicz and Chang, 2009; Taylor and Stefan, 2009), subsidence, and increased salinity intrusion. High levels of groundwater extraction have led to serious subsidence problems in cities such as Bangkok (Babel et al., 2006) and Mexico City (Romero-Lankao, 2010), which damage buildings, fracture pipes, and can increase flood risks (see also Jha et al., 2012). This problem can be compounded in coastal cities when saline intrusion reduces groundwater quality and erodes structures.

In many rapidly developing cities, the impact of climate change on water supplies will interact with growing population, growing demand, and economic pressures, potentially heightening water stress and negative impacts on the natural resource base, with effects for water quality and quantity. Caribbean nations, for example, with their expanding middle-class urban population, face sharply raised demands for water and the associated challenges of managing runoff, storm water, and solid wastes. Projected reductions in rainfall amounts at specific times in particular locations would aggravate such water stresses (Cashman et al., 2010). In Shanghai, climate change is expected to bring decreased water availability as well as flooding, groundwater salinization, and coastal subsidence. The city's population of 17 million is projected to continue expanding, often within areas that are "likely increasingly flood-prone" (de Sherbinin et al., 2007, p. 60). Groundwater depletion has contributed to land subsidence in these already vulnerable areas, reinforcing the water stresses and risks of erosion (de Sherbinin et al., 2007). In several large Andean cities, including Lima, La Paz, and Quito, declining volumes of glacial melt water have been observed, with expected further declines (Buytaert et al., 2010; Chevallier et al., 2011).

Several studies estimate how climate change will alter relationships among water users, exacerbating tensions and conflicts between the various end users (residential, commercial, industrial, agricultural, and infrastructural) (Roy et al., 2012; Tidwell et al., 2012). In small and mid-sized African cities, the effect of flooding on well water quality is a growing concern (Cissé et al., 2011). Floods, droughts, and heavy rainfall have also impacted agriculture and urban food sources, and can exacerbate food and water scarcity in urban areas (Gasper et al., 2011). But not all water systems are projected to experience negative impacts. Chicago's Metropolitan Water Reclamation District (MWRD) found that reduced precipitation due to climate change would decrease pumping and general operations costs, as sewers will contain less rainwater in drier seasons (Hayhoe et al., 2010).

Wastewater and sanitation systems will be increasingly overburdened during extreme precipitation events if attention is not paid to maintenance, the limited capacity of drainage systems in old cities, or lack of provision for drainage in most unplanned settlements and in many urban centers (Wong and Brown, 2009; Howard et al., 2010; Mitlin and Satterthwaite, 2013). In the city of La Ceiba, Honduras, stakeholders concluded that urban drainage and improved management of the Rio Cangrejal watershed were top priorities for protection against projected climate change impacts; the city lacks a stormwater drainage system but experiences regular flooding (Smith et al., 2011).

Flooding is often made worse by uncontrolled city development that builds over natural drainage channels and flood plains or by a failure to maintain drainage channels (often blocked by solid wastes where waste collection is inadequate). These problems are most evident in cities where there are no drains or sewers to help cope with heavy precipitation (Douglas et al., 2008) and no service to collect solid wastes (in many cities in low-income nations, less than half the population has regular solid waste collection; see Hoornweg and Bhada-Tata, 2012). Many cities in high-income nations also face challenges. An analysis of three cities in Washington State, assessing future streamflows and peak discharges, concluded that "concern over present (drainage) design standards is warranted" (Rosenberg et al., 2010, p. 347). Climate change was identified as a key driver affecting Britain's future sewer systems. According to the model used, the volume of sewage released to the environment by combined sewage overflow spills and flooding was projected to increase by 40% (Tait et al., 2008).

8.2.4.2. Energy Supply

Energy exerts a major influence on economic development, health, and quality of life. Any climate change-related disruption or unreliability in power or fuel supplies can have far-reaching consequences, affecting urban businesses, infrastructure, services (including healthcare and emergency services) and residents, as well as water treatment and supply, rail-based public transport, and road traffic management (Jollands et al., 2007; Finland Safety Investigations Authority, 2011; Halsnæs and Garg, 2011; Hammer et al., 2011).

Past experiences with power outages indicate some of the knock-on effects (Chang et al., 2007). New York City's blackout of 2003 lasted 28 hours and halted mass transport, surface vehicles due to signaling outages, and water supply (Rosenzweig and Solecki, 2010). A review of climate change impacts on the electricity sector (Mideksa and Kallbekken, 2010) projects reductions in the efficiency of water cooling for large electricity-generating facilities, changes in hydropower and wind power potential, and changing demand for heating or cooling in the USA and Europe. Low-income households in Chittagong use candles or kerosene lamps during frequent power outages; this was found to disturb children's studies, increase expenses, and overheat homes (Rahman et al., 2010).

Climate change will alter patterns of urban energy consumption, particularly with respect to the energy needed for cooling or heating (for a review, see Mideksa and Kallbekken, 2010). Climate change will bring increases in air conditioning demand and in turn heightened electricity demand (Radhi, 2009; see also Hayhoe et al., 2010, for a discussion of this in relation to Chicago). In temperate and more northern regions, winter temperature increases may decrease energy demand (Mideksa and Kallbekken, 2010). In most cases within individual cities, potential increases in summertime electricity demand from climate change will exceed reductions in winter energy demand reductions (Hammer et al., 2011). Less is known about the demand-side impacts in low- and lower-middle-income nations, where large sections of the urban population still lack access to electricity (Johansson et al., 2012; Satterthwaite and Sverdlik, 2012). Most of these nations are expected, as noted, to have increased mean temperatures or rising frequency of heat waves (IPCC, 2007).

Many cities' economies will be affected if water scarcity and variability interrupt hydropower supplies. For instance, reductions in hydroelectric generation will have impacts on the economies of many urban centers in Brazil as well as in neighboring countries (de Lucena et al., 2009, 2010; Schaeffer et al., 2011). Cities in sub-Saharan Africa often rely on hydropower for their electricity, and failures in supplies can lead "to a more general 'urban failure'" (Muller, 2007, p. 106). Laube et al. (2006) discuss water shortages in Ghana following low precipitation periods, and the potential for competition between hydropower and water provision, including to downstream urban centers. Declining water levels in the Hoover Dam have raised the possibility that Los Angeles will lose a major power source, and that Las Vegas will face a severe decline in drinking water availability (Gober, 2010).

Summer heat waves, with spikes in demand for air conditioning, can result in brownouts or blackouts (Mirasgedis et al., 2007; Mideksa and Kallbekken, 2010). Cities in the temperate regions of Australia already experience regular blackouts on hot summer days, largely due to residential air-conditioner use (Maller and Strengers, 2011). Research in Boston suggested that rising energy demands in hotter summers have meant a "disproportional impact on (the) elderly and poor, increased energy expenditures; loss of productivity and quality of life" (Kirshen et al., 2008, p. 241). Any increase in the frequency or intensity of storms may disrupt electricity distribution systems because of the collapse of power lines and other infrastructure (Rosenzweig et al., 2011; see also Chapter 10).

8.2.4.3. Transportation and Telecommunications

Climate change-related extreme events will affect urban transportation and telecommunication infrastructure, including a variety of capital stock, such as bridges and tunnels, roads, railways, pipelines, and port facilities, data sensors, and wire and wireless networks (Koetse and Rietveld, 2009; Hallegatte et al., 2011a; Jacob et al., 2011; Major et al., 2011). In the Gulf Coast region of the United States, 27% of major roads, 9% of rail lines, and 72% of ports are at or below 122 cm (4 ft) in elevation. With a storm surge of 7 m (23 ft), more than half the area's major highways, almost half the rail miles, 29 airports, and virtually all the ports are subject to flooding (Savonis et al., 2008). Assessing possible disruptions of transport networks within cities and urban systems is critical. Loss of telecommunication access during extreme weather events can inhibit disaster response and recovery efforts because of its critical role in providing logistical support for such activity (Jacob et al., 2011).

Ports are central to international trade and climate change poses substantial challenges related to exposed locations in coastal zones, low-lying areas, and deltas; long lifespans of key infrastructure and interdependencies with trade, shipping, and inland transport services that are also vulnerable (Oh and Reuveny, 2010; Asariotis and Benamara, 2012). Hurricane Sandy crippled the New York region, leading to a week-long shut-down of one of the largest container ports in the USA (Hallegatte et al., 2013).

Large sections of the urban population in low- and middle-income nations live in settlements without all-weather roads and paths that allow for emergency vehicle access and rapid evacuation. For instance, in Chittagong, Bangladesh, extremely narrow roads limit emergency access to most informal neighborhoods, exacerbating health and fire risks (Rahman et al., 2010). In Lagos's informal settlements, a 2006 resident survey ranked roads second to drainage in terms of needed facilities (Adelekan, 2010). Evacuations in low-income areas may also be hampered by hazardous locations, absence of public transport, and inadequate governance. Following the 2003 and 2006 floods in Santa Fe, Argentina, the lack of information and official evacuation mechanisms prevented timely responses; some residents also chose to stay in their homes to protect their possessions from looters (Hardoy and Pandiella, 2009).

Low-income urban residents can also be profoundly affected during and after extreme weather events that damage critical public transit links, prevent access to work, and heighten exposure to health risks. Interviews in Georgetown, Guyana, found that the limited transport access of low-income households during floods made them more prone to losing time from work or school, compared to wealthier households. Poorer households rarely owned cars, and wading barefoot through floodwaters exposed them to water-borne pathogens (Linnekamp et al., 2011). Some studies find urban women walk or use public transport more than men (World Bank, 2010c); hence, the gendered impact of transport disruptions may merit greater consideration (UN-HABITAT, 2011a; Levy, 2013).

The literature on urban transport and climate change focuses more on mitigation, with less attention to vulnerability, impacts, and adaptation (Hunt and Watkiss, 2011). Existing studies on impacts are often limited to the short-term demand side, particularly in passenger transport (Koetse and Rietveld, 2009). However, climate change creates several challenges for transport systems. The daily functioning of most transport systems is already sensitive to fluctuations in precipitation, temperature, winds, visibility, and for coastal cities, rising sea levels with the associated risks of flooding and damages (Love et al., 2010). Transport is highly vulnerable to climate variability and change, and the economic importance of transport systems has increased with the rise of just-in-time delivery methods, heightening the risk of losses due to extreme weather (Gasper et al., 2011).

In addition to adapting road transport, cities should ensure bridges, railway cuttings, and other hard infrastructure is resilient to climate change over their service lifespan (Jaroszweski et al., 2010). Few studies have examined the effects of climate change on railways, but rail system failures are known to be related to high temperatures, icing, and storms (Koetse and Rietveld, 2009; see Dobney et al., 2008, for future heat-related delays in UK railways; also Palin et al., 2013, offers a broad discussion of climate change effects on the UK rail network). Very few studies have examined the vulnerability of air- and sea-borne transport and infrastructure, but climate change could mean more and lengthier weather-related delays and disruption (Eurocontrol, 2008; Becker et al., 2012).

Loss of sea ice can benefit some cities by increasing opportunities for developing road networks or ports. However, it may be costly to adapt road, air, and water transport networks to the known environmental risks associated with such redevelopment (Larsen et al., 2008). For industries and communities in northern Canada, reduced freshwater-ice levels creates longer shipping seasons and could also promote new seaports in marine environments. But thawing of permafrost can also result in instability and major damage to roads, infrastructure, and buildings in and around northern cities and towns, and inland towns will require sizable investments to replace winter ice roads with land-based roads (Prowse et al., 2009).

The direct impacts of extreme weather on transport are more easily assessed than the indirect impacts or possible knock-on effects between systems. Studies have often examined the direct impacts of flooding on transport infrastructure, but the indirect costs of delays, detours, and trip cancellation may also be substantial (Koetse and Rietveld, 2009). Mumbai's 2005 floods caused injuries, deaths, and property damage but also serious indirect impacts as most city services were shut down without contact via rail, road, or air (Revi, 2005). Transport and other urban infrastructure networks are often interdependent and located in close proximity to one another, yet only a few assessments have considered the joint impacts (Kirshen et al., 2008; Hayhoe et al., 2010).

Transportation systems are critical for effective disaster response—for example, where populations have to be evacuated prior to an approaching storm or where provision is urgently needed for food, water, and emergency services to affected populations.

Key elements in cities' communications systems may have to be strengthened—for instance, to avoid masts toppling due to strong winds and electrical support facilities that need to be moved or protected against flooding (Zimmerman and Faris, 2010, p. 74). New York City's dispersed communications network faces several climate-related risks. Electrical support facilities can be flooded; cell phone towers can topple in strong winds or become corroded as sea levels rise (Zimmerman and Faris, 2010). In Alaska, telecommunications towers are settling as a result of warming permafrost (Larsen et al., 2008). Emergencies may generate a demand for communications that exceeds systems' capacities. During the extreme rainfall event in 2005, Mumbai's telecommunications networks ceased to function due to a mix of overload, shut down of the power system, and lack of diesel supplies for generators (Revi, 2005).

8.2.4.4. Built Environment, and Recreation and Heritage Sites

Housing ideally provides its occupants with a comfortable, healthy, and secure living environment and protects them from injuries, losses, damage, and displacement (Haines et al., 2013). For many low-income households, livelihoods also depend on home-based enterprises, and housing is key to protecting their assets and preventing disruption of their incomes. Decent housing has particular importance for vulnerable groups, including infants and young children (Bartlett, 2008), older residents, or those with disabilities or chronic health conditions.

Urban housing is often the major part of the infrastructure affected by disasters, according to Jacobs and Williams (2011). Extreme events such as cyclones and floods inflict a heavy toll, particularly on structures built with informal building materials and outside of safety standards (UNISDR, 2011). Dhaka's 1998 floods damaged 30 percent of the city's units; of these, more than two-thirds were owned by the lower-middle classes and the poorest (Alam and Rabbani, 2007). Adelekan (2012) shows that a relatively modest increase in wind speeds during storms caused widespread damage in central Ibadan. Relative to the preceding decade, the period from 1998 to 2008 showed higher mean maximum wind gusts and more frequent windstorms with peak gusts greater than 48 knots, and the impacts were severe in part because of the high concentration of residents in damaged buildings. Increased climate variability, warmer temperatures, precipitation shifts, and increased humidity will accelerate the deterioration and weathering of stone and metal structures in many cities (Grossi et al., 2007; Thornbush and Viles, 2007; Smith et al., 2008; Bonazza et al., 2009; Stewart et al., 2011).

Recreational sites such as parks and playgrounds will also be affected. In New York City, these are defined as critical infrastructure and are often located in low elevation areas subject to storm surge flooding (Rosenzweig and Solecki, 2010). Little research has examined the effects on urban tourism in particular (Gasper et al., 2011).

The increased risks that climate change brings to the built environment (Spennemann and Look, 1998; Wilby, 2007) also apply to built heritage. This has led to the Venice Declaration on Building Resilience at the Local Level Towards Protected Cultural Heritage and Climate Change Adaptation Strategies, which brings together UNESCO, UN-HABITAT, EC, and individual city mayors. An example is Saint-Louis in Senegal, a coastal city and World Heritage Site on the mouth of the Senegal river, which has frequent floods and large areas at risk from river and coastal flooding. There are initiatives to reduce flooding risks and relocate families from locations most at risk, but the local authority has very limited investment capacity (Diagne, 2007; Silver et al., 2013).

8.2.4.5. Green Infrastructure and Ecosystem Services

Climate change will alter ecosystem functions affected by changes in temperature and precipitation regimes, evaporation, humidity, soil moisture levels, vegetation growth rates (and allergen levels), water tables and aquifer levels, and air quality. It will also accentuate the value of ecosystems services and green infrastructure for adaptation. "Green infrastructure" refers to interventions to preserve the functionality of existing green landscapes (including parks, forests, wetlands, or green belts), and to transform the built environment through phytoremediation and water management techniques and by introducing productive landscapes (Foster et al., 2011b; La Greca et al., 2011; Zhang et al., 2011). These can influence the effectiveness of pervious surfaces used in storm water management, green/white/blue roofs, coastal marshes used for flood protection, urban agriculture, and overall biomass production. Mombasa will experience more variable rainfall as a result of climate change, making the expansion of green infrastructure more difficult (Kithiia and Lyth, 2011). Trees in British cities will be increasingly prone to heat stress and attacks by pests, including new non-native pathogens and pests that can survive under warmer or wetter conditions (Tubby and Webber, 2010). Urban coastal wetlands will be inundated with sea level rise. In New York City, remnant coastal wetlands will be lost to sea level rise because bulk heading and intensive coastal development will prevent their natural movement inland (Gaffin et al., 2012).

8.2.4.6. Health and Social Services

The effects of climate change will also be evident across urban public services including health and social care provision, education, police, and emergency services (Barata et al., 2011, see also Chapter 11). Most urban centers in low-income nations and many in middle-income nations lack adequate social and public service provision (Bartlett, 2008; UN-HABITAT, 2003a) while higher-income cities are only beginning to consider climate change in their health or disaster management plans (Brody et al., 2010).

Although there are few studies on adapting education, police, or other key services, a growing public health literature has discussed multi-sectoral adaptation strategies (Huang et al., 2011). Cities' existing public health measures provide a foundation for adapting to climate change, such as heat warning systems or disease surveillance (McMichael et al., 2008; Bedsworth, 2009). Negative climate impacts have been highlighted on some of the most vulnerable in society—including children (Ebi and Paulson, 2010; Sheffield and Landrigan, 2011; Watt and Chamberlain, 2011), the elderly (White-Newsome et al., 2011; Oven et al., 2012), and the severely disadvantaged (Ramin and Svoboda, 2009; see also Chapter 11).

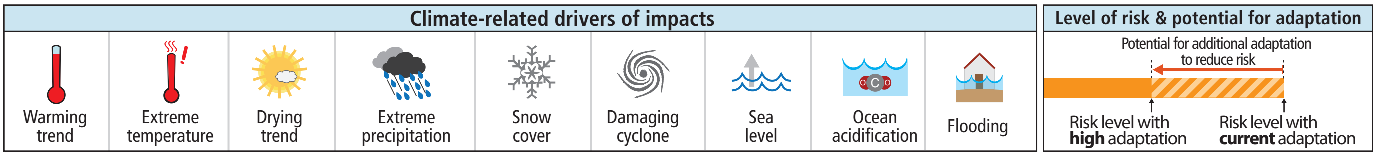
8.2.5. Urban Transition to Resilience and Sustainability

The question of how to promote increased resilience and enhanced sustainability in urban areas (as illustrated in Table 8-2) has become a central research topic and policy consideration. It is well recognized that climate change risks affect this process by heightening uncertainties and altering longstanding patterns of environmental risk in cities, many of which continue to face other significant stressors such as rapid population growth, increased pollution, resource demands, and concentrated poverty (Wilbanks and Kates, 2010; Mehrotra et al., 2011a). This section discusses how climate change increasingly affects municipal decision-making frames and alters local conceptions of cities as vehicles for economic growth, for political change, for meeting livelihoods and basic needs, as well as larger-scale goals of resilience and sustainability.

In recent years, different models of urban environmental transition have been introduced to illustrate the connections between health hazards and environmental impacts as cities and neighborhoods develop—for example, shifts from a "sanitary city" focused on public health and basic service provision to a "sustainable city" focused on long-term planning, resource efficiency, and ecosystem services (McGranahan, 2007). The latter includes consideration of a city's use of global and local sinks for wastes that lie outside its boundaries (McGranahan, 2007; Wilson, 2012). Within these models, key variables have been identified that make cities vulnerable to climate change (e.g., extensive infrastructure networks, high-density population in exposed or other sensitive sites).

There is the opportunity to promote societal transition that enhances resiliency and adaptive capacity in the face of accelerated climate change (Gusdorf et al., 2008; Ernstson et al., 2010; Mdluli and Vogel, 2010; Tompkins et al., 2010; Pelling and Manuel-Navarrete, 2011; Pelling, 2011a). Transition in this context can take place at a broad

Table 8-3 | Urban areas: Current and indicative future climate risks. Key risks are identified based on an assessment of the literature and expert judgments by Chapter 8 authors, with the evaluation of evidence and agreement presented in supporting chapter sections. Each key risk is characterized as very low to very high. For the near-term era of committed climate change (2030–2040), projected levels of global mean temperature increase do not diverge substantially across emission scenarios. For the longer-term era of climate options (2080–2100), risk levels are presented for global mean temperature increases of 2°C and 4°C above pre-industrial levels. For each time frame, risk levels are estimated for a continuation of current adaptation and for a hypothetical highly adapted state.



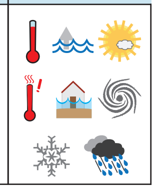
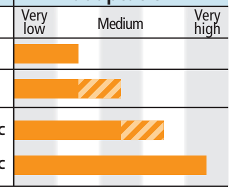
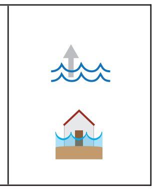
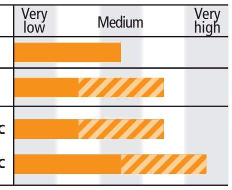
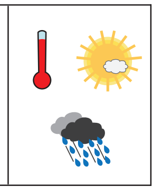
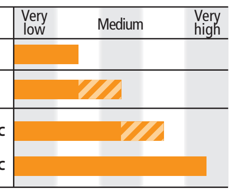
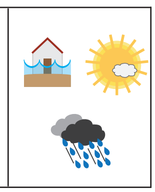
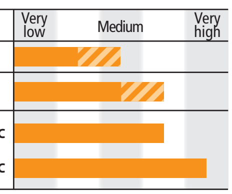
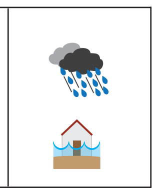
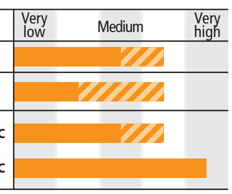
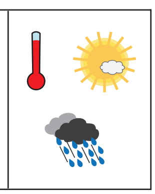
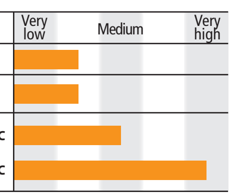
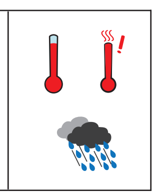
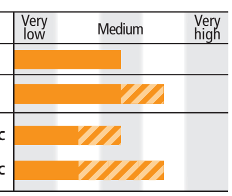
Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Modal urban (*medium confidence*) [8.2, 8.3, 8.4]	Climate change will have profound impacts on urban infrastructure systems and services, the built environment, and ecosystem services and hence on urban economies and populations. This could exacerbate existing social, economic, and environmental drivers of risk, especially for vulnerable groups who lack essential services. An appropriate urban governance frame and coordinated urban adaptation focused on the built environment, improved infrastructure, and services and risk reduction has significant potential for reducing key climate risks in the medium term and especially in the long term.		Present; Near term (2030 – 2040); Long term (2080 – 2100) 2°C, 4°C	 Very low / Medium / Very high
Coastal zone systems (*medium confidence*) [8.2, 8.3]	Coastal cities with extensive port facilities and large-scale industries are vulnerable to increased flood exposure. High-growth cities located on low-lying coastal areas are also at greater risk. There is a possibility of nonlinear increase in coastal vulnerability over the next two decades.		Present; Near term (2030 – 2040); Long term (2080 – 2100) 2°C, 4°C	 Very low / Medium / Very high
Terrestrial ecosystems and ecological infrastructure (*medium confidence*) [8.2, 8.3]	Ecosystem services will be impacted by altered ecosystem functions such as temperature and precipitation regimes, evaporation, humidity, and soil moisture levels, indicating close links with sustainable water management. Knowledge gaps exist with respect to thresholds to adaptation of various ecosystems.		Present; Near term (2030 – 2040); Long term (2080 – 2100) 2°C, 4°C	 Very low / Medium / Very high
Water supply systems (*high confidence*) [8.2, 8.3]	Adaptation response requires changes to network infrastructure as well as demand side management, to ensure sufficient water supplies, increased capacities to manage reduced freshwater availability, flood risk reduction, and water quality.		Present; Near term (2030 – 2040); Long term (2080 – 2100) 2°C, 4°C	 Very low / Medium / Very high
Waste water system (*high confidence*) [8.2, 8.3, 8.4]	Managing waste water flows improves water supply and ecosystem services. Reducing vulnerability of infrastructure may be easier in new areas, well-funded local bodies, or as part of scheduled interventions.		Present; Near term (2030 – 2040); Long term (2080 – 2100) 2°C, 4°C	 Very low / Medium / Very high
Green built infrastructure (*medium confidence*) [8.3]	Green infrastructure not utilized sufficiently in most cities. Climate change impacts can bring attention to the dual benefits of green infrastructure for climate change mitigation and impact management.		Present; Near term (2030 – 2040); Long term (2080 – 2100) 2°C, 4°C	 Very low / Medium / Very high
Energy systems (*high confidence*) [8.2, 8.4]	Most urban centers are energy intensive, with energy-related climate policies focused only on mitigation measures. A few cities have adaptation initiatives underway for critical energy systems. There is great potential for non-adapted, centralized energy systems to magnify and cascade impacts to national or transboundary consequences from localized extreme events.		Present; Near term (2030 – 2040); Long term (2080 – 2100) 2°C, 4°C	 Very low / Medium / Very high

