

Climate change and human health in cities

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7.1 Introduction

Current climate extremes and projections for future changes to climate have resulted in growing attention to the health effects of climate on all human populations, urban and rural (McMichael *et al.*, 2003; Confalonieri *et al.*, 2007; Costello *et al.*, 2009). Indeed, almost all the impacts of climate change have direct or indirect consequences for human health. However, for a number of reasons, city dwellers – especially those in low- and middle-income nations – are especially vulnerable to the health impacts of climate change.

In this chapter we present issues and case studies relevant to human health in cities under climate change conditions. In Section 7.2, we discuss the most relevant conclusions from the health chapter of the IPCC Fourth Assessment Report (Confalonieri *et al.*, 2007), looking at its application to cities. In Section 7.3, we present an overview of urban health outcomes and their climate-related drivers. In Section 7.4 the factors that can modify the impacts of climate change on human health in urban areas are discussed. Section 7.5 presents examples and case studies of adaptations that protect city residents from some of the health impacts and risks posed by climate change. A brief discussion of needed changes in energy, transportation, and other sectors to reduce emissions of harmful pollutants and provide co-benefits for human health is found in Section 7.6. The urgent need for better, more urban focused and targeted research is discussed in Section 7.7. Conclusions are presented in Section 7.8.

7.1.1 Why health and climate change for cities?

Urban populations are increasing in absolute numbers and relative to rural populations in every part of the world. According to the United Nations Population Fund (2007) the world is undergoing the largest wave of urban growth in history. In 1800 there were only 2 cities larger than a million inhabitants. By 1950 there were 75 cities of this size and by 2000 there were 380 “million-cities,” half of these in Asia (Satterthwaite *et al.*, 2008). Cities have also grown larger. In 2000, the largest 100 cities had an average of 6.3 million inhabitants. In 2008, more than half of the world’s population was living in cities and their surrounding areas. By 2030 this number is projected to reach almost 5 billion, with urban growth concentrated in Africa and Asia. While megacities are important a great deal of the new growth will occur in smaller towns and cities, which tend to have fewer resources (Bicknell and Dodman, 2009).

Because cities concentrate populations, extreme weather events such as intense precipitation, cyclonic storms, or storm surges affect a much larger number of people than when they strike less populated regions. Such damages may be exacerbated in the future, since extreme weather events are expected to increase in number and intensity under climate change (IPCC, 2007). Cities also concentrate poor populations who are especially vulnerable

to the effects of climate change because of the conditions in which they live. In low- and middle-income countries, poor slum dwellers can make up 50 to 60 percent of the urban population, living in precarious structures, often with little access to water, sanitation, electricity, health care, or emergency services (Huq *et al.*, 2007).

The concentration of populations in urban areas also tends to lengthen the supply lines for essentials such as water, food, and energy sources, and makes them more dependent on waste collection (and more susceptible when waste is not collected). Storms, floods, or droughts that disrupt these urban lifelines can have serious consequences for the health of city dwellers (McBean and Henstra, 2003).

Many cities are located in areas that are vulnerable to both existing and projected climate hazards. Most of the world’s mega-cities were originally established on seacoasts or beside major rivers that enabled trade and commerce or territorial control (Huq *et al.*, 2007). Cities such as Venice (Italy) and Mumbai (India), located on low-elevation seacoasts, are particularly vulnerable to sea level rise and storm surges. Of 180 countries with populations in low-elevation coastal zones, about 70 percent have large urban areas extending into that zone (McGranahan *et al.*, 2007). As cities have grown, many have expanded from their original, secure locations onto river deltas and floodplains, marshlands, or up steep hillsides and into other areas that are poorly suited for human habitation and are vulnerable to weather extremes. In many cases the expansion of the city itself has created hazards by filling in water courses or cutting down adjacent forests, increasing the risk of floods and landslides.

The ways in which cities are constructed – reducing vegetation, covering large areas with impermeable surfaces, and obstructing natural drainage channels – make many city dwellers more vulnerable to heat waves, heavy precipitation, and other extreme weather events, which are already increasing, likely as a result of climate change.

Many cities, even in high-income countries, are exposed to multiple stresses not related to climate change. Such stresses include lack of financial resources to meet the needs and demands of a growing population; aging, poorly maintained, inadequate, or non-existent infrastructure; poor land use planning and enforcement; inadequate resources for disaster preparedness; self-serving political institutions or outright corruption that divert resources from pressing problems; and increasing income disparity and growing numbers of impoverished families living in unplanned, unserved settlements and slums (Satterthwaite *et al.*, 2008). Severe weather events can combine with some or all of these stresses to create conditions of extreme hazard as demonstrated recently by:

- flash floods and landslides in Caracas, which killed 30,000 people in 1999 (Satterthwaite *et al.*, 2008)
- floods in Shanghai in 1998, which killed 3,000 and displaced 16 million in the Yangtze basin (de Sherbinin *et al.*, 2007)

- extreme heat in Paris in the summer of 2003, which contributed to an estimated 2,085 deaths out of a total of 15,000 for the whole of France (le Tertre *et al.*, 2006)
- monsoon floods in 2005 in Mumbai, which killed more than 1,000 (de Sherbinin *et al.*, 2007)
- intense rainfall combined with high-tide conditions that submerged more than 100 square kilometers of Dhaka in 1988, 1998, and 2004 (Alam and Rabbani, 2007)
- hurricane Katrina, which devastated New Orleans in 2005 and killed more than 1,800 people (Glantz, 2008).

In each of these instances, more than 1,000 people died and many more suffered serious health effects. Unless more action is taken to address the risk factors from current extreme weather events and from future climate change, events of this kind are very likely to become more common, and their health impacts will be even more severe.

7.1.2 Ways in which climate change will affect the health of city dwellers

Climate change is expected to exacerbate a number of existing threats to human health and well-being rather than to introduce new health effects (Costello *et al.*, 2009). Both direct and indirect impacts on human health are beginning to be observed under current climate conditions and are predicted to be amplified in the coming decades. The health of city dwellers is expected to be affected in the following ways:

- direct physical injuries and deaths from: extreme weather events such as tropical cyclones and other major storms with high winds; storm surges; intense rainfall that leads to flooding; or ice storms that damage trees and overhead structures and produce dangerous transport conditions
- illnesses resulting from the aftermath of extreme weather events that destroy housing, disrupt access to clean water and food and increase exposure to biological and chemical contaminants
- water-borne diseases following extended or intense periods of rainfall, ground saturation and floods and saline intrusion due to sea level rise
- food-borne diseases resulting from bacterial growth in foods exposed to higher temperatures
- illnesses and deaths from the expanded range of vector-borne infectious diseases
- respiratory illnesses due to worsening air quality related to changes in temperature and precipitation resulting in the formation of smog
- morbidity and mortality, especially among the elderly, small children, and people whose health is already compromised, as a result of stress from hotter and longer heat waves – which are aggravated by the urban heat island effect
- malnutrition and starvation among the urban (and rural) poor who have reduced access to food as a result of drought-induced shortages and price rises
- uprooting and migration of populations negatively affected by climate events to areas that are unable to provide the services they need.

7.1.3 The challenge for cities

As a primary climate change prevention measure, cities need to contribute more effectively to reducing their greenhouse gas emissions (Frumkin *et al.*, 2008) (See Chapter 4 on energy). While emission reductions will not prevent many of the damaging climate changes that are already underway and likely to continue in the next 50 to 100 years, it remains a critical task for high-income cities and countries, and for some middle-income cities and countries whose emissions are rapidly growing. Emission reductions will moderate the expected impacts of climate change over the long term. However, as Huq *et al.* (2007) and Satterthwaite *et al.* (2008) argue, low-income cities and their most vulnerable residents contribute relatively little to the worldwide complement of greenhouse gas emissions and thus the focus of their efforts will likely be more on identifying vulnerabilities and preparing adaptation strategies.

Because the world has failed so far to prevent the build-up of greenhouse gases in the atmosphere and thus to prevent health impacts that climate change is likely to inflict on city dwellers, a key task is to alter existing urban conditions that may combine with climate change and result in deaths, injuries, and illnesses in the population. In low- and middle-income cities and countries this requires a focus on meeting basic development needs – adequate housing; provision of infrastructure that supplies clean water, sanitation, and energy; education; and primary health-care services. Provision of these services will reduce vulnerability to many of the health impacts of climate change and increase the capacity of the most vulnerable to withstand some of the impacts that cannot be avoided. High-income cities already provide these services to most of their population, but often do this in a way that interacts with weather extremes to worsen impacts – by paving much of the urban landscape, for example, which exacerbates heat and flooding. Whether building new structures and services or modifying existing ones, cities need to alter the urban characteristics that worsen the impacts of extreme weather events and turn at least some of them into health and economic disasters. Anticipated climate change over the lifetime of the structures should also be taken into account. Otherwise such investments may be jeopardized by climate change.

In addition to long-term vulnerability reduction, cities need to undertake disaster preparedness planning, and develop early warning and emergency disaster relief systems (Few *et al.*, 2006). This will necessitate identifying, assessing, and monitoring disaster risks. The World Bank (2008) *Climate Resilient Cities* primer recommends preparing a disaster history and a city hazard profile map to identify areas vulnerable to natural hazards, an essential task for disaster planning. In addition to helping with longer-term adaptation planning, these actions will aid in the development of shorter-term plans to avoid disasters in areas that have proved to be prone to recurrent calamities. Improved urban planning and linking it to disaster risk reduction in climate change adaptation strategies will be necessary (Revi, 2008; GFDRR, 2009). Recovery and reconstruction will benefit from preparatory measures.

All these tasks are a challenge, though they are easier for higher-income cities, which are reasonably well-organized and resourced. A great many cities have committed to reducing emissions – and some have very ambitious targets. A smaller number of cities and urban regional governments have developed and are in the early stages of implementing plans to adapt to climate change (Penney, 2007; Bicknell and Dodman, 2009). The Cities of Stockholm and Toronto and the Greater London Authority have explicitly incorporated health concerns in their plans and activities (Ekelund, 2007; Toronto Environment Office, 2008; Mayor of London, 2008).

Cities in low-income countries face a much larger hurdle to prepare for climate change, for they need to develop basic structures and services to support adequate housing, water, sanitation, energy distribution, transportation, education, and health-care services and at the same time consider how to do this in a way that will increase adaptation and resilience for their residents and citizens. Some researchers express skepticism about the likelihood that municipal governments will act “to protect the populations within their jurisdiction from risks arising from climate change when they have shown so little inclination or ability to protect them from other environmental hazards” (Satterthwaite *et al.*, 2008, p. 2). They emphasize the need for support from national governments to provide the legal and institutional basis for reducing the risks from climate change and for support from the international community to provide the financial resources. They also discuss successful examples of engaging communities at risk in the process of determining how to adapt and, in some cases, where to move risky settlements (Huq *et al.*, 2007).

7.2 Health-related findings of the IPCC Fourth Assessment Report

Climate change and human health issues are addressed primarily in Chapter 8 of the IPCC’s Working Group II report *Impacts, Adaptation and Vulnerability* (Confalonieri *et al.*, 2007). The authors of the chapter reviewed more than 500 scientific publications related to climate change and health in the preparation of their report. They expressed high confidence that climate change has already altered the seasonal distribution of some allergenic pollen species, and medium confidence that climate change has already modified the distribution of select infectious disease vectors, and that it has increased heat wave-related deaths. The group also expressed high confidence that in future climate change-related exposures would lead to: increased malnutrition and related development effects; increased numbers of deaths, diseases, and injuries from heat waves, floods, storms, fires, and droughts; and increased cardio-respiratory morbidity and mortality from greater ground-level ozone. They also suggested that diarrheal diseases would increase (medium confidence) and more people would be at risk of dengue (low confidence). There may be health benefits from reduced cold weather. The report concluded that adverse health impacts would be greatest

in low-income countries but that adaptive capacity needs to be improved everywhere.

The Chapter 8 of the IPCC Fourth Assessment Report outlined three main mechanisms by which climate change may affect human health:

1. **Direct exposures to extreme climatic events.** These affect health through influences on human physiology (e.g., heat waves) or by provoking physical traumas caused by natural disasters such as storms and floods.
2. **Indirect effects from changes to the determinant factors of human health.** Relevant examples are the effects of the climate on the production of food, on the quality of the water and the air, and the ecology of vectors of infectious diseases (e.g., mosquitoes).
3. **Effects of climatic events on social welfare by disruption of social and economic systems.** For example, migration of populations dependent on subsistence farming to urban areas due to prolonged droughts, which can create a burden for resources and social safety mechanisms of the receiving communities.

There are a variety of modifying influences that can change exposures to extreme weather and climate change impacts or amplify or dampen their health effects. The IPCC chapter distinguished three kinds of modifying factors – environmental conditions, social conditions, and health system conditions (Confalonieri *et al.*, 2007). Environmental conditions include such attributes as location, available water resources, and status of ecological systems. Social conditions include income, knowledge, and the capacity to plan, responsiveness of authorities, and organization of vulnerable populations. Health system conditions refer to the underlying health status of the population (although this could also be characterized as a social condition), and the availability of primary health care and public health and emergency services.

In Figure 7.1 below, adapted from Confalonieri *et al.* (2007), we have added two additional modifying factors that are important for cities. These are density and demographics (see Section 7.4.4), and local infrastructure (see Section 7.4.2). The density of cities can increase vulnerability to the local manifestations of extreme weather and climate change in several ways: reducing green space and mature trees that have a cooling effect on ambient air, for example; creating barriers for natural air and water flow; and producing large quantities of biological waste that can contaminate floodwaters. The location, quality, and upkeep of local infrastructure – water supply, sanitation and drainage, roads and related structures such as culverts and bridges – can all play an important role in modifying health and other impacts of climate change. Ultimately, the level of vulnerability of these modulating systems will be important in the mitigation of adverse impacts, and should be considered when developing adaptation strategies for urban centers.

The IPCC chapter (Confalonieri *et al.*, 2007) described general health risks expected from climate change related to heat and cold; wind, storms, and floods; drought, nutrition, and food

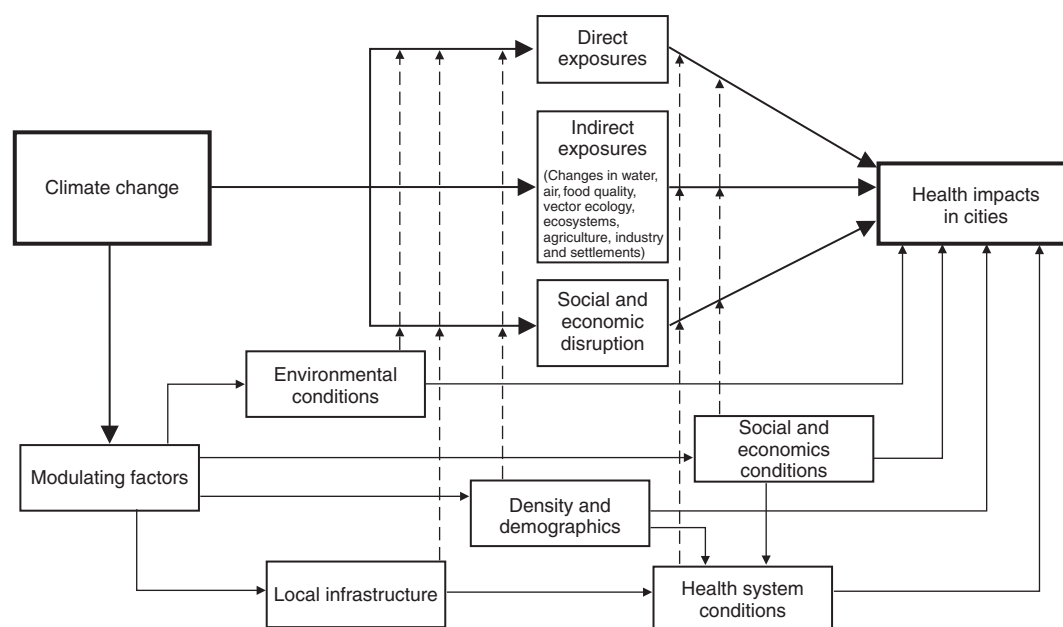


Figure 7.1: Three main mechanisms of how climatic processes may affect health in cities and its modulating factors.

Source: Adapted from Confalonieri *et al.*, (2007).

security; food safety; water; air quality; aeroallergens; and vector-borne, rodent-borne, and other infectious diseases. For the most part the IPCC's health chapter did not address specific urban health issues, though it did mention some urban examples. Since the Fourth Assessment was written, a growing number of authors have explored the impacts of climate change on cities, and more specifically the effects of climate change on the health of urban populations (e.g., Campbell-Lendrum and Corvalán, 2007; de Sherbinin *et al.*, 2007; Huq *et al.*, 2007; Satterthwaite *et al.*, 2008; Gosling *et al.*, 2009; Kovats and Akhtar, 2009; Romero Lankao and Tribbia, 2009). This chapter uses the broad typology of the IPCC chapter, but focuses on the health challenges that climate change appears likely to pose for urban centers.

7.3 Urban health outcomes and their drivers

Cities and city dwellers face many of the same climate-related health issues as the rest of the world's population, but because of the location of many cities, concentration of their populations, the density and impermeability of hard surfaces, the urban heat island effect, increased pressure on local ecosystems for water, concentration of wastes, and the existence of large areas of un- or underserved urban slums, cities have particular vulnerabilities that require assessment and redress.

As the following sections make clear, we expect that climate change will, on balance, increase the overall burden of illness and these deleterious effects are likely to be substantially magnified in urban areas, primarily due to high population densities.

There will be considerable local variation in the health impacts of climate change among cities in different regions, and between cities in the same region. The changes in temperature, precipitation, storminess, and other characteristics of climate change will vary significantly among regions with diverse geographical characteristics, weather patterns, and demographics. But the effects of climate change will also depend on the social, economic, and institutional conditions of each urban center that will determine their initial level of resilience (WHO, 2009; see Section 7.4).

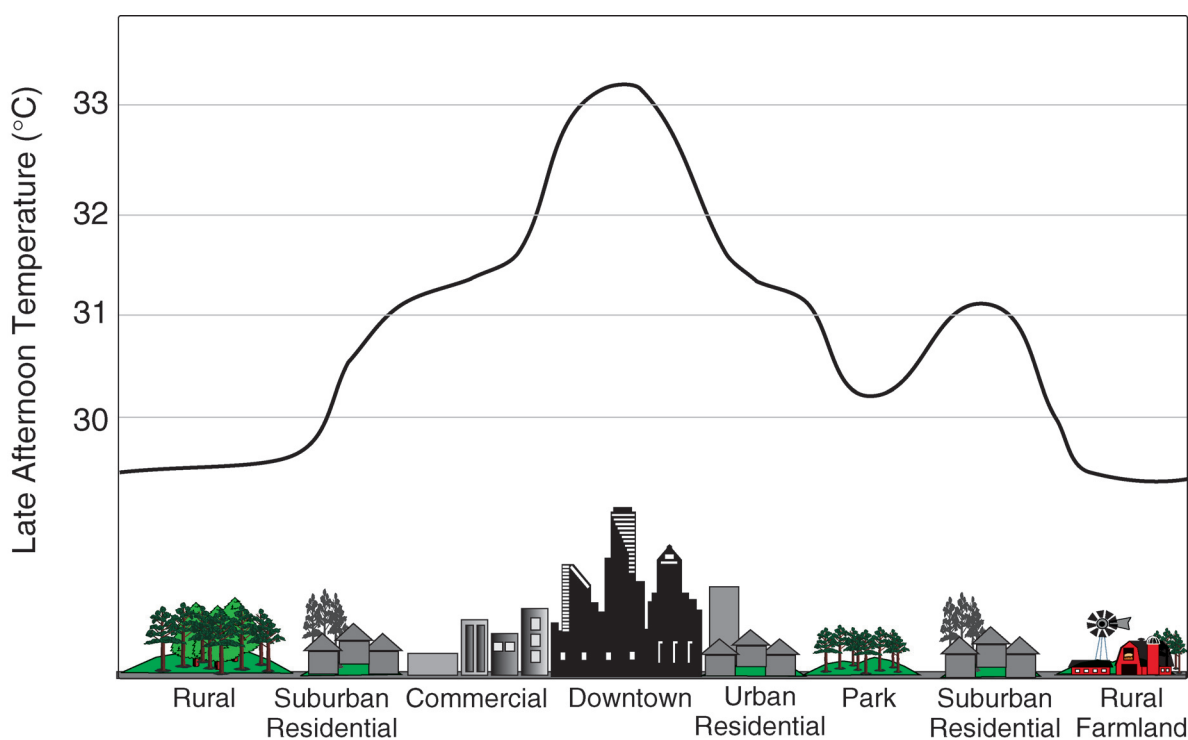
Table 7.1 provides a summary of the drivers and health outcomes linked to climate change. In the discussion of each driver, this chapter looks specifically at how these health concerns might play out specifically in cities.

