CHAPTER 4

THE IMPACTS OF CLIMATE CHANGE UPON URBAN AREAS

Climate change impacts are now well documented and technological advancement has led to a clearer understanding of future risks and impacts. With increasing urbanization, understanding the impacts of climate change upon the urban environment will become ever more important. Evidence is mounting that climate change presents unique challenges for urban areas and their growing populations. Where urban areas grow rapidly without regard to current and future resource demands and climate change, large numbers of people and their assets can find themselves vulnerable to a range of disruptive and damaging risks.

These impacts extend far beyond the physical risks posed by climate change, such as sea-level rise and extreme weather events. Cities could face difficulties in providing even the most basic services to their inhabitants as a result of climate change. Climate change may affect water supply, ecosystem goods and services, energy provision, industry and services in cities around the world. It can disrupt local economies and strip populations of their assets and livelihoods, in some cases leading to mass migration. Such impacts are unlikely to be evenly spread among regions and cities, across sectors of the economy or among socioeconomic groups. Instead, impacts tend to reinforce existing inequalities; as a result, climate change can disrupt the social fabric of cities and exacerbate poverty.

Although there is a burgeoning literature documenting climate change impacts in various cities, there are few comprehensive studies that evaluate the wider implications for cities across the globe. The purpose of this chapter is to identify and discuss the impact of climate change on cities, where an 'impact' is defined as a specific effect on natural or human systems, either positive or negative, that results from exposure to climate change.[1] The first section describes the physical climate change risks faced by cities and the extent of their variation across cities. 'Risk' is defined here as the combination of the magnitude of the impact with the probability of its occurrence.[2] The direct and indirect physical, economic, social and health impacts of these changes in cities are then reviewed in the context of existing vulnerabilities. Accordingly, impacts upon urban physical infrastructure, economies, public health and security are discussed, keeping in mind the differential impact of climate change upon specific vulnerable groups. The chapter then identifies key indicators of vulnerability to climate change for urban residents and cities themselves. Finally, the last section offers some conclusions and lessons for policy.

CLIMATE CHANGE RISKS FACING URBAN AREAS

Atmospheric and oceanic warming as a result of human activities has been observed over the past several decades.[3] Climate research has illuminated the link between global warming and the alteration of the Earth's water cycle, which has led to changes in precipitation frequency and intensity, cyclone activity, glacial melt and sea-level rise. These physical changes, and the associated responses of ecosystems and economies, have discernible implications for cities worldwide, although these implications are characterized by wide geographical variation. Many of these changes assume a gradual building of climate impacts and are becoming a reality already; however, a not yet fully explored implication relates to the possible effects of abrupt climate change events (see Table 4.1).

Climate change presents unique challenges for urban areas and their growing populations

This section describes the observed and predicted trends and geographical variations in physical climate change risks that confront urban settlements, including sea-level rise, tropical cyclones, heavy precipitation events, extreme heat events and drought. The local conditions generated by cities as a result of heat-island effects are also discussed, underscoring the exacerbated risks and unique challenges faced by the urban environment. The discussion in this chapter has been restricted to risks that have direct and indirect impacts upon urban settlements, and can be addressed through local planning and governance.

Sea-level rise

Sea-level rise refers to the increase in the mean level of the oceans.[4] Average sea levels have been rising around the world during recent decades, but with significant regional variation. The average rate of rise accelerated from 1.8mm per year between 1961 and 2003 to 3.1mm per year between 1993 and 2003.[5] Sea-level rise has occurred fastest in the central Pacific region away from the Equator, the

Table 4.1

Projected impacts upon urban areas of changes in extreme weather and climate events

Climate phenomena	Likelihood	Major projected impacts
Fewer cold days and nights	Virtually certain	Reduced energy demand for heating
Warmer and more frequent hot days and nights over most land areas	Virtually certain	Increased demand for cooling
Warmer temperatures	Virtually certain	Reduced disruption to transport due to snow, and ice effects on winter tourism Changes in permafrost, damage to buildings and infrastructures
Warm spells/heat waves: frequency increases over most land areas	Very likely	Reduction in quality of life for people in warm areas without air conditioning; impacts upon elderly, very young and poor, including significant loss of human life Increases in energy usage for air conditioning
Heavy precipitation events: frequency increases over most areas	Very likely	Disruption of settlements, commerce, transport and societies due to flooding Significant loss of human life, injuries; loss of, and damage to, property and infrastructure Potential for use of rainwater in hydropower generation increased in many areas
Areas affected by drought increase	Likely	Water shortages for households, industries and services Reduced hydropower generation potentials Potential for population migration
Intense tropical cyclone activity increases	Likely	Disruption of settlements by flood and high winds Disruption of public water supply Withdrawal of risk coverage in vulnerable areas by private insurers (at least in developed countries) Significant loss of human life, injuries; loss of, and damage to, property Potential for population migration
Increased incidence of extreme high sea level (excludes tsunamis)	Likely	Costs of coastal protection and costs of land-use relocation increase Decreased freshwater availability due to saltwater intrusion Significant loss of human life, injuries; loss of, and damage to, property and infrastructure Potential for movement of population

northeast Indian Ocean and in the North Atlantic along the coast of the US. The Equatorial western Pacific, central Indian Ocean and Australia's northwest coast have experienced the lowest rates of rise.[6] The Intergovernmental Panel on Climate Change (IPCC) predicts that global sea levels will continue to rise anywhere from 0.18 to 0.59m above 1980 to 1990 levels by the end of the 21st century.[7]