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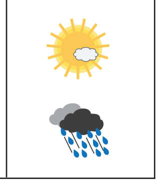
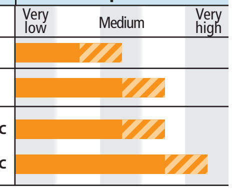
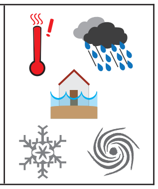
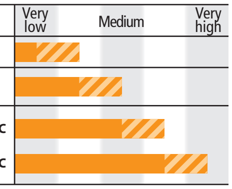
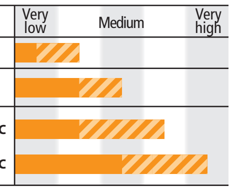
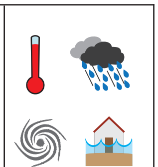
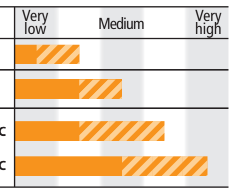
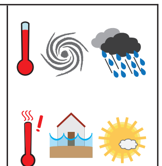
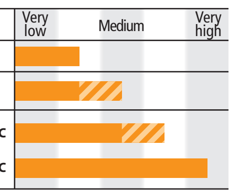
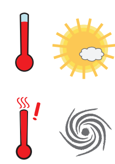
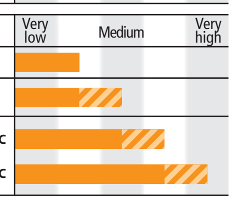
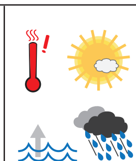
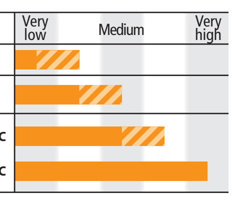
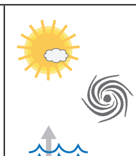
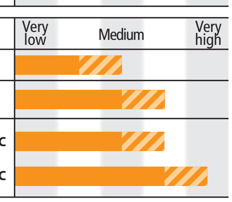
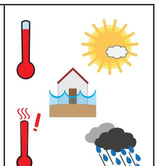
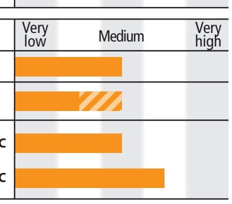
Table 8-3 (continued)

Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Food systems and security (*high confidence*) [8.2, 8.3]	Urban food sources are dependent on local, regional, and often global 8.2, 8.3 supplies. Climatic drivers can exacerbate food insecurity, especially of the urban poor. Enhanced social safety nets can support adaptation measures. Urban and peri-urban agriculture, local markets, and green roofs hold good prospects as adaptive measures, but are under-utilised in rapidly growing cities.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	
Transportation systems (*medium confidence*) [8.2, 8.3]	A difficult sector to adapt due to large existing stock, especially in developed country cities, leading to potentially large secondary economic impacts with regional and potentially global consequences for trade and business. Emergency response requires well-functioning transport infrastructure.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	
Communication systems (*medium confidence*) [8.2, 8.3]	Resilient communication systems are a critical component of emergency response, and therefore adaptation. The rise of decentralized and networked mobile communications offers great potential for real-time and easily accessed information dissemination and communication systems. Information quality control is a key element in realizing the potential of communications systems for early warning and adaptation.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	
Urban risks associated with housing (*high confidence*) [8.3]	Poor quality, inappropriately located housing is often most vulnerable to extreme events. Adaptation options include enforcement of building regulations and upgrading. Some city studies show the potential to adapt housing and promote mitigation, adaptation, and development goals simultaneously. Rapidly growing cities, or those rebuilding after a disaster, especially have opportunities to increase resilience, but this is rarely realized. Without adaptation, risks of economic losses from extreme events are substantial in cities with high-value infrastructure and housing assets, with broader economic effects possible.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	
Human health (*high confidence*) [8.2, 8.3, 8.4]	Health is a higher order risk impacted by key developmental issues including water supply, water and air quality, waste management, housing quality, sanitation, food security, and provision of health care services and insurance. Certain groups of people are particularly vulnerable, such as the elderly, the chronically ill, the poor, and the very young, and require targeted social care interventions. Longer term developmental improvements need considerable financial resources and coherent intergovernmental action, limiting prospects for near-term adaptation.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	
Human security and emergency response (*medium confidence*) [8.3, 8.4]	Security is linked to key developmental issues such as income, housing, health care, education, and food security. Moderate prospects as city governments can enhance emergency response services, to significantly reduce vulnerability for those who are most at risk. Where security and emergency forces have limited public trust, and especially with regard to gender issues, scope for supporting adaptation and risk management is considerably constrained.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	
Key economic sectors and services (*medium confidence*) [8.2, 8.3]	Large diversity across cities in terms of key economic sectors and adaptive capacity to disruptions in city services. Cities reliant on climate-sensitive tourism or agriculture may require economic diversification. Good prospects for advancing co-benefits through "green" and "waste" economy.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	
Livelihoods (*medium confidence*) [8.3]	Informal economy is more vulnerable, and often less adaptive in the short term. Social protection measures, in the specific context of urban livelihoods, are required.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	
Poverty and access to basic services (*high confidence*) [8.3]	Reducing basic service deficit could reduce hazard exposure, especially of the poor and vulnerable, alongside upgrading of informal settlements, improved housing conditions and enabling the agency of low-income communities. Significant prospects where adaptation is already being implemented as part of human development or social protection.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	

scale, but can also often occur with incremental changes, potentially precipitating regime level shifts (Pelling and Manuel-Navarrete, 2011). Although such shifts also can happen as a result of discrete regime failure (Pelling, 2011a), this is less common. Such transformational changes have been observed in a variety of urban disaster contexts. Most often they follow urban earthquake events (e.g., in Nicaragua, Guatemala, Turkey) but are also associated with flooding in Bangladesh (Pelling, 2011a). Disasters can enable regime level change at moments in history where competing approaches to development have political voice, an organizational base that articulates competing analysis of the causes of the disaster, and weak systemic counter response (Pelling, 2001a).

Climate change may exacerbate existing social and economic stressors in cities with the potential to affect urban livelihoods, engender political or social upheaval, or generate other negative impacts upon human security (Bunce et al., 2010; Siddiqi, 2011; Simon and Leck, 2010; see Chapters 22-30 for more detail). Climate change could potentially contribute to violent conflicts and spur migration from highly vulnerable sites in cities or increasingly environmentally stressed locales (Reuveny, 2007; Adamo, 2010; de Sherbinin et al., 2011). But there is considerable uncertainty regarding projections.

Migration may represent an important household strategy to adapt by diversifying income sources and livelihoods (Tacoli, 2009). Although climate change can significantly disrupt livelihoods, outcomes will depend on particular social structures, state institutions, and other broader determinants of human security (Barnett and Adger, 2007). In sum, "dwindling resources in an uncertain political, economic and social context are capable of generating conflict and instability, and the causal mechanisms are often indirect" between climate and conflict (Beniston, 2010, p. 567).

Different management solutions to climate change also have implications for equity (Pelling et al., 2012). For example, the privatization of urban water supply and sanitation systems can advantage specific groups over others. Conversely, community-based solutions that also build social capital can be a component in generating urban resilience. However, even these solutions may exacerbate inequality at the city level, with only those local areas with strong levels of social capital being able to benefit most from community led action or garner support from international and national partners (UN-HABITAT, 2007; Pelling et al., 2012).

Table 8-3 serves as the link between Section 8.2 (which focuses on climate change risks and impacts) and Section 8.3 (which focuses on adaptation). It summarizes key risks from climate change to urban areas and the potential to reduce risk through adaptation for the present, near term (2030–2040), and long term (2080–2100). Table 8-6 has comparable summaries of key risks and potential for adaptation for Dar es Salaam, Durban, London, and New York City. For the long term, under a global mean temperature increase of 2°C above preindustrial levels, many key risks increase from the near term. High adaptation can reduce these risk levels, although for most key risks not as much as high adaptation in the near term. For the long term under a temperature increase of 4°C above preindustrial levels, almost all key risks are "very high" and with many of them remain very high with high adaptation.

8.3. Adapting Urban Areas

8.3.1. Introduction

Since the Fourth Assessment Report, the literature on urban climate change adaptation has increased significantly, especially in three aspects:

- The examination of risks and vulnerabilities for particular cities
- The definition of "resilience" and identification of opportunities to strengthen resilience at all scales
- Documentation produced by or for particular city governments on adaptation.

There is less on local government decisions to include adaptation in plans and investment programs, but see Solecki (2012) and Roberts (2008, 2010) for exceptions. As described below, studies have also examined how to link adaptation and city development plans and adaptation measures for key sectors.

It has been suggested that "the complexities and uncertainties associated with climate change pose by far the greatest challenges that planners have ever been asked to handle" (Susskind, 2010, p. 219). Municipal and higher-level adaptation plans will need to take into account uncertainty about future climates and extremes. These will need to consider direct and indirect economic costs, including the trade-off of inaction and locking into ill-adapted infrastructure versus investment in adaptation when climate change is less than anticipated (Hallegatte et al., 2007a). Several U.S. studies have considered the cost on inaction for specific states (Niemi et al., 2009a,b,c; Repetto, 2011a,b, 2012a,b,c,d; Backus et al., 2012; Wilbanks et al., 2012).

While local governments are the fulcrum of urban adaptation planning, challenges include inadequate resources and technical capacities and a lack of data on climate-related risks and vulnerabilities. Existing climate models are not downscaled to the city level. Data on climate change risks are infrequently collected and often fragmented across city government departments (Hardoy and Pandiella, 2009). Many proposed adaptation measures respond to specific local or regional hazard risks that may not be directly climate related (Bulkeley, 2010). To encourage local dialog in adaptation planning, urban climate data need to be integrated geographically, across time scales, and consider the range of regional benefits and costs of climate policy (Ruth, 2010).

8.3.2. Development Plans and Pathways

As AR4 emphasized, many of the forces shaping greenhouse gas emissions also underlie development pathways—including the scale, nature, and location of investment in infrastructure (Wilbanks et al., 2007). These influence the form and geography of urban development as well as the scale and location of climate-related risks to urban buildings, enterprises, and populations. Local, provincial, and national governments share responsibility for encouraging new investments and migration flows away from high-risk sites through climate-sensitive disaster risk management, urban planning, and zoning and infrastructure investments. But the priority given to economic growth usually means this is rarely implemented with vigor (Douglass, 2002; Reed et al., 2013).

8.3.2.1. Adaptation and Development Planning

Urban adaptation is becoming important to some national and regional governments and many city governments. In high-income countries, interactions and division of responsibility between national and local level have been examined (see, e.g., Massetti et al., 2007, for Italy and Juhola and Westerhoff, 2011, for Italy and Finland); also local adaptation implementation through subsidies and flexible schemes in different contexts and the transfer of authority and resources to the city level (for the Netherlands; see Gupta et al., 2007). New decision making strategies for local governments consider the complexity and dynamics of evolving socio-ecological systems (Kennedy et al., 2011), for instance, adaptation plans and responses in Sydney to cope with sea level rise and storms (Hebert and Taplin, 2006) and adaptation planning in California (Bedsworth and Hanak, 2010).

The literature on urban adaptation in low- and middle-income nations has grown since AR4 (see Box 8-1 for publications since 2007). A 2011 review (Hunt and Watkiss, 2011) could draw on eight case studies in Asia, five in Africa, four in South America, as well as cases from Europe, Northern America, and Australasia.

Four issues can be highlighted around urban adaptation:

- Low- and middle-income nations have most of the world's current and future urban population.
- Key development issues of poverty and social inequality may be aggravated by climate change.
- Human agency among low-income inhabitants and organizations is important in building local responses.
- Well-functioning multilevel governance helps in developing adaptation strategies (Sánchez-Rodríguez, 2009).

Although few publications suggest specific operational strategies, they do stress the importance of the link between climate adaptation and development—urban infrastructure and other development deficits can contribute to adaptation deficits. Manuel-Navarrete et al. (2011) explore this interplay in the Mexican Caribbean, where hurricane exposure and vulnerability are influenced by political decisions and contingent development paths. Few reports exist on multidimensional approaches to operational adaptation. There are some examples of adaptation integrated with development interventions and addressing structural drivers of social and urban vulnerability—for instance, Climate Action Plans of Mexico City, Cartagena, and San Andrés de Tumaco (Sánchez-Rodríguez, 2009).

Despite growing acceptance of its importance, there are reasons for the general lack of attention to urban adaptation. First, national climate change policies usually give little attention to urban adaptation compared to sectors like agriculture. The ministries or agencies responsible for these policies often have little involvement in urban and little influence on those whose cooperation is essential, for example, for social policies, public works, and local government (Hardoy and Pandiella, 2007; Ojima, 2009; Roberts, 2010). Social policies and priorities influence the social and spatial distribution of climate-related risk and vulnerability—for instance, provision for health care, emergency services, and safety nets—yet few agencies recognize their potential role in reducing risk and vulnerability.

A second factor is the initial focus for many cities on mitigation rather than adaptation (with commitments made to lowering GHG emissions), in part because of the focus of international support. Local decision makers frequently view climate change as a marginal issue, but adaptation usually ranks lower than mitigation on the agenda (Bulkeley, 2010; Simon, 2010). Mexico City focuses on mitigation, but adaptation is still a vague concept (GDF, 2006, 2008) seen more, for instance, as a capacity to cope with floods through early warning systems than through comprehensive, long-term measures such as watershed management to reduce the speed and volume of flood waters. There is still little

Box 8-1 | Recent Literature on Urban Adaptation in Low- and Middle-Income Nations

Among the papers and books considering climate change adaptation in urban areas since 2007 are those on Cape Town (Mukheibir and Ziervogel, 2007; Ziervogel et al., 2010; Cartwright et al., 2012), Durban (Roberts, 2008, 2010; Roberts et al., 2012; Cartwright et al., 2013; Roberts and O'Donoghue, 2013), and other urban centers in Africa (Douglas et al., 2008; Wang et al., 2009; Lwasa, 2010; Kithiia and Lyth, 2011; World Bank, 2011; Adelekan, 2012; Castán Broto et al., 2013; Kiunsi, 2013; Silver et al., 2013); urban centers in Bangladesh (Alam and Rabbani, 2007; Jabeen et al., 2010; Banks et al., 2011; Haque et al., 2012; Roy et al., 2013); India (Revi, 2008; Sharma and Tomar, 2010; Saroch et al., 2011); Pakistan (Khan et al., 2008); Philippines (Button et al., 2013); and Latin America (Romero-Lankao, 2007, 2010; Hardoy and Pandiella, 2009; Hardoy and Romero-Lankao, 2011; Hardoy and Ruete, 2013; Hardoy and Velasquez Barrero, 2013; Luque et al., 2013). In China, discussions of division of responsibility between national and local levels include Teng and Gu (2007), Liu and Deng (2011), and Li (2013).

Other papers or books discussing urban adaptation in low- and middle-income nations include de Sherbinin et al. (2007), McGranahan et al. (2007), Agrawala and van Aalst (2008), Bartlett (2008), Kovats and Akhtar (2008), Ayers (2009), Bicknell et al. (2009), Tanner et al. (2009), Rosenzweig et al. (2011), Moser et al. (2010), World Bank (2010b), Manuel-Navarrete et al. (2011), Moench et al. (2011), UN-HABITAT (2011a), Bulkeley and Castan Broto (2013), and Bulkeley and Tuts (2013).

literature on adaptation for Brazilian cities (Ojima, 2009; Soares, 2009). In Sao Paulo, adaptation is limited to broad declarations about necessary actions, even as the city gets hit by floods, landslides, and water scarcity (Puppim de Oliveira, 2009; Nobre et al., 2010; Martins and da Costa Ferreira, 2011). The pressure on national and local governments to act is lessened by the scant public awareness of the importance of climate change adaptation (Nagy et al., 2007), and a "knowledge gap" between policy makers and scientists (Sánchez-Rodríguez, 2011). However, as Section 8.4 describes, interest in urban adaptation is growing, encouraged by the increasing engagement of transnational municipal networks and donor agencies (Bulkeley, 2013).

8.3.2.2. Disaster Risk Reduction and Its Contribution to Climate Change Adaptation

The growing concentration of people and activities in urban centers and the increasing number and scale of cities can generate new patterns of disaster hazard, exposure and vulnerability, as evident in the rising number of localized disasters in urban areas in many low- and middle-income nations associated with extreme weather (storms, flooding, fires, and landslides) (Douglas et al., 2008; UNISDR, 2009, 2011). This is relevant to climate change adaptation, given the increasing frequency and intensity of potentially hazardous weather events associated with climate change. Extreme weather events have also helped raise awareness of citizens and local governments of local risks and vulnerabilities.

Exposure to weather-related risk in growing urban areas increases when local governments fail to address their responsibilities by expanding or upgrading infrastructure and services and reducing risk through building standards and appropriate land use management (UNISDR, 2009, 2011). This is typical in countries with low per capita GDPs and weak local governance (i.e., in the first two categories of Table 8-2), and can be exacerbated by rapid urban population growth. Urbanization accompanied by more capable and accountable local governments can reduce disaster risk, as evident in the declines in mortality from extreme weather (and other) disasters in many middle- and all high-income nations (UNISDR, 2011). The most urbanized nations generally have the lowest mortality to these events (UNISDR, 2009).

Local government investment is usually a small proportion of total investment in and around an urban center, but has particular importance in risk reduction. Urban governments have explicit responsibilities for many assets that may be risk prone, often including schools, hospitals, clinics, water supplies, sanitation and drainage, communications, and local roads and bridges (IFRC, 2010).

Even where private provision for these assets is significant, local government usually coordinates such provision and has a significant planning and regulation role, ensuring buildings and infrastructure meet needed standards and guiding development away from high-risk areas.

From the late 1980s, some Latin American cities took a new approach to disaster risk, involving three processes:

- Detailed analyses of local disaster records, including smaller events than those in international databases
- Recognition that most disasters were the result of local failures to assess and act on risk
- Recognition of the central roles of local governments in disaster risk reduction, supported national and local civil defense organizations, working with civil society and settlements most at risk (UNISDR, 2009; IFRC, 2010).

This led to institutional and legislative changes at national or regional level (Gavidia, 2006; IFRC, 2010). In Colombia, a national law supports disaster risk reduction and a National System for Prevention and Response to Disasters, shifting the main responsibility for action to municipal administrations. In Nicaragua, the National System for Disaster Prevention, Mitigation and Response (SINAPRED) works with local government to integrate disaster mitigation and risk reduction into local development

Frequently Asked Questions

FAQ 8.1 | Do experiences with disaster risk reduction in urban areas provide useful lessons for climate-change adaptation?

There is a long experience with urban governments implementing disaster risk reduction that is underpinned by locally driven identification of key hazards, risks, and vulnerabilities to disasters and that identifies what should be done to reduce or remove disaster risk. Its importance is that it encourages local governments to act before a disaster—for instance, for risks from flooding, to reduce exposure and risk as well as being prepared for emergency responses prior to the flood (e.g., temporary evacuation from places at risk of flooding) and rapid response and building back afterwards. In some nations, national governments have set up legislative frameworks to strengthen and support local government capacities for this (Section 8.3.2.2). This is a valuable foundation for assessing and acting on climate-change related hazards, risks, and vulnerabilities, especially those linked to extreme weather. Urban governments with effective capacities for disaster risk reduction (with the needed integration of different sectors) have institutional and financial capacities that are important for adaption. But while disaster risk reduction is informed by careful analyses of existing hazards and past disasters (including return periods), climate change adaptation needs to take account of how hazards, risks, and vulnerabilities will or might change over time. Disaster risk reduction also covers disasters resulting from hazards not linked to climate or to climate change such as earthquakes.

processes (von Hesse et al., 2008; IFRC, 2010). Other initiatives in Central and South America include the influence of La Red (IFRC, 2010), the DIPECHO project "Developing Resilient Cities," and UNDP and GOAL in Central America. In growing numbers of cities in Asia (Shaw and Sharma, 2011) and Africa (Pelling and Wisner, 2009), experiences with community-driven "slum" or informal settlement upgrading has led to a recognition of its potential to reduce risk and vulnerability to extreme weather events, most effectively when supported by local government and civil defense response agencies (Boonyabancha, 2005; Archer and Boonyabancha, 2011; Carcellar et al., 2011).

The Homeless People's Federation of the Philippines developed a series of effective responses following major disasters, including community-rooted data gathering (assessing destruction and victims' immediate needs); trust and contact building; support for savings; registering community organizations; and identifying needs, including building materials loans for repairs. The effectiveness of these measures is much enhanced with local government support (Carcellar et al., 2011) and these experiences have helped inform community-based adaptation (Section 8.4).

International networks supporting innovation in disaster risk reduction and/or climate change adaptation and inter-city learning include La Red in Latin America which has been operating for 3 decades (IFRC, 2010) and the cities program of the Asian Disaster Preparedness Centre (ADPC). As donor interest has grown in supporting disaster risk management as a vehicle for climate change adaptation, a number of urban resilience programs have developed including ACCCRN (Asian Cities Climate Change Resilience Network; Brown et al., 2012), the UNISDR (United Nations International Strategy for Disaster Reduction Making Cities Resilient) network (Johnson and Blackburn, 2013), the ICLEI (Local Governments for Sustainability) city adaptation network, and UN-HABITAT's Cities and Climate Change Initiative.

Despite growing international support for urban disaster risk management, local governments have difficulty accessing the resources to make real change (von Hesse et al., 2008). Local government risk reduction investments are not seen as priorities and have to compete for scarce resources with what are judged to be more pressing needs. Effective policies are often tied to the terms of particular mayors or political parties (Mansilla et al., 2008; Hardoy et al., 2011). In most cases, risk reduction is not integrated into development plans or all relevant local government departments. Manizales, Colombia, is an exception: risk reduction has long been seen as part of local development and collective interests take precedence over party political interests (Hardoy and Velasquez Barrero, 2013).

Disaster risk management is increasingly positioned as a frontline sector for integrating climate change adaptation into everyday decision making and practices (IPCC, 2012), as seen in the plans of municipalities such as Tegucigalpa and Montevideo (Aragón-Durand, 2011). Where it is taken seriously, it offers real opportunities for synergy as the long-range nature of climate change concerns and its policy visibility can enhance local support for disaster risk management. There is considerable scope in international frameworks and national responsibilities for better coordination to make urban disaster risk management climate resilient (Aragón-Durand, 2008; IPCC, 2012).

8.3.3. Adapting Key Sectors

8.3.3.1. Adapting the Economic Base of Urban Centers

Section 8.2 described how climate change can change the comparative advantages of cities and regions—for instance, by influencing climate sensitive resources, water availability, and flooding risks. Many case studies show how extreme weather can impede economic activities, damaging industrial infrastructure and disrupting ports and supply chains (Section 8.2.3.4). Vugrin and Turnquist (2012) discuss design for resilience in distribution networks such as electric power, gas, water, food production, and manufacturing supply chains. This requires absorptive capacity (to withstand extreme weather), adaptive capacity (e.g., service provision through alternative paths), and restorative capacity (quick and cheap recovery).