7.3.1 Heat and cold (temperature extremes)

Mean temperatures are increasing around the world, and the frequency and intensity of heat waves also appear to be on the increase (Della-Marta *et al.*, 2007). Climate models predict increased frequency and intensity of heat waves for the future as well (Meehl and Tebaldi, 2004; IPCC, 2007). This poses direct threats to health through heat stress, especially for the elderly, young children, and those with pre-existing health problems. Heat waves are exacerbated in urban environments by the urban heat island effect, caused by the concentration of concrete and asphalt surfaces, reduction of vegetation, and anthropogenic heat sources. Urban temperatures can be as much as 8°C higher than the surrounding countryside, though typically the increase is more in the order of 3–4 degrees (Oke, 1997). Figure 7.2 provides an illustration of an urban heat profile compared to surrounding suburban and rural areas.

Table 7.1: Climate change-related drivers and outcomes for urban health.

Drivers	Health endpoint	Impact on cities	Degree of uncertainty	Key references
Temperature extremes	Mortality via heat exhaustion. Elderly most vulnerable	Pronounced (via urban heat islands)	Low (extensive evidence exists)	Kovats and Hajat, 2008; Bell <i>et al.</i> , 2008
Wind, storms, and floods	Mortality via physical trauma, drowning	Pronounced (population density in vulnerable areas)	Low (extensive evidence exists)	Guha-Sapir <i>et al.</i> , 2004; Ahern <i>et al.</i> , 2005
Drought	Malnutrition	Ambiguous	Medium (adaptive capacity is poorly understood)	Confalonieri <i>et al.</i> , 2007
Water quality	Diarrheal disease	Pronounced (flush contaminants, may overwhelm city water systems)	High (limited research)	Hunter, 2003; Kistemann <i>et al.</i> , 2002
Air quality	Respiratory illness	Pronounced (population density, pollution sources)	High (limited research, likely to vary greatly across cities)	Kinney, 2008; Holloway <i>et al.</i> , 2008; Steiner <i>et al.</i> , 2006
Aeroallergens	Allergies, asthma	Ambiguous	High (limited research, likely to vary greatly across cities)	USEPA, 2008
Vector-borne diseases	Malaria, dengue, others	Diminished – few vectors thrive in urban environments	High (scholarship on urban effects)	Lindsay and Birley, 1996

**Figure 7.2:** Urban heat island profile.

Source: Natural Resources Canada, Climate Change Impacts and Adaptation Division. Accessed at: http://adaptation.nrcan.gc.ca/perspective/health_3_e.php.

Increasing heat also contributes to smog formation and worsening air quality, both of which tend to be more problematic in urban than rural environments. In urban environments, the effects of heat on air pollution may have a much larger effect on mortality and morbidity than the direct effects of heat stress (Pengelly *et al.*, 2007).

The empirical literature shows that extreme heat events are associated with transient, but potentially substantial, increases in daily mortality (Kovats and Hajat, 2008). The 2003 European heat wave, which is estimated to have killed 70,000 people (Robine *et al.*, 2007), illustrates the deadly potential of temperature extremes. In Paris, where maximum temperatures exceeded 38°C for 6 days, the mortality rate tripled for at least 3 days (Kalkstein *et al.*, 2008). New York, Chicago, Shanghai, and other cities have also experienced higher death rates during heat waves when temperature values exceed about 30°C and nighttime values exceed 25°C (Davis *et al.*, 2003; Laaidi *et al.*, 2006; Tan *et al.*, 2007). The effects of heat waves are sometimes magnified by other forms of environmental stress. For example, heat in combination with increased aerosols can produce pulmonary and cardiovascular diseases (CCSP, 2008).

Almost all epidemiological evidence linking heat waves to mortality draws on urban data. This is borne out in research from high-income countries (e.g., Baccini *et al.*, 2008) and for the limited data available from the developing world (e.g., Bell *et al.*, 2008). While the primary reason for this urban emphasis appears to be data availability, evidence suggests that the urban heat island effect renders city dwellers without access to cooling particularly vulnerable to heat waves (Kunkel *et al.*, 1996).

The ability to combat heat stress varies over different segments of the population. The elderly, for example, have more difficulty acclimatizing to heat, especially when they are first exposed (Zimmerman *et al.*, 2007). Demographic changes may lead to urban populations that are even more vulnerable in the future, as the elderly population grows in absolute and relative numbers. In developed countries, 20 percent of the population in 2005 was aged 60 years or over, and by 2050 that proportion was projected to grow to 32 percent (UN, 2005). The elderly population in developed countries was greater than the number of children (under 14 years of age). The UN projects that by 2050 there will be two elderly persons for every child, and that in the developing world, the proportion of the population aged 60 or over will rise from 8 percent in 2005 to close to 20 percent by 2050 (UN, 2005).

Extreme cold temperatures also affect mortality and morbidity in those latitudes that experience winter. In most cities in Canada, the United States, and parts of Eurasia, there are higher death rates in the cold season (Davis *et al.*, 2003). The increase in global mean temperatures worldwide is expected to reduce cold-related mortality and morbidity, though expected decreases in cold-related morbidity have not yet been observed in Quebec (Gosselin *et al.*, 2008). There is no clear distinction between the impacts of cold on urban versus rural residents.

7.3.2 Wind, storms, and floods

Climate change is likely to bring increases in the frequency and intensity of heavy precipitation events and in the intensity of tropical cyclonic storms with larger peak wind speeds and heavier precipitation due to warmer sea surface temperatures. The frequency of tropical cyclonic storms is projected to stay constant or decline, although the IPCC is not confident in this conclusion, noting, “the apparent increase in the proportion of very intense storms since 1970 in some regions is much larger than simulated by current models for that period” (IPCC, 2007 Summary for Policymakers). Extratropical storm tracks are expected to expand poleward (IPCC, 2007).

A recent series of articles in *Environment and Urbanization* investigated existing and future threats of storms to Cotonou (Benin), Dhaka, Mumbai, Shanghai, and other cities, concluding, “it is within urban centers and urban governments that so much of the battle to prevent climate change from becoming a global catastrophe will be won or lost” (Huq *et al.*, 2007, p. 14). Storms surges and resultant floods pose particular threats to coastal areas, where most cities are located.

These extreme events create direct and indirect effects on health. Direct effects originate from the physical force of flowing floodwater, for example, causing deaths due to drowning. The physical impact of heavy rains and extreme winds due to climate change can cause injuries and deaths from collapsing structures or flying debris, electrocution from damaged power lines, vehicle accidents, and other mechanisms (Greenough *et al.*, 2001). Indirect effects such as contaminated water, compromised infrastructure, and slope instability may create risk of injury, and increase the chance of infectious disease (Ahern *et al.*, 2005; Confalonieri *et al.*, 2007).

Epidemiological evidence on the aggregate health impacts of storms and floods on cities is scarce, largely because a disproportionate share of the burden falls on developing countries due to vulnerability related to poor planning and prevention preparedness (Guha-Sapir and Below, 2002). Anecdotally, however, the impacts of floods and storms can be spectacularly large – for example, a two-week rainfall in 1999 resulted in extensive flooding in Caracas, Venezuela, killing an estimated 30,000 people (Jonkman, 2005). In July 2005, severe flooding in Maharashtra and Mumbai, India was caused by extremely heavy rainfall, up to 100 cm in one day; the flood killed at least 1,000 people and caused approximately US\$3.5 billion in damage (meteogreece, 2005). In August 2005, when the federal flood protection system in New Orleans failed during Hurricane Katrina, 80 percent of the city was flooded, leading to at least 1,836 deaths and resulting in economic damage of greater than US\$100 billion (Grossi and Muir-Wood, 2006). Globally, flooding has been estimated to have caused just over 200,000 deaths in the 30-year period ending in 2003 (Guha-Sapir *et al.*, 2004).

7.3.3 Drought

According to the IPCC Fourth Assessment Report (2007), rising greenhouse gas concentrations are likely to increase the risk of drought in many regions. An increase in mean temperatures of 2–3 °C could result in a decline in yields from rain-fed agriculture by as much as 50 percent in North Africa and other developing country regions (IPCC, 2007). In contrast to the other impacts discussed in this section, droughts usually exert indirect pressure on the health of city dwellers. The primary causal pathway linking drought to urban health is availability of food. A decrease in regional food production reduces availability and raises prices in cities to the degree that the poor are unable to buy sufficient food. (Drought also results in water shortages; this is discussed in Section 7.3.4 below.) This reduces food consumption among the poor, and can lead to malnutrition and even to starvation in extreme cases. The UN's Food and Agriculture Organization recently estimated that at this time more than 1 billion people in the world – one in six – are undernourished because of high food prices, low incomes, and unemployment caused by the global economic downturn around the world (FAO, 2009).

A recent analysis of the impact of extreme weather (heat waves, droughts, and heavy rains) on food production in 16 low- and middle-income countries, concluded that the urban poor would be most strongly affected by reduced supply and increased price of basic grains (Ahmed *et al.*, 2009). The urban poor in Bangladesh, Mexico, and Zambia were particularly vulnerable, according to the study.

Drought may also be an important factor in rural-to-urban migration in some parts of the world (Barrios *et al.*, 2006), which has its own set of public health ramifications. The resulting overcrowding, lack of potable water, food, and housing can increase the spread of infectious disease, for example meningitis and human immunodeficiency virus (HIV) (Molesworth *et al.*, 2003; del Ninno and Lundberg, 2005). Drought also affects water quality and quantity, increasing microbial and chemical load.

7.3.4 Water quantity and quality

Over and above the acute effects of flooding, climate change may reduce access to safe drinking water in cities – some of which already face shortages due to poor water distribution infrastructure and high levels of consumption. First, reductions in rainfall in some parts of the world may reduce seasonal stream flows and diminish available surface water. Surface temperatures tend to fluctuate more rapidly with reduced volumes of water. Also, rising temperatures will increase demand for water and for the services of the urban water supply system (Volschan, 2008) and the extraction of greater quantities of water from superficial and subterranean springs (Ashley and Cashman, 2006).

Rising temperatures can also threaten water systems that capture, store, and transfer water to cities. Increased evaporation

rates can reduce surface water levels and fresh water availability. Cities such as Delhi, which already transports water as much as 300 kilometers to supply 15 million residents, may have to extend their supply lines, coming into competition with other users and with ecological systems (Costello *et al.*, 2009).

Reduced surface water levels, in turn, can alter the exchange rate between groundwater and surface water, reducing the availability of fresh water supplies (Bates *et al.*, 2008). Growing cities that turn to groundwater for their water supply may deplete nearby aquifers and create problems with subsidence, as is the case in Mexico City (Bates *et al.*, 2008).

Cities such as Seattle, dependent on snow-melt for their water supply, are already seeing reductions in water availability (Adam *et al.*, 2009). Some cities and towns that depend on glacial-fed water catchments are currently facing the opposite problem as glaciers melt more quickly in higher global temperatures, creating the threat of inundation (Mool *et al.*, 2001). Over the longer term, however, these areas may face water scarcity as glaciers disappear.

At the beginning of this century, 21 percent of people in low-income countries had poor access to clean water and more than 50 percent lacked access to sanitation (Costello *et al.*, 2009). Reduced water supplies will exacerbate this problem, particularly in informal urban settlements and slums, leading to diarrheal and other diseases.

In urban areas close to seacoasts, saline intrusion caused by sea level rise and extreme events is another factor that can affect water and food supply quality. Also, extreme rainfall events increase runoff, potentially flushing contaminants and sediments into drinking water sources (Kistemann *et al.*, 2002). Each of these processes has the potential to affect urban dwellers, though the Walkerton, Ontario, *E. coli* and *Campylobacter* outbreak in 2000, which resulted in seven deaths and more than 2,300 cases of illness, shows that contamination of water sources from heavy rainfall and rural runoff can affect the residents of smaller towns and rural areas as well (O'Connor, 2002). City water systems that currently provide good quality water may fail under increased pathogen loading, and urban residents who rely on untreated surface water may fall ill even more frequently.

7.3.5 Air quality

Weather plays a central role in determining air pollution levels. Air flow patterns, which are likely to change as the climate warms, govern the dispersion of pollutants. High temperatures tend to accelerate secondary chemical reactions in the atmosphere, particularly those that lead to ground-level ozone. Spatial variations in emissions and air flow patterns mean that the local effects of anthropogenic changes in weather patterns defy generalization. Recent modeling has, however, illuminated some likely patterns in North America.

Knowlton *et al.* (2004) use an integrated modeling framework that combines climate and air-quality models to explore ozone concentrations in the New York metropolitan region under a range of climate scenarios. Their analysis suggests that climate change will engender a 4.5 percent increase in ozone-related mortality in the 2050s compared with the 1990s. More recent efforts to wed downscaled climate models to local atmospheric chemistry models show that air quality in Chicago, San Francisco, and several large Canadian cities is likely to suffer from increased ozone concentrations under plausible climate scenarios (Steiner *et al.*, 2006; Holloway *et al.*, 2008). In a national level analysis, Bell *et al.* (2007) developed climate scenarios and ozone models for 50 US cities. Their results show substantial variation across cities, although most project substantial increases in ozone concentrations under climate change. Cheng *et al.* (2009) conducted a similar analysis for south-central Canada, estimating that air pollution-related mortality could increase 20–30 percent by the 2050s and 30–45 percent by the 2080s, due largely to increases in ozone effects. The air pollution-related effects of temperature increases are expected to contribute much more to mortality than heat effects alone.

Climate change may also increase the frequency and severity of forest fires (Peterson and McKenzie, 2008), which can affect air quality over thousands of square kilometers.

7.3.6 Aeroallergens

Climate change will likely alter the onset of the spring pollen season in temperate zones, and some evidence suggests that the duration of the pollen season in some countries may lengthen, increasing allergic reactions (USEPA, 2008). These effects are due both to warming and to direct fertilization of plants by higher atmospheric concentrations of CO₂, and may be amplified by urban heat islands and urban CO₂ (Ziska *et al.*, 2003). Currently, the linkage between climate, aeroallergens, and health is not well understood however, and it is not known to what extent the effects may vary between cities and rural areas.

7.3.7 Vector-borne, food-borne, and water-borne diseases

According to the recent Lancet Commission on Managing the Health Effects of Climate Change, rising temperatures are expected to affect the spread and transmission of diseases carried by vectors such as mosquitoes, ticks, and mice (Costello *et al.*, 2009). Temperature affects the rates of pathogen maturation and replication in mosquitoes and insect density (Costello *et al.*, 2009). Warmer temperatures may contribute to the increased incidence of mosquito-borne diseases such as malaria, dengue, yellow fever, and West Nile. Schistosomiasis, leishmaniasis, Lyme disease, tick-borne encephalitis, hantavirus infections, and a number of other vector-borne diseases are also projected to increase as a result of climate change.

Malaria, dengue, West Nile and a number of other vector-borne illnesses are currently in a period of rapid expansion. More than 50 percent of the world's population is exposed to malaria, which

is estimated to cause 300–500 million acute illnesses each year and 1.1–2.7 million deaths, of which 90 percent are estimated to occur in Africa (UN Millenium Project, 2005), and the disease is reappearing elsewhere (Reiter, 2008). There are anecdotal reports of malaria increases in some Indian cities, attributed to breeding pools of stagnant water at construction sites and to water in “tap pits” below ground level, which have been dug during times of water shortage (Nagaraj, 2009). Malaria has also surged in some South American cities (Gubler, 1998). Malaria has recently been described as “probably the most climate-sensitive vector-borne disease” (Githeko, 2007); its incidence is affected not only by temperature but by precipitation, humidity, and wind. The attribution of the recent malaria resurgence to climate change is contested by some authorities, however, who argue that other factors such as reductions in public health expenditure are more important than increased temperature in the spread of these diseases (Reiter *et al.*, 2004).

Forty million cases of dengue and several hundred thousand of dengue hemorrhagic fever occur each year (Jelinek, 2009). High levels of dengue exist in Asia. The disease is expanding rapidly in Latin America and recently appeared in North America and northern Australia. The surge in cases of dengue in regions previously considered atypical, such as the south of the United States near the Mexican border, may be related to changes in spatial distribution of the insect vector due to climate change (Barclay, 2008). Dengue is described by researchers as an “urban disease” spread mainly by the *Aedes aegypti* mosquito, which breeds in still water in containers (Lapitan *et al.*, 2009). The disease spreads in poor, densely populated areas of cities with inadequate water supply. Beebe *et al.* (2009) attribute the resurgence of dengue in Australia to the installation of large numbers of domestic water tanks as a response to recent droughts.

The first West Nile virus outbreak occurred in North America in 1999, likely as a result of an import of the vector by international air transport. Since then, the disease has spread across the United States and most of Canada, transmitted by mosquitoes that acquire the virus from infected birds. Epidemics in 2002 and 2004 were linked to locations with drought or above-average temperatures, and a more virulent mutated strain that “responds strongly to higher temperatures,” suggesting that risk will increase with frequent heat waves (Karl *et al.*, 2009). The West Nile vector *Culex pipiens* (which also carries St. Louis encephalitis), is said to “thrive in city storm drains and catch basins, especially in the organically rich water that forms during drought” (Epstein and Defilippo, 2001).

It is hard to generalize about the extent of the risk that expansion of most mosquito-borne diseases will pose for urban areas, or about the extent to which climate change will contribute to this problem overall. Cities do not generally provide the best environments for reproduction of mosquitoes, though standing water in plant pots or urban detritus such as car tires can provide breeding places for these vectors (Hay *et al.*, 2002). Temperature, precipitation levels, humidity, and wind speeds, as well as the level of public health services all affect the proliferation of vectors and the spread of the diseases of concern.

The risk of food-borne illnesses is also expected to increase under climate change. *Campylobacter* is the most commonly reported gastrointestinal disease in Europe, with contaminated poultry a major source of the infection. Rapidly rising temperatures increase the colonization of broiler chicken flocks with *Campylobacter* (Kovats *et al.*, 2005). In a study of *Salmonella* infections in 10 countries in Europe, Kovats *et al.* (2004) found that illnesses were linearly associated with temperatures above 6°C and that temperature influenced about 35 percent of all cases in six of these countries. An Australian study also found a positive association between mean temperatures in the previous month and the number of reported cases of salmonellosis in five cities (D'Souza *et al.*, 2004).

The prevalence of food-borne illnesses is undoubtedly higher in tropical low-income countries than in Europe or Australia, but the absence of public health reporting in most low-income countries makes it difficult to estimate the impact of temperature increases. The World Health Organization has undertaken a recent study to better estimate the current incidence of food-borne diseases in developing countries, but the report is not expected until 2010. It is not known whether there is a specific pattern of food-borne illness associated with urban versus rural residency, though higher temperatures in urban environments might be expected to influence the number and extent of outbreaks in cities.

Water-borne illnesses are strongly associated with heavy rainfall. Charron *et al.* (2004) chronicled a host of *E. coli*, *Campylobacter*, *Cryptosporidium*, *Toxoplasmosis*, *Giardia*, *Leptospirosis*, and non-specific gastroenteritis outbreaks in North America since 1993 that have been associated with a sustained period of rainfall or an extreme rainfall event, which contaminated water and in some cases overwhelmed water-treatment systems.

7.4 Climate change and urban health outcomes: modifying influences

As indicated in Figure 7.1, there are a number of environmental, economic, and social factors that can influence health vulnerabilities and modify the health impacts of climate change in cities around the world. These modifying influences are discussed below.

7.4.1 Local geography and environmental conditions

The environmental conditions that amplify or reduce climate-related health effects are strongly linked to local geography. A number of studies that explore the health impacts of climate change on cities, including the direct effects of heat (Luber and McGeehin, 2008); vector-borne diseases (Gage *et al.*, 2008); water-borne diseases (Patz *et al.*, 2008); and air quality (Kinney, 2008) describe the way these climate-linked health effects vary by location, emphasizing the importance of understanding spatial scales and geographic influences on health.

Some of the factors that may amplify or reduce the susceptibility of city dwellers to the health effects of climate change include:

- proximity to seacoast, especially on low-lying river deltas and coastal areas that are subsiding
- location in tornado or hurricane zones
- arid regions with limited water supply
- dependence on glacier melt or snowmass for water supply
- mid-continental location with exposure to a wide range of temperatures.

Coastal cities, especially those that inhabit low-lying deltas and cities that have grown up on the edge of large tidal rivers are especially vulnerable to floods and storms. Globally, 13 percent of the world's urban population lives in a low-elevation coastal zone (LECZ) – a coastline area with an elevation of 10 meters or less (McGranahan *et al.*, 2007). Egypt, Bangladesh, and Vietnam have 38, 46, and 55 percent of their populations living within a LECZ, the majority in densely populated urban settings. In the Netherlands, 65 percent of the urban population lives in LECZ (McGranahan *et al.*, 2007). A recent review for the Organization for Economic Cooperation and Development (OECD) examined the current and projected exposure of port cities around the world to surge-induced flood events (Nicholls *et al.*, 2008). The top 10 cities in terms of population exposure were identified as Mumbai, Guangzhou, Shanghai, Miami, Ho Chi Minh City, Kolkata, Greater New York, Osaka-Kobe, Alexandria, and New Orleans. The study identified 30 cities that contain roughly 80 percent of exposure; of these, 18 cities are located in river delta zones. Cities with the greatest exposure to extreme sea levels also tend to be those with the greatest exposure to wind damage from tropical and extra-tropical cyclones. The total urban population exposure is expected to triple by the 2070s.