Thermal expansion, or the increase in volume of ocean water as it warms, is considered to be the leading cause of sea-level rise; but melting ice sheets may become ever more important in the future.[8] An additional factor contributing to rising sea levels is melting ice from glaciers and land masses such as Greenland and Antarctica. Since 1978, the total area of Arctic sea ice has declined by an average of 2.7 per cent each decade.[9] Satellite surveys over West Antarctica show glacial melting consistent with a rate of sea-level rise of 0.2mm per year and indicate that melting has accelerated during the early 2000s compared to the late 1990s.[10] Estimates of sea level rise due to ice loss from Antarctica and Greenland from 1993 to 2003 are about 0.21mm per year for both; but loss of these sheets in the future, even partially, could greatly alter the projections of sea-level rise.[11]

Sea-level rise and its associated impacts will, by the 2080s, affect five times as many coastal residents as they did in 1990

Studies of past warming events suggest that the Antarctic and Greenland ice sheets melt rapidly in response to warming, and could contribute to sea-level rise exceeding 1m per century.[12] Given that some physical processes of glacial ice melt are not yet well understood by climate scientists, it has been difficult to provide an estimate of the upper bounds of sea-level rise.[13] When considering what is known about glacial ice dynamics in tandem with the record of past ice-sheet melting, however, it is possible that the rate of future melting and related sea-level rise could be faster than widely thought. There may be temperature thresholds or 'tipping points' that accelerate melting to rates not yet experienced in modern times.

The direct effects of sea-level rise include increased storm flooding and damage, inundation, coastal erosion, increased salinity in estuaries and coastal aquifers, rising coastal water tables and obstructed drainage. However, a great many indirect impacts are also probable (e.g. changes in the functions of coastal ecosystems and in the distribution of bottom sediments). Since ecosystems such as wetlands, mangrove swamps and coral reefs form natural protections for coastal areas, changes to or loss of these ecosystems will compound the dangers faced by urban coastal areas.

Sea-level rise is a serious concern for coastal cities as rising water levels and storm surges can cause property damage, displacement of residents, disruption of transportation and wetland loss. This is especially so in the low-elevation coastal zone which, as indicated in Chapter 1, refers to the continuous area along coasts that is less than 10m above sea level. It is predicted that sea-level rise and its associated impacts will, by the 2080s, affect five times as many coastal residents as they did in 1990.[14] In coastal North African cities, a 1°C to 2°C increase in temperature could lead to sea-level rise exposing 6 to 25 million residents to flooding. Sea-level rise projections from 2030 to 2050 indicate that Egyptian cities in the Nile Delta will be severely affected, including Port Said, Alexandria, Rosetta and Damietta.[15] Low-lying coastal cities such as Copenhagen (Denmark), which lies at only 45m above sea level, will be especially vulnerable to sea-level rise. Many small island communities in the South Pacific are also highly vulnerable to rising sea levels. In fact, there is concern that sea-level rise and flooding will occur to such an extent that some Pacific islands will be completely submerged and entire communities displaced.[16]

The impacts of sea-level rise will continue to be felt globally even if greenhouse gas (GHG) emissions are drastically reduced given the time-lag between rising atmospheric and oceanic temperatures and the resulting sea-level rise.