When urban centers fail to adapt to risks, it may discourage new investment and lead enterprises to move or expand to safer locations. Multinational corporations and many national businesses are adept at changing location in response to changing opportunities and risks, including high insurance costs. Disasters can change perceptions of risk. Businesses may adapt to avoid impacts in their own facilities but be affected by impacts to utilities and other businesses or to their workforce and the services they use (schools, hospitals) (Hallegatte et al., 2011a; da Silva, 2012). Limited local capacity to reconstruct means increased vulnerability to future extreme events and less new investment weakens the economic base (Benson and Clay, 2004; Hallegatte et al., 2007b, 2011a). Past experience in the USA and Europe show the difficulties city governments can face in attracting new investment when a city or region's main activity weakens. If climate change forces changes to economic structure and business models, transitions may be hard to manage (Berger, 2003). Specific adaptation policies may make the transition more rapid and less painful. For instance, adaptation is generally cheaper and easier in greenfield sites—as low-risk sites are chosen, trunk infrastructure to appropriate standards is installed and building and land use regulations enforced. Retrofitting existing infrastructure and industries is generally more expensive (McGranahan et al., 2007).

Within and around urban centers, local governments may require several strategies to strengthen resilience including selective relocation, better land use planning, and revised building regulations to retrofit or flood-proof structures (Hanson et al., 2011). Synergies can be encouraged where land use management around a city supports rural livelihoods, and protects ecosystem services (Section 8.3.3.7). There may be opportunities for proactive adaptation outside larger cities where much of the future urban growth will occur. Manizales, Colombia, which has long had innovative environmental and disaster risk reduction policies has begun incorporating climate change and environmental management into its local development agenda, including the establishment of city climate monitoring systems (Hardoy and Velasquez Barrero, 2013). But most smaller urban centers are institutionally weaker and may lack the investment capacity and critical infrastructure.

Adapting the urban economic base may require short- and long-term strategies to assist vulnerable sectors and households. The consequences of climate change for urban livelihoods may be particularly profound

Frequently Asked Questions

FAQ 8.2 | As cities develop economically, do they become better adapted to climate change?

Cities and nations with successful economies can mobilize more resources for climate change adaptation. But adaptation also needs specific policies to ensure provision for good quality risk-reducing infrastructure and services that reach all of the city's population and the institutional and financial capacity to provide, and manage these and expand them when needed. Poverty reduction can also support adaptation by increasing individual, household, and community resilience to stresses and shocks for low-income groups and enhancing their capacities to adapt. This provides a foundation for building climate change resilience but additional knowledge, resources, capacity, and skills are generally required, especially to build resilience to changes beyond the ranges of what have been experienced in the past.

for low-income households who generally lack assets or insurance to help them cope with shocks (Moser and Satterthwaite, 2009). The informal sector is a significant part of the economy for most urban centers, providing employment for large numbers. But the effects of extreme weather on the informal economy are rarely considered, as in 2003 floods in Santa Fe, Argentina (Hardoy and Pandiella, 2009). In Kelurahan Pabean Pekalongan in Central Java, batik production, the primary livelihood, is being disrupted by increasingly frequent floods (UN-HABITAT, 2011b). Cash transfers and safety nets are being considered to help low-income groups cope with the short-term impacts of climate change (Sanchez and Poschen, 2009), as well as climate variability. But these will not address all the risks they face or support collective or public investments in risk-reducing infrastructure and services.

There is a growing discussion of the importance of support for a "green economy" with green infrastructure to help shift nations' economic and employment base toward lower carbon, more resilient, more sustainable patterns that respect regional and global ecological and resource limits. For urban centers, this means highlighting new (or adapted) business opportunities that limit anthropogenic climate change, resource depletion, and environmental degradation. Sometimes social inclusivity and eco-efficiency are included as mutually reinforcing principles (e.g., Allen and Clouth, 2012). The literature has begun to explore the changes needed in production systems (especially in carbon intensity, waste generation, and management), buildings, transport systems, electricity generation (including incorporating solar and wind), and consumption patterns of wealthier groups (Hammer et al., 2011; UN-HABITAT, 2012a,b,c,d; World Economic Forum, 2013). As yet, there is too little detailed discussion of how a green economy can be fostered in relation to particular cities or in regard to the incentives and regulations that can shift private investment to this.

The 'waste economy' in cities in low- and middle-income nations is important to the green economy, providing livelihoods (Hardoy et al., 2001; Hasan et al., 2002; Medina, 2007) and contributing to waste reduction and GHG emission reduction (Ayers and Huq, 2009). In Brazil's main cities, more than half a million people are engaged in waste picking and recycling (Fergutz et al., 2011), in Lima an estimated 17,000, and in Cairo 40,000 (Scheinberg et al., 2011). The ways city governments choose to work with (or ignore) those in this waste economy have obvious implications for employment and for resource use.

For some cities, there is documentation of the adaptation costs to protect or enhance the economic base. Hallegatte et al. (2013) assess present and future flood losses in the world's 136 largest coastal cities and show that the estimated costs of adaptation are far below the estimate of losses in the absence of adaptation. The paper also highlights the differences in the cities most at risk, depending on whether the ranking is by economic average annual losses or by such losses as a proportion of each city's GDP. In the first, it is mainly cities in high-income nations, in the second, mainly prosperous cities in middle-income nations.

Mombasa may have to redesign and reconstruct the city's ports, protect cement industries and oil refineries, and relocate some industries inland, all requiring major capital investments (Awuor et al., 2008). Adaptation can help protect many parts of Rio de Janeiro's diverse economy (including manufacturing, oil refineries, shipyards, and tourism) and the large populations living in informal settlements (favelas) on land at risk of landslides (de Sherbinin et al., 2007). Defenses needed to safeguard coastal industries and residential areas could threaten Rio's beach tourist industry and cause further erosion to other unprotected areas. As in most cities, making Rio's economic base more resilient to climate change means resolving such trade-offs and encouraging dialog among local stakeholders (Ruth, 2010).

As yet, there is little evidence that cities' adaptive capacities influence private sector investments. But private investment is influenced by the quality and availability of infrastructure and services that are an essential part of adaptive capacity. Many cities in Asian high growth economies are located in low-elevation coastal zones undergoing rapid urbanization and economic transformation (McGranahan et al., 2007). Cyclones are common in many of these coastal settlements. Rising concentrations of people, infrastructure, and industries along India's coasts, without adaptation, could mean nonlinear increase in vulnerability over the next 2 decades (Revi, 2008). The same is true for China (McGranahan et al., 2007). In most nations, urban governments find it difficult to prevent new developments on sites at risk of flooding, especially in locations attractive for housing or commerce, even when there are laws and regulations in place to prevent this (see Olcina Cantos et al., 2010, for an example in Alicante in Spain).

There are few economic assessments of climate change risks in West African coastal cities. Many cities or districts and their industries,

Frequently Asked Questions

FAQ 8.3 | Does climate change cause urban problems by driving migration from rural to urban areas?

The movement of rural dwellers to live and work in urban areas is mostly in response to the concentration of new investments and employment opportunities in urban areas. All high-income nations are predominantly urban and increasing urbanization levels are strongly associated with economic growth. Economic success brings an increasing proportion of GDP and of the workforce in industry and services, most of which are in urban areas. While rapid population growth in any urban center provides major challenges for its local government, the need here is to develop the capacity of local governments to manage this with climate change adaptation in mind. Rural development and adaptation that protects rural dwellers and their livelihoods and resources has high importance as stressed in particular in Chapters 9 and 13—but this will not necessarily slow migration flows to urban areas, although it will help limit rural disasters and those who move to urban areas in response to these.

infrastructure and tourism will be a challenge to protect, as in Cotonou (Dossou and Gléhouenou-Dossou, 2007), Lagos (Douglas et al., 2008), and Dakar (Wang et al., 2009).These and other important economic centers in the Gulf of Guinea (including Abidjan and Port Harcourt) have large areas close to mean sea level and highly vulnerable to erosion and rising sea levels. Rapid construction, destruction of mangrove swamps, and inadequate refuse collection compound the risks (Simon, 2010).

8.3.3.2. Adapting Food and Biomass for Urban Populations

Many urban dwellers in low- and middle-income countries suffer hunger, while a larger number face food and nutrition insecurity (Montgomery et al., 2003; Ahmed et al., 2007; Cohen and Garrett, 2010; Crush et al., 2012) owing more to their low incomes than to overall food shortages (Cohen and Garrett, 2010; Crush et al., 2012). For these low-income urban households, food expenditures generally represent more than half of total expenditures (Cohen and Garrett, 2010), putting them at particular risk from real increases in long-term food prices or temporary spikes associated with disasters.

Climate change impacts can have far-reaching influences on food security and safety, but these "will crucially depend on the future policy environment for the poor" (Schmidhuber and Tubiello, 2007, p. 708; see also Douglas, 2009). Agriculture has managed to keep up with rising demands worldwide, despite rapid population growth, the reduction in agricultural workers that accompanies urbanization, and dietary shifts that are more carbon and often land intensive (Satterthwaite et al., 2010). But food security may be eroded by competing pressures for water or bio-fuels. In addition, there may be tensions between managing land use to reduce flood risk and food and energy policies (Wilby and Keenan, 2012). Adapting urban food systems represents a major challenge and will necessitate radical changes in food production, storage, and processing (and in reducing waste), in transport/the supply chain, and in access (Godfray et al., 2010). Both supply and demand side constraints must be considered. Climate change-related constraints on agricultural production affect urban consumers through reduced supplies or higher prices; falling production and farmer incomes reduces their demand for urban goods and services; disruption to urban centers can mean disruption to the markets, services, or remittance flows on which agricultural producers rely (Tacoli, 2003). Thus, strengthening urban food security needs to take account of complex rural-urban linkages (Revi, 2008) and responses must bridge rural and urban boundaries.

Urban centers that are seriously impacted by extreme weather face serious challenges in ensuring that those affected have access to adequate and safe food and water supplies. Flooding, drought, or other extreme events often lead to food price shocks in cities (Bartlett, 2008) as well as spoiling or destroying food supplies for many households. After the 2004 floods in Bangladesh, Dhaka's rice prices increased by 30% and vegetable prices more than doubled, with urban slum dwellers and rural landless poor the worst affected (Douglas, 2009). When facing increased food prices, the urban poor adopt a range of strategies such as reduced consumption, fewer meals, purchasing less nutritious foods, or increasing income earning work hours, particularly for women and children (Cohen and Garrett, 2010). But these erode nutrition and health status, especially of the most vulnerable and fail to strengthen resilience, particularly in the context of more frequent disasters.

Adaptive local responses include support for urban and peri-urban agriculture, green roofs, local markets, and enhanced safety nets. Food price increases may be moderated by improving the efficiency of urban markets, promoting farmers' markets, and investing in infrastructure and production technologies (Cohen and Garrett, 2010). Food security may be enhanced by support for urban agriculture and street food vendors (Cohen and Garrett, 2010; Lee-Smith, 2010) and access to cheaper food or measures such as cash transfers (e.g., Brazil's Bolsa Familia Programme) or, for older groups, pensions (Soares et al., 2010). Initially rural in focus, cash transfer programs have expanded in urban areas, in some places reaching much of the low-income population (Johannsen et al., 2009; Niño-Zarazúa, 2010; Mitlin and Satterthwaite, 2013).

8.3.3.3. Adapting Housing and Urban Settlements

The built environment in urban areas has to adapt to the range of climate change impacts outlined in Section 8.2, in order to protect urban populations and economies and protect among society's most valuable assets. Knowledge and innovation are required for adapting existing and new buildings. This will be built on the bedrock of affordable housing appropriate for health and safety, built to climate-resilient standards and with the structural integrity to protect its occupants long term against extreme weather (UNISDR, 2009, 2011). The resilience of poor quality housing, often at risk from extreme weather, can be enhanced via structural retrofitting, interventions that reduce risks (for instance, expanding drainage capacity to limit or remove flood risks), and non-structural interventions (including insurance). Attention to all three is more urgent where housing quality is low, where settlements are on high-risk sites, and in cities where climate change impacts are greatest. Enhancing the resilience of buildings that house low-income groups will usually be expensive and may face political challenges (Roaf et al., 2009).The range of actors in the housing sector, the myriad connections to other sectors and the need to promote mitigation and adaptation, as well as development goals, point to the importance of well-coordinated strategies that can support resilience (Maller and Strengers, 2011).

There have been studies in increasing numbers of cities to identify measures to adapt housing (and other buildings) and discussions on revising standards, although it is difficult to set standards with uncertain forecasts and scenarios and evolving risks (Engineers Canada, 2008). There is less evidence of the action plans, budget commitments, and regulation changes to implement them. Measures identified in a Bangkok assessment included flood-proofing homes, building elevated basements, and moving power-supply boxes upstairs, along with keeping enough food, water, fuel, and other supplies for 72 hours; it also pointed to regulatory changes to bolster resilience including land use restrictions in floodplains and other at-risk sites and revised safety and fire codes for buildings and other structures (BMA, GLF, and UNEP, 2009). Cape Town's climate change framework (2006) proposed housing interventions including regulations for building informal housing, in part to reduce the need for emergency response and anticipate projected climate change. Regulations in New York and Boston are being updated to address climate-related risks (City of Boston, 2011; City of New York, 2011). London and Melbourne's adaptation plans both consider strategies combining green infrastructure and housing interventions (GLA, 2010; UN-HABITAT, 2011a).

8.3.3.3.1. Housing and other buildings and extreme heat

More attention is being paid to extreme heat in particular cities (e.g., City of Chicago 2008, 2010; City of Toronto, 2013; Tomlinson et al.,2011, for Birmingham; Matzarakis and Endler, 2010, for Freiberg; GLA, 2010, for London; and Giguère, 2009, for Quebec), also in regard to low-income housing in Athens (see Sakka et al., 2012).

Attention is required to buildings that provide protection from hot days and to populations more vulnerable to extreme heat, including those who work outside (see Box CC-HS). In locations with large daily variations in temperature, the response can include upgrading homes with limited ventilation and low thermal mass. Chicago's 2008 Climate Action Plan discussed the need for innovative cooling ideas for property owners (City of Chicago, 2008, p. 52). Air conditioning and other forms of mechanical cooling are too expensive, unavailable for the many urban households with no electricity, and maladaptive when electricity generation contributes to GHG emissions. Residents' vulnerabilities may be exacerbated if electricity supplies are unreliable; blackouts tend to occur on the hottest days when demand is highest (Maller and Strengers, 2011, p. 3). The literature on adaptations for extreme heat focuses on high-income nations and more attention is required to this in urban centers in low- and middle-income nations.

Passive cooling can be used in both new-build and retrofitted structures to reduce solar and internal heat gains, while enhancing natural ventilation or improving insulation (Hacker and Holmes, 2007; Roberts, 2008a,b). Passive designs, using super-insulation, ventilation, and other measures to ensure energy is not required for most of the year, as in the Beddington Zero Energy Development (BedZED) in London (Chance, 2009) or Germany's Passive Haus standard (Rees, 2009), have set precedents for mitigating household emissions but they can simultaneously contribute to adaptation. Thermal mass can be used for cooling, "because it introduces a time-delay between changes in the outside temperature and the building's thermal response necessary to deal with the high daytime temperatures" (Hacker and Holmes, 2007, p. 103). Structures in southern Europe already use solar shading, ventilation, and thermal mass to promote enhanced cooling (Hacker and Holmes, 2007). Simulations for London (under UKCIP02 Medium-High emissions scenarios) suggest that passive designs are an "eminently viable option for the UK, at least over the next 50 years or so" (Hacker and Holmes, 2007, p. 111). There are several obstacles though: opening windows may be hampered by security concerns or noise pollution (Hacker and Holmes, 2007). Modern windows may not ventilate well, and site restrictions and cost can impede the use of passive cooling in refurbishing existing buildings (Roberts, 2008a).

8.3.3.3.2. Housing and disaster-preparedness measures

When populations are displaced or temporarily evacuated, provision for emergency shelters and services have to be able to respond, especially for vulnerable residents. For instance, after Cyclone Larry in Queensland (in 2006) and New South Wales' coastal flooding (in 2007), officials recalled the strains faced in shelters and the coordination difficulties with emergency health workers, police, insurance, and other agencies (Jacobs and Williams, 2011). This points to the range of social support, structural strategies, and interagency efforts that local authorities may develop to adapt to climate change. For many urban centers, there is also the issue of how to move populations at risk, which presents many challenges (Roaf et al., 2009).

Urban centers facing extreme heat require plans that provide early warning for citizens, inform them of measures they can take and ensure adequate water provision, back up electricity, emergency health care, and other public services focused on vulnerable residents, especially infants and the elderly in hospitals and residential facilities (Brown and Walker, 2008; Hajat et al., 2010) or living alone. Public buildings with cooling may also be required. Cities with responses to hot days for those most at risk are mainly from high-income nations. Several hundred million urban dwellers in low- and middle-income nations have no access to electricity (Johansson et al., 2012) or mechanical devices that help with cooling.

8.3.3.4. Adapting Urban Water, Storm, and Waste Systems

It is challenging to summarize key adaptation strategies from the highly heterogeneous mix of urban areas across the globe. In high-income and some middle-income nations, virtually all the urban population is served by drinking quality water piped to the home 24 hours a day, by systems of sanitation that minimize risks of fecal contamination and by storm and surface drainage. Many urban centers in such nations may face serious climate change-related challenges for water, but do not have to address the fact that much of their population lacks piped water, toilets, or storm drains. They can also bill users for much of the funds required for water provision and management.

At the other extreme are a very large number of urban centers with large deficits in provision for water, sanitation, and drainage and with weak, under-resourced institutions (UN-HABITAT, 2003b; UNEP, 2012). Around a billion people live in informal settlements where providers responsible for water and sanitation are often unwilling to invest or not allowed to do so (Mitlin and Satterthwaite, 2013). New York City can develop a plan to ensure adequate water supplies costing billions of dollars (Solecki, 2012); many cities in sub-Saharan Africa have not only very large deficits in piped water, sewers, and drains but also very limited investment capacities (see, e.g., Kiunsi, 2013, for Dar es Salaam).

Some studies have sought to estimate the costs of adapting urban water and sanitation systems, pointing to the need for significant investments (Arnell, 2009). Muller (2007) suggests that US$1 to 2.7 billion is required annually in sub-Saharan African cities to adapt existing water infrastructure; this does not include the cost of addressing deficient infrastructure. Another US$1 to 2.6 billion a year is required to adapt new developments (including water storage, waste water treatment, and electricity generation).

8.3.3.4.1. Adapting urban water supply systems

For cities with climate change adaptation plans, water and waste water management are usually important components (see, e.g., Helsinki Region Environmental Services Authority, 2012). Major et al. (2011) list a range of cities that have begun to adapt water systems and other infrastructure including Boston, London, Halifax (Canada), New York, Seattle, and Toronto. The U.S. government has developed a guide for adaptation strategies for water utilities (EPA, 2013). But developing such measures is not yet commonplace.

Supply-side approaches to seasonal water shortages are frequently advocated. An analysis of 21 draft Water Resources Management Plans in the UK found that agencies usually favored reservoirs and other supply-side measures to adapt to climate change, although authors suggest that demand-side interventions may also be needed (Charlton and Arnell, 2011). To expand its reservoir capacity after 1998 floods exposed existing infrastructure, Rotterdam developed plans combining adaptation and urban renewal goals, mixing economic activities with water-based adaptive designs, including "water retention squares" and green roofs, floating houses, and networks of channels (Van der Brugge and De Graaf, 2010). Seattle has used demand-side strategies to cut water consumption including aggressive conservation measures, system savings, and price increases (Vano et al., 2010).

In Mexico City, a number of measures in the water sector have been proposed many times since the 1950s but not acted on, including a decrease in water use and the restoration and management of urban and rural micro-basins (Romero-Lankao, 2010). Adaptation measures have been conceived as too general and lacking institutional commitment. In Durban, where the water sector is revenue earning and seen as critical to development, the importance of climate change adaptation was recognized as a priority (Roberts, 2010). In Cape Town, which faces profound challenges in ensuring future supplies, water management studies identified the need to consider climate change and population and economic growth (Mukheibir and Ziervogel, 2007). During the 2005 drought, the local authority substantially increased water tariffs, considered a most effective way to promote efficient water usage (Mukheibir, 2008). Other measures may include water restrictions, reuse of gray water, consumer education, or technological solutions such as low-flow systems or dual flush toilets (Mukheibir and Ziervogel, 2007).

In Phoenix, Arizona, a rapidly expanding desert city projected to reach 11 million people by 2050, most peripheral growth depends on groundwater (Bolin et al., 2010). Simulations explored how water usage may be reduced to achieve safe yield while accommodating future growth. Reducing current high use may be achieved through urban densification, increased water prices, and water conservation measures (Bolin et al., 2010). Gober et al. (2010) agree that stringent demand and supply policies can forestall "even the worst climate conditions and accommodate future population growth, but would require dramatic changes to the Phoenix water supply system" (Gober et al., 2010, p. 370). Here and in other cities in Arizona, supply-side management including active management of groundwater and groundwater storage is combined with extensive demand side measures (Colby and Jacobs, 2007).

In Quito, where reduced freshwater supplies are projected with glacier retreat and other climate-related changes, local government has formulated a range of adaptation plans, including encouraging a culture of rational water use, reducing water losses, and developing mechanisms to reduce water conflicts (Hardoy and Pandiella, 2009). However, community participation in planning and implementation has not been considered (Hardoy and Pandiella, 2009). Participatory water planning has occurred elsewhere in Latin America: stakeholders in Hermosillo, Mexico, identified and prioritized specific adaptations such as rainwater harvesting and water-saving technologies (Eakin et al., 2007).

Several cities actively encourage rainwater harvesting while others are considering its potential. Since 2004, in New South Wales, Australia, homeowners have been required to ensure that newly built houses use 40% less potable water than an established benchmark level of consumption, through water-saving measures such as water-efficient shower heads, dual-flush toilets, rainwater tanks and grey water treatment systems (Warner, 2009). Many low-income Caribbean households rely on rainwater collection systems for domestic use. Extending existing communal collection and distribution systems would require community financing or governmental interventions, as well as overcoming resistance from higher-income residents (Cashman et al., 2010). Rainwater harvesting has been promoted in several cities in India (Shaban and Sharma, 2007).

8.3.3.4.2. Waste and storm water management

More attention has been given to adaptations to help ensure sufficient water supplies than to increasing the capacity of sewer and drainage systems, or adapting them to allow for the impacts of heavier rainfall or sea level rise. We noted earlier the very large deficiencies in provision for drainage for urban centers in low- and many middle-income nations.

In St. Maarten, Netherlands Antilles, the government (after a storm water modeling study) is developing a flood warning system and considering such institutional adaptations as a new decision-support framework, centralized geographic information system (GIS) for infrastructure planning and public education, along with structural measures such as draining areas with a high groundwater table (Vojinovic and Van Teeffelen, 2007). City management in Toronto, Canada, has prioritized an upgrade of storm water and wastewater systems (Kessler, 2011). Deak and Bucht (2011) analyze past hydrological structures in Lund, Sweden, and use the concept of indigenous blue infrastructure to question current storm water management in the urban core. Cities in California have a range of flood management methods but Hanak and Lund (2012) suggest that they will also require forward-looking reservoir operation planning and floodplain mapping, less restrictive rules for raising local funds, and improved public information on flood risks. Willems and Arnbjerg-Nielsen (2013) suggest that climate change adaptation for urban drainage systems requires a reevaluation of the technical solutions implemented over the last 150 years. The objective is cities that interact with water (including storms) in a healthy, environmentally friendly, and cost-efficient way. This includes the incorporation of roads and parks into the active drainage system and the use of blue and green storm water infrastructure (Section 3.3.3.7). These authors also note that this implies changing roles for water scientists, water managers, and water engineers as well as for water users, property owners, insurers, city planners, and politicians (Willems and Arnbjerg-Nielsen, 2013; see also Willems et al., 2012). Many governments in the last 20 years have developed integrated water resource management (UNEP, 2012) with linkages between provisions for water, sanitation, and drainage and other sectors, and a recognition of the need to work with a range of partners, consider broader development goals, identify tensions or trade-offs (Willems and Arnbjerg-Nielsen, 2013), and implement low-regret anticipatory solutions. For cities, this often includes management of groundwater use and water catchment in areas outside their jurisdiction and thus collaboration with other local governments (WMO, 2008). Most examples of this are in high-income nations (for an exception, see Bhat et al., 2013).