Cities that are already on the path of tropical cyclones and tornadoes will be most at risk from increases in the intensity or extent of these storms and the related health effects. According to the United Nations Prevention Web (2009), the largest populations currently at risk are found in: Bangladesh, China, India, Japan, Korea, Madagascar, Philippines, Taiwan, and the United States. Almost 30 percent of the population of Taiwan is exposed, compared to 19 percent of the population in Philippines, 18 percent in Japan, and 15 percent in the United States.

The El Niño–Southern Oscillation (ENSO) affects temperature, precipitation, storm tracks, and the frequency of tropical cyclones in many regions of the world, especially the west coast of South America, Southeast Asia and the northwest of North America (see Chapter 3). Episodes of El Niño have been more frequent, persistent, and intense since the mid 1970s compared with the previous 100 years (WHO, 2005), but it is unclear whether this is related to anthropogenic climate change. Two very intense episodes of El Niño in 1982–3 and 1997–8 combined with land use changes caused floods, droughts, and landslides, causing many deaths and damaging infrastructure and impacting economic activity in urban areas of Asuncion, Havana, the Panama Canal watershed, and Quito (Satterthwaite *et al.*, 2007). Climate

fluctuations related to ENSO are also linked to a range of diseases, including malaria, cholera, and dengue (Haines, 2008).

The effect of rising temperatures will be felt unevenly across the world. Cities in northerly latitudes and continental locations may feel the effect of increased and more extreme heat waves most, because people in these locations tend to be less acclimated to warm weather. Geographic features such as the location of nearby water bodies, topography, prevailing winds, and other factors may modify these effects (Lombardo, 1985 in Ribeiro, 2008). A recent study investigated future heat-related mortality impacts on six cities (Boston, Budapest, Dallas, Lisbon, London, and Sydney) by applying temperature projections from the UK Met Office HadCM3 climate model to temperature–mortality models (Gosling *et al.*, 2009). The results demonstrate that mortality is more likely to increase in cities with greater temperature variability combined with health- and age-related factors rather than with the change in mean temperature alone.

The extent to which the natural local environment has been changed and/or degraded is also a major factor in amplifying or reducing the health impacts on people in cities from climate change. Deforestation, for example, can increase the impacts of heavy precipitation events. A recent assessment of natural hazards in Indonesia indicates that landslides are increasing as a result of heavy rainfalls combined with deforestation and the expansion of development into unstable hillslope areas (Marfai *et al.*, 2008). Between 2000 and 2007, 57 landslide disasters occurred in the Central Java province. The most severe of these occurred in the town of Banjarnegara, causing 142 deaths and damaging 182 houses. The city of La Paz, Bolivia, is also prone to landslides triggered by heavy prolonged rainfall on low-income, self-built settlements on steep, unstable slopes (O'Hare and Rivas, 2005). Although more drought is predicted for this region under climate change, more intense precipitation events are also likely to occur, which will aggravate the current risks if measures are not taken to adapt.

7.4.2 Local infrastructure and urban planning

Cities depend on a wide range of infrastructure networks and systems to assure the health of their residents, as outlined in Table 7.2.

This infrastructure is meant to supply or assure the necessities of life and health to city dwellers. Transportation networks bring in food and other products, allow city dwellers to get to jobs and services and to escape from disasters; water distribution systems supply water – sometimes from very far away; sewage and garbage collection systems remove harmful wastes; energy systems provide power for lighting, cooking, food storage, heating, air conditioning, and transportation; communications systems provide warning of weather-related and other problems; emergency services help rescue residents in difficulty; and so on. When one or more of these systems is absent (as is the case in many unplanned urban slums and informal settlements around the world), works

poorly, is overwhelmed or breaks down, urban residents are more vulnerable to health problems (Hardoy and Pandiella, 2009).

The very large numbers of the urban poor who live in unplanned settlements in low- and middle-income cities have limited access to infrastructure and other services that urban residents in high-income countries take for granted. The absence of these services aggravates their vulnerability to current weather extremes and to climate change. A recent assessment of climate impacts in Kampala described some of the problems that arise in that city as a result of a very limited infrastructure system combined with heavy rainfall (Mabasi, 2009). Most residential areas and slums have no stormwater drainage systems. The natural drainage channels that exist are increasingly obstructed by construction of informal settlements as well as new commercial buildings. There is very limited solid waste collection in Kampala, which results in garbage and plants clogging drains, and leads to localized flooding even with light rainfall. Only 8 percent of Kampala houses are connected to the city's sewer system. The rest rely on pit latrines, or even dispose in plastic bags thrown into garbage pits or water channels (Kyalimpa, 2009). Uganda's national adaptation plan for action (Republic of Uganda, 2007) reports that heavy rains have already increased in intensity and frequency, resulting in a growing number of floods, mainly in the low-income settlements in low-lying areas of Kampala, which have affected almost half a million city residents. Floodwaters are usually contaminated by the overflow from latrines, septic tanks, and sewers (Mabasi, 2009). One of the health effects seen from flooding in Kampala is cholera, with 200 cases and four fatalities in 2002 (Alajo *et al.*, 2006; Kovats and Ebi, 2006), and more than 200 cases in 2006. Other health effects of the floods were not well monitored, but it is likely that other illnesses also occurred as a result of these floods (Few and Matthies, 2006). At the time of writing – in the fall of 2009 – flood warnings are again being sounded for Kampala.

Well-built urban infrastructure and good urban planning can moderate the impacts of climate change. In the case of cities in low-income countries, urban planning that diverts the construction of informal settlements from flood-prone areas could reduce the impacts of high-intensity rain events. Developing sewage and drainage infrastructure for areas that are not currently serviced would also reduce impacts.

During the European heat wave of 2003, the cold storage systems of 25–30 percent of food-related establishments in France were found to be inadequate (Létard *et al.*, 2004, cited in IPCC (2007a) and Bobylev, 2009). Electricity demand for air conditioning increased, but the heat undermined electricity production by raising the temperature of river water used for cooling in power plants. Six nuclear plants, dependent on river water for cooling, were shut down. A similar situation arose in July of 2009, when a summer heat wave put a third of France's nuclear power stations out of commission (Pagnamenta, 2009).

Climate change-related natural disasters can severely damage urban infrastructure which, in turn, can impede the availability of water, food, energy, transportation services, and other inputs

Table 7.2: *Urban physical infrastructure systems and their contribution to health.*

Types of urban infrastructure	Examples	Contribution to health of city dwellers
Transportation	• Roads and highways (including bridges, tunnels, culverts, street and traffic lights) • Railways, including terminals • Ports, canals and waterways, and ferries • Mass transit systems (commuter rail, subways, bus terminals) • Pedestrian walkways and bicycle paths • Airports and air navigation systems	• Transport of food, medical supplies • Access to services, including health services • Access to employment • Access for emergencies and emergency services
Water management	• Drinking water supply, including storage reservoirs, filtration, treatment, and distribution systems • Sewage collection, treatment, and disposal • Stormwater/drainage systems • Flood control systems (dikes, levees, floodgates, pumping stations, etc.)	• Provision of clean water for drinking and washing • Removal of potentially hazardous biological wastes • Control of floods
Waste management	• Waste collection • Landfills and incinerators • Hazardous waste disposal facilities	• Removal and disposal of potentially hazardous wastes
Energy	• Electrical power generation, grid, substations, etc. Natural gas storage and distribution • Petroleum storage and distribution • Steam or hot water generation and distribution for district heating systems	• Provision of energy sources for lighting, heating, cooking, refrigeration, air conditioning
Health	• Hospitals and community health-care centers • Ambulance and emergency treatment services • Public health services (vaccination, education, etc.)	• Treatment for illnesses and injuries • Prevention of illness
Communications	• Radio towers and signaling systems • Mobile phone networks • Telephone, television, and internet cable systems • Dedicated telecommunications networks (such as those used for emergency services)	• Communication of health information • Warning and advice • Emergency communications
Urban green space	• Parks and other green spaces • Water courses and wetlands • Urban trees and vegetation	• Cooling in hot weather • Natural drainage • Space for recreation
Geophysical monitoring networks	• Meteorological monitoring (and warning) systems • Tidal monitoring • Fluvimetric systems (for gauging river flow)	• Advanced warning of problem conditions

relevant for the maintenance of the quality of urban life and, consequently, of health. For example, a succession of deadly midwinter ice storms that hit the eastern Canadian provinces in January 1998 demolished 130 electricity transmission towers carrying electricity from distant hydroelectric dams, felled 30,000 utility poles, and damaged millions of trees, especially in the cities of Montreal and Ottawa. More than 4.7 million Canadians were without power, in some cases for up to three weeks. The storms resulted in 28 deaths, mainly from trauma or hypothermia, and almost 1,000 serious injuries (Lecomte *et al.*, 1998). More than 100 people were treated for carbon monoxide poisoning from using generators indoors to heat their homes (Risk Management Solutions, 2008). The cities of Kingston, Montreal, Ottawa, and Smiths Falls declared states of emergency, and the army was called in to help stranded residents and to clear fallen trees and debris. Rural residents, especially dairy farmers and maple syrup producers, were also very hard hit. Climate change

is expected to bring more frequent freezing rain events to parts of Canada over the next several decades (Lemmen *et al.*, 2008).

When new or updated infrastructure systems are built, they should be planned with climate change in mind to safeguard the infrastructure investment. Sewage treatment plants should be situated to avoid flooding from intense rains, sea level rise and storm surges (see Chapter 5 on water). Combined sewage and stormwater systems, which exist in many urban centers, should be separated to avoid contaminating stormwater overflow. Water distribution systems need to be maintained to prevent the loss of large quantities of treated water through fissures in the pipes, to avoid wasting water in situations of drought and water shortage. Consideration also has to be given to the dangers of cascading failures in interdependent infrastructure such as water distribution systems that depend on electrical power. Convergent infrastructure – where electrical power lines, communications, and

[VULNERABILITY] Box 7.1 United Kingdom floods in 2007**Jennifer Penney***Clean Air Partnership*

For the most part, cities in high-income countries have well-developed infrastructure, though as it is presently constructed it may not provide sufficient protection in the face of extreme weather, as evidenced by the floods that swept much of the United Kingdom in June and July of 2007. The wettest weather the UK had experienced since records began caused the “country’s largest peacetime emergency since World War II” (Pitt, 2008), flooding 55,000 properties in dozens of towns and cities, stranding 7,000 people who were rescued from floodwaters by emergency crews, and causing the deaths of 13 people. Flooding of water treatment

plants and electrical substations left half a million people without drinking water or electrical power. Thousands were stranded on flooded roads, rail lines, and even schools. Several nursing homes were evacuated. Tens of thousands of people were made homeless and thousands remained so a year after the floods receded. Apart from the deaths reported by Pitt (2008), evidence of health effects from the flooding is mainly anecdotal, and includes acute stress, depression, and other mental health problems; asthma attacks resulting from exposures to mould in flood-damaged buildings; and diarrhea. Because the existing infrastructure and emergency services in the UK are well-developed, the health impacts were much less severe than they might have in the case of similar floods in poorly organized urban environments in low-income countries.

other systems are carried by the same physical infrastructure – can also be a problem (Bobylev, 2009).

7.4.3 Social and economic conditions

Social and economic conditions can also increase or decrease vulnerability to the health effects of climate change. Romero Lankao and Tribbia (2009) conducted a meta-analysis of the literature on vulnerability, adaptive capacity, and resilience in urban centers, and identified a wide range of social and economic determinants of vulnerability including:

- *individual factors* such as age, gender, ethnicity, migrant status, and pre-existing health problems (which is discussed further in Section 7.4.4 on density and demographics)
- *individual assets* such as income, employment, education, housing (quality, access)
- *collective assets* such as concentrated affluence, stability, location, services (access, quality), infrastructure (access, quality), and technology
- *institutional (political) factors* such as knowledge, policy responses, governance practices, urban planning, political power, patronage, and (not specifically mentioned by Romero Lankao and Tribbia) structural adjustment policies by international lending agencies that force national governments to reduce social spending
- *institutional (social) factors* such as social networks and community-based organizations (Romero Lankao and Tribbia, 2009).

It is beyond the scope of this chapter to discuss all of these modifying factors; however, a few of them are examined below.

7.4.3.1 Individual assets

A variety of individual assets are widely accepted as “determinants of health” and contribute to the level of vulnerability

of human populations to the health effects of climate change (PHAC, 2009). These include income, social status, education and literacy, employment and working conditions, and life skills, which are to a large extent interdependent. The poor are less well nourished, more susceptible to illness, and are less able to protect themselves and to recover from adverse events such as floods, heat waves, or droughts. Poverty limits the locations where low-income people can live – often forcing them into illegal settlements in risky locations on floodplains or unstable hillsides that have little or nothing in the way of infrastructure services (Bartlett *et al.*, 2007). In these areas they are exposed to disease vectors, including mosquitoes, resulting from lack of liquid or solid waste management (WHO, 2005; Kjellstrom *et al.*, 2007). The poor have fewer resources and skills for building housing that is more resilient to storms and floods, or to recover when extreme weather events damage their communities, shelters, belongings, or their health (HDR, 2007).

Winchester and Szalachman (2009) recently described the vulnerability of the urban poor in Latin America and the Caribbean (LAC) to climate change. Two out of three poor people in the region live in cities. In countries such as Honduras, Nicaragua, and Paraguay, more than 50 percent of urban residents are poor. The earnings of the urban poor are low, their employment precarious, they have little access to social security, and have low levels of formal education and skills. They tend to live in overcrowded conditions (three or more people to a room) in poorly constructed housing with poor or non-existent sanitation, limited access to clean drinking water, waste in the streets, and indoor air pollution from cooking over wood. Many of the urban poor live in neighborhoods with high levels of crime and violence.

7.4.3.2 Collective assets

Collective assets include general affluence, physical infrastructure (which has already been discussed), stability, services,

and technology. Affluent countries spend more on infrastructure and services that reduce vulnerability even when large disparities of income remain within the population. They are more likely to have functional health and emergency services that can intervene to reduce health impacts of extreme weather and climate change (UNEP, 2008).

Stability can also amplify or diminish the impacts of climate change on health. Unstable nations – such as Afghanistan, Democratic Republic of the Congo, Iraq, Somalia, Sudan, and Zimbabwe (Foreign Policy, 2009) – characterized by weak government with little practical control over much of their territories, absence of public services, widespread corruption and criminality, large numbers of refugees, and economic disarray, are unable to prepare for climate change or to adequately respond to extreme weather events. Several authors argue that drought and other manifestations of climate change have already contributed to the instability of countries such as Sudan (Oxfam, 2009).

7.4.3.3 Institutional factors

There are many institutional factors that can contribute to protecting urban communities from the health effects of climate change, or conversely make them more vulnerable. Cities that are institutionally well-organized and resourced are much better situated to plan climate change programs and implement them. The specific institutional factors that could reduce the vulnerability of city dwellers to climate change include:

- government stability
- public sector economic resources
- existence of infrastructure networks that provide clean water, sanitation, energy, and public transportation
- primary care and public health services with the capacity to investigate and plan for weather-related hazards
- legal authority to act (and enforcement capacity) in areas of concern, including flood plain management, land use planning, building codes, water quality standards, etc.
- political and/or executive leadership (Penney, 2007)
- government culture including “pro-poor” attitude (Satterthwaite *et al.*, 2008), orientation towards long-range planning; low levels of corruption and political patronage (Romero Lankao and Tribbia, 2009)
- access to historical and current local meteorological information, as well as to regional climate projections that can help identify weather trends, extremes and possible future conditions
- robust disaster risk management planning and emergency response systems.

See Section 7.5.1 on adaptive capacity for further discussion of these issues.

7.4.4 Density and demographics

The concentration of human populations in cities has both advantages and disadvantages with respect to the impacts of climate change. By bringing together more people, urban centers

also concentrate knowledge, skills and resources, giving rise to the potential for creative and effective responses to climate change. Human populations are concentrating in cities in every region of the world (Martine, 2009). Currently, 50 percent of the global population dwells in cities, but this percentage is expected to grow above to 60 percent over the next three decades (Wilby, 2007). The world urban population is likely to increase by 3.1 billion between 2007 and 2050 (UN Population Division, 2008), as a result of general population growth, continuing rural–urban migration and the transformation of rural settlements into urban centers. Although populations are increasingly concentrating in urban areas, cities have been spreading out in recent years, with the average density of built-up areas in industrialized countries decreasing from an average of 3,545 to 2,835 persons per km² in the period 1990–2000, and in developing countries from 9,560 to 8,050 persons per km² in the same period (Dodman, 2009).

The concentration of populations in cities is widely regarded as positive for reducing greenhouse gas emissions, although a variety of other factors affect energy use and emissions from towns and cities, especially general levels of consumption. However, increasing the concentration of populations in urban areas, especially in low- and middle-income countries, increases vulnerability to the impacts of climate change. As Dodman (2009) points out, the effects of climate change over relatively small land areas can affect large numbers of people who live in dense concentrations. This is particularly worrisome when urban populations continue to grow in coastal cities that are already subject to sea level rise and cyclonic storms (McGranahan *et al.*, 2007), or arid mountain zones with water shortages (Karl *et al.*, 2009). Much of the increase in urban populations in developing countries is concentrated in informal settlements and slums (UN-HABITAT, 2003), whose lack of infrastructure is a factor in vector- and water-borne diseases, stress, and overall mortality. The spread of hard surfaces and reduction of green space in growing urban agglomerations also contributes to health effects related to heat waves and floods.

Climate change is likely to increase rural–urban and in some cases urban–urban migration, as a result of drought, flood, coastal zone inundation, and extreme weather events. Large migrations and damage to existing housing are likely to contribute to the growth of informal or squatter settlements in urban areas. Migratory processes affect the spatial distribution of endemic infectious diseases. Confalonieri (2008) described two surges in the increase of infectious disease as a result of drought-related migration: (1) an increase in the number of malaria cases in Maranhão state resulting from the return of migrants after the end of the 1982–3 El Niño-related drought; and (2) epidemics of visceral leishmaniasis, observed in some cities in the northeast of Brazil in the early 1980s and early 1990s, due to the advance of drought in this region.

In urban areas where appropriate infrastructure is in place and maintained, the concentration of population, wealth, and resources can provide the wherewithal to build climate resilience cost-effectively (Dodman, 2009). Satterthwaite *et al.* (2007)

emphasizes that making safe areas of urban land available for low-income urban groups is critical for reducing vulnerability.

Current forms of urbanization often curtail household food production and may cause environmental damages through long-distance transport (Kjellstrom *et al.*, 2007). During and after extreme events, people in cities may be cut off from food supplies or may be subject to unaffordable rises in the cost of food. Keeping production of foods close to or in urban centers can bring positive aspects for health and the environment related to urban food security and nutrition. However, it may also create some risks to human health, especially in developing countries where urban lands and irrigation waters may be contaminated by human and chemical wastes (Lock and van Veenhuizen, 2001).

In all regions, people at greatest risk of climate change are the urban poor, the elderly, children (see Box 7.2), the medically infirm, and marginalized populations. A recent study of 16 developing countries found that the urban, wage-labor-dependent poor were particularly vulnerable to climate volatility that reduces agricultural productivity and raises the price of staple foods, especially in Africa, Bangladesh, Indonesia, and Mexico (Ahmed *et al.*, 2009).

The elderly are also at increased risk, especially if they are socially isolated and living on limited incomes. They may not be able to move out of harm's way, augmenting their chances of suffering both physical stress and trauma. This was borne out in New Orleans, where 67 percent of casualties due to Hurricane Katrina were 65 years of age or older (Sharkey, 2007). Elderly people have diminished capacity to regulate body temperature, and many have underlying medical conditions that can be exacerbated by the stress of exposure to extreme heat. During the 2003 European heat wave, excess mortality was estimated at 20 percent for those aged 45–74 years, 70 percent for those aged 75–94, and 120 percent for people older than 94 (European Commission, 2008).

Children, like seniors, are considered one of the most vulnerable groups in weather-related disasters (Wilbanks *et al.*, 2007). Children make up a large proportion of the population in the countries that are most vulnerable to climate change, including the urban areas. Children under five typically make up 10–20 percent of the population in low-income countries, compared to approximately 4 percent of the population in high-income countries. Children under 18 constitute 40–50 percent of the population in the most vulnerable countries, compared to an average of 20 percent of the population in rich countries (Bartlett, 2009).

7.4.5 Health system conditions

In general, the better that public health and primary health-care systems are able to cope with current levels of disease and climate variability, the better prepared they will be for climate change (Nerlander, 2009). Health system conditions that may help reduce the impacts of climate change include universal access to primary health-care providers, laboratory services, and

standardized diagnosis and reporting systems, which are crucial for national health surveillance (Nerlander, 2009).

In 1994, the US Public Health Functions Steering Committee (Frumkin *et al.*, 2008) listed ten essential services that make up a strong public health system and which should afford some protection from the health effects of climate change. These include:

1. monitoring health trends and diseases to identify community health problems
2. investigating and diagnosing health problems and health hazards in the community
3. informing and educating the public and policymakers about health issues
4. mobilizing community partnerships to identify and solve health issues
5. developing policies and plans to strengthen individual and community health efforts
6. enforcing laws and regulations that protect health and safety
7. linking people and personal health-care services
8. ensuring the competence of the health-care workforce
9. evaluating the accessibility and quality of personal and population-based health services
10. conducting new research to provide insights and solutions to health problems.

There are a number of more specific health system conditions that may amplify or reduce the health impacts of climate change. These include:

- involvement of the health sector in planning of water, sanitation, and other health-sensitive services (Nerlander, 2009)
- reliable information from meteorological monitoring systems, linked to early health warning systems to help the population protect itself from the health effects of heat, floods, storms, and other extreme weather (Costello *et al.*, 2009)
- surveillance systems that identify when climate-sensitive illnesses emerge or suddenly increase (Frumkin *et al.*, 2008)
- public health education to guide personal responses to heat, food-borne and water-borne illnesses and other climate-related illnesses (Frumkin *et al.*, 2008)
- vector control and the detection and treatment of vector-borne diseases (Nerlander, 2009).

7.5 Adaptation

In the past decade, general awareness of climate change has grown, and weather trends, extreme events, and related impacts are being associated with climate change. Many cities around the world have advocated, developed, and implemented actions to reduce greenhouse gas emissions, but until recently have not begun to consider adaptation. This is changing since weather in many cities has become noticeably more extreme. City governments are responsible for many services and infrastructure affected by climate variability and change: electricity distribution; water supply and wastewater; stormwater

[VULNERABILITY] Box 7.2 Children's health and climate change**Gregorio De Simone***Instituto Oswaldo Cruz, Fiocruz*

Bartlett (2008) summarized many of the vulnerabilities of children to climate change impacts:

- children are more likely to experience life-threatening diarrhea as a result of exposure to water- and sanitation-related illnesses spread by intense rainstorms and floods
- droughts that lead to food shortages are likely to lead to malnutrition, affecting the health and development of poor children
- children are particularly at risk of malaria, expected to spread as temperatures rise around the world
- asthma and other respiratory illnesses affected by air quality are on the rise, with the greatest increase among children, and asthma deaths are expected to increase 20 percent by 2016
- children have higher mortality rates than adults (except for the elderly) in heat waves, especially in cities
- the quality of care for children is reduced when families are adversely affected by weather events.

Because of immature organs and nervous systems, more rapid metabolisms, lower immunity, and lack of experience, children are especially vulnerable to the health effects of a variety of climate-related risks (Balbus and Wilson, 2000; Patz *et al.*, 2000; Bunyavanich *et al.*, 2003; Martens and McMichael, 2002; Haines and Patz, 2004). Children exposed

to floods in Nepal were twice as likely to die as adults, and pre-school girls were five times more likely to die than adult women (Bartlett, 2008). Children exposed to extreme heat, vector-borne diseases, reduced food supply, scarce or contaminated water, air pollution, allergens, and weather-related disasters – all likely to be exacerbated by climate change – are also more likely to experience long-term repercussions than adults. For example, children born in Africa during drought years are significantly more likely to be malnourished or stunted (UNDP, 2007).

Some urban children are particularly at risk, especially those growing up in urban slums in low-income countries. Nowadays, hundreds of millions of children live in conditions of urban poverty, and in some slum areas 25 percent of children die before the age of five, indicating their susceptibility to disease and injury. Bartlett (2008) cites the example of Nairobi, where children in the Embakasi slum have a mortality rate of 254 per thousand for children under five, compared to 62 per thousand for children for children across the whole of Nairobi and 113 per thousand for children in Kenya's rural areas.

Climate change is an issue not just for today's children; it poses long-term risks for generations of children to come. Many of today's children will live into the 2080s, by which time climate change will be much more entrained unless actions to reduce emissions are undertaken now. (Waterston and Lenton, 2000).

management; roads and bridges, and public health (see relevant chapters in this book). As a consequence, a growing number of city governments are beginning to consider how to respond to extreme weather and climate change and protect the health of their residents.

The capacity to adapt to climate change varies substantially from region to region, city to city.

Factors that affect adaptive capacity include: availability of economic resources; governance; institutional capacity; socio-cultural factors such as social support networks; and access to and deployment of adaptive technologies.

A key factor that will affect human health is the adequacy of economic resources available for these efforts. Individuals and families with more economic resources are able to afford emergency measures and medical services, and to stockpile supplies in preparation for a climatic event. Urban centers with greater economic resources can decrease impacts and vulnerability if they use these resources to create a more climate-resilient city. This is bolstered by new networks of towns and cities such as the Urban Leaders Adaptation Initiative in the United States and the Alliance for Resilient Cities in Canada, which meet via electronic conferencing systems to learn about recent

impacts research, climate change risk assessments for municipal infrastructure, and emerging municipal adaptation programs and strategies (CCAP, 2009; Clean Air Partnership, 2009).

Adaptive capacity also depends on access to technologies, training, and skills development. Cities that have greater access to technologies can install early warning detection systems. Individual access to technologies such as computers and internet communications systems, telephones, radio, and television can decrease vulnerability by increasing access to information, weather alerts, and health advice.

As Satterthwaite and his colleagues (2007) have argued, many of the urban areas that need to adapt the most urgently to preclude major impacts have serious gaps in these building blocks of successful adaptation.

7.5.1 Reducing vulnerability to human health effects from climate change

The reduction of urban human health vulnerability can be achieved by the implementation of measures indirectly and directly related to the health sector and service. We present here the ones that can influence the reduction of health risk, being indirectly and directly linked with it.

7.5.1.1 Overview of general adaptation measures that reduce health risks

Most activities that increase urban adaptation to climate change also reduce the health impacts of climate change, even if they are not directly linked to the health sector and health services. Campbell-Lendrum and Corvalán (2007) suggest that promotion and adoption of “Healthy Cities” strategies, for example, are simultaneously beneficial for climate change mitigation, adaptation, and population health. Proactive adaptation measures – implemented before major impacts are seen – are likely to be less disruptive and costly than reactive adaptation (Dickinson, 2007). An efficient and effective emergency response by trained and well-equipped personnel can transform a catastrophic situation into one that is manageable, with minimum loss or impact to human health and well-being. Some general adaptation measures that could reduce the vulnerability of city dwellers to climate change include:

- incorporation of climate change information and projections into standards, policies, and codes such as those governing where and how to construct or update stormwater and flood control systems, transportation infrastructure and buildings, thereby increasing the safety of urban areas near coasts and rivers
- relocation of populations from floodplains and steep hillsides to safer locations to reduce deaths, diseases, and injuries from floods and landslides (especially if the relocation involves provision of soundly constructed housing, infrastructure, and transportation services)
- reducing impermeable surfaces through provision of green space, urban trees (which are likely to survive in poor neighborhoods of low-income cities only if cooking fuel is accessible and affordable), vegetation, and other means such as permeable pavements and green roofs, reducing flooding and decrease the urban heat island in cities
- extension and maintenance of essential infrastructure services such as drinking water supply and sanitation, taking account of changing climate conditions (such as a potential shortfall in water supply, or increased intensity of rainfall) to decrease illness and deaths due to water shortages or contaminated floodwaters
- energy and water conservation programs that reduce pressure on these systems in conditions of extreme heat or drought, and ensure the continuity of these critical services.

7.5.1.2 General adaptation measures for the health sector

The health sector does not directly influence many or most of the factors that directly contribute to vulnerability to climate change. However, there are a number of general adaptation measures that the health sector could undertake to improve knowledge of the health effects of climate change and motivate appropriate protective action by agencies with more direct responsibilities for the structures and services that affect the vulnerability of city dwellers to climate variability and change. Among these measures are:

- strengthening health systems in countries and cities where these are weak, ensuring universal primary care with providers

who have been educated about climate-linked health problems (Campbell-Lendrum and Corvalán, 2007)

- understanding and mapping health hazards related to climate variability and change
- developing climate-based early warning systems coupled with response plans and activities and evaluation of their effectiveness (Confalonieri *et al.*, 2007)
- analysis of meteorological data such as temperature trends and changing ecological factors such as the conditions that could support rapid reproduction of mosquitoes and other disease vectors
- tracking and assessment of diseases and health trends related to climate change
- communications on the health effects of climate change to inform the public about potential health effects and what they can do to protect themselves from weather-related illnesses and injuries
- advice to decision-makers about the likely health impacts of climate change
- collaboration with city officials responsible for the planning and design of buildings, public spaces, transportation networks, emergency management, and disaster risk reduction to ensure that health considerations are appropriately included
- communication with community leaders to encourage proactive action by individual households and communities to reduce vulnerability
- emergency medical care systems to provide trauma care and during emergency periods to help provide uninterrupted care for people with conditions requiring regular treatment (e.g., AIDS medications)
- ensuring a competent public and primary health-care workforce trained to recognize and manage health threats that may be associated with climate change
- evaluation of climate change preparedness plans, health communications and intervention strategies to ensure that these are effective in reducing risks and impacts (Ebi, 2005; Frumkin *et al.*, 2008; Griffiths *et al.*, 2009).

The health sector also needs to protect its own services and facilities from the impacts of climate change. This may include “climate-proofing” health centers, hospitals, nursing homes, ambulance stations, and other facilities in order to ensure that they can provide effective services during floods, storms, black-outs, and other emergencies.

The World Medical Association (2009) has strongly recommended that medical professionals be trained in climate change impacts and adaptation options and actions (see Box 7.3). Increasing the capacity of the health-care workforce and the number of health-care professionals, and promoting and encouraging health-care workers to work with other sectors may also be necessary.

7.5.2 Adaptation measures for specific health risks

In addition to general measures that reduce health risks and increase the capacity of the health service to respond to these

[ADAPTATION] Box 7.3 The World Medical Association's Declaration on Health and Climate Change

In October 2009, the World Medical Association passed a Declaration on Health and Climate Change that included a large number of recommendations with respect to reducing the health impacts of climate change. Among other things, the Declaration called on physicians and national medical associations to:

- urge local, national, and international organizations focused on adaptation, mitigation, and development to involve physicians and the health-care community to ensure that unanticipated health impacts of development are minimized, while opportunities for health promotion are maximized
- build professional awareness of the importance of the environment and global climate change to personal, community, and societal health
- work to improve the ability of patients to adapt to climate change and catastrophic weather events
- work with others to educate the general public about the important effects of climate change on health and the need to both mitigate climate change and adapt to its effects
- develop concrete actionable plans/practical steps as tools for physicians to adopt in their practices; health authorities and governments should do the same for hospitals and other facilities
- advocate that governments undertake community climate change health impact assessments, widely disseminate the results, and incorporate the results into planning for mitigation and adaptation
- urge colleges and universities to develop locally appropriate and continuing medical and public health education on the clinical signs, diagnosis, and treatment of new diseases that are introduced into communities as a result of climate change, and on the management of long-term anxiety and depression that often accompany experiences of disasters
- work with others, including governments, to address the gaps in research regarding climate change and health
- report diseases that emerge in conjunction with global climate change, and participate in field investigations
- encourage governments to incorporate national medical associations and physicians into country and community emergency planning and response
- call upon governments to strengthen public health systems in order to improve the capacity of communities to adapt to climate change
- prepare physicians, physicians' offices, clinics, hospitals, and other health-care facilities for the infrastructure disruptions that accompany major emergencies, in particular by planning in advance the delivery of services during times of such disruptions.

Source: WMA Declaration of Delhi on Health and Climate Change (<http://www.wma.net/en/30publications/10policies/c5/index.html>)

risks discussed in previous sections, the following describes a number of measures designed to reduce some of the specific health risks presented in Section 7.3.

7.5.2.1 High temperatures, heat waves, and the urban heat island

A number of adaptation measures to reduce the urban heat island effect in cities are being studied, promoted, and implemented. Yamamoto (2004) classifies these activities into three broad categories. The first – *reduction of exhaust heat* – includes initiatives to improve the efficiency of energy-using products and air conditioning systems; optimal operation of air conditioning systems (including restraints on nighttime operations); improvements in building insulation; increasing the reflectivity of walls and roofing materials; traffic-control measures and active transportation; cooling buildings with sea or lake water; capture and use of exhaust heat from industrial plants and other point sources; use of photovoltaic and solar thermal energy.

The second category – *improvement of urban surface cover* – includes increasing the reflectivity and water-retention of paving materials; green roofs; tree planting; and provision of more open water by pond construction and other initiatives. Cities in high-income countries have recently developed a number of programs designed to expand the installation of green roofs; use of reflective roof, road, and building surfaces; and increase the urban tree canopy (Acclimatise, 2006; USEPA, 2009).

The third category – *generation of air movement through urban corridors* – involves improving the orientation of buildings and roads to take advantage of cooling wind or water pathways and the construction of large-scale parks and green spaces. Some cities have also experimented successfully with reducing heat by improving air movement. Stuttgart, for example, has designated a “wind path” that allows cool mountain air to flow into the heart of the city; and Seoul removed part of a double-decked road and restored the previously buried Cheong-Gye River, which helps channel cool sea breezes into the area around the river (Droege, 2008; Ichinose *et al.*, 2006).

Public health departments have also taken measures to address health impacts from heat waves. In conjunction with longer-term actions to reduce the urban heat island, the mandate of these groups is the more immediate task of protecting the population from heat waves. One adaptation action that has become more common in cities in high-income countries is the development of a heat-health warning system (Kalkstein *et al.*, 2008). This system will usually involve one or more of the following actions:

- public health alerts through radio and television, triggered by expected high temperatures alone, by temperature–humidity indices (such as the Humidex), synoptic analysis to identify city-specific air masses associated with high mortality, and other systems (Kovats and Ebi, 2006)
- information about the need to stay hydrated and stay cool, which may be passively disseminated (by leaflets, for example) or more actively broadcast along with the heat warnings

- advice to those who care for the elderly and other vulnerable groups (often distributed at the beginning of the summer season, and sometimes specific alerts and advice when hot days are expected)
- telephone hotlines to provide advice to concerned members of the public
- opening of air-conditioned “cooling centers”
- extended hours for public swimming pools
- activation of “buddy systems” to check on vulnerable persons in their homes or to look out for heat stress symptoms among co-workers
- outreach to the homeless; and other actions.

Heat-health warning systems that include health interventions for vulnerable populations are considered to be effective in reducing deaths (Bernard and McGeehin, 2004; Ebi *et al.*, 2004; Koppe *et al.*, 2004). However, few systematic studies have been done to formally evaluate the effectiveness of these specific programs for saving lives.¹

High temperatures exacerbate poor air quality, which compounds heat-health risks. Measures to improve air quality, such as reducing emissions from vehicles, promotion of mass and active modes of transportation, and introducing incentives for clean energy sources may reduce this additional risk, as well as decrease greenhouse gas emissions (Kojima *et al.*, 2000).

7.5.2.2 Food availability

The decline in food availability as a result of drought or floods and rising food prices impact urban poor populations heavily, reducing their intake of food and the diversity and nutritional value of foods consumed (Cohen and Garrett, 2009). Resilient cities are able to provide food to their inhabitants in the face of shock and change (Larsen and Barker-Reid, 2009). A growing number of non-governmental organizations support urban and peri-urban agriculture in parts of Africa and South America as a partial solution to this problem. Urban agriculture is promoted as a way of increasing not only food security, but the mental and emotional resilience of the population. Urban agriculture may also contribute to sustainable management of urban open spaces, including flood zones, buffer zones, steep slopes, roadsides, river banks, and water harvesting areas (Dubbeling *et al.*, 2009). Urban agriculture also encourages the maintenance of open space in cities. Hamin and Gurran (2009) suggest that moderately dense cities with green corridors and open space throughout the city may be the most effective urban form for climate change adaptation. Food may be grown in open areas within the city or on its periphery, in backyards, school yards, on wastelands, on rooftops, in container gardens, hydroponic operations, and possibly even vertical farms (Larsen and Barker-Reid, 2009; Despommier, 2009).

A number of cities now formally support urban agriculture as a means of increasing food security and income for city dwellers, reducing greenhouse gas emissions, and/or adapting to climate change. Cities with formal policies and programs to support urban agriculture include: Accra, Kampala, and Nairobi in Africa; Bangkok, Beijing, Mumbai, and Shanghai in Asia; Brisbane and Melbourne in Australia; Brasilia and Havana in Latin America; and New York City in North America.

The risks of urban agriculture to health and the environment, if not managed properly, as well as the benefits should be considered. There are health concerns about urban agriculture, especially in those areas if wastewater is used to irrigate crops or food is grown in contaminated soils (Cole *et al.*, 2008). Urban agriculture may also increase diseases from disease vectors attracted by agricultural activity and transmission of diseases from animal husbandry (Lock and van Veenhuizen, 2001).

7.5.2.3 Vector-borne diseases

Climate change is only one factor among many that contribute to the expansion of vector-borne diseases (Semenza and Menne, 2009). However, a wide range of vector-borne diseases are “climate-sensitive,” expanding their range or living longer in warmer weather, for example, or breeding in conditions that are more frequently created by changing weather patterns. Vector-borne diseases of concern include those listed in Table 7.3.

Surveillance and mapping of these illnesses as they appear and spread, as well as the conditions that give rise to them will be an important preparatory step in adaptation. Adaptation will also require application of existing vector-control strategies, which may include (Abdallah and Burnham, 2000):

- **Environmental controls:** altering breeding sites by draining or filling places where water collects; ensuring regular disposal of refuse; maintaining clean shelters and personal hygiene

Table 7.3: Climate-sensitive, vector-borne diseases.

Vector	Diseases
Mosquitoes	Malaria, filariasis, dengue, yellow fever and West Nile virus
Sand flies	Leishmaniasis
Triatomines	Chagas disease
Ixodes ticks	Lyme disease, tick-borne encephalitis
Tsetse flies	African trypanosomiasis
Blackflies	Onchocerciasis
Rodents	Leptospirosis, plague, hantavirus

Source: Reid and Kovats (2009), Semenza and Menne (2009).

¹ See Kovats and Ebi (2006) for a review of heat response measures in Europe and the United States.

- **Mechanical controls:** protective clothing, screens or bednets, traps, food covers, lids or polystyrene beads in latrines
- **Biological management:** using living organisms or products against vector larvae, such as fish that eat larvae (e.g., tilapia), bacteria that produce toxins against larvae, free-floating ferns that prevent breeding, etc.
- **Chemical controls:** including repellents, insecticides, larvicides and other pesticides.

A combination of these methods – what the World Health Organization refers to as “integrated vector management” or IVM (WHO, 2004) – will be needed for the control of most vectors. An integrated vector management strategy requires:

- knowledge of factors influencing local vector functioning, spreading of disease and rates of incidence.
- collaboration of the health sector and other sectors (such as water, solid waste, sewage disposal, stormwater, housing, construction, urban food producers, etc.)
- health communications, education and engagement with local communities (WHO, 2004).

Enhanced or new vaccination programs may be appropriate for some climate-sensitive diseases as well (Gould and Higgs, 2009; Ortiz Bultó *et al.*, 2006).

7.5.2.4 Food-borne illnesses

Contamination of food can happen at any point at which food is grown, transported, processed, sold, stored, prepared, or eaten. Rising temperatures are expected to increase the incidence of food poisoning as microbes can multiply more quickly. Warmer weather will support the survival of flies and other pests that can contaminate food. Refrigeration failure is more likely to occur in hot weather (Menne *et al.*, 2008). Intense rainfall and floods may also contaminate water sources from which urban residents draw water for washing or cooking food and contribute to food poisoning.

Protecting urban populations from these problems requires a strong public health response, including intensified public education alerting the population to the potential threat of increased contamination and ways to handle food and avoid food-borne diseases (D’Souza *et al.*, 2004). Timely information to food producers and food handlers is also essential (Menne *et al.*, 2008), as is public health inspection of places where food is commercially processed or prepared. Quality control measures for food storage and handling may need to be upgraded in light of a changing climate. General adaptation measures including those that protect electricity transmission and distribution systems and measures that reduce flooding and water contamination will also provide some protection against food-borne illnesses.

7.5.2.5 Water-borne diseases

Water-borne diseases are also likely to increase under climate change, as a result of problems associated with:

- reduced water supply – leading to reduced sanitation, personal hygiene and effluent dilution
- extreme rainfall – leading to increased pathogen loading, particularly in areas with inadequate stormwater management, aging water treatment plants or combined sewer-stormwater systems (Patz *et al.*, 2008)
- direct effects of higher temperatures – favorable to microorganism reproduction (Semenza and Menne, 2009).