Urban water systems usually depend on reliable electricity supplies and can be energy intensive—for instance, in conveying or treating water from distant or low-quality sources. Integrated planning (e.g., in concert with energy conservation, water catchment management and green infrastructure strategies) can minimize conflicts, support local industries, and ensure equitable access to water in cities.

8.3.3.5. Adapting Electric Power and Energy Systems

The heavy dependence of urban economies, infrastructure, services, and residents on electricity and fossil fuels means far-reaching consequences if supplies are disrupted or unreliable (Section 8.2.4.2). With mitigation concerns dominating the literature and urban energy policy discussions, there is less focus on adaptation issues (Carmin et al., 2009; Mdluli and Vogel, 2010). The UNFCCC's estimates for investment to address climate change (UNFCCC, 2007) did not include the costs of adapting the energy sector (Fankhauser, 2010). Key issues relating to energy sector adaptation, including generation and distribution, are usually national or regional and are discussed in Chapter 10. But urban governments' and residents' responses are also important. Research has suggested that "private autonomous measures will dominate the adaptation response as people adjust their buildings, [or] change space-cooling and -heating preferences…" (Hammer et al., 2011, p. 27). A few cities have adaptation initiatives underway for energy systems; others have begun to consider the steps needed (Hammer et al., 2011). Some relevant local urban concerns are the extent of the need for autonomous provision or back-up generating capacity, and the functioning of emergency services when energy supplies are disrupted or unreliable. The interrelations between energy and other sectors suggest the need for an integrated approach in understanding vulnerability and shaping appropriate responses (Gasper et al., 2011).

Despite growing concern about the potential impact of climate change and extreme weather events for the oil industry in Canada, USA, and Mexico and how hurricanes, floods, and sea level rise will disrupt oil, gas, and petrochemical installations (Levina et al., 2007; Savonis et al., 2008), few adaptation studies have been undertaken.

8.3.3.6. Adapting Transport and Telecommunications Systems

Urban centers depend on transport and telecommunications systems for daily functioning and for vital regional, national, and international supply chains. For instance, 80% of the food consumed in London is imported (Best Foot Forward, 2002). The Great Lakes–St. Lawrence route in the USA supports 60,000 jobs and US$3 billion worth of annual movement of goods (Ruth, 2010). Most large and successful cities have also spread spatially, and well-functioning transport systems support the decentralization of the workforce and businesses. Many cities, for instance, depend on underground electric rail systems which require protection from the considerable risk from flooding, such as New York and London (Eichhorst, 2009). Adapting all these systems to the impacts of climate change (including hot days, storms, and sea level rise) poses many challenges (Mehrotra et al., 2011b).

8.3.3.6.1. Transport systems

Four different aspects to adaptation strategies for transport can be highlighted: maintain and manage; strengthen and protect; enhance redundancy; and, where needed, relocation. Cities that have developed adaptation plans usually include attention to more resilient transport systems (UN-HABITAT, 2011a). Melbourne's adaptation plan notes that intense storms and wind may lead to blocked roads and disrupt traffic lights, trains, and trams and that these disruptions can be exacerbated by such compounding factors as power disruptions and emergency situations (City of Melbourne, 2009). Adaptation will require transport planners to take a whole-of-life approach to managing infrastructure, and constantly update risk assessments (Love et al., 2010). Coordination at national, regional, and local levels is important for implementing adaptation strategies in the transport sector, as climate change impacts are widespread and extend across scales (Regmi and Hanaoka, 2011). Interdisciplinary approaches can include changing meteorological hazards as well as social and political values and the governance framework for more resilient transport systems (Jaroszweski et al., 2010).

8.3.3.6.2. Adapting roads

Climate change may increase the costs of maintaining and repairing road transport networks (see Hayhoe et al., 2010, for discussion of changing conditions in Chicago). In Durban, revised road construction standards may be needed (Roberts, 2008). Coastal road adaptation may require strengthening barriers and designing roads or realigning them to higher locations to cope with sea level rise (Regmi and Hanaoka, 2011).

Transport planners are beginning to reassess maintenance costs and traditional materials—for instance, stiffer binding materials to cope with rising temperatures and softer bitumen for colder regions (Regmi and Hanaoka, 2011). But cost considerations may impede their use. The Chicago Department of Transportation decided not to use more permeable, adaptive road materials because of higher cost, although costs may fall with greater economies of scale as demand rises for such materials (Hayhoe et al., 2010). Road maintenance costs vary widely, depending on local context, and future climate scenarios. In Hamilton, New Zealand, increases in rainfall in spring (within one scenario) or winter (in another) would increase road repair costs while decreases in rainfall in other seasons could decrease them; results depend upon the scenario and further investigation was recommended (Jollands et al., 2007).

8.3.3.6.3. Adapting surface and underground railways

Underground transport systems are specific to cities and of great importance to the functioning of many major cities. They may have "particular vulnerabilities related to extreme events, with uniquely fashioned adaptation responses" (Hunt and Watkiss, 2011, p. 14). Heat impacts are often significant, as these systems gradually warm due to engine heat, braking systems, and increased passenger loads. To cope with increasing frequency of hot days, substantial investments in ventilation or cooling may be necessary (Love et al., 2010). For New York City's subways, the system's age, fragmented ownership, overcapacity, and in some cases floodplain location may augment the challenge of adaptation (Zimmerman and Faris, 2010, pp. 69-70). Storm surge flooding from Hurricane Sandy flooded eight under-river subway tunnels, severely impacting mobility and economic activity (Blake et al., 2012).

Rail systems that struggle to cope with existing climate variability may require considerable investment to withstand higher temperatures and more extreme events (see Baker et al., 2010). Railway systems may be more vulnerable to climate variability than the road system, which can more easily redirect traffic (Lindgren et al., 2009). The costs of delays and lost trips due to extreme weather events, analyzed in Boston (Kirshen et al., 2008) and Portland (Chang et al., 2010) were found to be small relative to the damage to infrastructure and other property. Floodplain restoration, use of porous pavements, and detention ponds may help address the projected increased flooding in Portland (Chang et al., 2010).

In flood-prone cities, transport systems may require more stringent construction standards, design parameters, or relocation. Much of central Mumbai is built on landfill areas and prone to flooding, but they contain the main train stations and train lines as well as large populations and a large part of the city's economy. Rising sea levels may cause shifts at the sub-surface level of landfill areas and structural instabilities (de Sherbinin et al., 2007).

8.3.3.6.4. Ports

Section 8.2 outlined the many ways in which ports can be impacted by climate change and the investments required to take account of these. Many ports remain largely unaware of the potential threats of climate change, or are slow to consider appropriate adaptation measures (Becker et al., 2012). Rotterdam's Climate Proof Programme includes as key components flood safety and accessibility for ships and passengers (Rotterdam Climate Initiative, 2010; Vellinga and De Jong, 2012). A climate risk study for the Port of Muelles el Bosque (Cartagena, Colombia) analyzed projected changes in sea level rise, storm surge height, precipitation, temperature, and wind patterns and their direct and indirect effects on port assets and operations, surrounding environment and communities, and on the trade of goods transported through the port and this helped catalyze adaptation investments (Stenek et al., 2011).

There are also the deficits in basic infrastructure noted in Section 8.2 that inhibit adaptation including the lack of all-weather roads and paths in informal settlements that constrain rapid evacuation and limit access for emergency vehicles.

8.3.3.6.5. Telecommunications

A wide range of components and sub-systems for telecommunications systems that are within cities may need adaptation to the impacts of climate change, including telephone poles and exchanges, cables, mobile telephone masts and data centers (Engineering the Future, 2011; Chapman et al., 2013).

8.3.3.7. Green Infrastructure and Ecosystem Services within Urban Adaptation

Ecosystem based adaptation has relevance for many chapters (see Box CC-EA). Ecosystem-based adaptation in urban areas as part of the climate change adaptation strategy seeks to move beyond a focus on street trees and parks to a more detailed understanding of the ecology of indigenous ecosystems, and how biodiversity and ecosystem services can reduce the vulnerability of ecosystems and people. Strategies to achieve biodiversity goals (developing corridors for species migration, enlarging core conservation areas, identifying areas for improved matrix

Box 8-2 | Ecosystem-Based Adaptation in Durban

Durban has adopted an ecosystem-based adaptation approach as part of its climate adaptation strategy. This required a series of steps (Roberts et al., 2012):

- A better understanding of the impacts of climate change on local biodiversity and the management Durban's open space. The projected warmer and wetter conditions seem to favor invasive and woody plant species.
- Improved local research capacity that includes generating relevant local data.
- Reducing the vulnerability of indigenous ecosystems as a short-term precautionary measure.
- Enhancing protected areas owned by local government and developing land use management interventions and agreements to protect privately owned land areas critical to biodiversity and ecosystem services. This can be supported by government incentives and regulation to stop development on environmentally sensitive properties, the removal of perverse incentives, and support for affected landowners.
- The promotion of local initiatives that contribute jobs and promote skills and environmental education within ecosystem management and restoration programs. Durban has initiated a large-scale Community Reforestation Programme where community level "tree-preneurs" produce indigenous seedlings and help plant and manage the restored forest areas as part of a larger strategy to enhance biodiversity refuges and water quality, river flow regulation, flood mitigation, sediment control, and improved visual amenity. Advantages include employment creation, improved food security, and educational opportunities.

management to enhance ecological viability) can have adaptation co-benefits. Recognizing that the adaptation deficit is both in the lack of conventional infrastructure and the loss of ecological infrastructure, the approach includes an interest in how ecosystem restoration and conservation can contribute to food security, urban development, water purification, waste water treatment, climate change adaptation, and mitigation (Roberts et al., 2012). The growing attention to ecosystem services includes adaptations in urban, peri-urban, and rural areas that use opportunities for the management, conservation, and restoration of ecosystems to provide services and increase resilience to climate extremes. They can also deliver co-benefits (e.g., purifying water, absorbing runoff for flood control, cleansing air, moderating temperature, and preventing coastal erosion) while helping contribute to food security and carbon sequestration (Newman, 2010; Foster et al., 2011b; GLA, 2011; Roberts et al., 2012; see also Institute for Sustainable Communities, 2010; City of New York, 2011; Oliveira et al., 2011; Tallis et al., 2011; Wilson et al., 2011; Helsinki Region Environmental Services Authority, 2012). These approaches are particularly important in low- and many middle-income countries where livelihoods for some urban residents and much of the peri-urban population depend on natural resources. But there are considerable knowledge gaps in determining the limits or thresholds to adaptation of various ecosystems and where and how ecosystem-based adaptation is best integrated with other adaptation measures. There is also some indication that the costs of ecosystem-based adaptation in urban contexts might be higher than expected, in large part because costs are higher for land acquisition and ecosystem management (Roberts et al., 2012; Cartwright et al., 2013).

Box 8-2 describes how ecosystem-based adaptation is being developed in Durban. Another example is addressing flood risk through catchment management that includes community-based partnerships supported by full cost accounting and payment for ecosystem services—rather than the more conventional canalization of rivers (Kithiia and Lyth, 2011; Roberts et al., 2012).

Although much of the early innovation in ecosystem services and green infrastructure was geared to address water shortages or flooding, its importance for climate change adaptation is increasingly recognized.

Green spaces in cities are beneficial for absorbing rainfall and moderating high temperatures. Urban forests and trees can provide shading, evaporative cooling and rainwater interception, and storage and infiltration services for cities (Pramova et al., 2012). Increasing tree cover is proposed as a way to reduce UHI. Cooling effects are especially high in large parks or areas of woodland but the land these are on face competition from developers, as well as management challenges (Pramova et al., 2012). The rapid and often unregulated expansion of cities in low- and middle-income nations may also have left a much lower proportion of the urbanized area as parks and other green spaces.

There is also lack of detailed knowledge on the climatic effects of specific urban plants and vegetation structures (Mathey et al., 2011) and on other important aspects such as the influence of green areas in local circulation patterns and impact on urban fluxes and urban metabolism (Chrysoulakis et al., 2013). In addition, green infrastructure projects may select plant material for particular purposes that do not support habitat values or large ecosystem function and greater ecosystem services.

Some city governments have focused on green infrastructure within built up areas. In the USA, Portland and Philadelphia have encouraged green roofs, porous pavements, and disconnection of downspouts to reduce storm water at much lower cost than increasing storm water storage capacity (Foster et al., 2011b). Some cities have invested in green infrastructure linked to both regeneration and climate change adaptation. The Green Grid for East London seeks to create "a network of interlinked, multi-purpose open spaces" to support the wider regeneration of the sub-region, enhancing the potential of existing and new green spaces to connect people and places, absorb and store water, cool the vicinity, and provide a mosaic of habitats for wildlife (GLA, 2008, p. 80). New York has a well-established program to protect and enhance its water supply through watershed protection. This includes city ownership of crucial land outside the city and working with land owners and communities to balance protection of drinking water with facilitating local economic development and improving waste water treatment. There is also an ambitious green infrastructure plan within the city, including porous pavements and streets, green and blue roofs, and other measures to control storm water. The program is costly, compared to constructing and operating a filtration plant, but is the most cost-effective choice for New York (Bloomberg and Holloway, 2010; Foster et al., 2011b).

The coastal city of Quy Nhon in Vietnam is reducing flood risks by restoring a 150-hectare zone of mangroves (Brown et al., 2012). Singapore has used several anticipatory plans and projects to enhance green infrastructure including its Streetscape Greenery Master Plan, constructed wetlands or drains, and community gardens (Newman, 2010). Authorities in England and the Netherlands are recognizing the linkages between spatial planning and biodiversity, but without much direct response to climate change adaptation. Barriers to action include short-term planning horizons, uncertainty of climate change impacts, and problems of creating habitats due to inadequate resources, ecological challenges, or limited authority, and data (Wilson and Piper, 2008).

In Mombasa, the Bamburi Cement Company rehabilitated 220 hectares of quarry land (Kithiia and Lyth, 2011). The resulting Haller Park attracts more than 150,000 visitors per year, and has the potential to create adaptation co-benefits. Cape Town has initiated community partnerships to conserve biodiversity, including the Cape Flats Nature project with the para-statal South African National Biodiversity Institute. Participating schools and organizations explore ecosystem services (such as flood mitigation and wetland restoration), and the project facilitates "champion forums" to support conservation efforts (Ernstson et al., 2010, p. 539).

Dedicated green areas within urban environments compete for space with other city-based needs and developer priorities. The role of strategic urban planning in mediating among competing demands is potentially useful for the governance of adaptation as demonstrated in London, Toronto, and Rotterdam (Mees and Driessen, 2011). The experience in Durban (see Box 8-2) also faces many challenges (Roberts et al., 2012), including an assumption that ecosystem-based adaptation is an easy alternative to the constraints that limit the implementation and effectiveness of "hard engineering" solutions (Roberts et al., 2012; Kithiia and Lyth, 2011). Experience in Durban shows that implementing an ecologically functional and well-managed, diverse network of bio-infrastructure requires data collection, expertise, and resources, and to have direct and immediate co-benefits for local communities and ensure integration across institutional and political boundaries. There are substantial knowledge gaps such as determining where the limits or thresholds lie; many ecosystems have been degraded to the point where their capacity to provide useful services may be drastically reduced (TEEB, 2010).

The review by Burley et al. (2012) of the wetlands of South East Queensland, Australia, indicates that adaptations focused on wetland and biodiversity conservation may impact urban form in coastal areas. A study of changes in tree species composition, diversity, and distribution across old and newly established urban parks in Bangalore, India, aims to find ways to increase ecological benefits from these biodiversity hotspots (Nagendra and Gopal, 2011). When Leipzig applied a new approach to evaluating the impacts on local climate of current land uses and proposed planning policies, using evapotranspiration and land surface emissivity as indicators, green areas and water surfaces were found to have cooling effects, as expected, but some policies increased local temperatures (Schwarz et al., 2011).

Some aspects of mitigating climate change in urban areas requires a dense urban form to maximize agglomeration economies in more efficient resource use and waste reduction and to reduce urban expansion, reliance on motorized transport, and building energy use. But adaptation may require an urban form that favors green infrastructure and open space for storm water management, species migration, and urban cooling (Hamin and Gurran, 2009; Mees and Driessen, 2011). Higher densities can prevent the maintenance of ecologically viable systems with high biodiversity and exacerbate the urban heat island, in turn generating the need for more cooling, increasing energy use, and further escalating the urban heat island effect. This is the "density conundrum" (Hamin and Gurran, 2009, p. 242): At what point are densities too high to maintain ecologically viable systems with high biodiversity, especially given that urbanization has already compromised the ability of ecosystems to buffer urban development from hazards? This situation will be further exacerbated by new hazards (e.g., floods, fires) to which systems are or will be exposed as the result of climate change (Depietri et al., 2012).

8.3.3.7.1. Green and white roofs

Green and white roofs, introduced in a range of cities, have the potential to create synergies between mitigation and adaptation. Rooftop vegetation helps decrease solar heat gain while cooling the air above the building (Gill et al., 2007), thus improving the building's energy performance (Mees and Driessen, 2011; Parizotto and Lamberts, 2011). It can reduce cooling demand and often the use of air conditioning with its local contribution to heat gain and its implications for GHG emissions (Jo et al., 2010; Zinzi and Agnoli, 2012). Rooftop vegetation can also retain water during storms, reducing stormwater runoff (Voyde et al., 2010; Palla et al., 2011; Schroll et al., 2011) and promoting local biodiversity and food production. Studies have compared the performance of living roofs across different plant cover types, levels of soil water, and climatic conditions (see, e.g., Simmons et al., 2008; Jim, 2012). Hodo-Abalo et al. (2012) confirm that a dense foliage green roof has a greater cooling effect on buildings in Togolese hot-humid climate conditions. Several field experiments combined with simulated modeling of impacts in the USA also confirm the positive thermal behavior of green roofs compared to alternative roof coverings (e.g., Getter et al., 2011; Scherba et al., 2011; Susca et al., 2011). Durban has a pilot green roof project on a municipal building; indigenous plants are being identified for the project and rooftop food production is being investigated (Roberts, 2010). New York's lack of space for street-level planting helped encourage the adoption of living roofs (Corburn, 2009). Under its Skyrise Greenery project, Singapore has provided subsidies and handbooks for rooftop and wall greening initiatives (Newman, 2010). Based on field tests in the UK, Castleton et al. (2010) find that older buildings with poor insulation benefit more from green roofs than newer structures built to higher insulation standards. Wilkinson and Reed (2009) suggest that the overshadowing caused by buildings in city centers may mean lower potential for green roof retrofits compared to installations in suburban areas and smaller towns with lower rise buildings. Benvenuti and Bacci (2010) highlight the availability of water as the main limiting factor in the realization of green roofs.

A recent meta-analysis suggests that green roofs and parks may have limited effects on cooling. Findings on green roofs were mixed; some studies, but not all, showed lower temperatures above green sections. An urban park was found to be about 1°C cooler than a non-green site and larger parks had a greater cooling effect. Yet studies were mainly observational, lacking rigorous experimental designs. It remains unclear whether there is a simple linear relationship between a park's size and its cooling impact (Bowler et al., 2010) .

Cool roofs or white reflective roofs use bright surfaces to reflect shortwave solar radiation, which lowers the surface temperature of buildings compared to conventional (black) roofs with bituminous membrane (Saber et al., 2012). There is also some work on roads and pavements with increased reflectivity (Foster et al., 2011b). Some studies have quantified the cooling benefits from white roofs in various urban settings—in Hyderabad (Xu et al., 2012), in Sicily (Romeo and Zinzi, 2011), and in the North American climate (Saber et al., 2012). Comparisons between green and white roofs have also been undertaken. Ismail et al. (2011) investigated their cooling potential on a single-story building in Malaysia, and Zinzi and Agnoli (2012) explored the difference in a Mediterranean climate. Results suggest that local conditions play a dominant role in determining the best treatment. Hamdan et al. (2012), for instance, found a layer of clay on top of the roof as the most efficient for passive cooling purposes in Jordan, compared to two different types of reflective roofs.

8.3.3.8. Adapting Public Services and Other Public Responses

As city risk and vulnerability assessments become more common and detailed, they provide a basis for assessing how policies and services can adapt. Section 8.2 noted health impacts that can arise or be exacerbated by climate change that will increase demands on health care systems—including those linked to air pollution, extreme weather, food or water contamination, and climate-sensitive disease vectors. For air quality, additional research is still needed to understand the complex links between weather and pollutants in the context of climate change (Harlan and Ruddell, 2011). Important synergies can be achieved through combining mitigation and adaptation strategies to improve air quality, reduce private transport, and promote healthier lifestyles (Harlan and Ruddell, 2011; see also Bloomberg and Aggarwala, 2008).

In responding to disasters, health care and emergency services (including ambulance, police, and fire fighting) will have increased workloads while also ensuring that their systems can adapt. Their effectiveness can be enhanced by good working relationships with other key government sectors and with civil protection services including the army and the Red Cross/Red Crescent national societies. For cities without a robust early warning system or an emergency response network, adapting to climate change may require significant improvements in staffing, resources, and preparedness plans, for example, the data and personnel to deal with vulnerable residents during heat waves. Particular attention may be required to provide emergency services for informal settlements lacking adequate roads or infrastructure and, when needed, evacuation plans for all those that have to move. There is little evidence of consideration to changes in services in response to climate change in the city case studies listed in Box 8-1.

Enhanced emergency medical services may help cope with extreme events while health officials can also improve surveillance, forecast the health risks and benefits of adaptation strategies, and support public education campaigns. Public health systems may need to increase attention to disease vector control (e.g., screening windows, eliminating breeding grounds for the mosquitoes that are vectors for malaria and dengue) and bolster food hygiene measures linking to increased flooding and temperatures. The costs of adapting health care systems may be considerable—for instance, modifying buildings and equipment, training staff, and setting up comprehensive surveillance and monitoring systems that can capture the health risks of climate change, as well as other risks.

Schools and day-care centers may need risk and vulnerability assessments. School buildings can be designed and built to serve as safe shelters during floods or storms to which those at risk can move temporarily—although it is also important after a disaster to quickly reestablish functioning schools both for the benefit of children and their parents (Bartlett, 2008).

8.4. Putting Urban Adaptation in Place: Governance, Planning, and Management

This section discusses what we have learned about introducing adaptation strategies into the decision processes of urban governments, households, communities, and the private sector. Many aspects of adaptation can be implemented only through what urban governments do, encourage, allow, support, and control. This necessarily involves overlapping responsibilities and authority across other levels of government as well (Dietz et al., 2003; Ostrom, 2009; Blanco et al., 2011; Corfee-Morlot et al., 2011; McCarney et al., 2011; Kehew et al., 2013). Approaches include new urban policies and incentives for action, as well as ensuring that existing policies reduce risk and vulnerability (Urwin and Jordan, 2008; Bicknell et al., 2009; Brugmann, 2012). Transformation should be considered where fundamental change to economic, regulatory, or environmental systems is seen as the most appropriate mechanism for reducing risk and where maintaining existing systems offers little scope for adaptation (Pelling and Manuel-Navarrete, 2011), for instance resettlement or abandonment of previously developed land.

City governments that have developed adaptation policies recognize the value of an iterative process responsive to new information, analyses, or frameworks (National Research Council, 2010). In a range of cities, it has proved useful to have a unit responsible for this within city government, drawing together relevant data, informing key politicians and civil servants, encouraging engagement by different sectors and departments, and consulting with key stakeholders (Roberts, 2010; Brown et al., 2012).