Adaptation strategies to reduce water-borne diseases include:

- improved management of water demand and maintenance of water distribution systems to help avoid critical water shortages (Menne *et al.*, 2008)
- watershed protection such as vegetative buffers to reduce contamination of water from runoff (Patz *et al.*, 2008)
- improved city disposal systems to capture and treat wastes
- extending and improving urban stormwater management systems incorporating expected increases in intensity of storms
- separation of combined sewage and stormwater systems and stronger regulations controlling septic systems
- “well-head alert systems” that warn water system and water supply managers when rainfall conditions approach levels of concern, similar to predictive forecasts and warning systems (Auld *et al.*, 2004).

Public health services such as public alerts, including boil water alerts about the potential threat of increased contamination, and enhanced surveillance and monitoring programs for water-borne diseases (Ebi and Nyong, 2009) can also help protect urban populations.

7.5.3 Extreme weather events

Extreme weather events, such as extreme precipitation (intense rain, thunderstorms, heavy snowstorms, and icestorms), hurricanes, and tornadoes, can have serious impacts on the health of city dwellers through direct personal injuries; damage to housing, roads, water services and electricity distribution; disruption of transportation, employment, health services; and other mechanisms. The kinds of extreme weather expected as a result of climate change will vary from region to region and consequently adaptation responses will be different. However, effective adaptation will combine urban development strategies that incorporate knowledge of the current and future risks of extreme weather with disaster risk reduction planning and robust emergency response systems.

Recent international discussions on combining climate change adaptation and disaster risk reduction have resulted in a general framework for reducing the risks of extreme weather events (CCD, 2008; UNISDR, 2008; Mitchell and van Aalst, 2008). The Hyogo Framework for Action, agreed at the World Conference on Disaster Reduction in January 2005 sets out five broad areas for action to reduce the impacts of extreme weather (see Table 7.4).

Table 7.4: Actions to enhance adaptation and reduce disaster risk to health from extreme weather.

General framework	Specific areas for action
1. Make disaster risk reduction a national and local priority	• Initiate high-level policy dialogue on disaster risk reduction and adaptation to climate change • Ensure formalized multi-sectoral coordination of risk-reduction activities • Create mechanisms to engage communities
2. Identify, assess, and monitor disaster risks and enhance early warning	• Provide high-quality information about climate hazards • Conduct vulnerability assessments • Establish or strengthen early warning systems • Undertake public information programs to help people understand risks and respond to warnings • Support research programs on resilience
3. Build a culture of safety and resilience	• Disseminate best practices • Provide public information programs on local and personal actions that contribute to safety and resilience • Publicize community successes • Train the media on climate-related issues • Develop education curricula on climate adaptation and risk reduction
4. Reduce underlying risk factors	• Incorporate climate risk considerations in land use planning, water management, environmental management • Maintain and strengthen protective works such as coastal wave barriers, levees, floodways, and flood ponds • Require routine assessment and reporting of climate risks in infrastructure and building projects and other engineering works • Develop social safety nets
5. Strengthen disaster preparedness for effective response at all levels	• Revise preparedness plans and contingency plans to account for projected changes in existing hazards and prepare for new hazards • Create evacuation mechanisms and shelter facilities

Source: UNISDR (2008).

Flooding is the most frequent weather-related disaster, affects the largest number of city dwellers, and is predicted to worsen under climate change. A number of cities have developed comprehensive strategies to reduce flooding and its health and impacts. The city of Pune in India is one of these cities (see Box 7.4).

7.6 Policies and policy issues

“It is within urban centers and urban governments that so much of the battle to prevent climate change from becoming a global catastrophe will be won or lost” (Huq *et al.*, 2007).

7.6.1 Mitigation policies that benefit health

Many cities in high-income countries and in some middle-income countries have developed and are implementing programs to reduce greenhouse gas emissions. Typical strategies include energy conservation programs for buildings; expansion of combined heat and power or district heating plants; capture of methane from sewage treatment and landfill sites; renewable energy installations; innovative systems to cool downtown buildings using lake or sea water; initiatives to expand the provision and use of public transportation systems and reduce use of private vehicles; investment in active transportation through

pedestrian zones, bicycle lanes and other means; and tree planting and green roof strategies.

Many of these initiatives are expected to reduce health risks and/or improve health outcomes in the short or long term. Initiatives that reduce the burning of fossil fuels for example, not only reduce carbon dioxide emissions, but also reduce the release of air contaminants and improve air quality, with a positive impact on respiratory and related diseases. Cifuentes *et al.* (2001) estimated that implementing currently available technologies to reduce fossil-fuel use could result in approximately 64,000 fewer deaths between 2000 and 2020 in Mexico City, Santiago, São Paulo, and New York alone and significantly reduced mortality in China. Embedding active transportation, walking, and cycling into urban design would improve cardiovascular health and reduce obesity (Saelens *et al.*, 2003), potentially reducing the 1.9 million deaths per year associated with physical inactivity (WHO, 2002). Studies of the benefits and monetary costs of major air pollution control efforts have concluded that benefits, at least in developed countries, far outweigh the costs (Kjellstrom *et al.*, 2007). Policies and actions to control air pollution from vehicles and industry can be important interventions for health equity as well as for mitigation of greenhouse gas emissions.

Climate change mitigation is a much lower priority for cities in low-income countries. These cities are much smaller contributors to greenhouse gas emissions overall, although the

[ADAPTATION] Box 7.4 Disaster risk management in Pune, India**Jennifer Penney***Clean Air Partnership*

The city of Pune in Maharashtra State, India, has a population of more than 3.5 million people and is located where the Mula and Mutha rivers meet. (UNISDR, 2009) The city suffers from floods most years (Sen *et al.*, 2003) and has had at least one severe flood every decade for the last 60 years (Bhosale, 2008). These floods have displaced and destroyed the property of families living on the river banks, disrupted transportation and communications, destroyed drainage and sewage system works, eroded the river banks, and had adverse effects on the health of Pune's residents. More than 5,000 families were adversely affected by floods in 2005 and 2006. The city anticipates more frequent floods due to climate change (UNISDR, 2009).

In 2006–7 the Pune Municipal Corporation (PMC) began preparing a comprehensive Disaster Management Plan, with the participation of several municipal departments, law enforcement agencies, the state government, and educational institutes. Participating municipal departments included the fire brigade, river improvement department, public transportation, health, public relations, education, electricity, and irrigation (Bhosale, 2008). Working together, these departments created a systematic plan to reduce flooding. They developed a detailed drainage map of the city and began by analyzing hourly rainfall intensity and how it might affect low-lying areas and sites where drainage was not functioning, identifying 39

vulnerable areas on both sides of the Mutha River. This work built on the Pune Slum Census carried out by local NGOs, who mapped slums in Pune with attention to slums that were especially vulnerable to flooding. This mapping also showed how uncoordinated municipal action in response to the flooding would negatively impact many of the slum dwellers (Sen *et al.*, 2003).

Implementation of the Disaster Management Plan involved dredging the rivers to remove silt and increase their water carrying capacity (Patil, 2008a); clearing stormwater drains; expanding drainage systems along the road network; widening flood plain areas to accommodate high water levels; lengthening bridges and enhancing soil porosity to improve infiltration (UNISDR, 2009). PMC also undertook afforestation projects in a hilly area of the city, and built small earthen check dams. The municipal government also strengthened flood monitoring and early-warning systems and protections for families. These activities have not provided complete protection from flooding; in August 2008, following two days of heavy rains, the Mula River flooded several areas and displaced almost 500 families (Patil, 2008b). However, fewer households were affected than in 2005 and 2006. In 2009 the Pune Municipal Council established a flood-control response team with 24-hour emergency numbers, and with resources to relocate residents of flooded areas.

Source: UNISDR (2009). Adaptation to Climate Change by Reducing Disaster Risks: Country Practices and Lessons. United Nations International Strategy for Disaster Reduction. Geneva.

consumption habits of the wealthier residents of these cities are contributing to rapid increases in emission levels (Huq *et al.*, 2007). Nevertheless, some programs in low-income countries have positive outcomes both for reducing emissions and for health. Solid fuels such as charcoal, wood, dung, and coal used for domestic purposes in low-income cities kill an estimated 1.5 million each year in developing countries. Improved stoves can cut back indoor smoke levels and fuel use considerably, which improves health, reduces costs for purchasing fuel, and reduces emissions (Kjellstrom *et al.*, 2007). A large-scale transition to cleaner-burning fossil fuels would reduce greenhouse gas emissions by a modest 1–10 percent in these countries, but reduce excess deaths by 13–38 percent (Bailis *et al.*, 2005, cited in Campbell-Lendrum and Corvalán, 2007).

7.6.2 Adaptation policies that benefit health

Mitigation strategies are designed to reduce the long-term impacts of climate change and though many such strategies may have a positive short-term impact on health, this benefit is not usually a primary goal. In contrast, many adaptation strategies are designed to reduce the impacts of extreme weather and climate change in the short- and medium-term. Most of the impacts of climate change have a health component. Hence, adaptation strategies aimed at diminishing the urban heat island effect, decreasing

floods, ensuring water or food supply, or controlling disease vectors are all expected to reduce illness, injuries, and deaths.

Many adaptation strategies coincide with the development needs of low-income cities (Satterthwaite, 2009) – the extension of water, stormwater, and sanitation infrastructure, the construction of safe and decent housing, and the provision of primary health care and public health services capable of responding to climate-related health problems.

This does not mean that all adaptation strategies will positively contribute to development or to health outcomes. If informal settlements on floodplains are razed to reduce the risk of floods without alternative housing and land arrangements made for and with the residents, for example, the affected populations may be left without shelter and worse off than before. It is important for those who promote relocation strategies as a means of reducing the impacts of floods or other climate-related problems to consider these issues.

And finally, a focus on reducing climate-related risks may not be possible in some of the most vulnerable cities that are already struggling with epidemic levels of HIV/AIDS, which is not climate-sensitive, or are trying to cope with the immediate needs of large numbers of malnourished migrants from war-torn regions.

7.6.3 Combining mitigation, adaptation, and health strategies

There are several areas where climate change mitigation and adaptation strategies overlap and reduce the health impacts of climate change especially from heat and air pollution. It may be easier to gain the support of local governments for such “win-win-win” strategies than for strategies with more limited benefits.

For example, passive methods of cooling buildings such as shading, reflective roofs, natural ventilation (convective cooling), insulation, placement of nearby trees, green roofs, and permeable pavements will all reduce heat loads on buildings, reduce the need for air conditioning, improve comfort, and reduce heat impacts for the occupants. Where electricity is produced by fossil fuels, these strategies will also reduce greenhouse gas emissions.

However, mitigation, adaptation, and health strategies do not always clearly coincide. For example, mitigation proponents tend to support high densities in cities as a means of minimizing commuter distances and vehicle emissions, and common energy schemes that reduce emissions. However, high densities also contribute to the urban heat island effect, reduce green space and trees, and increase the likelihood of urban flooding (Laukkonen *et al.*, 2009). A coordinated local response is necessary to address these kinds of contradictions, and resolve potential conflicts (Laukkonen *et al.*, 2009).

7.6.4 Coordinated action on climate change adaptation and health

Action to reduce the impacts of climate change on the health of city dwellers will need to occur both within and outside the traditional sphere of the health sector. The specific role of the health sector is to:

- reduce the contribution of the sector to climate change (e.g., energy conservation in health facilities)
- investigate and analyze the local health effects of current weather variability and climate change
- ensure that local staff are trained to recognize and manage emerging health threats associated with climate change
- strengthen health surveillance systems that monitor the appearance and spread of climate-sensitive illnesses
- develop and implement early warning and public outreach systems for heat waves, severe air pollution episodes, water-borne and vector-borne illnesses
- ensure that health considerations are taken into account in city-level mitigation and adaptation planning
- collaborate with other local government sectors in developing preparedness plans for events such as heat waves, wildfires, intense rainfall, floods, and windstorms. (Plans should include: neighborhood communication and response systems; shelters; transport and evacuation plans; and clinical facilities with surge capacity.

- support communities in developing the capacity to adapt through vulnerability mapping, community sanitation projects, neighborhood response systems or “buddy systems” to check on vulnerable people during extreme weather events
- ensure that the health needs of disaster victims are taken care of, including continuity of ongoing care programs (such as HIV medication and kidney dialysis), and mental health services
- make hospitals, clinics, and other health-care facilities as safe as possible from weather disasters (Frumkin and McMichael, 1998; Frumkin *et al.*, 2008; Kovats and Akhtar, 2009).

Many of the activities that are necessary for cities to adapt to climate change are the responsibility of other sectors – city planning, energy, transportation, and water and stormwater infrastructure for example – but the health sector can play an important advocacy role in encouraging action to protect the health and lives of city dwellers from the impacts of climate change. Local public health departments have also participated in the development of citywide adaptation strategies in a number of cities internationally, including London, New York City, and Toronto (London, 2008; New York City, 2009; City of Toronto, 2008).

Public health departments can play an important role in almost all stages of citywide adaptation planning and implementation including:

- *Increasing awareness and engaging the public and stakeholders in considering the need for adaptation* – highlighting health concerns is often a good way to draw attention to the issue and to motivate action
- *Assessing city vulnerabilities to climate change* – health issues are a major aspect of vulnerability to climate change, so the participation of the health sector is critical for this stage of adaptation planning
- *Reviewing the effectiveness of existing policies and programs that seek to protect the population from climate extremes* (e.g., flood controls) – the health sector needs to be involved in reviewing the strengths and weaknesses of its own programs, and may be able to contribute information necessary for a comprehensive evaluation of the programs and services operated by other departments
- *Identifying adaptation options* – again, the health sector could contribute in identifying and analyzing adaptation options, ensuring that broad health considerations be taken into account
- *Piloting adaptation strategies and incorporating adaptation into policies and programs*
- *Monitoring and evaluating results* – assessing the implementation and the effectiveness of adaptation strategies from a health perspective.²

7.6.5 Barriers to action

While many advances have been made in understanding what must be done to protect health from climate change, there exist

² See Berry, 2008 for more information on the potential role of the health sector in adaptation planning.

[ADAPTATION] Box 7.5 Advanced Locality Management (ALM) in Mumbai, India: Fostering climate resilience through community-based approaches

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Located on the western coast of India, Mumbai, earlier known as Bombay, is the economic capital of India. The city has witnessed exceptional population growth (present population is 15 million including 3 million floating population) due to rapid industrialization and emergence of many business and service sector employment opportunities. The progression of settlements (including 55 percent slum dwellers) coupled with the changing lifestyle of urban folks in a rapidly globalizing city environment has resulted in widespread vulnerability in the city, which is highly prone to hydro-meteorological disasters that are projected to escalate in intensity and frequency due to climate change. Flooding and water-logging in low-lying areas is an annual occurrence in Mumbai and has become a grave concern as monsoon rains can bring the city to a halt for hours or even days. The urban populace of Mumbai is not yet prepared to deal with climate-induced catastrophes. The flood of 2005, during which 994 mm of rain fell in a single day, resulting in the deaths of more than 500 people, was the worst in the city's recorded history.

This case study is about an initiative called Advanced Locality Management (ALM), a volunteer movement with its origin in the proliferation of diseases due to filthy surroundings in certain residential areas. Concerned citizens, frustrated by the limited outreach of municipal services, formed a Street Committee in 1996 to clean up their nearby areas. Volunteers, including women and children, started cooperating in collecting garbage in the vicinity, separating household waste, and composting organic materials. This unique voluntary initiative, which began in just a few streets, was later replicated at the city level by the Municipal Corporation of Greater Mumbai (MCGM) and included in its 2006 Charter. Today, there are about 800 ALM groups covering a population of about 2 million in the city. Women manage 80 percent of the ALMs.

ALM groups contribute significantly to the separation of household waste, and recyclable waste (20 percent of total waste) is directed to identified rag pickers. These rag pickers are the local poor and are earning a livelihood through ALMs. At the neighborhood scale, about 55 percent of the organic/biodegradable waste is being composted and applied to local gardens. Construction and demolition debris is directed to low-lying areas for landfill, reducing the burden on dumping sites. ALMs prevent approximately 20 to 25 tons of garbage per day from reaching the dumps. This offers a significant contribution for curbing greenhouse gases produced by burning municipal waste. There is a significant reduction in total waste reaching disposal sites, reducing the burden on municipal systems.

Household waste not only degrades the local environment but much of this waste find its way into uncovered stormwater drains causing waterlogging and temporary flooding. As partnerships between the municipal agency and neighborhood groups, ALMs have helped people learn to care for the areas

beyond their own premises and to cooperate to solve local problems. The city government supports this community-led effort, as it not only reduces the stress on municipal systems but also helps to reduce flood risk and water-borne diseases.

In addition to separating domestic garbage, clearing garbage and composting, ALMs contribute to improving water supplies and drainage, beautifying neighborhoods, maintaining roads, filling potholes, surfacing pavements and streets, and controlling pests and stray animals.

An ALM can be formed by a neighborhood or street of about 1,000 households and is registered with the local municipal ward office, which appoints an officer to respond to citizens' concerns. The ALM committee members are selected democratically and generally include a range of neighborhood representatives including women and the elderly. ALM committees play a key role in encouraging citizens to take an active role in monitoring the city administration at the ward level. At the same time, the actions of local citizens have resulted in environmental improvements and climate-related risk reduction.

The ALM movement initially spread in areas with severe environmental degradation especially in medium-income neighborhoods. Volunteers themselves contribute small amounts of money to maintain the functioning of the organizations. MCGM has ordered their officials to give priority to ALM problems and issues.

Community-owned institutions such as the ALMs are vital for local climate resilience building. ALM could help in organizing drills for disaster scenarios, and conducting training in search and rescue. By mobilizing local resources, and volunteering with other relief agencies the ALMs proved to be very helpful in the Mumbai flood in 2005.

There is active advocacy and consultation among ALM groups and municipal agencies. This encourages transparency and accountability throughout the process. Harmonizing local government-ALM relations is critical to effective functioning. Success stories in some areas can provide examples to help resolve issues in others.

The ALM process can be replicated where local issues are dealt with at the municipal level in a decentralized way. This initiative has greatly benefited community-based waste management, greening through urban gardening, etc. These efforts contributed to reducing flood and health risk in these localities. Further, collective community action is building climate resilience by promotion of recycling, water reuse, rain-water harvesting, reduced dumping/burning of waste, and so on. ALMs stand as an important example of a community-based approach for fostering climate resilience.

Source: Surjan, A. and R. Shaw (2009). Enhancing disaster resilience through local environment management: Case of Mumbai, India. Disaster Prevention and Management, 18(4), 418–433.

many barriers to action. However, there are barriers to action that are specific to cities and to city governments that deserve more discussion.

The existing urban form is a major barrier. Many cities have expanded into flood zones and up hillsides, making them more vulnerable to floods and landslides. Cities have paved over and destroyed natural drainage systems, which also makes them more vulnerable to floods. Hard surfaces that are the hallmark of city development create urban heat islands. Altering this form will take a considerable investment and many decades (Huq *et al.*, 2007).

Although research about the health effects of climate change has increased considerably in the last few years, and international organizations such as the World Health Organization and the World Medical Association have been devoting growing attention to the issue, there remains a relatively weak understanding of health impacts, especially among city officials. There needs to be more attention to analyzing the health impacts of current extreme weather on cities and assessing how future climate change could alter these impacts for better or worse. City leaders and the public need a clearer understanding of the importance of and potential for protective action.

Uncertainty about the timing and extent of impacts plays a role in the inertia of cities. Those responsible for infrastructure engineering make decisions based on past weather conditions and are reluctant (or are constrained by legal standards) to change this practice and incorporate future projections. Apparent conflicts in the predictions – for more droughts *and* for more floods in many regions, for example – also serve to confound decision-makers. The lack of regional climate projections in most areas of the world also creates a barrier to planning for the conditions of the future. Organizations such as the Public Infrastructure Engineering Vulnerability Committee (PIEVC) of Engineers Canada have been making headway in that country by developing and testing a risk assessment framework to evaluate the resilience of a variety of types of city infrastructure to climate change. Using this system, and with the involvement of city officials in each community where risk assessments are done, PIEVC has evaluated water and sewage treatment systems, bridges, roads, buildings, and other forms of infrastructure. This tool and others like it may encourage city officials in high-income countries to adapt infrastructure to the expected impacts of climate change.

There are relatively few visionary city leaders who are willing to devote political capital to strong mitigation and adaptation programs. Although public pressure for mitigation programs has been growing in high-income countries, there is relatively little pressure on political figures to develop adaptation programs, partly because urban residents do not generally connect damaging weather events to climate change. Political figures who have the next election in mind rather than long-term impacts and planning want to spend scarce financial

resources on more immediate and more visible projects that will win votes.

Some adaptation measures are so complex or expensive that they can only be undertaken with the support of many different departments of the city government, or at senior levels of government. Coordination across departmental silos is notoriously difficult and the coordination across different levels of government even more so. There are examples of urban centers where interdepartmental coordination on climate change is well organized: King County, Washington, is a North American leader in this area. The UK government has also provided support and pressure for action at the city level by financing the United Kingdom Climate Impacts Programme and instituting a system of National Indicators for Local Authorities, which includes indicators on both mitigation and adaptation.

Financial resources remain a major barrier. Cities generally have relatively low capacity to raise funds, relying primarily on property taxes, and financial support from senior levels of government for expensive projects such as infrastructure has waned. Similarly the availability of international development funds for urban infrastructure projects for cities in developing countries has been reduced in recent decades.

Despite all these barriers, there are a growing number of cities that have taken up the challenge of working to reduce the health and other impacts of climate change. Networks of cities have begun to share their strategies and experiences and encourage their members to prepare for climate change. The Alliance for Resilient Cities in Canada, and the Urban Leaders Adaptation Initiative in the United States are among the leaders in this activity. Increasingly, international institutions such as WHO, UN-HABITAT, and the World Bank are supporting the preliminary efforts of cities to understand the risks of climate change and to mitigate and adapt.

7.7 Research and data needs

In recent years, research that analyzes the relationship between climate change and health has surged (WHO, 2009). Intergovernmental programs, national governments, health sector organizations, and academic institutions and national governments have initiated many new studies related to the vulnerability of populations to climate change. There has also been an increase in research on climate change and cities. The Cities and Climate Change Symposium, hosted by the World Bank in Marseilles in June 2009, made a substantial contribution to this literature. With the exception of the extensive literature on the urban heat island effect, there has not been a great deal of research that specifically investigates health effects of climate change on cities, though this is also beginning to change. There remain many uncertainties about the range and magnitude of impacts of climate change on the health of city dwellers.

The IPCC (Confalonieri *et al.*, 2007), Frumkin *et al.* (2008) and WHO (2009) have identified the need for more specific research in the following areas related to climate change and health:

- understanding the risks to health of climate change, including: identification of key health indicators to monitor; improved quantification and evaluation of current climate–health relationships especially in low- and middle-income countries; identification of vulnerable populations and life stages; emerging impacts and modeling future risks
 - identifying the effectiveness (including cost-effectiveness) of health sector interventions by means of systematic reviews of the evidence base for interventions; studies of the effectiveness of informing communities and engaging them in interventions to improve climate-related health outcomes
 - study of the health implications of climate-related decisions in other sectors such as energy, transportation, water and wastewater, food and agriculture
 - development and testing of decision-support tools such as vulnerability and adaptation assessments and of operational predictions for weather-related hazards such as heat waves and floods; improved understanding of decision-making processes; and research on effective communications on health and climate-related issues
 - improvement of methods for understanding the costs and benefits of investment in health protection including the health costs of inaction and the costs and benefits of greenhouse gas mitigation.
- These recommendations for expanded and improved research are not specific to cities, though undoubtedly the knowledge derived from research in these areas would be of benefit to developing adaptation plans for urban environment. But, given the particular manifestations of climate-related health problems already evident in cities and the proportion of the world's population that lives in urban environments, a more specific program of city-centered urban research is warranted. Addressing climate change health issues with a focus on their urban manifestations – emergency preparedness, smog, infectious disease, contaminated food and water – will save lives. Research of value would include:
- improved understanding of the linkages between climate change and urban health, as well as the effects of different geographic, social, economic, environmental, and political contexts
 - linkage of climate change and urban health research with existing research investigating global city health, and health equity
 - empirical studies of health impacts of extreme events as they occur in cities internationally, including descriptions and assessments of the urban populations most affected; actions of the health sector and other relevant sectors during and after the events; communications and emergency response; and underlying conditions such as state of infrastructure, housing, sanitation and other factors that affected the health outcomes
 - assessment of specific shortfalls in population and health data that would allow for more robust assessments of human health effects linked to extreme weather events and climate change, and development of methods, including community-based methods, to collect this data in low- and middle-income cities (e.g., Sen *et al.*, 2003)
 - more city-specific climate change vulnerability assessments that include an evaluation of health risks from current and future climate
 - studies of the impact of rising temperatures and heat waves on water availability and quality and related health issues in urban settings
 - evaluation of the risks for health of inadequate stormwater and sewage infrastructure, and of waste collection in informal urban settlements subjected to heavy rainfall
 - assessment of the potential health effects of adaptation strategies such as low-impact drainage systems, adopted in urban environments
 - investigation of the urban conditions that contribute to the reproduction and expansion of specific insect or rodent vectors that carry climate-sensitive pathogens; and development, testing, and evaluation of strategies for control of these vectors in urban environments
 - study of the health effects of urban mitigation strategies including strategies to reduce emissions from energy conservation, transportation, fuel switching (from solid fuels used for cooking in most low-income countries), and other interventions
 - modeling of the effects of interventions to reduce the urban heat island effect in specific settings (e.g., Rosenzweig *et al.*, 2006) together with assessments of potential improvements to health outcomes as a result
 - comparative evaluation of the effectiveness of existing heat alert and response systems
 - research evaluating the costs and benefits of adaptation and mitigation programs expected to have impacts on health.
- There are many challenges to conducting this research. In many low- and middle-income countries there is limited information. Primary care and public health services are limited, and so is information on the extent of climate-sensitive or other illnesses. Meteorological information is scant, and region-specific climate projections are not available in many parts of the world. WHO has identified several barriers in addition to these data shortages including: limited financial resources available for this kind of research; weak incentives for interdisciplinary applied research; allocation of most health research funding to technological and curative solutions rather than population health; and weak institutional partnerships between researchers and decision-makers (Campbell-Lendrum *et al.*, 2009).
- To overcome barriers, WHO recommends linking researchers and decision-makers in an iterative process of consultation that involves civil society and especially representatives of vulnerable groups. WHO also recommends establishing a virtual

[ADAPTATION] Box 7.6 Toronto, Canada: Maps help to target hot weather response where it is needed most

Stephanie Gower

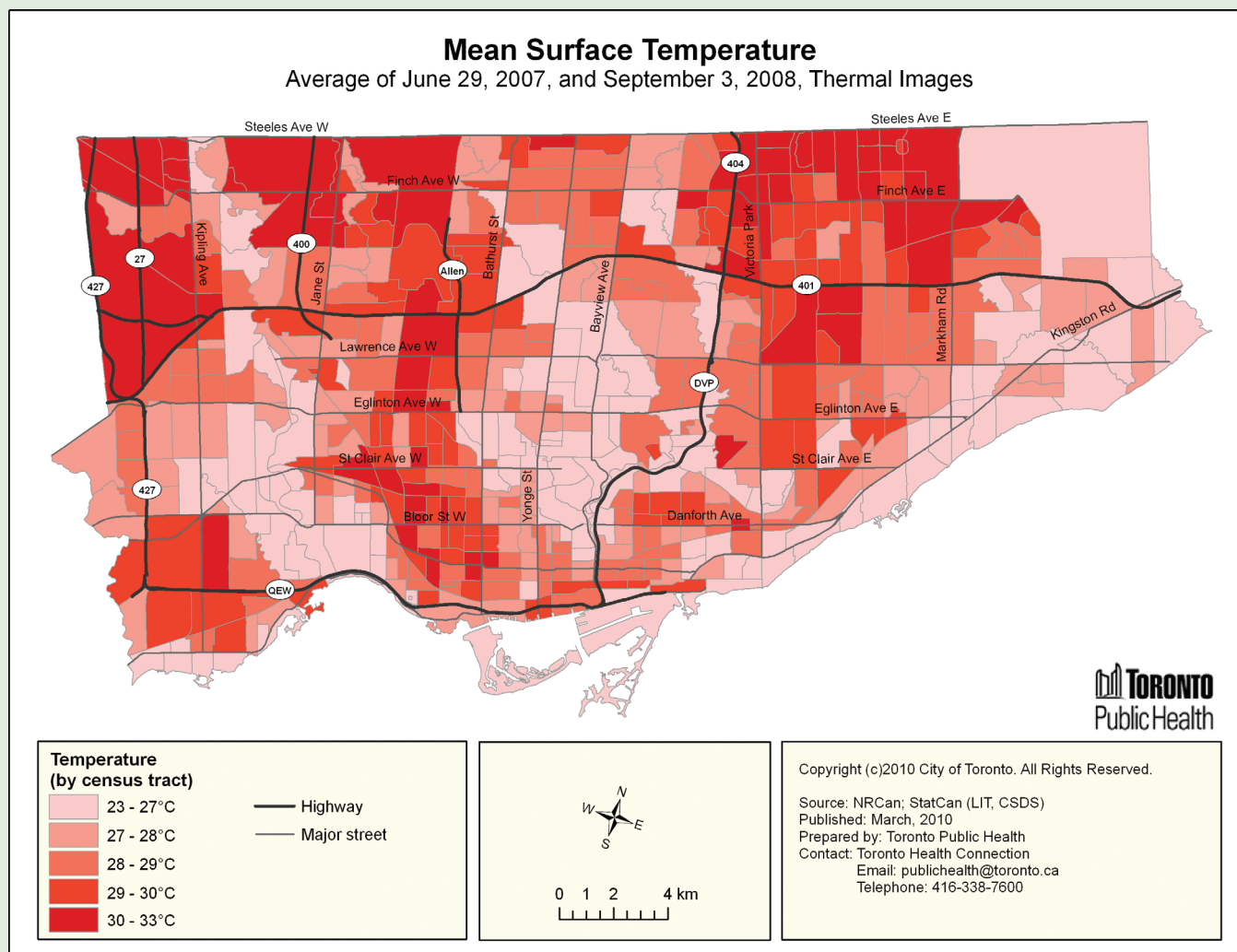
Healthy Public Policy Team, Toronto Public Health

In 1999, the City of Toronto implemented a heat alert and response system with the goal of reducing heat-related illness and death in Toronto. The system was the first in Canada and is considered a premiere example of climate change adaptation. Toronto calls a heat alert when a hot air mass is forecast and the likelihood excess deaths due to heat is greater than 65 percent. The alert is broadcast by local media, and advises the public to take precautions. The alert also activates Toronto's Hot Weather Response plan, which coordinates the effort of several municipal and community agencies to provide heat-related services to vulnerable populations such as socially isolated seniors, children, people with chronic and pre-existing illnesses, and people who are marginally housed or homeless. However, there is currently little information to

guide where response measures such as opening cooling centers or extending pool hours will be most likely to reach these groups.

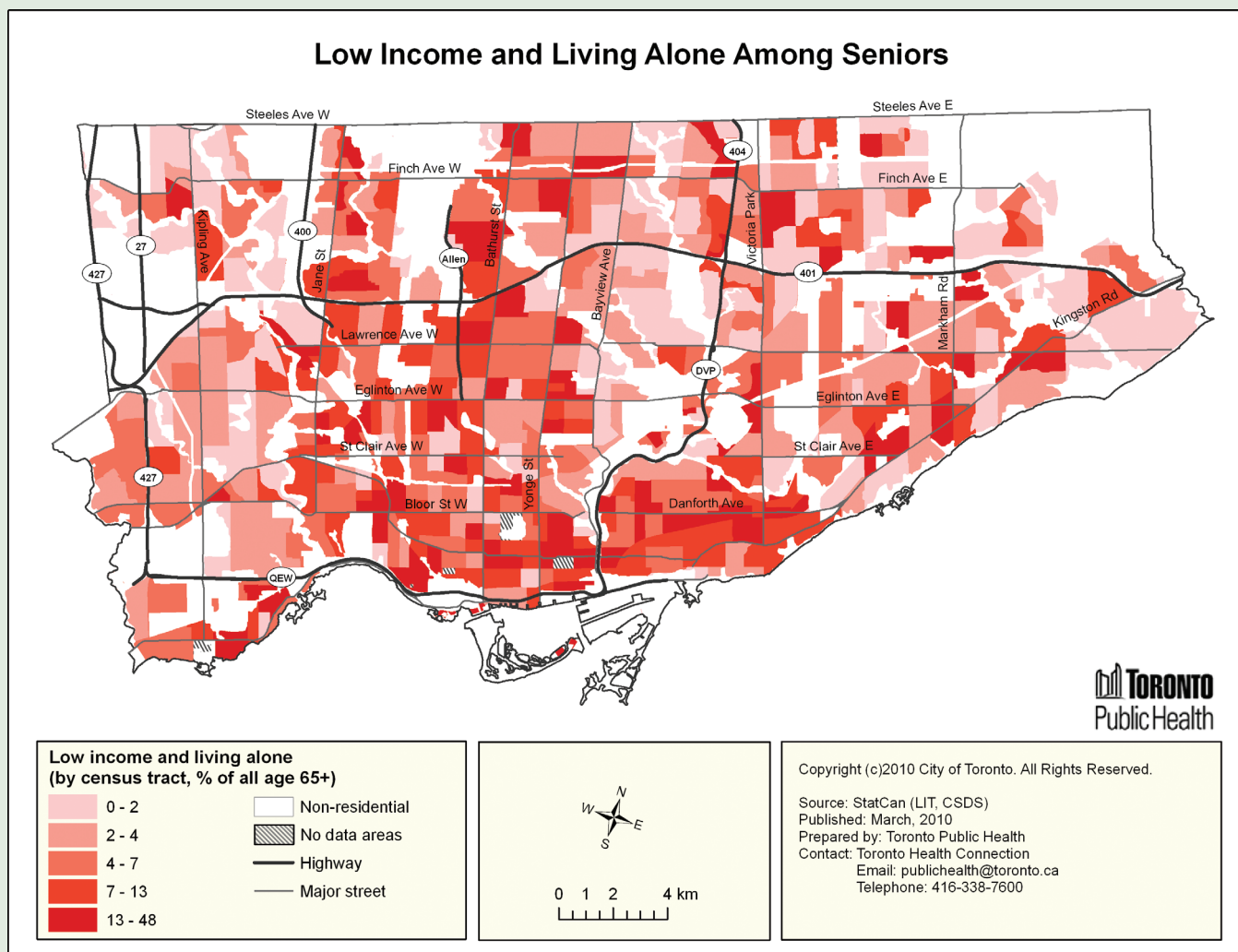
To ensure that hot weather response services are delivered where they are most needed, Toronto Public Health (TPH) partnered with experts in geographical information systems (GIS) and epidemiology to link current knowledge about risk factors for heat-related illness with mapping data that are available for the social and physical environment in Toronto.

The project's prototype maps characterize the spatial variation of factors that are likely to increase exposure to heat in Toronto, such as surface temperature, and factors such as low income and age that may affect people's resilience to extreme heat. Two samples of these maps are shown in Box Figures 7.1 and 7.2.



Box Figure 7.1: *Spatial variation in surface temperature (degrees C) in Toronto, Canada.*

Source: © City of Toronto 2010. Preliminary map, reprinted with the permission of Toronto Public Health.



Box Figure 7.2: Distribution of low income seniors living alone by census tract in Toronto, Canada. Low-income senior is represented as percentage of those age 65+ below the 2005 after-tax LICO (low-income cutoff).

Source: © City of Toronto 2010. Preliminary map, reprinted with the Permission of Toronto Public Health.

To enable multiple risk factors to be considered together, the project team is now finalizing a map that integrates multiple risk factors into a summary index of overall vulnerability. To aid in short- and long-term planning, maps will also be created that overlay vulnerability to heat with access to existing hot weather facilities and services.

With support from Natural Resources, Canada's Regional Adaptation Collaboratives Program, Toronto Public Health is now testing advanced geospatial statistical techniques designed to locate pockets of vulnerable people, refining the maps to include information about population density, and determining a way to validate the approach. Before finalizing

the mapping tool and an associated map series, TPH will also gather feedback on the prototype maps from staff and volunteers who implement hot weather response across the city.

About 120 deaths per year are currently attributed to extreme heat in Toronto, and heat-related mortality could double by the 2050s and triple by the 2080s (Pengelly *et al.*, 2007). To ensure a long life for the GIS tool and associated map products, Toronto is creating guides for data maintenance and updating, and will share its methods with other interested jurisdictions. Toronto must be prepared to cope with potentially much higher health-related impacts from heat in the future.

[ADAPTATION] Box 7.7 Pilot projects to protect Canadians from extreme heat events**Peter Berry***Health Canada*

Extreme heat events pose a growing public health risk in many regions of Canada, as a result of a changing climate. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report concludes that the frequency of extreme heat events is very likely to increase with climate change (IPCC, 2007a). The increase is a public health concern for Canada, which is experiencing rapid growth in the population of seniors, a group that has been identified as particularly vulnerable to the health impacts of extreme heat. Gosselin *et al.* (2008) project that in the absence of further adaptations there will be an increase of 150 excess deaths annually by 2020 in the province of Quebec, 550 excess deaths by 2050, and 1,400 by 2080.

Communities in Canada are adapting to the increase in extreme heat events by implementing heat alert and response systems (HARS), which are designed to prevent mortality and morbidity during extreme heat events by delivering timely warnings and interventions. HARS are operating in a number of Canadian cities, with established systems in communities such as Toronto and Montreal. To facilitate the development and improvement of such systems across the country, communities require information about optimal approaches to mobilize public health and emergency management officials to address these hazards implement and the most effective adaptations.

In 2007, Health Canada launched a four-year program to increase the resiliency of individuals and communities to the health impacts of extreme heat events. To accomplish this goal pilot HARS are being developed in four Canadian

communities – Winnipeg (Manitoba), the Assiniboine Health Authority Region (Manitoba), Windsor (Ontario), and Fredericton (New Brunswick). The objectives of the pilot projects are to identify effective adaptations for protecting health along with protocols for the design, implementation, and evaluation of regional and municipal HARS. Communities have been selected in areas of Canada that are characterized by different climate, socio-economic, demographic, governance, and institutional conditions and challenges.

The pilot communities are developing and implementing HARS for the summer of 2011 through local participatory processes. Each community has developed an advisory committee that comprises a range of government departments and stakeholders, such as those who have a role in health care, emergency preparedness, seniors and healthy aging, social services and housing, mental health and addictions, communications, police, fire and paramedic services and utilities. These committees ensure that the HARS meet their unique community needs, in an effort to protect those most vulnerable to heat-health risks. Further, the development of measures to protect citizens is being informed by extreme heat and health vulnerability assessments, table-top (simulation) exercises, and the establishment of education and outreach strategies.

Broad collaboration among Health Canada, the pilot communities, and key stakeholders is aimed at fostering increased knowledge of heat-health risks and local adaptive capacity to support the sustainability of HARS in these communities beyond the life of the four-year program. The tools developed and learnings derived from the program will be used to inform a Heat Alert and Response System Best Practices Guidebook, which will be disseminated to public health and emergency management officials across Canada.

forum on climate change and health research, as well as the creation of expert panels to provide oversight, produce best practice guidance, and share tools. It would be of great value if one of these expert panels focused on climate change and health in cities.

Early research on the climate change impacts used global climate models (GCMs) in a top-down way to develop scenarios for different locations (Huq, 2008). Other studies used a more bottom-up approach to identify vulnerable places and people. Studies, now tend to combine top-down and bottom-up information to develop adaptation strategies.

The current generation of climate change impacts research is actively linked to the people whose lives will be affected,

often in cities. Researchers are working with decision makers who will use their research, from project design, implementation and communication. This work includes partnerships with local governments, and non-governmental organizations (Huq, 2008).

Cities in poor countries face many constraints, including limited research capacity and lack of facilities for developing adaptation (Haines *et al.* 2004). Institutions and mechanisms are needed to promote effective interactions among researchers, policymakers, and of city groups to facilitate the appropriate incorporation of research findings into policies (Haines *et al.* 2004). The goal is to protect and improve public health in both current and future climates (Haines and Patz, 2004).

7.8 Concluding comments

Determinants of human health are forecast to worsen under climate change. Cities concentrate populations who are particularly vulnerable to the effects of climate change. When extreme weather events such as intense precipitation, cyclonic storms, or storm surges strike in cities they affect a much larger number of people than when they strike less populated regions. In both high-income and developing countries, the severe weather events associated with climate change combined with the many stresses on cities can create conditions of extreme health hazard to city residents.

Flooding is the most frequent weather-related disaster. It affects the largest number of city dwellers, and is predicted to worsen under climate change. The impacts of floods and storms can be spectacularly large in cities – leading to many thousands of deaths and resulting in economic damage in the billions.

Poorer air quality and increased ozone concentrations in metropolitan regions will engender substantial increases in ozone-related mortality. Evidence linking heat waves to mortality both from high-income countries and for the limited data available from the developing world suggests that the urban heat island effect renders city dwellers without access to cooling particularly vulnerable to heat waves. Moreover, urban air pollution related effects of temperature increases will contribute sustainably more to mortality than heat effects alone. Indirect health effects on city dwellers from climate change include reduced access to food and expanded exposure to infectious diseases.

Climate change mitigation and adaptation strategies can overlap and reduce the health impacts of climate change especially from heat and air pollution. Passive methods of cooling buildings such as shading, reflective roofs, natural ventilation (convective cooling), insulation, placement of nearby trees, green roofs and permeable pavements will all reduce heat loads on buildings, reducing the need for air conditioning, improving comfort, and reducing heat impacts for the occupants. Implementing such “win-win-win” strategies can have multiple benefits. However, mitigation, adaptation, and health strategies do not always clearly coincide and these goals need to be examined in any proposed policy.