The capacity of local authorities to work effectively, alone or with other levels, is constrained by limited funding and technical expertise, institutional mechanisms, and lack of information and leadership (Gupta et al., 2007; Carmin et al., 2013). Established development priorities and planning practices in functions like land-use, construction, or infrastructure provision may not be aligned with the goals or practice of adaptation (Ostrom, 2009; Pelling, 2011a; Garschagen, 2013). Many national governments face comparable constraints and still do not recognize the importance of local governments in adaptation (OECD, 2010). Local adaptive capacity can benefit from disaster risk reduction (Schipper and Pelling, 2006; UNISDR, 2008). New national legislation and institutions on disaster risk reduction have helped in some cases to strengthen and support local government capacity (Section 8.3.2.2), but as with other forms of adaptation, they require budgetary support and an increase in local professional capacities to be effective locally (Johnson, 2011).

8.4.1. Urban Governance and Enabling Frameworks, Conditions, and Tools for Learning

Enabling conditions and frameworks to support urban adaptation are grounded in institutional structures, values and local competence, interest, awareness, and analytical capacity (Moser and Luers, 2008; Birkmann et al., 2010). Preconditions for sound adaptation decision making relate to principles of good urban government (what government does) and governance (how they work with other institutions and actors including the private sector and civil society) (OECD, 2010; Bulkeley et al., 2011; Garschagen and Kraas, 2011). This includes science-policy deliberative practice and vulnerability assessment (National Research Council, 2007, 2008, 2009; Renn, 2008; Adger et al., 2009; Kehew, 2009; Moser, 2009; Corfee-Morlot et al., 2011). Civil society has important roles, for instance through community risk assessment, and the incorporation of local knowledge, preferences, and norms (Tompkins et al., 2008; van Aalst et al., 2008; Shaw et al., 2009; Fazey et al., 2010; Krishnamurthy et al., 2011). Human behavior, values, and social norms have a role and can evolve through dialog and understanding (Dietz et al., 2003; Moser, 2006; Ostrom, 2009), and engagement with stakeholders over time is key to effective adaptation (Bulkeley et al., 2011; Kehew et al., 2013). This has to allow consideration of dominant development trajectories and alternatives that can be approached by transformative adaptation. The capacity to act within urban settings varies with the organizational context for development (Section 8.1, Table 8-2), including the level of decentralization (Blanco et al., 2011; Corfee-Morlot et al., 2011; McCarney et al., 2011).

8.4.1.1. Multi-Level Governance and the Unique Role of Urban Governments

A framework for urban governance emerges from the challenges that climate change brings to multilevel risk governance. Figure 8-4 summarizes key actors and their relationships. Here, knowledge, policy, and action are produced through the interaction, across scales, of three kinds of actors (based on Corfee-Morlot et al., 2011):

- Knowledge producers (academic science, community, business, and non-governmental organization (NGO) produced research)
- Knowledge actors or users (most important here is local government often in collaboration with partners)
- Knowledge filters who can mediate between knowledge production and action (the media, lobby groups, and boundary organizations that help in translation) (Carvalho and Burgess, 2005; Leiserowitz, 2006; Ashley et al., 2012).

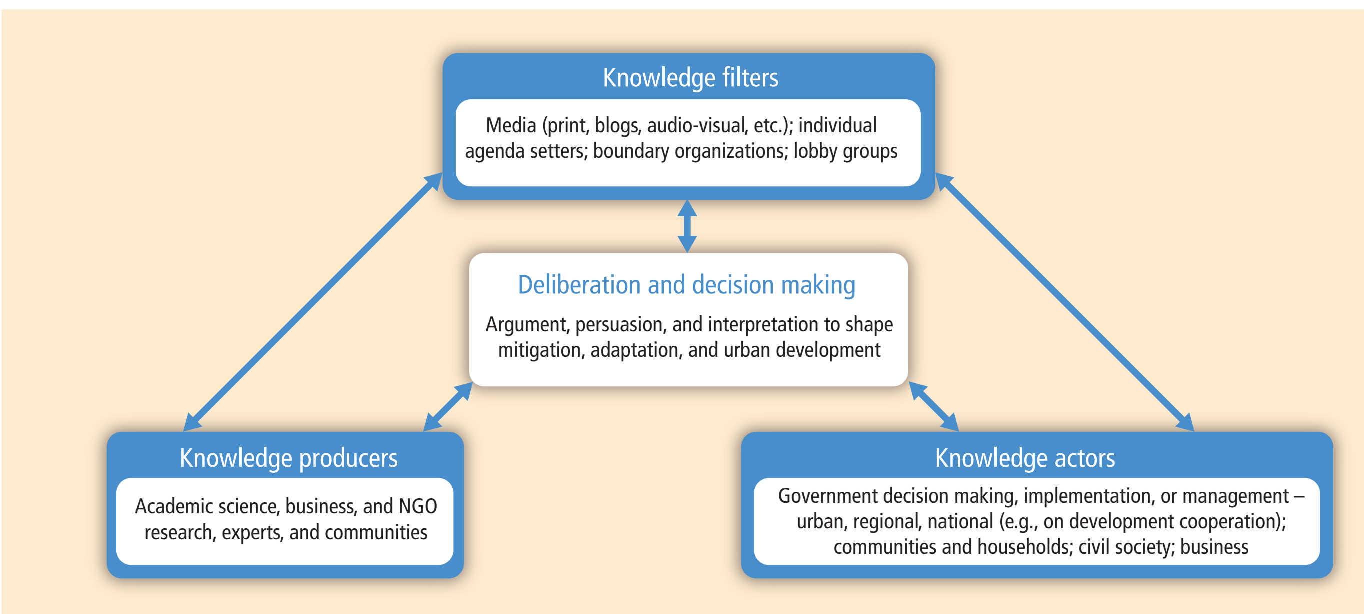


Figure 8-4 | The co-production of knowledge and policy for adaptation, mitigation, and development in urban systems (adapted from Corfee-Morlot et al., 2011).

Urban governments, provided with authority for relevant policy decisions, are central to this process (Blanco et al., 2011; Corfee-Morlot et al., 2011; McCarney, 2012; Kehew et al., 2013). Good practice also hinges in part upon the credibility, legitimacy, and salience of science policy processes; a strong local evidence base of historical and projected data on climate change; and ongoing, open processes to support dialog between government, civil society, and expert advisors (Cash and Moser, 2000; Cash et al., 2006; National Research Council, 2007; Preston et al., 2011; Kehew et al., 2013; see also Chapter 2). Timely and salient communication is important where a key role is played by the media, lobby groups, and boundary organizations that "translate" scientific or expert information for local communities and sometimes also help to shape the questions of scientific inquiry (Jasanoff, 1998; Gieryn, 1999; Moser, 2006; Moser and Dilling, 2007; Moser and Luers, 2008). Good governance facilitates the mediation of policy and decision processes across these different actors, spheres of influence, sources of information, and resources, to co-produce knowledge and support learning and action over time.

While urban governments have authority for many relevant adaptation decisions, they can be enabled, bounded, or constrained by national, subnational, or supranational laws, policies, and funding and land use and infrastructure planning decisions (OECD, 2010; Brown, 2011; Carter, 2011; Martins and da Costa Ferreira, 2011; Arup and C40, 2012; Kehew et al., 2013). This includes establishing formal mandates for urban adaptation action, without which adaptation becomes optional or discretionary, dependent on local-level interest and resources, and particularly vulnerable to leadership change. Where mandates for adaptation exist, they have been important in driving local level action (Kazmierczak and Carter, 2010). New mandates (formal or informal) may also require institutional changes (Roberts, 2008; Lowe et al., 2009; Kazmierczak and Carter, 2010).

The level of complexity is raised in large metropolitan areas, especially when they are growing rapidly. Action has to be coordinated and harmonized across multiple urban jurisdictions; often dozens of them (e.g., Mexico City, São Paulo, London, and Buenos Aires) and occasionally hundreds (e.g., Abidjan and Tokyo) (McCarney et al., 2011; McCarney, 2012), for instance to implement flood protection of contiguous land areas (Hallegatte et al., 2011b). Although there is some evidence of innovative responses at subnational levels to plan for extreme weather events and climate change, limited capacity and experience at local government level suggests the need for support from higher levels of government (Norman and Nakanishi, 2011; EEA, 2012; Gurran et al., 2012).

Policies and incentives need to be aligned to work coherently across multiple levels of government to define and deliver effective urban adaptation. This often involves institutions at different levels with different scopes of authority (Young, 2002; Bulkeley and Kern, 2006; Cash et al., 2006; Mukheibir and Ziervogel, 2007; Urwin and Jordan, 2008; Kern and Gotelind, 2009; Corfee-Morlot et al., 2011; EEA, 2012). Water authorities, for instance, may operate at water-basin level, representing both national and local interests while operating independently of urban authorities. Failing to ensure consistent alignment and integration in risk management can lock in outcomes that raise the vulnerability of urban populations, infrastructure, and natural systems even where pro-active adaptation policies exist (Urwin and Jordan, 2008; OECD, 2009; Benzie et al., 2011). Local government capacity is important, as well as the institutions that facilitate coordination across multiple, nested, poly-centric authorities with potential to mainstream adaptation measures and tailor national goals and policies to local circumstances and preferences. Horizontal coordination and networking across actors and institutions in different municipalities and metropolitan areas can accelerate learning and action (Aall et al., 2007; Lowe et al., 2009; Schroeder and Bulkeley, 2009).

Consultation and awareness-raising can help avoid the kind of public backlash that occurred when the French government sought to ban urban development and require strategic retreat in areas of risk to coastal flooding after the 2010 storm Xynthia (Laurent, 2010; Przyluski and Hallegatte, 2012). There can also be vested interests and trade-offs where near-term development conflicts with longer-term adaptation and resilience goals. Public engagement, openness, and transparency can help ensure democratic debate to balance public interests and longer-term goals against the short-term benefits of unconstrained development. Urban governments are uniquely situated to understand local contexts, raise local awareness, respond to citizens' and civil society pressures, and work to build an inclusive policy space (Grindle and Thomas, 1991; Brunner, 1996; Cash and Moser, 2000; Brunner et al., 2005; Healey, 2006). Urban governments can also promote understanding of climate change risk and help to create a common vision for the future (Moser, 2006; Moser and Dilling, 2007; Ostrom, 2009; Corfee-Morlot et al., 2011). The fact that preferences are more homogeneous within smaller units (Ostrom, 2009) provides opportunities for leadership and innovation that may not exist at higher levels of governance. Urban governments, so often responsible for a substantial share of urban infrastructure (Arup and C40, 2012; Hall et al., 2012), are also central to the interface between climate change and development, including provision for essential infrastructure and services (Bulkeley and Kern, 2006; Bulkeley, 2010). Urban planning structures, processes, and plans can integrate and mainstream adaptation plans and risk management into urban and sectoral planning with a clear time frame, mandate, and resources for implementation (Agrawala and Fankhauser, 2008; Bicknell et al., 2009; Brugmann, 2012), even if functional authority is at national or subnational regional levels (Hall et al., 2012). Many urban governments show growing awareness and analytical capacity in adaptation planning but there is less evidence in implementation and influence on key sectors (Roberts, 2010).

Local government decisions can be driven by short-term priorities of economic growth and competitiveness (Moser and Luers, 2008) and addressing climate change can mean taking a longer-term perspective (Leichenko, 2011; Pelling, 2011a; Romero-Lankao and Qin, 2011; Viguié and Hallegatte, 2012). Tension also exists between economic growth and the needs of the large, often growing, numbers of ill-served urban poor (Bicknell et al., 2009) whose resilience to climate change will depend on infrastructure and services. The challenges in low- and middle-income countries are exacerbated by relative inattention from international donors to urban policy and development concerns, as they have historically worked through national government planning processes, which may not capture the needs of urban populations (Mitlin and Satterthwaite, 2013). Donors may also prefer visible physical infrastructure projects over local institution and capacity-building investments. Most national governments in high-income countries also have yet to fully embrace local adaptation initiatives (McCarney et al., 2011).

8.4.1.2. Mainstreaming Adaptation into Municipal Planning

Mainstreaming adaptation into urban planning and land use management and legal and regulatory frameworks is key to successful adaptation (Lowe et al., 2009; Kehew et al., 2013). It can help planners rethink traditional approaches to land use and infrastructure design based on past trends, and move toward more forward looking risk-based design for a range of future climate conditions (Kithiia, 2010; Solecki et al., 2011; Kennedy and Corfee-Morlot, 2013), as well as reducing administrative cost by building resilience through existing policy channels (Urwin and Jordan, 2008; Benzie et al., 2011; Blanco et al., 2011). Mainstreaming through local government policies and planning ensures that investments and actions by businesses and households contribute to adaptation (Kazmierczak and Carter, 2010; Sussman et al., 2010; Brown, 2011; Mees and Driessen, 2011). But this must avoid overloading already complex and inadequate planning systems with unrealistic new requirements (Roberts, 2008; Kithiia, 2010); particularly in many low- and middle-income countries, these systems are already stressed by lack of information, institutional constraints, and resource limitations.

Mainstreaming may best be initiated by encouraging pilot projects and supporting experimentation by key sectors within local government. Assigning responsibility to specific departments can make the adaptation (and mitigation) message easier to understand by local governments and other stakeholders and the associated responsibilities and actions clearer and simpler to identify and assign (Roberts, 2010; UN-HABITAT, 2011a; Roberts and O'Donoghue, 2013). Pilot projects and sectoral approaches ground adaptation in practical reality (Roberts, 2010; Tyler et al., 2010; UN-HABITAT, 2011a; Brown et al., 2012). As actors in each sector in local government come to understand their roles and responsibilities, the basis for integration and cross-sectoral coordination is formed.

The literature suggests that opportunities to mainstream climate change into urban planning and development are still largely missed (Sánchez-Rodríguez, 2009). The planning agenda can already be full (Measham et al., 2011). Challenges in information, institutional fragmentation, and resources (Sánchez-Rodríguez, 2009; Wilson et al., 2011) make it difficult to introduce the additional layer of climate change planning (Roberts, 2008; Kithiia, 2010), which may also be seen merely as "add-ons" (Kithiia and Dowling, 2010, p. 474).

Other challenges also limit progress—for instance the lack of leadership and of focal points on urban adaptation (see Section 8.4.3.4 for more detail). In times of economic hardship (e.g., the current recession), local authorities with already limited resources may prioritize conventional economic and development goals over "environmental" issues including climate change adaptation (Shaw and Theobald, 2011; Solecki, 2012). A further challenge is getting the timely evaluation of emerging adaptation measures (Hedger et al., 2008; Preston et al., 2011).

Experience with adaptation programs show they are often more cross-sectoral, cross-institutional, and complex. They operate across a range of scales and timelines; are rooted in local contexts; involve many stakeholders; and include high levels of uncertainty (Roberts et al., 2012; Roberts and O'Donoghue, 2013). Standardized guidelines for action are less relevant and urban adaptation practitioners have identified instead the need for "clarity, creativity, and courage" (ICLEI Oceania, 2008, p. 62). In all instances, where progress on adaptation planning is observed, local leadership is a central factor (Carmin et al., 2009, 2013; Measham et al., 2011).

8.4.1.3. Delivering Co-Benefits

Important opportunities also exist to combine adaptation and mitigation goals in urban housing policies (and the energy sources they draw on), infrastructure investments, and land use decisions—especially in high- and middle-income countries (Satterthwaite, 2011). Co-benefits for mitigation and for transformation require a reconsideration of dominant development pathways and of possible alternatives both within and beyond the urban core, influencing, for instance, local environments along with water basin management and coastal defense regimes (Urwin and Jordan, 2008; OECD, 2010). Examples of positive and negative interactions between urban adaptation and mitigation strategies suggest that these strategies will need to be assessed and managed to achieve co-benefits (Viguié and Hallegatte, 2012; Kennedy and Corfee-Morlot, 2013). Viguié and Hallegatte (2012) demonstrate that despite trade-offs, careful planning can yield adaptation-mitigation co-benefits across greenbelt policies, flood zoning, and transportation policies. Local governments may be able to address both adaptation and mitigation using pre-existing tools and policies such as building standards, transport infrastructure planning, and other urban planning tools (Hallegatte et al., 2011a). It may be possible to avoid or limit trade-offs by developing institutional links between the different policy areas at the level of local planning (Swart and Raes, 2007; Viguié and Hallegatte, 2012; Kennedy and Corfee-Morlot, 2013).

Adaptation can produce development co-benefits in urban areas including safer, healthier, and more comfortable urban homes and environments and reduced vulnerability for low-income groups to disruptions in their incomes and livelihoods (Kousky and Schneider, 2003; Bicknell et al., 2009; Burch, 2010; Clapp et al., 2010; Roberts, 2010; Anguelovski and Carmin, 2011;Hallegatte et al., 2011a). Local development co-benefits may be particularly important to highlight in low- and middle-income countries, where lack of policy buy-in accompanies limited local capacity (UN-HABITAT, 2011a) and where current climate change challenges appear marginal compared with development deficits (Roberts, 2008; Kithiia and Dowling, 2010; Kiunsi, 2013). Urban authorities in India can see adaptation as a priority if it also addresses development and environmental health concerns (Sharma and Tomar, 2010).

Development and climate change adaptation are often seen as separate challenges in a subnational planning context. A review in OECD countries showed only Japan and South Korea championing climate action as integral to subnational development planning, although Finland and Sweden have innovative subnational climate policies and action programs funded by central government (OECD, 2010). For most OECD countries, urban development and adaptation are tackled separately. Yet policy research finds that successful adaptation is rooted within and harmonized with such development priorities as poverty reduction, food security, and disaster risk reduction (Moser and Luers, 2008; Bicknell et al., 2009; Measham et al., 2011).

8.4.1.4. Urban Vulnerability and Risk Assessment Practices: Understanding Science, Development, and Policy Interactions

A critical aspect of urban climate risk governance is the integration of scientific knowledge into decision making, building on exchange among scientists, policymakers, and those at risk (Vescovi et al., 2007; National Research Council, 2009; Government of South Africa, 2010; Rosenzweig and Solecki, 2010). International policy advisory agencies with an interest in urban adaptation can augment this (Sonover et al., 2007; ICLEI, 2010), but will depend on local capacity and engagement to produce, access, and use climate change information and processes (Hallegatte et al., 2011a; Carmin et al., 2013). Local and regional boundary organizations can be influential in making scientific and technical information more salient to decision makers (Bourque et al., 2009; Corfee-Morlot et al., 2011). In many instances, key boundary functions are carried out by nearby academic or research communities and these can also be a source of leadership for urban adaptation (Sánchez-Rodríguez, 2009; Government of South Africa, 2010).

Even where detailed vulnerability or risk assessments exist, their influence may be limited if decision makers do not access and use this information. Urban master plans or strategic plans with a time horizon of 10 or more years can incorporate climate risks and vulnerabilities, but assessments must be available to influence such plans. Moser and Tribbia (2006), exploring how decision makers access and use information, find that resource managers tend to rely more on informal sources (maps or in-house experts, media, and Internet) than on scientific journals. This reinforces the point made earlier in regard to producers of scientific and information and knowledge actors to needing to work closely with decision makers in the production and communication of scientific information (Cash et al., 2003, 2006; Moser, 2006; Corfee-Morlot et al., 2011).

8.4.1.5. Assessment Tools: Risk Screening, Vulnerability Mapping, and Urban Integrated Assessment

Assessments of risk and vulnerability to the direct and indirect impacts of climate change are often the first step in getting government attention, especially when put in the context of development policy objectives (Hallegatte et al., 2011a; Mehrotra et al., 2011a; see also Section 8.2). Including risk management information in infrastructure design at the planning or design phase can mean lower retrofit costs later on (Baker, 2012; World Bank, 2012). A variety of planning and assessment tools can be helpful, including impact assessment, environmental audits, vulnerability mapping, disaster risk assessment and management tools, local agenda 21 plans, and urban integrated assessment as part of public investment planning and as used by community organizations (Haughton, 1999; UN-HABITAT, 2007; Baker, 2012). Governments can ensure that up-to-date climate information is available to the private sector to support adaptation (Agrawala et al., 2011; see also Section 8.4.2.3). Some of these tools provide entry points and a means for participatory engagement, but often give little consideration to adaptation (Gurran et al., 2012). More reliable, specific, and downscaled projections of climate change and tools for risk screening and management can help engage relevant public sector actors and the interest of businesses and consumers (AGF, 2010a; UNEP, 2011).

Local climate change risk assessments, vulnerability, and risk mapping can identify vulnerable populations and locations at risk and provide a tool for urban adaptation decisions (Ranger et al., 2009; Hallegatte et al., 2011a; Livengood and Kunte, 2012; Kienberger et al., 2013). The LOCATE methodology (Local Options for Communities to Adapt and Technologies to Enhance Capacity), which integrates hazard and vulnerability mapping to inform choices about which populations, infrastructure, and areas to prioritize for action (Annecke, 2010) is being tested in eight African countries; in each, an NGO is working with communities on across-project design and implementation, monitoring, evaluation, and learning.

Tools that organize and rank information on vulnerability in different locations often aim to identify relative and absolute differences in risk and resilience capacity (Milman and Short, 2008; Hahn et al., 2009; Posey, 2009; Manuel-Navarrete et al., 2011). They vary from quick screenings to fuller risk analyses and evaluations of adaptation options (Hammill and Tanner, 2011). Preston et al. (2011), noting the wide variety of functions and methods in 45 vulnerability mapping studies, suggest that effectiveness is guided by identifying clear goals, robust technical methods, and engagement of the appropriate user communities. Halsnæs and Trærup (2009) recommend the use of a limited set of indicators; engagement with representatives of local development policy objectives; and a stepwise approach to address climate change impacts, development linkages, and economic, social, and environmental dimensions. Methods for application across scale (Kienberger et al., 2013), considering the urban environment as a system, allow for better understanding of interconnections between root causes, risk production, cascading impacts, and vulnerabilities (Kirshen et al., 2008; UNISDR, 2011; da Silva et al., 2012).

Downscaling of climate scenarios, systems models, and urban integrated assessment modelling at local scales integrate information in a forward-looking framework to support urban policy assessment (e.g., van Vuuren et al., 2007; Dawson et al., 2009; Hall et al., 2010; Hallegatte et al., 2011a; Walsh et al., 2011; Viguié and Hallegatte, 2012). Integrated assessment modelling considers the driving forces of urban vulnerability and climate change impacts alongside possible policy responses and their outcomes. By integrating knowledge, this provides a tool for policy makers to examine and better understand synergies and trade-offs across policy strategies (Dawson et al., 2009; Viguié and Hallegatte, 2012). These modeling frameworks take time to build and to be incorporated into decision-making processes. Although early results are promising, they also highlight the difficulty of producing tools that can be easily used by local governments (e.g., see also Hall et al., 2012; Walsh et al., 2011, 2013).

Despite growing attention, useful assessment of climate change at urban spatial scales is generally lacking (Hunt and Watkiss, 2011). A small number of cities, largely in high-income countries, have quantified

Frequently Asked Questions

FAQ 8.4 | Shouldn't urban adaptation plans wait until there is more certainty about local climate change impacts?

More reliable, locally specific, and downscaled projections of climate change impacts and tools for risk screening and management are needed. But local risk and vulnerability assessments that include attention to those risks that climate change will or may increase provide a basis for incorporating adaptation into development now, including supporting policy revisions and more effective emergency plans. In addition, much infrastructure and most buildings have a lifespan of many decades so investments made now need to consider what changes in risks could take place during their lifetime. The incorporation of climate change adaptation into each urban center's development planning, infrastructure investments and land use management is well served by an iterative process within each locality of learning about changing risks and uncertainties that informs an assessment of policy options and decisions.

local climate change risks; even fewer have quantified possible costs under different scenarios. Some exceptions exist: Durban has developed a benefit-cost model for adaptation options (Cartwright et al., 2013), and there have been urban climate risk assessments in low- or middle-income developing countries as part of targeted development cooperation programs, supported by external partners (World Bank, 2011, 2013). Sea level rise and coastal flood risk, health, and water resources are among the most studied sectors; energy, transport, and built infrastructure get far less attention (Hunt and Watkiss, 2011; World Bank, 2011, 2013; Roy et al., 2012). Science and climate change information is increasingly available, but socioeconomic drivers of vulnerability and impacts, and opportunities and barriers to adaptation are less well studied and understood (Measham et al., 2011; Romero-Lankao and Qin, 2011).

8.4.2. Engaging Citizens, Civil Society, the Private Sector, and Other Actors and Partners

8.4.2.1. Engaging Stakeholders in Urban Planning and Building Decision Processes for Learning

A common vision of a future resilient, safe, and healthy city can be the first step to achieving it (Moser, 2006; Moser and Dilling, 2007; Corfee-Morlot et al., 2011; UN-HABITAT, 2011a). Participatory processes figure prominently in cities that have been leaders in urban adaptation (Rosenzweig and Solecki, 2010; Brown et al., 2012; Carmin et al., 2012b). The conceptual literature agrees that participatory decision making is essential where uncertainty and complexity characterize scientific understanding of policy problems (Funtowicz and Ravetz, 1993; Liberatore and Funtowicz, 2003). Many have argued that the institutional features of the risk management decision-making process—participatory inclusiveness, equity, awareness raising, deliberation, argument, and persuasion—will determine the legitimacy and effectiveness of action (Dietz et al., 2003; Lim et al., 2004; Mukheibir and Ziervogel, 2007; Corfee-Morlot et al., 2011). Yet the review of 45 vulnerability mapping exercises found that only 40% included stakeholder participation, raising questions about the legitimacy and salience of contemporary approaches (Preston et al., 2011). It also highlights the challenge local governments face to garner resources, including technical expertise and institutional capacity, to organize and use participatory processes to strengthen rather than delay adaptation decision making (Carmin et al., 2013).

In many urban settings, civil society and the private sector already have significant and positive roles in support of adaptation planning and decisions. Some studies show that despite limited information, adaptation at urban scale is moving ahead, particularly through initial planning and awareness raising (Lowe et al., 2009; Anguelovski and Carmin, 2011; Hunt and Watkiss, 2011). Experience in a handful of cities—for example, Cape Town, Durban, London, New York—shows that a wide number and variety of engaged stakeholders at early stages in a risk assessment creates political support and momentum for follow-up research and adaptation planning (Rosenzweig and Solecki, 2010; Anguelovski and Carmin, 2011; Hunt and Watkiss, 2011). In informal settlements with little or no formal infrastructure and services, stakeholder engagement is a means for participatory community risk assessment, where local adaptive capacity is built in part through local knowledge (Livengood and Kunte, 2012; Kiunsi, 2013). Over time, institutional mechanisms can be built that support innovation, collaboration, and learning within and across sectors to advance urban adaptation action, but it takes time and resources (Mukheibir and Ziervogel, 2007; Burch, 2010; Roberts, 2010; Anguelovski and Carmin, 2011).

8.4.2.2. Supporting Household and Community-Based Adaptation

In well-governed cities, community groups and local governments are mutually supportive, providing information, capacity, and resources in maintaining local environmental health and public safety, which in turn can support adaptation. Where local government has not yet formulated an adaptation strategy, community groups can raise political visibility for climate risks and provide front-line coping (Wilson, 2006; Granberg and Elander, 2007), and also begin to address gender disparities in urban risks (Björnberg and Hansson, 2013).

The full range of infrastructure and services needed for resilience is generally affordable only in middle- and upper-income residential developments in low- and lower-middle income countries. In most cities and neighborhoods, where infrastructure coverage is incomplete and household incomes limited, community organizations—or community-based adaptation—offer a rich resource of adaptive capacity to cope and to prepare for future risk. A range of studies document the depth of knowledge and capacities held by local populations around reducing exposure and vulnerability (Anguelovski and Carmin, 2011; Dodman and Mitlin, 2011; Livengood and Kunte, 2012). For a high proportion of the households that live in informal urban settlements, household and community-based adaptation is their only means of responding to risk. They are well used to coping with environmental hazards (Wamsler, 2007; Adelekan, 2010; Jabeen et al., 2010; Livengood and Kunte, 2012; Kiunsi, 2013). Some seek to modify hazards or reduce exposure—for example, through ventilation and roof coverings to reduce high temperatures; barriers to prevent floodwater entering homes; keeping food stores on top of high furniture; and moving temporarily to safer locations (Douglas et al., 2008). A study in Korail, one of Dhaka's largest informal settlements, showed the range of household responses to flood risk (see Figure 8-5). These include barriers across door fronts, increasing the height of furniture, building floors or shelves above the flood line, and using portable cookers (Jabeen et al., 2010). Provision for ventilation, creepers, or other material on roofs and false ceilings helped to keep down temperatures. These are important near-term adaptations, and there are similar responses in many informal settlements (e.g., Adelekan, 2010; Kiunsi, 2013), but they do not generate capacity to adapt to future risk.

There are multiple constraints on action for low-income households. Even where there are early warnings, a lack of trust in the security of their property and the right to return, along with fears for personal safety in shelters, are deterrents against evacuation (Jabeen et al., 2010; Hardoy et al., 2011). Tenants and those with the least secure tenure are often among the most vulnerable and exposed to hazards but also are usually unwilling to invest in improving the housing they live in and less willing to invest in community initiatives. Community-based responses are often reactive, addressing current more than future risks, though they may embody alternative development values and support local transformation. Shifting the burden of adaptation to the community level alone is unlikely to bring success. There are limits to what community action can do in urban areas. For instance, communities may build and maintain local water sources, toilets, and washing facilities or construct or improve drainage (see for instance the programs in cities in Pakistan described in Hasan, 2006) but they can neither provide the network infrastructure on which these depend (e.g., the water, sewer, and drainage mains and water treatment) nor can they improve city-region governance (Bicknell et al., 2009). Work on cities in the Caribbean and Latin America indicates the need for supportive links to community networks and/or local government for community-level adaptation to be effective (Pelling, 2011b; Mitlin, 2012).

There is some recognition that strengthening the asset base of low-income households helps increase their resilience to stresses and shocks, including those related to climate change (Moser and Satterthwaite, 2009). It has become more common for local governments to work with community-based organizations in upgrading their homes and settlements in disaster risk reduction (UNISDR, 2009, 2011; IFRC, 2010; Pelling, 2011b), and community-based adaptation is building on these experiences and capacities (Archer and Boonyabancha, 2011; Carcellar et al., 2011). Communities can have close relationships with formal state and market institutions, shaping subsequent adaptive capacity for members. Most housing and infrastructure upgrading programs mean that those living in low-income settlements become incorporated into "the formal" city and this often means an increased expectation on the state to reduce vulnerability, including long-term and strategic adaptation investments through access to schools, health care, infrastructure, and safety nets (Ferguson and Navarrete, 2003; Imparato and Ruster, 2003; Boonyabancha, 2005; UN Millennium Project, 2005; Fernandes, 2007; Almansi, 2009).

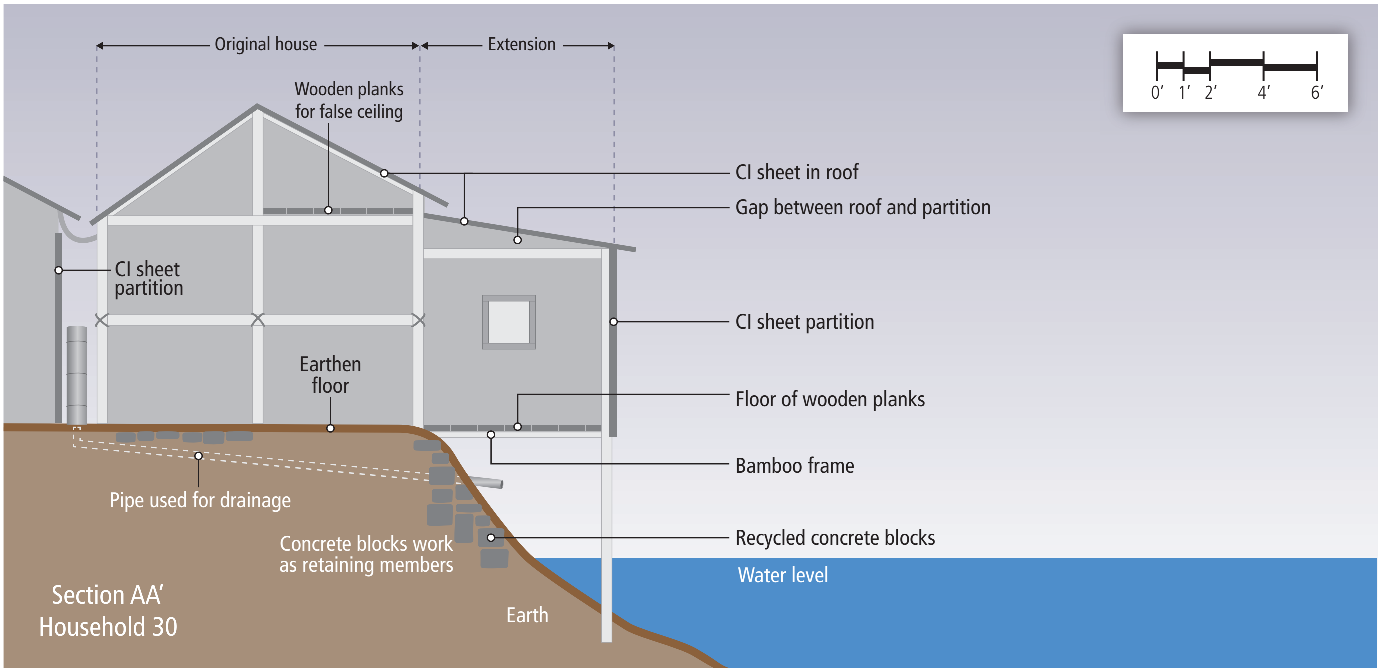


Figure 8-5 | Household adaptation—a cross-section of a shelter in an informal settlement in Dhaka (Korail) showing measures to cope with flooding and high temperatures (Jabeen et al., 2010). CI = corrugated iron.

There can still be obstacles. Where climate change or disaster risk is seen as distant or low probability, the immediate pressures of poverty tend to dominate local agendas (Banks et al., 2011). In many informal settlements, the issue of land tenure is also difficult to resolve and impedes upgrading programs (Boonyabancha, 2005, 2009; Almansi, 2009) and thus local-level adaptation action.

In a growing number of cities, residents' organizations supported by grassroots leaders and local NGOs are mapping and enumerating their informal settlements with eventual support and recognition from city governments (Patel and Baptist, 2012). This provides the data and maps needed to plan the installation or upgrading of infrastructure and services. Some of these enumerations also collect data on risks and vulnerabilities to extreme weather and other hazards (UN-HABITAT, 2007; Carcellar et al., 2011; Pelling, 2011b; Livengood and Kunte, 2012). For example, community surveys in the Philippines identified at-risk communities under bridges, in landslide-prone areas, on coastal shorelines and river banks, near open dumpsites, and in flood-prone locations (Carcellar et al., 2011). This mapping raises awareness among inhabitants of the risks they face, as well as getting their engagement in planning risk reduction and making early warning systems and emergency evacuation effective (Pelling, 2011b). Table 8-4 illustrates the contemporary limits of community-based action across key sites of coping and adaptation—highlighting where strategic partnerships, especially with a supportive municipal government, have key advantages.

IFRC (2010) identifies three broad requirements for successful urban community-based disaster risk reduction that can be extended to assess coping and adaptive capacity: the motivation and partnership of stakeholders; community ownership, with flexibility in project design; and sufficient time, funding, and management capacity. The effectiveness of community-based action also depends on how representative and inclusive the community leaders and organizations are (Appadurai, 2001; Wamsler, 2007; Banks, 2008; Houtzager and Acharya, 2011; Mitlin, 2012); their capacity to generate pressure for larger changes within government; and the relations between community organizations and government (Boonyabancha and Mitlin, 2012). Community-based adaptation can support transformation where it engages with key development agendas to reduce poverty and vulnerability (Sabates-Wheeler et al., 2008), and can address local inequalities and adverse power relations at district, city, national, and transnational levels (Mohan and Stokke, 2000). But urban governance regimes are often resistant to change and civil society organizations can be marginalized or co-opted, reducing the scope for transformative adaptation (Pelling and Manuel-Navarrete, 2011).

8.4.2.3. Private Sector Engagement and the Insurance Sector

Cities are attractive to private enterprises because so much business activity, private investment, and demand are concentrated there. Private enterprises generally favor cities with functioning city infrastructure and a wide range of services. As noted earlier, much investment for sound adaptation will need to come from households and firms of all sizes (Agrawala and Fankhauser, 2008; Bowen and Rydge, 2011). Brugmann (2012) argues that effective adaptation depends on catalyzing market-based investments. Beyond acting to protect their own interests, businesses are stakeholders in urban decision making, positioned to exploit new opportunities that arise from climate change (Chapter 14; see also Khattri et al., 2010). Private service providers and professional associations—including architects, engineers, and urban planners—can influence the pace and quality of adaptation efforts where an understanding of climate change is part of professional training and knowledge (McBain et al., 2010). Even when considering more political

Table 8-4 | The possibilities and limitations of focused activity for community groups on climate change coping and adaptation.

Capacity/focus of action	Coping: drawing on existing resources to reduce vulnerability and hazardousness and contain impacts from current and expected risk.	Adaptation: using existing resources and especially information to reorganize future asset profiles and entitlements to better position the household in light of anticipated future risk, and to prepare for surprises.
Physical: buildings and critical community-level infrastructure	Often possible to improve these although tenants will have little motivation to do so.	Limits in how much risk reduction is possible within settlement (i.e., without trunk infrastructure to connect to).
Physical: land and environment	Local hazard reduction through drain cleaning, slope stabilization, etc. is a common focus of community-based action (although there are fewer incentives where the majority of residents are short-term tenants or threatened with eviction).	External input required to design local hazard reduction works in ways that will consider the impacts of climate change 20 years or more in the future.
Social: health, education	Many examples of community-based action to improve local health and education access and outcomes, often with strong NGO and/or local government support.	Health care and education are amenable to supporting adaptation by providing long-term investments in capacity building. They are rarely framed in climate change adaptation terms.
Economic: local livelihoods	Livelihoods routinely assessed as part of household assessments of coping capacity in urban areas. More rarely is there a local livelihood focus for community-based coping.	Livelihoods and wider economic entitlements are key to individual adaptive profiles, but are seldom considered as part of urban community-based adaptation programs.
Institutional: community organization	Local community strengthening is a common goal of interventions aimed at building coping capacity. Risk mapping, early warning, risk awareness, community health promotion, and shelter training are common foci increasingly applied to urban communities. Local savings groups may have important roles.	Local community strengthening is a core element of planning for adaptation but there are few assessments of the medium-/long-term sustainability of outcomes. Where these have been undertaken, close ties to wider civil society networks or supportive local government were evident and these helped community organizations and actions to persist.
Institutional: external influence	It is unusual for coping programs to include an element of external advocacy aimed at changing policy or practices in local government.	Despite being core to determining future adaptation, there are very few examples of urban community based adaptation projects that include a targeted focus or parallel activity aimed at shifting priorities and practices in local government and beyond to support community capacity building.

Key: green = many cases of activity; amber = few cases of activity; red = very few cases of activity.

issues around the support of adaptation efforts (AGF, 2010b,c), most studies conclude that the need for adaptation investments will far exceed available funds from public budgets (Chapter 15; see also Agrawala and Fankhauser, 2008; World Bank, 2010d; Hedger, 2011).

For markets to favor urban adaptation, the private sector will need to see financial justification for involvement, for example, to ensure business continuity. A survey of companies on the most serious risks they faced (Aon, 2013) ranked weather/natural disasters 16th and climate change 38th although some higher ranked risks such as commodity prices (8th) or distribution/supply chain failure (14th) may be associated with climate change. Risk rankings differed by region (in Asia Pacific weather/natural disasters were 8th) and by sector (for agribusiness, weather/natural disasters were 2nd). Failure of climate change adaptation (as 'governments and business fail to enforce or enact effective measures to protect populations and transition businesses impacted by climate change') was listed by World Economic Forum (2013, p. 46) as one of the most likely environmental risks over the next 10 years and with having a high impact if the risk was to occur. Private sector actors may not be well positioned to consider the big adaptation questions, including changes in land use, development, and infrastructure planning (Redclift et al., 2011). For example, in Cancun, Mexico, close relationships between government and the corporate sector and the push for lucrative development have perpetuated an urban development model that generates climate change risk by increasing the hazard exposure of capital intensive, large-scale coastal development (Manuel-Navarrete et al., 2011). Without transformative change in urban development planning, private sector investments in adaptation will remain limited, such as designing buildings to withstand hurricanes but not tackling where development occurs. In the Cancun case, most investment comes from the state, for example, in beach replenishment and policies for rapid disaster recovery (Manuel-Navarrete et al., 2011).

The Private Sector Initiative of the UNFCCC Nairobi Work Programme offers support for businesses to integrate climate change science into their business planning, including in urban infrastructure and technology developments (http://unfccc.int/adaptation/nairobi_work_programme/private_sector_initiative/items/6547.php). This shows that both public and private (including civil society) actors can have a role in providing regional data and projections of socioeconomic trends, climate change, urban water supply and management practices, land use and building trends, and hazard mapping (UNEP, 2011). A review shows anecdotal evidence of large businesses investing in vulnerability assessments, yet few beginning to invest in adaptation (Agrawala et al., 2011). While some private sector actors take action against climate change risks, many postpone upfront investments for longer-term benefits against uncertain risks. Eakin et al. (2010) and Chu and Schroeder (2010) suggest that the private sector becomes more prominent when local governments and civil society action is limited, but this raises the issue of what incentives are required, especially in regard to low-income countries and communities.

Particularly in wealthier countries and communities, insurance markets can share and spread financial risk from climate change, for example, to help limit damages and manage risks in urban flood-prone areas (Rosenzweig and Solecki, 2010; see also Chapters 10 and 14). Risk-differentiated property insurance premiums can incentivize individuals and businesses to invest in adaption and retrofitting property or to avoid building in high-risk areas (Mills, 2007, 2012; Fankhauser et al., 2008). Relevant insurance instruments include health and life insurance for individuals; property and possession insurance for home and commercial property owners; and micro-insurance or micro-finance mechanisms to support those in low-income urban communities that are not covered by commercial insurance (see Box 8-3). Catastrophe bonds may be developed to cover some urban climate risks, but experience to date suggests they are quite narrowly written for specific events in specific locations, not providing the broad protection necessary to limit catastrophic risk in a changing climate and urban context (Keogh et al., 2011; Brugmann, 2012). Multicat Mexico 2009 is a catastrophe bond used to reinsure the Natural Disaster Fund covering the Mexican territory against hurricanes and earthquakes. This provides resources to mitigate losses up to US$50 million for hurricanes (Aragón-Durand, 2012). The insurance industry can also help shape urban adaptation initiatives, collaborating with building owners, developers, and governments to inform and encourage action.

Private investment or standard insurance markets will not protect low-income urban dwellers (Ranger et al., 2009; Hallegatte et al., 2010). For example, around half of Mumbai's population lives in informal settlements mostly without protective infrastructure and at increasing risk of flooding under most climate change scenarios (McFarlane, 2008; Hallegatte et al., 2010; Ranger et al., 2011). This population (and most of those living in informal settlements in other cities) will not be served by insurance because of the low ability to pay, high risks, and the high transaction costs for companies of administering many small policies. Low-income groups rely instead on local solidarity and government assistance when disaster hits (Hallegatte et al., 2010). In addition, where risk levels exceed certain thresholds, insurers will abandon coverage or set premiums unaffordable to those at risk. Insurance reduces the net risk and loss potential in urban areas, but can also increase inequality in security within neighborhoods or across cities unless coupled with government action to help manage risk in low-income communities (da Silva, 2010).

In many informal settlements, informal savings groups give members (mostly women) quick access to emergency loans (Mitlin, 2008). Where access to formal banking is limited, but social capital is high, those living in informal settlements have also pooled their savings for collective investments that reduce risk in their settlements or allow them to negotiate land and support for new homes (Manda, 2007; d'Cruz and Mudimu, 2013; Satterthwaite and Mitlin, 2014).

For the private sector to fulfill its potential to facilitate urban adaptation, public policy may need to establish enabling conditions in markets (see also Section 8.3), for example, targeting payment for provision of ecosystem services to deliver urban adaptation benefits that otherwise fall outside the market system. Such services include storm buffering and flood protection by paying for mangrove protection in coastal zones or urban green space along river-ways (Fankhauser et al., 2008; Roberts et al., 2012). In building construction, well-documented examples of market failure exist. Private investment in weather proofing new construction and retrofitting existing stock may fail to occur without regulatory intervention. This is an area where municipal governments often have authority to act. Public policy and funding is also needed to

Box 8-3 | Micro-finance for Urban Adaptation

Micro-finance schemes may contribute to pro-poor, urban adaptation through a variety of different instruments including micro-credit, micro-insurance, and micro-savings to help households and small entrepreneurs without access to formal insurance or commercial credit markets. These have been applied mostly in rural areas, usually benefitting those with some property (and thus not the poorest of rural populations). As Hammill et al. (2008, p. 117) state: "*The value MFS holds for climate change adaptation is in its outreach to vulnerable populations through a combination of direct and indirect financial support, and through the long-term nature of its services that help families build assets and coping mechanisms over time, especially through savings and increasingly through micro-insurance—products and sharing of knowledge and information to influence behaviours.*" Although typically more costly than commercial loans, micro-finance can support entrepreneurial undertakings by those unable to get bank loans, help diversify local economies, and empower women in particular, which can in turn contribute to adaptive capacity in a local context (Agrawala and Carraro, 2010; Moser et al., 2010). Micro-finance also provides a means for donors to deliver support to low-income groups without creating an ongoing dependence on aid. But there is a need to target it well to avoid encouraging growth in areas prone to climate risk (Hammill et al., 2008; Agrawala and Carraro, 2010). A limitation of micro-finance for adaptation is that it typically provides credit to individuals, so it is not easily used to finance collective investments—for instance, improving drainage—and it can be a route to indebtedness during disaster recovery. There has been some experience of pooling savings, for example, in low-income communities to set up City Development Funds in Asia, from which they can draw loans for disaster rehabilitation among other things (Archer, 2012). Von Ritter and Black-Layne (2013) explore the possible role for microfinance and crowd funding to support local climate change action e.g. finance small decentralized energy solutions or "climate-proof" homes; they also suggest the new Green Climate Fund could support such activity through its private sector window.

protect the poorest and most vulnerable households, and to ensure or enable action by the private sector. This may include filling gaps in insurance markets (Mills, 2007; Fankhauser et al., 2008; IPCC, 2012; UN-HABITAT, 2011c); helping provide information about risks particularly where this is highly uncertain; and encouraging pro-active engagement by the private sector, as in the UK where vulnerability assessment is required for infrastructure investments (Agrawala et al., 2011). There are examples of urban governments leading by example, requiring the integration of adaptation considerations into public operations and infrastructure investments through procurement requirements, which in turn affects private sector providers. Thus, even where markets exist and are well-functioning, all levels of government may need to engage the private sector in adaptation. Public-private initiatives also have a role providing educational and skill development resources to ensure that the professional networks of private service providers are trained in the latest decision tools, assessment methods, and practices (McBain et al., 2010; da Silva, 2012). Where markets do not exist or do not function well, there will be an even larger role for policy and public investments to support urban adaptation.

8.4.2.4. Philanthropic Engagement and Other Civil Society Partnerships

Philanthropic and other civil society support for urban adaptation is gaining momentum at all levels. The most diverse and numerous are local actions undertaken by community-based organizations, as described above. Philanthropic organizations demonstrate the enabling role that can be played by international civil society to support urban adaptation, particularly in cities and communities in low- and lower-middle-income countries. The coming together of grassroots civil society organizations to form international collaborations and networks can also strengthen the framing role of civil society while retaining local accountability and focus to support adaptation. Some examples include:

- Rockefeller Foundation's support for the Asian Cities Climate Change Resilience Network (ACCCRN) (Moench et al., 2011; Brown et al., 2012)
- The Asian Coalition for Community Action Program managed by the Asian Coalition for Housing Rights
- The Asian Disaster Reduction and Response Network (ADRRN)
- Philippines Homeless People's Federation, working with local governments to identify and help those most at risk to natural disasters (Carcellar et al., 2011)
- Shack/Slum Dwellers International (SDI), a network of community-based organizations and federations of the urban poor in 33 countries in Africa, Asia, and Latin America and their local support NGOs.