Not all adaptation strategies will positively contribute to development or to health outcomes. If informal settlements on floodplains are razed to reduce the risk of floods without alternative housing and land arrangements made for and with the residents, for example, the affected populations may be left without shelter and worse off than before.

Barriers to effective response to climate change in cities include existing urban forms and lack of information. Altering existing urban conditions that combine with climate change to result in deaths, injuries, and illnesses in the population will be key to protecting health in cities. In low- and middle-income

cities this requires a focus on meeting basic development needs – adequate housing, provision of infrastructure that supplies clean water, sanitation, and energy, education, and primary health care services. Altering the urban characteristics that worsen the impacts of extreme weather events will decrease the likelihood of events turning into health and economic disasters. Anticipating climate change over the lifetime of the urban structures can preclude investments in urban infrastructure from being jeopardized by climate change.

There is a weak understanding of the urban health impacts of climate change among officials at all levels, national, sub-national, and city. The health sector can play an important advocacy role in encouraging that action is taken to protect the health and lives of city dwellers. Health officials could undertake to improve knowledge of the health effects of climate change and motivate appropriate protective action by agencies with more direct responsibilities for urban design and city services – city planning, energy, transportation, and water and storm water infrastructure. Promotion and adoption of “Healthy Cities” strategies will be simultaneously beneficial for climate change mitigation, adaptations and population health.

Many of the manifestations of climate-related health problems are already evident in cities. Provided that appropriate infrastructure is in place, urban areas with their concentration of wealth and resources provide unique opportunities to build large-scale, cost-effective resilience, thereby reducing health vulnerability to climate change. A more specific urban health-centered climate change research program is warranted to support health protection needs of the increasing proportion of the world’s population residing in cities. These efforts will be successful if the efforts of local governments are supported by their national and regional governments.

Evidence of the potential impacts of climate change on urban population health is growing. The magnitude and significance of these impacts will vary according to specific modulating factors of the cities, such as population density, social, economic, political, geographic, and environmental characteristics as well as medical and infrastructure services. Local government jurisdictions over these modulating factors vary, with many local governments responsible for basic infrastructure and national governments responsible for health and other critical systems, impacts are best addressed by cooperative effort between local and senior orders of government.

There are still large uncertainties and more study is necessary. Nevertheless, urgent action is required to ensure that:

1. the connections between climate change and health in cities are made clear to public health practitioners, city planners, policymakers, and the general public
2. urban practitioners take immediate responsibility to integrate climate change into planning in all areas of public health, food systems, infrastructure, and land use planning, thereby increasing the potential to create more healthy and sustainable communities

3. adaptation strategies focus on activities that eliminate health disparities, improve neighborhood conditions, and protect those who will be most impacted by climate change
4. national governments address the health risks of climate change to avoid unnecessary costs and hardship for health care and social systems, by devoting necessary resources to developing the adaptive capacity of local governments, communities, and individuals.

Without effective adaptation strategies, climate change will increase health and other impacts in the world's cities where the majority of population resides. The costs of the health impacts due to climate change (increased illness, injury, disease, death) will further weaken stressed local social systems. Cities provide unique opportunities to marshal resources and wealth to build resilience and health protective policies and programs. The implementation of health-care adaptation measures will differ among cities, each of which has its own specific modulating influences, and different social, economic, cultural, and political realities, but concerted action for knowledge gathering and sharing can strengthen the needed efforts at the individual city level.

REFERENCES

- Abdallah, S. and G. Burnham (Eds.) (2000). *Public Health Guide for Emergencies*. John Hopkins University and International Red Cross/Red Crescent Societies. Federation of Baltimore, MD.
- Acclimatise (2006). *Adapting to Climate Change: Lessons for London*. London Climate Change Partnership.
- Adam, J., A. Hamlet, and P. Lettenmaier (2009). Implications of global climate change for snowmelt hydrology in the twenty-first century. *Hydrological Processes*, **23**, 962–972.
- Ahern, M., R. Kovats, P. Wilkinson, R. Few, and F. Matthies (2005). Global health impacts of floods: epidemiologic evidence. *Epidemiologic Reviews*, **27**, 36–46.
- Ahmed, S., N. Diffenbaugh, and T. Hertel (2009). Climate volatility deepens poverty vulnerability in developing countries. *Environmental Research Letters*, **4**.
- Alajo, S., J. Nakavuma, and J. Erume (2006). Cholera in endemic districts in Uganda during El Nino rains: 2002–2003. *African Health Science*, **6**, 93–97.
- Alam, M. and G. Rabbani (2007). Vulnerabilities and responses to climate change for Dhaka. *Environment and Urbanization*, **19**, 81–97.
- Ashley, R. and A. Cashman (2006). *Infrastructure to 2030: Telecom, Land Transport, Water and Electricity*. OECD.
- Auld, H., D. MacIver, and J. Klaassen (2004). Heavy rainfall and waterborne disease outbreaks: the Walkerton example. *Journal of Toxicology and Environmental Health, Part A*, **67**, 1879–1887.
- Baccini, M., A. Biggeri, G. Accetta, et al. (2008). Heat effects on mortality in 15 European cities. *Epidemiology*, **19**, 711–719.
- Balbus, J. and M. Wilson (2000). *Human Health and Global Climate Change: A Review of Potential Impacts in the United States*, Pew Center on Global Climate Change. Accessed Feb 8, 2011, [http://lwww.ewclimate.org/~warming-in-depth/la11re~ortslhulnanhealtl\\$index.cftn](http://lwww.ewclimate.org/~warming-in-depth/la11re~ortslhulnanhealtl$index.cftn).
- Barclay, E. (2008). Is climate change affecting dengue in the Americas? *The Lancet*, **371**, 973–974.
- Barrios, S., L. Bertinelli, and E. Strobl (2006). Climatic change and rural–urban migration: the case of sub-Saharan Africa. *Journal of Urban Economics*, **60**, 357–371.
- Bartlett, S. (2008). Climate change and urban children: impacts and implications for adaptation in low- and middle-income countries. *Environment and Urbanization*, **20**, 501–519.
- Bartlett, S. (2009). Children: a large and vulnerable population in the context of climate change. Paper prepared for Expert Group Meeting on Population Dynamics and Climate Change, 24–25 June, 2009. Accessed Feb 8, 2011, www.unfpa.org/webdav/site/global/users/schensul/public/CCPD/papers/Bartlett%20Paper.pdf.
- Bartlett, S., D. Dodman, J. Hardoy, D. Satterthwaite, and C. Tacoli (2009). Social aspects of climate change in urban areas in low- and middle-income nations. Contribution to the World Bank Fifth Urban Research Symposium *Cities and Climate Change: Responding to an Urgent Agenda*. Accessed Feb 8, 2011, www.urs2009.net/docs/papers/Satterthwaite.pdf.
- Bates, B., Z. W. Kundzewicz, S. Wu, and J. P. Palutikof (2008). *Climate Change and Water*, Technical Paper of the Intergovernmental Panel on Climate Change, Geneva: IPCC Secretariat.
- Beebe, N., R. Cooper, P. Mottram, and A. Sweeney (2009). Australia's dengue risk driven by human adaptation to climate change. *PLoS Neglected Tropical Diseases*, **3**, e429.
- Bell, M. L., R. Goldberg, C. Hogrefe, et al. (2007). Climate change, ambient ozone, and health in 50 US cities. *Climatic Change*, **82**, 61–76.
- Bernard, S. and M. McGeehin (2004). Municipal heatwave response plans. *American Journal of Public Health*, **94**, 1520–1521.
- Berry, P. (2008). Vulnerabilities, adaptation and adaptive capacity. In J. Seguin (Ed.), *Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity*, Ottawa: Health Canada.
- Bhosale, R. (2008). *Disaster Management and Flood Control: An Initiative by Pune Municipal Corporation*. Presentation to Building a Local Government Alliance for Disaster Risk Reduction Consultative Meeting, UNISDR, Barcelona, 22–23 May 2008.
- Bicknell, J., D. Dodman and Satterthwaite, D. (2009). *Adapting Cities to Climate Change: Understanding and Addressing the Development Challenges*. London, UK: Earthscan.
- Bobylev, N. (2009). Urban underground infrastructure and climate change: opportunities and threats. *Russian Academy of Sciences*. Accessed Dec 21, 2009, <http://www.urs2009.net/docs/papers/Bobylev.pdf>.
- Bunyavanich, S., C. Landrigan, A. McMichael, and P. Epstein (2003). The impact of climate change on child health. *Ambulatory Pediatrics*, **3**, 44–52.
- Campbell-Lendrum, D. and C. Corvalán (2007). Climate change and developing-country cities: implications for environmental health and equity. *Journal of Urban Health*, **84**, doi:10.1007/s11524-007-9170-x.
- Campbell-Lendrum, D., R. Bertollini, M. Neira, K. Ebi, and A. McMichael (2009). Health and climate change: a roadmap for applied research. *Lancet*, **16**, 1663–5.
- CCAP [Center for Clean Air Policy] (2009). *Urban Leaders Adaptation Initiative*. Accessed Feb 8, 2011, www.ccap.org/index.php?component=resources&program=6.
- CCD [Commission on Climate Change and Development] (2008). *Links Between Disaster Risk Reduction, Development and Climate Change*, UNISDR Secretariat, Geneva. Accessed Dec 21, 2009, www.ccdcommission.org/Filer/pdf/pb_disaster_risk_reduction.pdf.
- CCSP (2008). *Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems*, Report by the US Climate Change Science Program and the Subcommittee on Global Change Research. USEPA, Washington, DC, USA.
- Charron, D., M. Thomas, D. Waltner-Toews, J. Aramini, and T. Edge (2004). Vulnerability of waterborne diseases to climate change in Canada: a review. *Journal of Toxicology and Environmental Health*, **67**, 1667–1677.
- Cheng, C., M. Campbell, Q. Li, et al. (2009). Differential and combined impacts of extreme temperatures on human mortality in south-central Canada: Part II. *Air Quality and Atmospheric Health*, **1**, 223–235.
- Cifuentes, V., N. Borja-Aburto, N. Gouveia, G. Thurston, and D. Davis (2001). Assessing the health benefits of urban air pollution reductions associated with climate change mitigation (2000–2020): Santiago, São Paulo, México City, and New York City. *Environmental Health Perspectives*, **109**, 419–426.

- Clean Air Partnership (2009). *Alliance for Resilient Cities* Accessed Feb 8, 2011, www.cleanairpartnership.org/arc.
- Cohen, M. and J. Garrett (2009). *The Food Price Crisis and Urban Food (In)Security*, Human Settlements Working Paper Series. Accessed Feb 8, 2011, www.iied.org/pubs/pdfs/10574IIED.pdf.
- Cole, D., D. Lee-Smith, and G. Nasinyama (2008). *Healthy City Harvests: Generating Evidence to Guide Policy on Urban Agriculture*, Lima, Peru, and Kampala, Uganda: Urban Harvest and Makerere University Press.
- Confalonieri, U. (2008). *Mudança Climática Global e Saúde Humana no Brasil*. Parcerias Estratégicas /Centro de Gestão e Estudos Estratégicos. Brasília: Centro de Gestão e Estudos Estratégicos: Ministério da Ciência e Tecnologia, n.27.
- Confalonieri, U., B. Menne, R. Akhtar, *et al.* (2007). Human health. In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, UK: Cambridge University Press.
- Costello, A., M. Abbas, A. Allen, and S. Ball (2009). Managing the health effects of climate change. *The Lancet*, **373**, 1693–1733.
- Davis, R., P. Knappenberger, W. Novicoff, and P. Michaels (2003). Decadal changes in summer mortality in U.S. cities. *International Journal of Biometeorology*, **47**, 166–175.
- Della-Marta, P., M. Haylock, J. Luterbacher, and H. Wanner (2007). Doubled length of western European summer heat waves since 1880. *Journal of Geophysical Research*, **112**.
- del Ninno, C. and M. Lundberg (2005). Treading water: the long term impact of the 1998 flood on nutrition in Bangladesh. *Economic Human Biology*, **3**, 67–96.
- de Sherbinin, A., A. Schiller, and A. Pulsipher (2007). The vulnerability of global cities to climate hazards. *Environment and Urbanization*, **19**, 39–64.
- Despommier (2009). A farm on every floor. *New York Times*, August 23, 2009. Accessed Feb 8, 2011, www.nytimes.com/2009/08/24/opinion/24Despommier.html?_r=2.
- Dickinson, T. (2007). *The Compendium of Adaptation Models for Climate Change* (1st edition), Environment Canada, Adaptation and Impacts Research Division.
- Dodman, D. (2009). *Urban density and climate change: an agenda for mitigation and adaptation*. Paper prepared for Expert Group Meeting on Population Dynamics and Climate Change, London.
- Droege, P. (2008). *Urban Energy Transition From Fossil Fuels to Renewable Power*. University of Newcastle, NSW, Australia and World Council for Renewable Energy: Elsevier.
- D'Souza, R., N. Becker, G. Hall, and K. Moodie (2004). Does ambient temperature affect foodborne disease? *Epidemiology*, **15**(1), 86–92.
- Dubbeling, M., M. C. Campbell, F. Hoekstra, and R. van Veenhuizen (2009). Building resilient cities. *Urban Agriculture Magazine*, **22**.
- Ebi, K. (2005). Improving public health responses to extreme weather events. In W. Kirch, B. Menne, and R. Bertolinni (Eds.), *Extreme Weather Events and Public Health Responses*, Berlin, Germany: Springer.
- Ebi, K. and A. Nyong (2009). *The Health Risks of Climate Change*, Commonwealth Health Ministers' Update. Accessed Feb 8, 2011, www.thecommonwealth.org/files/190382/FileName/2-EbiandNyong_2009.pdf.
- Ebi, K., T. Teisberg, L. Kalkstein, L. Robinson, and R. Weiher (2004). Heat watch warning systems save lives: estimated costs and benefits for Philadelphia 1995–98. *Bulletin of the American Meteorological Society*, **85**, 1067–1073.
- Ekelund, N. (2007). *Adapting to Climate Change in Stockholm*, City of Stockholm.
- Epstein, P. and C. Defilippo (2001). West Nile virus and drought. *Global Change and Human Health*, **2**, 105–107.
- European Commission (2008). *Addressing the Social Dimensions of Environmental Policy: A Study on the Linkages Between Environmental and Social Sustainability in Europe*. Accessed Feb 8, 2011, ec.europa.eu/social/BlobServlet?docId=1574&langId=en.
- FAO (2009). *The State of Food Insecurity in the World 2009: Economic Crises – Impacts and Lessons Learned*. Rome: Food and Agriculture Organization of the United Nations.
- Few, R., H. Osbahr, L. M. Bouwer, D. Viner, and F. Sperling (2006). *Linking Climate Change Adaptation and Disaster Risk Management for Sustainable Poverty Reduction*, Report for the Vulnerability and Adaptation Resource Group, Washington.
- Few, R. and F. Matthies (2006). *Flood Hazards and Health: Responding to Present and Future Risks*, London, UK: Earthscan.
- Foreign Policy (2009). *Failed States Index*. Accessed Dec 21, 2009, www.foreignpolicy.com/articles/2009/06/22/the_2009_failed_states_index.
- Frumkin, H. and A. McMichael (2008). Climate change and public health: thinking, communicating, acting. *American Journal of Preventative Medicine*, **35**, 403–410.
- Frumkin, H., J. Hess, G. Luber, J. Malilay, and M. McGehehin (2008). Climate change: the public health response. *American Journal of Public Health*, **98**, 435–445.
- Gage K., T. Burkot, R. Eisen, and E. Hayes (2008). Climate and vectorborne diseases. *American Journal of Preventative Medicine*, **35**, 436–50.
- Gartland, L. (2008). *Urban Heat Islands: Understanding and Mitigating Heat in Urban Areas*. London, UK: EarthScan.
- GFDRL (2009). *Reducing Disaster Risks for Sustainable Development*, Global Facility for Disaster Reduction and Recovery. Accessed Feb 8, 2011, http://gfdrr.org/docs/GFDRL_Brochure.pdf.
- Githeko, A. (2007). Malaria, climate change, and possible impacts on populations in Africa. In *HIV, Resurgent Infections and Population Change in Africa*, International Studies in Population, Volume 6, Dordrecht, the Netherlands: Springer.
- Glantz, M. H. (2008). Hurricane Katrina as a “teachable moment”. *Advances in Geoscience*, **14**, 287–294. Accessed Feb 8, 2011, www.adv-geosci.net/14/287/2008/.
- Gosling, S. N., G. R. McGregor, and J. A. Lowe (2009). Climate change and heat-related mortality in six cities. Part 2: climate model evaluation and projected impacts from changes in the mean and variability of temperature with climate change. *International Journal of Biometeorology*, **53**, 31–51.
- Gosselin, P., D. Belanger, and B. Doyan (2008). Health impacts of climate change in Quebec. In J. Seguin (Ed.), *Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity*, Ottawa: Health Canada.
- Gould, E., and S. Higgs (2009). Impact of climate change and other factors on emerging arbovirus diseases. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, **103**, 109–121.
- Greenough, G., M. McGehehin, S. Bernard, *et al.* (2001). The potential impacts of climate variability and change on health impacts of extreme weather events in the United States. *Environmental Health Perspectives*, **109**, 191–198.
- Griffiths, H., M. Rao, F. Adshead, and A. Thorpe (2009). *The Health Practitioner's Guide to Climate Change: Diagnosis and Cure*. London, UK: Earthscan.
- Grossi, P. and R. Muir-Wood (2006). The 1906 San Francisco Earthquake and Fire: Perspectives on a Modern Super Catastrophe. Newark, CA, USA: Risk Management Solutions.
- Gubler, D. (1998). Resurgent vector-borne diseases as a global health problem. *Emerging Infectious Diseases*, **4**, 442–450.
- Guha-Sapir, D. and R. Below (2002). *Quality and Accuracy of Disaster Data: A Comparative Analyses of 3 Global Data Sets*. Technical report, WHO Centre for Research on the Epidemiology of Disasters.
- Guha-Sapir, D., D. Hargitt, and P. Hoyois (2004). *Thirty Years of Natural Disasters 1974–2003: The Numbers*. Louvain, Belgium: Presses Universitaires de Louvain.
- Haines, A. (2008). Climate change and health: strengthening the evidence base for policy. *American Journal of Preventative Medicine*, **35**, 411–3.
- Haines, A. and J. Patz (2004). Health effects of climate change. *JAMA*, **291**, 99–103.
- Haines, A., S. Kuruvilla, and M. Borchert (2004). Bridging the implementation gap between knowledge and action for health. *Bulletin of the World Health Organization*, **82**, 724–732.