Many disaster events are small and local but, taken together, have a widespread and cumulative impact on the development prospects of low-income households and communities, underscoring the need for enhanced civil society engagement and coordination (UNISDR, 2009). Civil society organizations are well placed to address the local conditions and some of the structural root causes of vulnerability, necessary for successful urban adaptation. For example, the scale and range of recent disaster events in Asian cities suggest a growing need for new support mechanisms to facilitate action among local stakeholders—one that should include local government as well as local civil society organizations (Shaw and Izumi, 2011). Where urban civil society is well coordinated and has legitimacy, it can offer alternative models for urban governance and adapting to climate change to assist local governments (Mitlin, 2012). Elsewhere ad hoc coalitions of civil society actors, or even uncoordinated activity in some cities, provide a de facto delivery mechanism for accessing basic infrastructure and rights as part of development and disaster response (Pelling, 2003), although the lack of coordination limits the scale and scope of adaptive capacity. Many civil society initiatives have developed models of infrastructure delivery that are not centered on urban adaptation but have relevance for it, in part through activities designed to reduce disaster risk and increase management capacity (see Hasan, 2006).

8.4.2.5. University Partnerships and Research Initiatives

Since AR4, interest in urban aspects of adaptation has grown in the research community and its funders, as is evident in the number of conferences on this topic, both within social and behavioral sciences and in engineering and city planning sciences. More professional societies are considering their roles and responsibilities. Some cities are tapping into relevant networks; for instance, the Urban Climate Change Research Network (UCCRN) brings together researchers and city planners to exchange knowledge and build a coalition of awareness and policy (Rosenzweig et al., 2010). Other examples include London's use of scenarios generated by UK Climate Impact Programme by University of Oxford's Environmental Change Institute (Carmin et al., 2013); the Urbanization and Global Environmental Change Programme (UGEC) of the International Human Dimensions Programme on Global Environmental Change; the Earth System Science Partnership (ESSP), a pioneer in promoting social science and knowledge exchange; the Land-Ocean Interactions in the Coastal Zone program; Integrated Research on Disaster Risk (IRDR) co-sponsored by the International Council for Science (ICSU), the International Social Science Council (ISSC), and the United Nations International Strategy for Disaster Reduction (UNISDR); and research on urban adaptation in Africa supported by the International Development Research Centre (IDRC).

Individual academic institutes have also begun to support urban adaptation efforts. The Urban Observatory in Manila has become a regional hub for climate change science and urban adaptation; the Universiti Kebangsaan in Malaysia hosts a Malaysian Network for Research on Climate, Environment and Development (MyCLIMATE) focused on awareness and capacity in industry and civil society (Shaw and Izumi, 2011); the Climate and Disaster Resilience Initiative (Kyoto University, CITYNET, and UNISDR) works with city managers and practitioners (Shaw and IEDM Team, 2009); and Latin American networks such as FLACSO (Facultad Latinoamericana de Ciencias Sociales) provide leadership across the region in disaster risk reduction, management, and climate change adaptation. Individual centers have also become more engaged in urban adaptation, for instance, UNAM (Universidad Nacional Autónoma de México) in Mexico and the International Centre for Climate Change and Development (ICCCAD) in Dhaka (Mehrotra et al., 2009; Anguelovski and Carmin, 2011). There remains a challenge to reform university curricula to include urban adaptation and mitigation.

8.4.2.6. City Networks and Urban Adaptation Learning Partnerships

Opportunities for accelerating learning and action may stem from horizontal coordination and networking across actors, professions, and institutions in different municipalities and metropolitan areas. The growing interest in urban adaptation is also seen in the growth of transnational networks and coalitions working across organizational boundaries to influence outcomes, both nationally and internationally (Bulkeley and Betsill, 2005; Bulkeley and Moser, 2007; Rosenzweig et al., 2010) and providing an institutional foundation to concerted effort and collaboration at the city level (Aall et al., 2007; Romero-Lankao, 2007; Kern and Gotelind, 2009). ICLEI's Cities for Climate Protection has been extensively analyzed in the literature (Betsill and Bulkeley, 2004; Lindseth, 2004; Betsill and Bulkeley, 2006; Aall et al., 2007) with a broad conclusion that they are influencing decision making and offer an effective means of sharing experience and learning. Other examples include the Climate Alliance, the C-40 Large Cities Climate Leadership Group, and the Urban Leaders Adaptation Initiative in the USA (OECD, 2010). The United Cities and Local Governments (UCLG) network, representing local governments within the United Nations, also has a growing interest in adaptation. The Asian Cities Climate Change Resilience Network, mentioned above, also encourages inter-city learning for officials and local researchers (Brown et al., 2012). The Making Cities Resilient network, supported by the UN International Strategy for Disaster Risk Reduction (UNISDR), promotes a 10-point priority agenda for city governments, building on good risk reduction practices (UNISDR, 2008; see also Johnson and Blackburn, 2013). Another example of the influence of city networks is the signing of the Durban Adaptation Charter in December 2011 by 107 mayors representing more than 950 local governments at COP17 (Roberts and O'Donoghue, 2013), signaling their intention to begin addressing climate change adaptation in a more concerted and structured way (Rosenzweig et al., 2010). The initial focus of some city networks was on mitigation but attention and leadership on adaptation is growing (as in the U.S. Urban Leaders Adaptation Initiative; Foster et al., 2011a).

8.4.3. Resources for Urban Adaptation and Their Management

Resources for urban adaptation action can come from public and private sectors, domestic and international. Table 8-5 summarizes the main funding sources and financial instruments. In high-income countries, local governments are responsible for an estimated 70% of public spending in urban areas and roughly 50% of public spending on environment infrastructure, often in partnership with other levels of government (OECD, 2010). The scale and source of funds contributing to adaptation varies widely by location and depends in part on the extent to which local authorities can tax residents, property owners, and businesses. A survey of 468 cities conducted by Carmin et al. (2012a) found that most (60%) are not receiving any financial support for their adaptation actions. Of the small percentage of cities receiving funding, the most common source of support is from national governments (24%). A smaller number of cities (9%) reported funding from subnational governments while others (8%) reported support from private foundations and non-profit organizations; only 2 to 4% of the cities reported receiving financial support from international (bilateral and multilateral) financial institutions such as multilateral development banks and this varied widely by region (Carmin et al., 2012a). Some of the environmental innovation in Latin America over the last 20 years is associated with decentralization that has strengthened fiscal bases for cities, along with more elected mayors and more accountable city governments (Campbell, 2003; Cabannes, 2004); Latin American cities have also reported multilateral development banks as the most prevalent source of funding for adaptation representing about 21% of funding to date (Carmin et al., 2012a). In Africa and Asia, a high proportion of urban governments still have very limited investment capacities, as most of their revenues go to salaries and other recurrent expenditures (UCLG, 2011). UCLG data points to the large difference in annual expenditure per person by local governments, ranging from more than US$6000 in some high-income nations to less than US$20 in most low-income nations (UCLG, 2010).

As Table 8-5 indicates, large cities with strong economies and administrative capacity can best attract external funding (including transfers from higher levels of government) and raise internal funding for adaptation. Less prosperous and smaller urban centers and cities with fragmented governance structures or administrations lacking in capability have worse prospects. A key issue is "unfunded mandates"—responsibilities assigned to cities with no increase in funding and capacity (UCLG, 2011)—and this can happen with new responsibilities around climate change (Kehew et al., 2012; Tavares and Santos, 2013). Funding regimes and supportive legal frameworks need to integrate urban climate change risk management and adaptation into development.

8.4.3.1. Domestic Financing: Tapping into National or Subnational Regional Sources of Funding and Support

For adaptation specifically, domestic public funding is one of the most significant and sustainable sources in many countries. Initiatives to green local fiscal policies are spreading, including congestion charges on motor vehicles and value-capture land taxes that make the cost of environmental externalities visible, and/or the benefits of infrastructure and services to property owners (e.g., transport, water, and wastewater services). Such measures can promote private investment in risk management while mobilizing local revenue sources. Local fiscal incentives can lead to maladaptation where urban government budgets and actions are financed by land sales, which in turn promote urban sprawl or development in areas at risk (Drejza et al., 2011; Merk et al., 2012). Greening local fiscal policies will need to identify and address these kinds of concerns.

Grants, loans, and other revenue transfers from national or regional (subnational) governments are also important sources, for instance to compensate local governments for the spillover environmental benefits of their expenditures (OECD, 2010; Hedger, 2011; Hedger and Bird, 2011). An example is municipal funding in Brazil, where the allocation of tax revenues is based on ecosystem management performance (Box 8-3).

Other innovative financial mechanisms for urban adaptation include revolving funds and the energy services company ("ESCO") model (OECD, 2010). Revolving funds can be developed from a variety of revenue streams such as Clean Development Mechanism projects (Puppim de Oliveira, 2009), and savings from energy efficiency investments in

Table 8-5 | Main sources of funding and financial instruments for urban adaptation.

Sources of funding	Types	Instruments	What can be funded (with some examples of funds)	Urban capacity required to access funding
Local: public	Local revenue raising policies: taxes, fees, and charges or use of local bond markets	• Local taxes (e.g., on property, land value capture, sales, businesses, personal income, vehicles…) • User charges (e.g., for water, sewers, public transport, refuse collection) • Other charges or fees (e.g., parking, licenses)	• Urban infrastructure and services • Urban adaptation programs and planning processes • Urban capacity building	Cities with well-functioning administrative and institutional capacity and adequate funding from local revenue generation and intergovernmental transfers
Local: public-private	Public-Private Partnerships (PPP) contracts and concessions	• Concessions and private finance initiatives to build, operate, and/or maintain key infrastructure • Energy performance contracting	Medium to large-scale infrastructure with strong private goods (to allow rents for private sector)	Cities with strong capacity for legal oversight and management
Local or national: private or public	National or local financial markets	• Commercial loans • Private bonds • Municipal bonds	Basic physical infrastructure (need for collateral)	Well-functioning local or national financial markets that city governments can access
National: public	National (or state/ provincial) revenue transfers or incentive mechanisms	• Revenue transfers from central or regional government • Payment for ecosystem services or other incentive measures	• Urban payment for environmental services in Brazil • Sweden's KLIMP climate investment program	Cities with good relations with national governments, strong administrative capacity to design and implement policies and plans
International: private	Market-based investment	• Foreign direct investment, joint ventures	• Industrial infrastructure • Power generation infrastructure	Cities with strong national enabling conditions and policies for investment
International sources	Grants, concessional financing (e.g., Adaptation Fund)	• Grants, concessional loans, and loan guarantees through bilateral and multilateral development assistance • Philanthropic grants	• Urban capacity building • Urban infrastructure adaptation planning	Typically requires strong multi-level governance—cities with good relations with national governments. Cities with low levels of administrative and financial market capacity.

Box 8-4 | Environmental Indicators in Allocating Tax Shares to Local Governments in Brazil

In Brazil, part of the revenues from a value-added state government tax (ICMS) must be redistributed among municipalities. Three-quarters is defined by the federal constitution with the remaining 25% allocated by each state government. The state of Paraná introduced the ecological ICMS (ICMS-E) in 1992 against the background of state-induced land use restrictions (protected areas) for several municipalities, which prevented them from developing land but provided no compensation. For example, 90% of the Piraquara municipality was designated as a protected watershed, supplying the Curitiba metropolitan region with water (May et al., 2002).

States have different systems in place, but there are many commonalities. Revenues are allocated based on the proportion of a municipality's area set aside for protection, and protected areas are weighted according to different categories of conservation management (higher for biological reserves, for instance, than for areas of tourist interest). Paraná and some other states evaluate the protected areas based on physical and biological quality (fauna and flora); quality of water resources; physical representativeness; and quality of planning, implementation, and maintenance.

The ICMS-E, built on existing institutions and administrative procedures, has had very low transaction costs (Ring, 2008). Evaluations show it has been associated with improved environmental management and the creation of new protected areas (May et al., 2002). It has also improved relations with the surrounding inhabitants as they start to see these areas as an opportunity to generate revenue, rather than an obstacle to development.

Adapted from OECD, 2010.

municipal buildings to feed public funds for investments that yield adaptation benefits. Local governments in high- and some middle-income countries may also have direct access to bond markets or loans from national (or regional) development banks or financial institutions (OECD, 2010; Merk et al., 2012). Local access to capital markets can be facilitated through risk-sharing mechanisms or guarantees provided by development banks, for example, the German government's Development Bank KfW provides low-interest loans to local banks which then finance energy-efficient renovations in residential and commercial buildings (OECD, 2010; Pfliegner et al., 2012).

A key challenge is determining how far adaptation funding should be geared to target associated policy realms. The very high costs of extreme weather events in many urban areas, and the fact that climate change usually increases these risks, indicates the need for increased funding and attention from national budgets for risk reduction and early warning and evacuation procedures within urban areas, alongside other adaptation measures (World Bank, 2010a,e; Hallegatte and Corfee-Morlot, 2011). The urban funding gap may be particularly wide for "soft" rather than "hard" infrastructure investments, yet both can be a motor for resilience.

8.4.3.2. Multilateral Humanitarian and Disaster Management Assistance

The international humanitarian community is increasingly active in urban contexts, with relevance for adaptation capacity (IFRC, 2010). Non-climate-related disasters (including earthquakes and tsunamis) provide a learning opportunity, and the sector is beginning to review experience and develop appropriate tools and guidelines for urban contexts (e.g., ALNAP, 2012). In 2009, humanitarian groups formed a reference group on meeting humanitarian challenges in urban areas, setting a 2-year action plan in 2010, and developing a database of urban-specific aid tools, the Urban Humanitarian Response Portal (http://www.urban-response.org/). Policies sensitive to the needs of internally displaced urban populations are a big challenge for the sector, especially where the resident population is chronically poor (Crawford et al., 2010; Zetter and Deikun, 2010); so too are appropriate responses to increased urban food insecurity (Battersby, 2013).

The systematic programming of climate change adaptation into multilateral humanitarian, disaster response, and management funding within development cooperation is in its infancy. Urban dimensions are under-developed although this is changing (UNISDR, 2009, 2011; IFRC, 2010). The World Bank's Global Facility for Disaster Reduction and Recovery (GFDRR) explicitly includes adaptation to climate change. Its Country Programmes for Disaster Risk Management and Climate Change Adaptation 2009–2011, and more recently 2014–2016, seek to deepen engagement in some priority countries (GFDRR, 2009, 2013; World Bank, 2013). The GFDRR, with UNISDR, has also advocated for more integrated policy and advisory services at the technical level (see Mitchell et al., 2010). A 2009–2011 survey of reports from 82 governments on disaster risk reduction and urban and climate change issues found some progress in both areas (Figure 8-6; UNISDR, 2011).

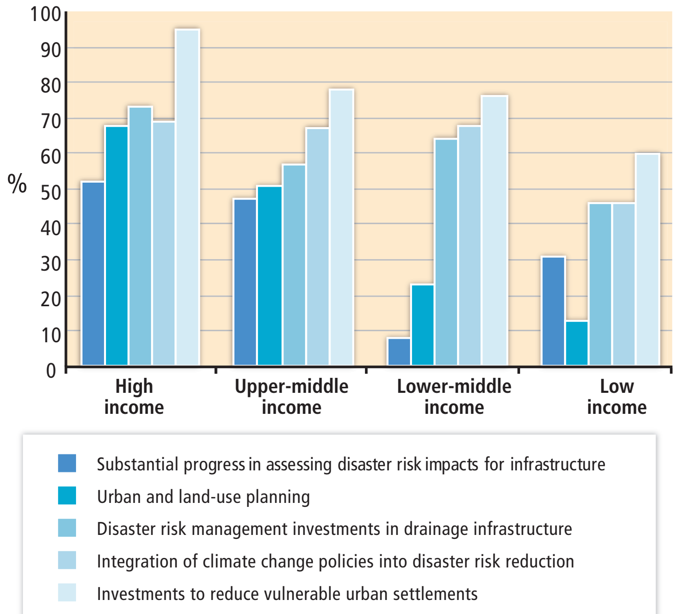


Figure 8-6 | Progress reported by 82 governments in addressing some key aspects of disaster risk reduction by countries' average per capita income (UNISDR, 2011).

Despite progress, many urban governments lack the capacity to address disaster risk reduction and management. Almost 60% of the countries surveyed by the UN (80% of lower-middle-income countries) reported that local governments have legal responsibility for disaster risk management, but only about a third had dedicated budget allocations, mostly in upper-middle- and high-income countries (UNISDR, 2011). Figure 8-6 highlights attention to investments in drainage infrastructure, but much less in urban and land use planning in lower-middle- and low-income countries. Progress in integrating climate change policies into disaster risk reduction was reported by more than two-thirds of governments in high-, upper-middle-, and lower-middle-income countries but under half of low-income countries.

8.4.3.3. International Financing and Donor Assistance for Urban Adaptation

The limited data available show attention to urban areas in the growing levels of international development financing available to support adaptation (e.g., OECD, 2013; World Bank, 2013). Development finance is a key source of support for adaptation in many low- and middle-income countries, but many vulnerable cities and municipalities are poorly positioned to access available funding (ICLEI, 2010; Paulais and Pigey, 2010), for their often very large deficits in risk-reducing infrastructure and services. In some local governments, international programs offer the main source of institutional and financial support for mitigation and adaptation work at the local level, but this can raise the danger of a "donor-driven model" (where the funding agency's agenda does not coincide with local priorities); experience shows that without strong and lasting local ownership, programs are unsustainable once support is withdrawn (Hedger, 2011; OECD, 2012). More international funding for adaptation and mitigation is being committed, largely as Official Development Assistance (ODA), and governments are broadly on track delivering on their international promises (see, e.g., the Cancun Agreements) to scale up international climate finance (Buchner et al., 2012; Clapp et al., 2012). Less in evidence are sound institutional arrangements to make this support available to urban governments. The *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX) calls for arrangements that will allow adaptive urban management systems to evolve with changing social and environmental dynamics (IPCC, 2012) but international channels for development finance have yet to adjust to this call to action.

Recent data suggest that a small share of total flows of climate-related ODA targets adaptation (UNEP, 2011; OECD, 2012), and some of this is supporting urban adaptation (e.g., see OECD, 2013; World Bank, 2013). OECD estimates bilateral ODA commitments targeting climate change to be in the range of US$11 to US$20 billion per year on average in 2010–2011 for both adaptation and mitigation; of this, roughly 20 to 40% targets adaptation (OECD, 2013). One in-depth assessment of five major donors, covering concessional and non-concessional finance, estimated adaptation to be 30% of their climate change portfolio, mostly targeted to water and sanitation (about 75%) (UNEP, 2011). The rest were for other relevant sectors (i.e., transport, policy loans, disaster risk reduction), but with energy and health largely overlooked (UNEP, 2011; see also Atteridge et al., 2009). Despite growing attention to climate change, many bilateral agencies have historically had very limited engagement with urban initiatives (Mitlin and Satterthwaite, 2013). Some authors also note the difficulty in distinguishing adaptation from development finance, which limits the accuracy of such estimates (Tirpak et al., 2010; Buchner et al., 2012).

Despite the uncertainties in tracking adaptation ODA, OECD statistics (OECD, 2013) show that there is some attention to urban issues today.[2] Urban adaptation is estimated to represent about 20% of bilateral climate adaptation portfolios, equivalent to US$0.65 to US$1.6 billion per year (on average over 2010–2011). Slightly more than half of this goes to projects in urban centers with between 10,000 and 500,000 inhabitants while the rest goes to large cities with 500,000 or more inhabitants. The major sectors are water (about 38%, considering projects that had adaptation as principal or significant) and sanitation (another 6%) (OECD, 2013). The largest providers of urban adaptation ODA in these years were Japan (an average of US$683 million a year in commitments), Germany (US$333 million); France (US$111 million); and South Korea, European Union Institutions, Spain, and Denmark (between US$48 and US$80 million). The largest recipients were Vietnam (US$232

[2] Data and information as found in the OECD DAC-CRS 2013, www.oecd.org/dac/stats/rioconventions.htm (last accessed: September 7, 2013). These estimates derive from data and project descriptions in the OECD DAC-Creditor Reporting System. It is based on a project-by-project review of qualitative information in the 2013 version of the database describing official development finance from bilateral agencies and the EU institutions. This subset of "urban" adaptation activities describes those projects that identify the geography of beneficiaries as urban and that include a verifiable location (e.g., metropolitan Lima); data were organized by key characteristic of each urban location (i.e., population size and recipient country). Only urban areas with populations of 10,000 or more are included here. Projects are marked with climate adaptation "Rio marker"; this data set includes all projects marked as targeting climate adaptation, either as a principal objective or as those with it as a significant objective.

million); Bangladesh (US$146 million); China (US$100 million); and the Philippines, Peru, Indonesia, and Kenya (US$52 to US$76 million).

Around 70% of urban adaptation aid is dedicated to "hard" infrastructure while about 10% goes to "soft" measures to support capacity building related to urban infrastructure planning and adaptation. So OECD data suggest that urban adaptation is a recent but significant objective in climate aid activities but it is still only a small part of overall ODA portfolios (OECD, 2013).

Conventional channels for development finance appear to have the biggest role in adaptation financing in low- and middle-income countries, though new vertical funds are also emerging. The proliferation of multiple, single purpose funding mechanisms runs contrary to long-standing harmonization principles of sound development cooperation (Hedger, 2011; OECD, 2012). This more complex funding architecture makes it difficult for smaller actors such as local authorities to access sources for timely adaptation investments.

Development assistance can be better targeted if reconciled with bottom-up, locally based planning processes that take climate risks into account, and programs aiming to be mainstreamed into urban development over time (Brugmann, 2012). Research shows the lack of well-defined priorities in partner countries, combined with a donor tendency to "control" funds for short-term results and a large variety of different funding instruments results in fragmented delivery systems and unclear outcomes (Brown and Peskett, 2011). Even where climate strategies exist to guide action—as in Bangladesh, an "early mover" on adaptation planning—the plan is often neither costed nor sequenced, making it an inadequate framework for finance delivery (Hedger, 2011). A key to improving effectiveness of international public finance will be building the capacity for country-led planning processes identifying priority actions for targeting adaptation funds. National Adaptation Plans of Action (NAPAs) have become a principal way of organizing adaptation priorities in Least Developed Countries, but the majority of plans do not explicitly include urban projects and do not reflect local government perspectives (UN-HABITAT, 2011c).

A number of authors conclude that international development finance is failing to tackle urban adaptation financing needs (Parry et al., 2009; Paulais and Pigey, 2010; ICLEI, 2011; UN-HABITAT, 2011c). Some suggest that national governments could set up funds supported by international finance (governmental, philanthropic, or both) and on which urban governments and community-based organizations can draw (Paulais and Pigey, 2010; Satterthwaite and Mitlin, 2014). In some middle-income countries, such as Indonesia, a more effective and sustainable strategy than a focus on external funding may be national policy reforms and incentives to steer investment to priority needs (Brown and Peskett, 2011). There is also a need to mobilize domestic public and private investment to ensure delivery of adaptation at national and urban levels (Hedger, 2011; Hedger and Bird, 2011; OECD, 2012). Accessing all these sources of development finance for urban adaptation will require institutional mechanisms to support multi-level planning and risk governance (Corfee-Morlot et al., 2011; Carmin et al., 2013).

8.4.3.4. Institutional Capacity and Leadership, Staffing, and Skill Development

Leadership is critical for generating interest in urban adaptation and championing awareness and institutional change to bring action (Anguelovski and Carmin, 2011; Carmin et al., 2012a). Creating a climate change and environmental focal point or office in a city can help coordinate climate action across government departments or agencies (Roberts, 2008, 2010; Anguelovski and Carmin, 2011; Hunt and Watkiss, 2011; OECD, 2011; Brown et al., 2012). Yet there may be downsides when this function is housed in the environmental line department—see Durban (Roberts, 2008), Boston (City of Boston, 2011), and Sydney (Measham et al., 2011)—since they are typically among the weakest parts of city government with limited influence (Roberts, 2010).

Although there is growing evidence of urban adaptation leadership (Lowe et al., 2009; Anguelovski and Carmin, 2011; Foster et al., 2011b), there are also important political constraints at the local level. Powerful

Box 8-5 | Adaptation Monitoring: Experience from New York City

The adaptation monitoring approach developed for New York City has four indicator elements: (1) physical climate change variables; (2) risk exposure, vulnerability, and impacts; (3) adaptation measures; and (4) new research in each of these categories. Examples of indicators arising from these categories include the percentage of building permits issued in a given year in current Federal Emergency Management Agency (FEMA) coastal flood zones, and in projected 2080 coastal flood zones; a tally of building permits with measures to reduce precipitation runoff; an index based on insurance data that measures the insurer's perception of the city's infrastructure-coping capacity; an index that measures the rating of city-issued bonds or infrastructure operators for capital projects with climate change risk exposure; the detailed trend of weather-related emergency/disaster losses (whether insured or uninsured, relative to the total asset volume); and the number of days with major telecommunication outages (wireless versus wired), correlated with weather-related power outages. Data criteria were decided through a scientist-stakeholder consensus with designated groups to evaluate prospective indicators and their values. This case study shows the need for interdisciplinary, longitudinal data collection and analysis systems along with an inclusive, transparent process for stakeholder engagement to interpret the data (Jacob et al., 2010).

vested interests may oppose attention to adaptation and promote development on sites at risk. As noted earlier, concerns about employment and competitiveness make it difficult for local governments to focus on the more distant implications of climate change. This is especially so during periods of economic hardship (Shaw and Theobald, 2011; Solecki, 2012). A key step forward is institutionalizing different types of behavior and norms.

Beyond goal setting and planning, the literature also suggests the need for regulatory frameworks to require relevant behavior and investment. Governments can institute small changes, such as job descriptions that require actions and provide incentives to act in new ways (e.g., for line managers and sector policy makers) or by providing training and clear guidance to staff (Moser, 2006; Carmin et al., 2013; Tavares and Santos, 2013). Budgetary transparency and metrics to measure progress on adaptation can also help to institutionalize changes in planning and policy practice (OECD, 2012).

8.4.3.5. Monitoring and Evaluation to Assess Progress

Adaptation leaders and funding institutions need tools for monitoring and evaluating urban adaptation actions to justify investments but these are not well developed yet or widely implemented in urban areas (Kazmierczak and Carter, 2010). This requires indicators that show if adaptation is taking place, at what pace, and in what locations. Relevant evaluation criteria include cost, feasibility, efficacy, co-benefits (direct and indirect), and institutional considerations (Jacob et al., 2010). Assessment methods can capture outcomes of adaptation decisions, or the decision-making processes themselves—ideally both. Monitoring is challenging for adaptation, especially urban, given the lack of standard metrics, the differences in local contexts, and the often localized nature of adaptation (Lamhauge et al., 2012; Spearman and McGray, 2012).

City authorities, NGOs, and researchers have begun to design adaptation monitoring and evaluation frameworks. Box 8-5 presents the experience of New York City. Development of standard tools offers scope for international benchmarking and coordination across scales of assessment, for example, by associating local indicators of resilience with those in the Hyogo Framework for Action (that prioritize disaster risk reduction) and the post-2015 development agenda (IFRC, 2011).

Monitoring and evaluation focusing on the effectiveness of donor aid on climate adaptation is a growing area of research (Chaum et al., 2011; Lamhauge et al., 2012; Spearman and McGray, 2012). Recent work shows the urgent need for consistent and internationally harmonized data collection to support monitoring. This is a concern for both adaptation and wider disaster risk reduction spending, suggesting a systemic challenge to the architecture of international finance (Kellett and Sparks, 2012). Steps are being made through multi-site assessment programs, in some instances including treatment of urban issues. For example, the World Bank recently included an adaptive capacity index as part of an analysis of risk and adaptation options for five cities in Latin America and the Caribbean. The methodology was previously applied in Guyana, where it demonstrated a gap between national and city level adaptive capacity (Pelling and Zaidi, 2013).

Monitoring also needs to consider the delivery and use in cities of international climate finance to ensure that funds are being effectively directed (Chaum et al., 2011; Hedger, 2011). This is especially important for cities at an early stage of planning, implementing, and monitoring of adaptation, as they can learn from one another's experiences. There is some evidence that international agencies overburden partner organizations and countries (including in some cases city authorities) with monitoring requirements; with limited local capacities, this can detract from further program design and implementation.

8.5. Annex: Climate Risks for Dar es Salaam, Durban, London, and New York City

Refer to Table 8-6 for four city profiles of current and indicative future climate risks, covering Dar es Salaam, Durban, London, and New York. Each summarizes the present, near-term (2030–2040), and long-term (2080–2100) climate risks and the potential for risk reduction through adaptation. As noted earlier, data should not be compared between cities but trends in adaptive capacity and impact can be drawn out.

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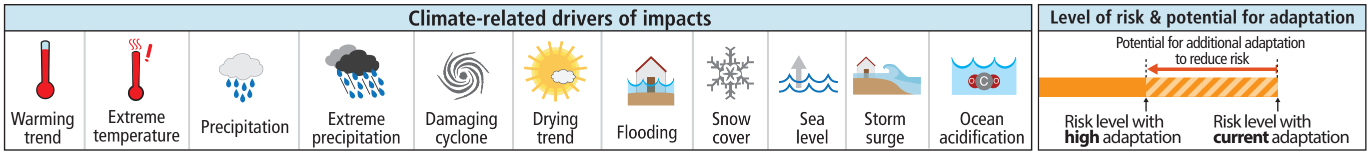
Table 8-6 | Current and indicative future climate risks for Dar es Salaam, Durban, London, and New York City.



Dar es Salaam

Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Coastal zone systems (*medium confidence*) [8.3.3.3, 8.3.3.4]	Construction of coastal protection structures such as sea walls and groynes to minimize coastal erosion and land inundation in Dar es Salaam. Medium prospects due to high costs.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	Very low · Medium · Very high
Terrestrial ecosystems and ecological infrastructure (*low confidence*) [8.3.3.7, Table 8-2]	Demarcation and protection of green areas, provision of more drainage systems, and protection of urban wetlands and ground water resources. Low prospects due to poor development control including land use management.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	Very low · Medium · Very high
Water supply systems (*high confidence*) [8.2.4.1, 8.3.3.4, Table 8-2]	Improvement in Dar es Salaam's water resources management and increased coverage and efficiency in water supply systems. Medium prospects as some of these measures are already being implemented.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	Very low · Medium · Very high
Waste water system (*high confidence*) [8.2.4.1, 8.3.3.4, Table 8.2]	Increase in spatial coverage of sewerage and improvement of on-site excreta disposal systems. Low prospects for extending sewer coverage; higher prospects for expanding onsite disposal systems.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	Very low · Medium · Very high
Energy systems (*very high confidence*) [8.2.4.2]	Reduced dependence on hydropower as the main source of energy by replacing it with natural gas. Very high prospects as the country has vast resources of natural gas.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	Very low · Medium · Very high
Food systems and security (*high confidence*) [8.3.3.2]	Urban and peri-urban agriculture and new adaptation policies to take into account impacts of climate change on food costs and supply chain. Enhanced social safety nets can support adaptation measures.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	Very low · Medium · Very high
Transportation and communication systems (*medium confidence*) [8.2.4.3, 8.3.3.6]	New design standards in context of climate change and enforcement of development controls. Low prospects as climate change issues are yet to be mainstreamed in the sector.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	Very low · Medium · Very high

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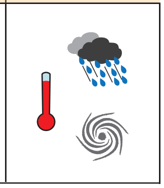
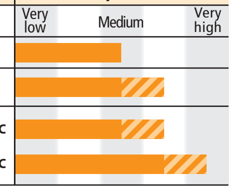
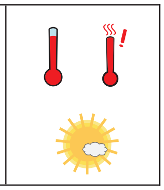
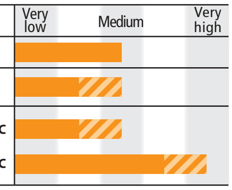
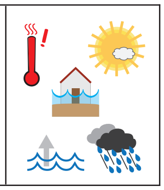
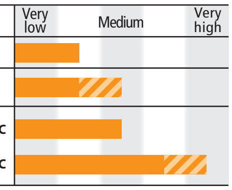
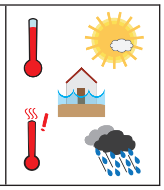
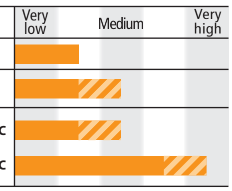
Table 8-6 (continued)

Dar es Salaam (continued)				
Key risk	**Adaptation issues & prospects**	**Climatic drivers**	**Timeframe**	**Risk & potential for adaptation**
Housing (*high confidence*) [8.2.4.4,8.3.3.3]	Climate change adaptation plans, new building codes, effective development control, and upgrading of informal settlements. High prospects as some of these measures are already being taken into account.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	
Human health (*medium confidence*) [8.3.3]	Improvement of water supply, solid waste management, housing conditions, land use planning and food security, and provision of health insurance. Medium prospects as these are key development issues that require a lot of financial resources.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	
Key economic sectors and services (*medium confidence*) [8.3.3.1]	Improvement of storm water infrastructure and transport networks. Use of natural gas as main source for power generation, relocating of key economic activities and infrastructure along coastal buffer areas. A mixture of high and low prospects due to availability of natural gas and high requirements of financial resources.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	
Poverty and access to basic services (*high confidence*) [8.3.3]	Formalizing informal economic sector, upgrading of informal settlements, improvement of housing conditions and empowering local communities in tackling problems related to climate change. High prospects as this is already being implemented as a development issue.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	

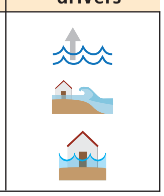
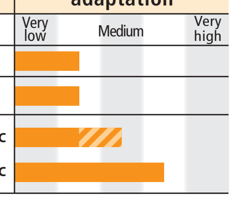
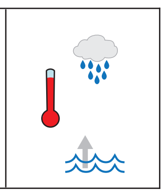
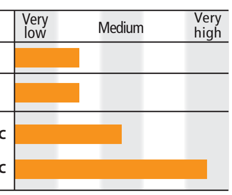
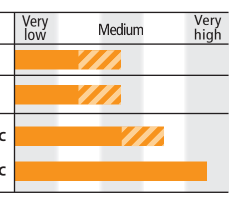
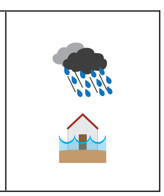
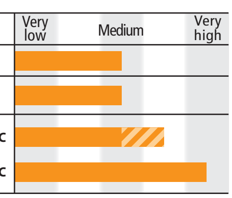
Durban				
Key risk	**Adaptation issues & prospects**	**Climatic drivers**	**Timeframe**	**Risk & potential for adaptation**
Coastal zone systems (*medium confidence*) [8.3.3.3]	Maintaining and restoring Durban's coastal ecosystems. Use of coastal protection structures such as geofabric sand bags, retaining walls, groynes, and a beach nourishment scheme to minimize coastal erosion and infrastructure damage. Use of a development setback line and in some instances strategic retreat to protect infrastructure. High prospects as systems for coastal protection exist and are being improved, but may be overwhelmed by the increase in severity and frequency of storm surges over time.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	
Terrestrial ecosystems and ecological infrastructure (*medium confidence*) [8.3.3.4]	Design and implementation of a fine-scale systematic conservation plan to protect a representative and persistent system of local biodiversity and related ecosystem services. Remove non-climate threats e.g., by managing alien invasive species. Medium prospects due to lack of human and financial resources to protect and manage system and poor enforcement of contraventions.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	
Water supply systems (*high confidence*) [8.3.3.4]	Demand and supply side management required. Reduce non-revenue water losses. Use of ecological infrastructure to improve level of assurance. Medium prospects as measures are already being implemented or considered.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	
Waste water system (*high confidence*) [8.3.3.4]	Increase in spatial coverage of Durban's waterborne sewerage system and use of appropriate alternative services in areas too costly to serve with waterborne systems. Recycling of waste water to potable standards. Medium prospects as measures are already being implemented or investigated.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	

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Table 8-6 (continued)

Durban (continued)				
Key risk	**Adaptation issues & prospects**	**Climatic drivers**	**Timeframe**	**Risk & potential for adaptation**
Energy systems (*medium confidence*) [8.3.3.5]	No integration of energy policy with adaptation policy or practice. Need to avoid maladaptation e.g., increased electricity use for cooling in response to rising temperatures. Low prospects as institutional structures not yet in place to drive this integration.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low — Medium — Very high
Food systems and security (*high confidence*) [8.3.3.2]	Need to change planting dates and to provide increased crop irrigation. Need to take into account the impacts of climate change on the full food supply chain. Low prospects as climate change not yet considered a serious threat.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low — Medium — Very high
Transportation and communications systems (*medium confidence*) [8.3.3.6]	New design standards in context of climate change and enforcement of development control. Medium prospects as climate change issues are beginning to be considered in the transportation sector.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low — Medium — Very high
Housing (*high confidence*) [8.3.3.3]	New building codes, effective development control, upgrading of informal settlements, and retrofitting of existing housing stock. Changes in stormwater policy, preparation of master drainage plans, use of attenuation facilities, and calculation of new floodlines. Promotion of higher densities to reduce pressure on ecological infrastructure. Medium prospects as measures are already being implemented or being investigated.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low — Medium — Very high
Human health (*high confidence*) [8.3.3]	Improvement of basic services, housing conditions, land use planning, and food security. Extend coverage of primary health care and health insurance. Maintain and extend vector control. Ensure ability to deal with the impacts of large-scale disasters through inter-sectoral coordination. Low to medium prospects due to limited human and financial resources.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low — Medium — Very high
Key economic sectors and services (*medium confidence*) [8.3.3.1]	Durban is a logistics, manufacturing, and tourist center. Need to protect and properly locate vulnerable infrastructure in coastal areas, particularly port-related infrastructure. High prospects because of the national economic significance of the port and petro-chemical sectors and local economic significance of tourism.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low — Medium — Very high
Poverty and access to basic services (*high confidence*) [Box 8-2, 8.3.3.7]	Formalizing informal economic sector, upgrading informal settlements, provision of interim services to informal settlements, improving housing conditions, and increasing the adaptive capacity of local communities (especially through ecosystem based adaptation). Use of climate change adaptation interventions to create employment opportunities. Medium prospects because of the scale of the problem and related costs.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low — Medium — Very high

London				
Key risk	**Adaptation issues & prospects**	**Climatic drivers**	**Timeframe**	**Risk & potential for adaptation**
River/coastal zone systems (*high confidence*) [8.3.3.4]	London is currently well protected from tidal flooding and has utilized an "adaptation pathways" approach to ensure it identifies and delivers a flexible long-term tidal flood risk management plan to maintain a high standard of protection through the century.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low — Medium — Very high

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Table 8-6 (continued)

London (continued)				
Key risk	**Adaptation issues & prospects**	**Climatic drivers**	**Timeframe**	**Risk & potential for adaptation**
Terrestrial ecosystems and ecological infrastructure (*medium confidence*) [8.3.3.7]	Adaptation is compromised primarily by habitat fragmentation and can be exacerbated, especially in wetland habitats, by invasive species. The city is taking an approach that promotes the multifunctional benefits of ecologically designed urban green spaces to benefit adaptation with restoring ecological function.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	Very low / Medium / Very high
Water supply systems (*high confidence*) [8.3.3.4]	London faces increasing water security issues during droughts created by higher relative per capita consumption, aging infrastructure, a rapidly growing population, and projected diminishing resources. Resilience is being increased through programs to reduce consumption and increase the diversity of supply.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	Very low / Medium / Very high
Waste water system (*high confidence*) [8.3.3.4]	Much of London is served by a combined rain and foul water drainage system that regularly overflows into the River Thames. Population growth, urban creep, and projected more intense rainfall will further challenge the system. The city is working with the relevant drainage partners to manage this increasing risk through a combination of gray and green infrastructure.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	Very low / Medium / Very high
Energy systems (*medium confidence*) [8.3.3.5	The city's energy security is threatened by a reduction in national generation capacity and the resilience of local distribution systems not matching the increasing demand. The city is responding through increasing energy efficiency and local energy production to improve resilience. Some concern over amplifications effects of energy system failure during heat or cold shocks.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	Very low / Medium / Very high
Food systems and security (*low confidence*) [8.3.3.2]	London's food supply is globalized and access is strongly influenced by global food prices relative to income, as well as regional and national agricultural productivity.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	Very low / Medium / Very high
Transportation and communication systems (*medium confidence*) [8.3.3.6]	London is served by a complex communications and public transport network, which though vulnerable in parts has sufficient redundancy to be resilient at the strategic level. Detailed risk assessments are informing an investment program in the transport network that will deliver increasing resilience to climate impacts.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	Very low / Medium / Very high
Housing (*high confidence*) [8.3.3.3]	London has an extensive historic housing stock that demonstrates poor thermal performance in summer and winter and poor water efficiency. A significant proportion of this housing stock is at risk of flooding. There is improving integration between mitigation and adaptation policy implementation at the regional level, but insufficient funding and levers to implement widespread adaptation.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	Very low / Medium / Very high
Human health (*high confidence*) [8.2.2.1, 8.2.3.1]	Health observation systems and care delivered through the National Health Service respond well but need to integrate better with social care provision to be more proactive, especially for vulnerable groups such as the elderly.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	Very low / Medium / Very high

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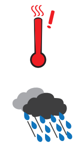
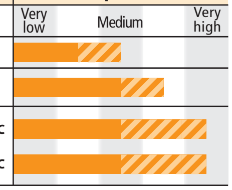
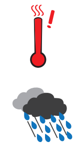
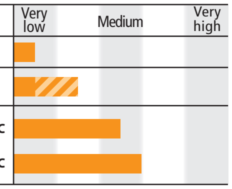
Table 8-6 (continued)

London (continued)				
Key risk	**Adaptation issues & prospects**	**Climatic drivers**	**Timeframe**	**Risk & potential for adaptation**
Key economic sectors and services (*medium confidence*) [8.3.3.1]	London's economy is dominated by service sector activities, particularly finance and including global businesses that expose it to failure in external markets that may be associated with climate change impacts or management. Business continuity is routinely integrated into business plans. Failure of essential infrastructure, including transport and energy networks, has short-term impacts.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C / 4°C	
Poverty and access to basic services (*high confidence*) [8.3.3.8]	A significant proportion of the population struggles to pay their energy and water bills. Pockets of deprivation create areas of high vulnerability to climate risks, compounded by low levels of community capacity / social networks.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C / 4°C	

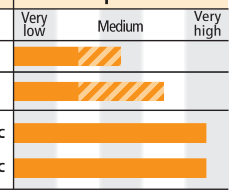
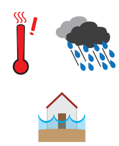
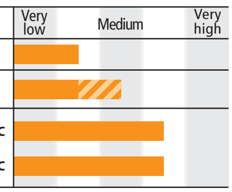
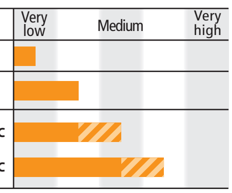
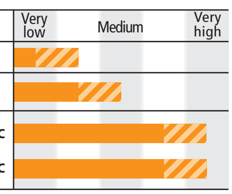
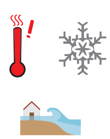
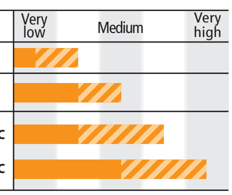
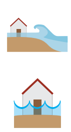
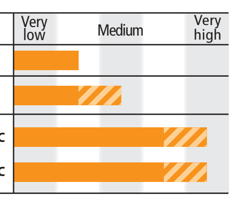
New York City				
Key risk	**Adaptation issues & prospects**	**Climatic drivers**	**Timeframe**	**Risk & potential for adaptation**
Coastal zone systems (*very high confidence*) [8.2]	NYC is highly vulnerable to coastal storm events and sea level rise associated flooding. Integration of infrastructure and policy changes with opportunity to enhance ecosystem service services is possible.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C / 4°C	
Terrestrial ecosystems and ecological infrastructure (*high confidence*) [8.2.4.5; 8.3.3.4]	Promotion of ecosystem restoration efforts consistent with the current degraded state of most of NYC's ecosystem function. A need exists for continued land use protection of the city's water supply region.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C / 4°C	
Water supply systems (*medium confidence*) [8.3.3.4, 8.3.3.7]	NYC maintains an extremely extensive and resilient water supply infrastructure. Long-term adaptation could potentially include heightened drought management and interagency coordination with other water supply demand entities in region.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C / 4°C	
Waste water system (*medium confidence*) [8.2.3.3,8.2.4.1]	NYC maintains an extremely extensive and resilient waste water infrastructure. Gray and green infrastructure adaptation to limit effects of extreme precipitation events and combined sewer overflows will be necessary.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C / 4°C	
Energy systems (*medium confidence*) [8.2.4, 8.2.4.2]	NYC is served by an extensive energy generation and distribution system, most of which is operated by private companies or semi-public authorities. Peak load demand adaptation, especially for cooling demand will be necessary, as will adaptation for distribution disruptions associated with extreme events including ice storm events and coastal storm surge.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C / 4°C	
Food systems and security (*medium confidence*) [8.3.3.2]	NYC is connected to a regional, national, and global food distribution system. Adaptation will be necessary to ensure that food processing and distribution systems within the city can be resilient in the face of potential extreme event impacts.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C / 4°C	

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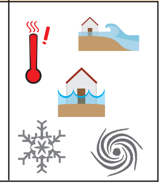
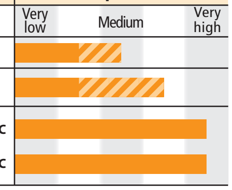
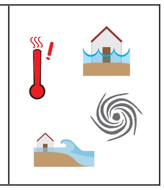
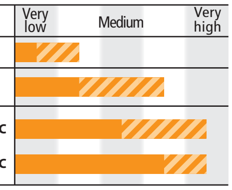
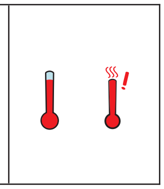
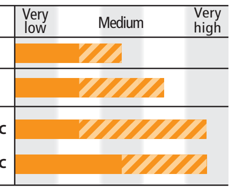
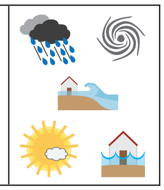
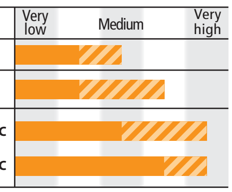
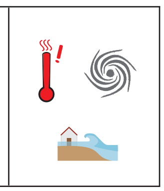
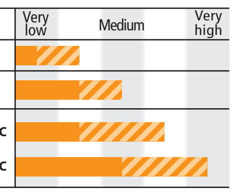
Table 8-6 (continued)

New York City (continued)				
Key risk	**Adaptation issues & prospects**	**Climatic drivers**	**Timeframe**	**Risk & potential for adaptation**
Transportation systems (*high confidence*) [8.2.2.2, 8.3.3.6]	NYC is served by a complex and redundant transportation and communications infrastructure. Numerous vulnerabilities to extreme events are present that result in short-term disruption. Long-term sea level rise and increased flood frequency can result in increased disruption and will require adaptation strategies.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	
Housing (*high confidence*) [8.1.3, 8.2.4, 8.3.3.3]	NYC includes approximately 1 million buildings and similar structures. These maintain a broad range of vulnerabilities to climate change particularly associated with flooding and extreme heat events. Adaptation strategies could include retrofit construction practices, especially in coastal zone locations or areas affected by urban heat island conditions.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	
Human health (*high confidence*) [8.2.3.1]	Great diversity of health conditions of the 8.3 plus million residents is associated with a wide range of human health vulnerabilities to climate change. The very young, aged, and otherwise health-compromised face heightened risk and require adaptation strategies, particularly focused on heat stress and disease.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	
Key economic sectors and services (*medium confidence*) [8.3.3.1]	NYC has a diverse economic base focused on service-related industries with regional, national, and global connections. Adaptation will be necessary to limit vulnerability and enhance resilience in the face of large-scale extreme events such as Hurricane Sandy.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	
Poverty and access to basic services (*medium confidence*) [8.3.3.8]	NYC has an extensive public service provision capacity. Adaptation will be necessary to ensure that more frequent or more intense extreme events will not limit this capacity.		Present Near term (2030 – 2040) Long term (2080 – 2100) 2°C 4°C	

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