- Hamin, E. and N. Gurran (2009). Urban form and climate change: balancing adaptation and mitigation in the U.S. and Australia. *Habitat International*, **33**, 238–245.
- Hardoy, E. and Pandiella (2009). Urban poverty and vulnerability to climate change in Latin America. In J. D. Bicknell, D. Dodman, *et al.* (Eds.), *Adapting Cities to Climate Change: Understanding and Addressing the Development Challenges*, London, UK: Earthscan.
- Hay, S. D. Rogers, S. Randolph, *et al.* (2002). Hot topic or hot air? Climate change and malaria resurgence in East African highlands. *Trends in Parasitology*, **18**, 530–534.
- HDR (2007). *Human Development Report 2007/2008: Fighting Climate Change: Human Solidarity in a Divided World*. Human Development Report Office. Accessed Feb 8, 2011, http://hdr.undp.org/en/reports/global/hdr2007-2008/papers/de%20la%20fuente_alejandro_2007.pdf.
- Holloway, T., S. N. Spak, D. Barker, *et al.* (2008). Change in ozone air pollution over Chicago associated with global climate change. *Journal of Geophysical Research*, **113**.
- Hsieh, C., T. Aramaki, and K. Hanaki (2007). The feedback of heat rejection to air conditioning load during the night-time in subtropical climate. *Energy and Buildings*, **39**, 1175–1182.
- Hunter, P. R. (2003). Climate change and water-borne and vector-borne disease. *Journal of Applied Microbiology*, **94**, 37–46.
- Huq, S. (2008). Who are the real climate experts? *New Scientist*, No. 2649, April 2, 2008.
- Huq, S., R. S. Kovats, H. Reid, and D. Satterthwaite (2007). Reducing risks to cities from disasters and climate change [Editorial]. *Environment and Urbanization*, **19**, 3–15.
- Ichinose, T., Y. Bai, J. Nam, and Y. Kim (2006). Mitigation of thermal stress by a large restoration of inner-city river (Cheong-Gye Stream in Seoul). *Proceedings of ICUC*, **6**, 358–361.
- IPCC (2007a). *Climate Change 2007: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson (Eds), Cambridge, UK, and New York, USA: Cambridge University Press.
- IPCC (2007b). Summary for Policymakers. In S. Solomon, D. Qin, M. Manning, *et al.* (Eds.), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, UK, and New York, USA: Cambridge University Press.
- Jelinek, T. (2009). Trends in the epidemiology of dengue fever and their relevance for importation into Europe. *Euro Surveill*, **14**, 19250. Accessed Dec 21, 2009, www.eurosurveillance.org/ViewArticle.aspx?ArticleId=19250.
- Jonkman, S. (2005). Global perspectives on loss of human life caused by floods. *Natural Hazards*, **34**, 151–175.
- Kalkstein, L., J. Greene, D. Mills, *et al.* (2008). Analog European heat waves for U.S. cities to analyze impacts on heat-related mortality. *American Meteorological Society*, 1–11.
- Karl, T., J. Melillo, T. Peterson, and S. Hassol (2009). *Global Climate Change Impacts in the United States*. Cambridge, UK: Cambridge University Press.
- Kinney, P. (2008). Climate change, air quality, and human health. *American Journal of Preventative Medicine*, **35**, 459–67.
- Kistemann, T., T. Classen, C. Koch, *et al.* (2002). Microbial load of drinking water reservoir tributaries during extreme rainfall and runoff. *Applied and Environmental Microbiology*, **68**, 2188–2197.
- Kjellstrom, T., S. Friel, J. Dixon, *et al.* (2007). Urban environmental health hazards and health. *Equity Journal of Urban Health*, **84**, N1.
- Knowlton, J., C. Rosenthal, B. Hogrefe, *et al.* (2004). Assessing ozone-related health impacts under a changing climate. *Environmental Health Perspectives*, **112**, 1557.
- Kojima, M., C. Brandon, and J. Shah (2000). *Improving Urban Air Quality in South Asia by Reducing Emissions from Two-Stroke Engine Vehicles*, World Bank.
- Koppe, C., G. Jendritzky, R. Kovats, and B. Menne (2004). *Heat Waves: Risks and Responses* Copenhagen, Denmark: World Health Organization.
- Kovats, S. and R. Akhtar (2009). Climate, climate change and human health in Asian cities. *Environment and Urbanization*, **20**, 165.
- Kovats, R. and K. Ebi (2006). Heatwaves and public health in Europe. *European Journal of Public Health*, **16**, 592–599.
- Kovats, S. and S. Hajat (2008). Heat stress and public health: a critical review. *Annual Review of Public Health*, **29**, 04.
- Kovats, R., S. Edwards, and S. Hajat (2004). The effect of temperature on food poisoning: a time-series analysis of salmonellosis in ten European countries. *Epidemiology and Infection*, **132**, 443–453.
- Kovats, R., S. Edwards, D. Charron, *et al.* (2005). Climate variability and campylobacter infection: an international study. *International Journal of Biometeorology*, **49**, 207–214.
- Kunkel, K. E., S. A. Changnon, B. C. Reinke, and R. Arritt (1996). The July 1995 heat wave in the Midwest: a climatic perspective and critical weather factors. *Bulletin of the American Meteorological Society*, **77**, 1507–1518.
- Kyalimpa, J. (2009). *Looming Problems with Kampala's Water*, Inter Press Service Accessed Feb 8, 2011, <http://ipsnews.net/news.asp?idnews=43592>.
- Laaidi, M., K. Laaidi, and J.-P. Besancenot (2006). Temperature-related mortality in France, a comparison between regions with different climates from the perspective of global warming. *International Journal of Biometeorology*, **51**, 145–153.
- Lapitan, J., P. Brocard, R. Atun, and C. Tantinimitkul (2009). City health system preparedness to changes in Dengue fever attributal to climate change: an exploratory case study. Presentation to the *5th Urban Research Symposium on Cities and Climate Change*, Marseille, France.
- Larsen, K. and F. Barker-Reid (2009). Adapting to climate change and building urban resilience in Australia. *Urban Agriculture Magazine*, **22**.
- Laukkonen, J., P. K. Blanco, J. Lenhart, *et al.* (2009). Combining climate change adaptation and mitigation measures at the local level. *Habitat International*, **33**, 287–292.
- Lecomte, E., A. Pang, and J. Russell (1998). *Ice Storm '98*, Toronto and Boston: Institute for Catastrophic Loss Reduction and Institute for Business and Home Safety.
- Lemmen, D. S., F. J. Warren, J. Lacroix, and E. Bush (2008). In *From Impacts to Adaptation: Canada in a Changing Climate 2007*, Government of Canada, Ottawa, ON, pp. 227–274.
- Létard, V., H. Flandre, and S. Lepeltier (2004). *La France et les Français face à la canicule: les leçons d'une crise*. Report No. 195 (2003–2004) to the Sénat, Government of France. Cited in IPCC, 2007a. Available (in French) on www.senat.fr.
- le Tertre, A., A. Lefranc, D. Eilstein, *et al.* (2006). Impact of the 2003 heatwave on all-cause mortality in 9 French cities. *Epidemiology*, **17**, 75–79.
- Lindsay, S. and M. Birley (1996). Climate change and malaria transmission. *Annals of Tropical Medicine and Parasitology*, **90**, 573–588.
- Lock, K. and R. van Veenhuizen (2001). Balancing the positive and negative health impacts. *Urban Agriculture Magazine*, **1**, 3.
- Lombardo, M. (1985). *Ilha de calor nas metrópoles: o exemplo de São Paulo*. São Paulo, Brazil: HUCITEC.
- Luber, G. and M. McGehehin (2008). Climate change and extreme heat events. *American Journal of Preventative Medicine*, **35**, 429–435.
- Mabasi, T. (2009). *Assessing the Impacts, Vulnerability, Mitigation and Adaptation to Climate Change in Kampala City*, Uganda Pentecostal University, Kampala, Uganda. Accessed Dec 21, 2009, www.urs2009.net/docs/papers/Mabasi.pdf.
- Marfai, L., L. King, D. Singh, *et al.* (2008). Natural hazards in Central Java Province, Indonesia: an overview. *Environmental Geography*, **56**, 335–351.
- Martens, P. and M. McMichael (2002). *Environmental Change, Climate, and Health: Issues and Research Methods*. Cambridge, UK: Cambridge University Press.
- Martine, G. (2009). Population dynamics and policies in the context of global climate change. Paper prepared for Expert Group Meeting on Population Dynamics and Climate Change, London, June 24–25, 2009.
- Mayor of London (2008). *The London Climate Change Adaptation Strategy: Draft Report*. Greater London Authority, London, UK. Accessed Dec 21, 2009, www.london.gov.uk/mayor/publications/2008/08/climate-change-adapt-strat.jsp.

- McBean, G. and D. Henstra (2003). *Climate Change, Natural Hazards and Cities*, Institute for Catastrophic Loss Reduction Research Paper Series, No. 31, March 2003.
- McGranahan, G., D. Balk, and B. Anderson (2007). The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment and Urbanization*, 19, 17–37.
- McMichael, A. J., D. H. Campbell-Lendrum, C. F. Corvalán, et al. (2003). *Climate Change and Human Health: Risks and Responses*. Geneva, Switzerland: WHO.
- Meehl, G. A. and C. Tebaldi (2004). More intense, more frequent, and longer lasting heat waves in the 21st century. *Science*, 305, 994–997.
- Menne, B., F. Apfel, S. Kovats, and F. Racioppi (2008) *Protecting Health in Europe from Climate Change*. Geneva, Switzerland: WHO Press.
- Mitchell, T. and M. van aalst (2008). *Convergence of disaster risk reduction And Climate Change Adaptation: A Review for DFID*. Accessed Dec 21, 2009, www.preventionweb.net/files/7853_ConvergenceofDR-RandCCA1.pdf.
- Molesworth, A., S. Cuevas, H. Connor, A. Morse, and M. Thomson (2003). Environmental risk and meningitis epidemics in Africa. *Emerging Infectious Diseases*, 9, 1287–1293.
- Mool, P., S. Bajracharya, and S. Joshi (2001). *Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods: Monitoring and Early Warning Systems in the Hindu-Kush Himalayan Region, Nepal*.
- Nagaraj, N. (2009). Malaria thrives in cities. *Times of India*. May 25, 2009.
- Natural Resources Canada (2007). *Climate Change Impacts and Adaptation Division*. Accessed Feb 8, 2011, http://adaptation.nrcan.gc.ca/perspective/health_3_e.php.
- Nerlander, L. (2009). *Climate Change and Health*, Commission on Climate Change and Development. Accessed Feb 8, 2011, www.ccdcommission.org/Filer/commissioners/Health.pdf.
- New York City (2009). *PlaNYC*. Accessed Feb 8, 2011, www.nyc.gov/html/planyc2030/html/plan/climate.shtml.
- Nicholls, R., S. Hanson, C. Herweijer, et al. (2008). Ranking of port cities with high exposure and vulnerability to climate extremes: exposure estimates. *OECD Working Papers*, 1.
- O'Connor (2002). *Report of the Walkerton Inquiry: The Events of May 2000 and Related Issues*. Accessed Feb 8, 2011, www.attorneygeneral.jus.gov.on.ca/english/about/pubs/walkerton/part1/.
- O'Hare, G. and S. Rivas (2005). The landslide hazard and human vulnerability in La Paz City, Bolivia. *The Geographical Journal*, 171, 239–258.
- Oke, T. (1997). Urban climates and global change. In A. Perry and R. Thompson (Eds.), *Applied Climatology: Principles and Practices*, London, UK: Routledge.
- Ortiz Bultó, P., A. Rodríguez, A. Valencia, et al. (2006). Assessment of human health vulnerability to climate variability and change in Cuba. *Environmental Health Perspectives*, 114, 1942–1949.
- Oxfam (2009). *Climate Change and Security: Oxfam Fact Sheet*. Accessed Feb 8, 2011, www.oxfamamerica.org/files/climatechangeandsecurity-factsheet.pdf.
- Pagnamenta, R. (2009). French add Rolls-Royce to nuclear power project. *The Times*. Accessed Feb 8, 2011, http://business.timesonline.co.uk/tol/business/industry_sectors/article6837467.ece.
- Patil, N. (2008a). PMC says no problem, we're ready to tackle floods. *Express India*. Accessed Feb 8, 2011, www.expressindia.com/latest-news/pmc-says-no-problem-were-ready-to-tackle-floods/317973/.
- Patil, N. (2008b). Flood of fear engulfs helpless city. *Express India*. Accessed Feb 8, 2011, www.expressindia.com/latest-news/Flood-of-fear-engulfs-helpless-city/347725/.
- Patz, J., M. McGeehin, S. Bernard, and K. Ebi (2000). The potential health impacts of climate variability and change for the United States. *Environmental Health Perspectives*, 108, 367–376.
- Patz, J., S. Vavrus, C. Uejio, and S. McLellan (2008). Climate change and water borne disease risk in the Great Lakes region of the U.S. *American Journal of Preventative Medicine*, 35, 451–458.
- Pengelly, L., M. Campbell, C. Cheng, et al. (2007). Anatomy of heat waves and mortality in Toronto: Lessons for public health protection. *Canadian Journal of Public Health*, 98, 364–368.
- Penney, J. (2007). *Cities Preparing for Climate Change: A Study of Six Urban Regions*, Clean Air Partnership, Toronto.
- Peterson, D. and D. McKenzie (2008). *Wildland Fire and Climate Change*, US Department of Agriculture, Forest Service, Climate Change Resource Center. Accessed Feb 8, 2011, www.fs.fed.us/ccrc/topics/wildland-fire.shtml.
- PHAC (2009). *What Determines Health?* Public Health Agency of Canada. Accessed Feb 8, 2011, www.phac-aspc.gc.ca/ph-sp/determinants/index-eng.php.
- Pitt, M. (2008). *Lessons Learned From the 2007 Floods: The Pitt Review*, Cabinet Office. Accessed Feb 8, 2011, www.cabinetoffice.gov.uk/thepittreview/final_report.aspx.
- Reid, H. and S. Kovats (2009). Special Issue on health and climate change of TIEMPO, *Bulletin on Climate and Development*, Issue 71.
- Reiter, P. (2008). Global warming and malaria: knowing the horse before hitching the cart. *Malaria Journal*, 7, S3.
- Reiter, P., C. Thomas, and P. Atkinson (2004). Global warming and malaria: a call for accuracy. *Lancet Infectious Diseases*, 4, 323–324.
- Revi, A. (2008). Climate change risk: an adaptation and mitigation agenda for Indian cities. *Environment and Urbanization*, 20, 207–229.
- Ribeiro, W. (2008). *Impactos das Mudanças Climáticas em Cidades no Brasil*. Parcerias Estratégicas /Centro de Gestão e Estudos Estratégicos. Brasília: Centro de Gestão e Estudos Estratégicos, Ministério da Ciência e Tecnologia.
- Risk Management Solutions (2008). *The 1998 Ice Storm: 10-Year Retrospective*, RMS Special Report. Accessed Feb 8, 2011 www.rms.com/publications/1998_Ice_Storm_Retrospective.pdf.
- Republic of Uganda (2007). *Climate Change: Uganda's National Programmes of Action (2007)*. Accessed 20 October 2009, www.preventionweb.net/english/professional/policies/v.php?id=8578.
- Robine, J., S. Cheung, S. Le Roy, H. Van Oyen, and F. Herrmann (2007). *Report on Excess Mortality in Europe During Summer 2003*. EU Community Action Programme for Public Health.
- Romero Lankao, P. and J., Tribbia (2009). *Assessing Patterns of Vulnerability, Adaptive Capacity and Resilience Across Urban Centers*, National Center for Atmospheric Research, Mexico. Accessed Dec 21, 2009, www.urs2009.net/docs/papers/Romero.pdf.
- Rosenzweig, C., W. Solecki and R. Solsberg (2006). *Mitigating New York City's Heat Island with Urban Forestry, Living Roofs, and Light Surfaces*, New York State Energy Research and Development Authority.
- Saelens, B., J. Sallis, and L. Frank (2003). Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. *Annals of Behavioral Medicine*, 25, 80–91.
- Satterthwaite, D. (2009). *Social Aspects of Climate Change in Urban Areas in Low and Middle Income Nations*. Accessed Dec 21, 2009, www.urs2009.net/docs/papers/Satterthwaite.pdf.
- Satterthwaite, D., S. Huq, M. Pelling, H. Reid, and P. Romero Lankao (2007). *Adapting to Climate Change in Urban Areas: The Possibilities And Constraints in Low- and Middle-Income Nations*, Human Settlements Working Paper Series Climate Change and Cities No. 1. London, UK: IIED.
- Semenza, J. and B. Menne (2009). Climate change and infectious diseases in Europe. *Lancet*, 9, 365–375.
- Sen, S. N., P. K. Maiti, A. Ghosh, and R. Ghosh (2003). Status and scope of Boro rice cultivation in West Bengal. In R. K. Singh, M. Hossain, and R. Thakur (Eds.), *Boro Rice*, Los Banos: IIRRI, pp. 137–156.
- Sharkey, P. (2007). Survival and death in New Orleans. *Journal of Black Studies*, 37, 482–501.
- Steiner, S., R. Tonse, A. Cohen, R. Goldstein, and R. Harley (2006). Influence of future climate and emissions on regional air quality in California. *Journal of Geophysical Research*, 111, D18303.
- Surjan, A. and R. Shaw (2009). Enhancing disaster resilience through local environment management: case of Mumbai, India. *Disaster Prevention and Management*, 18(4), 418–433.
- Tan, J., Y. Zheng, G. Song, et al. (2007). Heat wave impacts on mortality in Shanghai, 1998 and 2003. *International Journal of Biometeorology*, 51, 193–200.

- Toronto Environment Office (2008). *Ahead of the Storm: Preparing for Climate Change*, Accessed Feb 8, 2011, www.toronto.ca/teo/pdf/ahead_of_the_storm.pdf.
- UN (2005). *World Population to Increase by 2.6 Billion Over the Next 45 Years*. Press Release POP/918.
- UN-HABITAT (2003). *The Challenge of Slums: Global Report on Human Settlements 2003*. Accessed Feb 8, 2011, www.unhabitat.org/pmss/listItemDetails.aspx?publicationID=1156.
- UN Millenium Project (2005) *Coming to Grips with Malaria in the New Millennium*, Task Force on HIV/AIDS, Malaria, TB, and Access to Essential Medicines, Task Force on Malaria.
- UN Population Division (2008). *World Urbanization Prospects: The 2007 Revision*. Accessed Feb 8, 2011, www.un.org/esa/population/publications/wup2007/2007WUP_ExecSum_web.pdf
- UN Population Fund (2007). *State of the World Population 2007*. Accessed Feb 8, 2011, www.unfpa.org/swp/2007/english/introduction.html.
- UNDP (2007). *Human Development Report 2007/2008, Fighting Climate Change: Human Solidarity in a Divided World*, United Nations Development Programme, New York, USA.
- UNEP (2008). *Health Security through Healthy Environments*. Accessed Feb 8, 2011, www.unep.org/health-env/pdfs/WHOLibrevilleReport.pdf.
- UNISDR (2008). *Climate Change and Disaster Risk Reduction*, Briefing Note 01. Accessed Feb 8, 2011, www.preventionweb.net/files/4146_ClimateChangeDRR.pdf.
- UNISDR (2009). *Adaptation to Climate Change by Reducing Disaster Risks: Country Practices and Lessons*. Geneva, Switzerland: United Nations International Strategy for Disaster Reduction.
- United Nations Prevention Web (2009). www.preventionweb.net/english/.
- USEPA (2008). *Global Change Research Program: Review of the Impacts of Climate Variability and Change on Aeroallergens and their Associated Effects*, Technical Report EPA/600/R-06/164F, US Environmental Protection Agency.
- USEPA (2009). *Reducing Urban Heat Islands: Compendium of Strategies*, describes mitigation measures that communities can take to address the negative impacts of urban heat islands.
- Volschan Jr., I. (2008). Efeitos das mudanças climáticas sobre os sistemas de abastecimento de água e de esgotamento sanitário da cidade do Rio de Janeiro: uma visão preliminar. In P. P. Gusmão, P. S. Carmo, and S. B. Vianna (Eds.), *Rio próximos 100 anos. O Aquecimento Global e a Cidade*, Rio de Janeiro, Brazil: Instituto Pereira Passos, Volume 1, pp. 199–210.
- Waterston, T. and S. Lenton (2000). Public health: sustainable development, human induced global climate change, and the health of children. *Childhood*, **82**, 95–97.
- WHO (2002). *The World Health Report 2002*. Geneva, Switzerland: WHO. Accessed Feb 8, 2011, www.who.int/whr/2002/en/.
- WHO (2004). *Global Strategic Framework for Integrated Vector Management*. Accessed, http://whqlibdoc.who.int/hq/2004/WHO_CDS_CPE_PVC_2004_10.pdf.
- WHO (2005). *El Niño and its Health Impact*, Fact sheet 192. Accessed Dec 21, 2009, www.who.int/mediacentre/factsheets/fs192/en/index.html.
- WHO (2009). *Medium-Term Strategic Plan 2008–2013*, Amended (Draft) Proposed Programme Budget 2010–2011, A62/11 Climate change and health.
- Wilbanks, T. J., P. Romero Lankao, M. Bao, *et al.* (2007). Industry, settlement and society. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability: Contributions of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, UK: Cambridge University Press, pp. 357–390.
- Wilby, R. L. (2007). A review of climate change impacts on the built environment. *Built Environment*, **33**, 1.
- Winchester, L. and R. Szalachman (2009). *The Urban Poor's Vulnerability to the Impacts of Climate Change in Latin America and the Caribbean: A Policy Agenda*. Accessed Dec 21, 2009, www.urs2009.net/docs/papers/Winchester.pdf.
- World Bank (2008). *Climate Resilient Cities Primer: Reducing Vulnerabilities to Climate Change Impacts and Strengthening Disaster Risk Management in East Asian Cities*. Accessed Feb 8, 2011, http://siteresources.worldbank.org/EASTASIAPACIFICEXT/Resources/climatecities_fullreport.pdf.
- World Medical Association (2009). *WMA Declaration of Delhi on Health and Climate Change*, New Delhi. Accessed Feb 8, 2011, www.wma.net/en/30publications/10policies/c5/index.html.
- Yamamoto, Y. (2004). Measures to mitigate urban heat islands, Chapter 6, Does ambient temperature affect foodborne disease? *Epidemiology*, **15**, 1.
- Zimmerman, R., C. Restrepo, B. Nagorsky, and A. Culpén (2007). Vulnerability of the elderly during natural hazard events. In *Proceedings of the Hazards and Disasters Research Meeting*, Boulder, CO, USA. Accessed Dec 21, 2009, www.colorado.edu/hazards/work/hdrm_proceedings.pdf.
- Ziska, D., D. Gebhard, S. Frenz, *et al.* (2003). Cities as harbingers of climate change: common ragweed, urbanization, and public health. *The Journal of Allergy and Clinical Immunology*, **111**, 290–295.