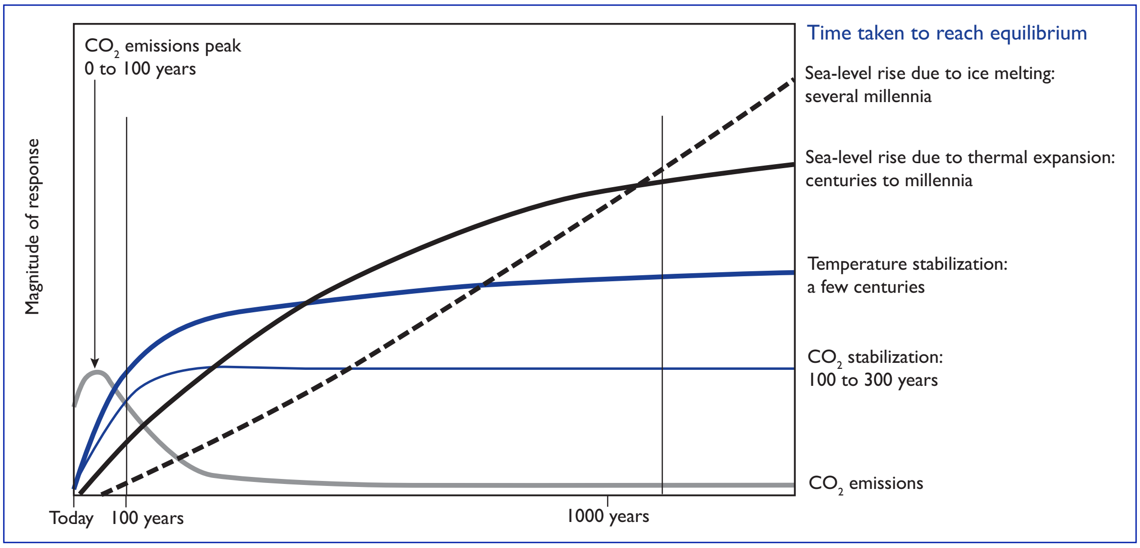

Figure 4.1

Relationship between CO_2 emissions reduction, temperature stabilization and sea-level rise

Note: After CO_2 emissions are reduced and atmospheric concentrations stabilize, surface air temperature continues to rise slowly for a century or more. Thermal expansion of the ocean continues long after CO_2 emissions have been reduced, and melting of ice sheets continues to contribute to sea-level rise for many centuries. This figure is a generic illustration for stabilization at any level between 450 and 1000 parts per million, and therefore has no units on the response axis. Responses to stabilization trajectories in this range show broadly similar time courses; but the impacts become progressively larger at higher concentrations of CO_2.

Source: IPCC, 2001a, p17

Regardless of future emission levels, past emissions have set sea-level rise on a trajectory that will not stabilize for millennia. Figure 4.1 presents a theoretical picture of this phenomenon: even if CO_2 emissions are reduced and atmospheric concentrations stabilized, global air temperature continues to rise for centuries and sea-level rise continues for millennia. Although emissions mitigation may prevent ever-worsening effects, the Earth is already 'locked into' a certain extent of climate change.[17]

Tropical cyclones

Tropical cyclones are weather systems associated with thunderstorms and strong winds that are characterized by their wind circulation patterns and a well-defined centre.[18] These systems are so named because they originate near the Equator. Similar systems that originate in the mid-latitudes[19] are referred to as 'extra-tropical cyclones'. Both of these result in waves and storm surges (i.e. temporary offshore rise of water) that can damage property and threaten the safety of individuals in the affected area. Cyclones are classified as 'storms' when sustained wind speeds reach between 63km to 118km per hour, while a hurricane is a tropical cyclone with sustained wind speeds exceeding 118km per hour.[20]

Globally, tropical cyclones and extra-tropical storms have been increasing in intensity since the 1970s as measured by their wind speed and other indices of a storm's destructive power. With the exception of the South Pacific Ocean, all tropical cyclone basins show increases in wind speed, wind strength and storm duration, with the greatest increases in the North Atlantic and northern Indian oceans.[21] Although tropical storms have not increased in frequency, extreme extra-tropical storms have increased in number in the Northern Hemisphere since 1950.[22]

Accumulating evidence also suggests that the strongest storms are getting stronger around the world. The maximum wind speeds for satellite-observed cyclones between 1981 and 2006 show the increasing occurrence of cyclone wind speeds greater than the median. While the number of low-intensity hurricanes (category 1) has remained approximately constant, they occur less often as a percentage of the total number of hurricanes. On the other hand, hurricanes in the strongest categories (4 and 5) have almost doubled in number and in proportion (from around 20 per cent to around 35 per cent during the same period). These changes have been observed in all of the world's ocean basins.[23]

Although the relationship between temperature and formation of storm systems is not completely understood, increased temperature does correlate with increased occurrence of tropical cyclones and extra-tropical storms.[24] Rising sea surface temperatures change the Earth's water cycle, disrupting ocean currents and altering precipitation patterns, which may lead, in part, to the increases in storm intensity observed over the past several decades.[25] With global warming, potential intensity (i.e. the upper bound of cyclone intensity) is predicted to increase in most regions of tropical cyclone activity.[26]

The implications of increased cyclone activity and intensity are far reaching for cities. Power outages during storms disrupt transportation, economic activity and supply of potable water. Physical destruction caused by storms is often extremely expensive to repair and results in fatalities and injuries to humans and wildlife. Furthermore, inundation of water during storms can contaminate water supplies with saltwater, chemicals and waterborne diseases.

Tropical cyclones and extra-tropical storms have been increasing in intensity since the 1970s

Heavy precipitation events

Heavy precipitation events are defined as the percentage of days with precipitation that exceeds some fixed or regional threshold compared to an average 'reference period of precipitation from 1961–1990'.[27] On average, observations indicate that heavy one-day and heavy multi-day precipitation events have increased globally throughout the 20th century and these trends are very likely to continue throughout the 21st century.[28] Deviations from average weather patterns have been observed globally, with an increase in the frequency of heavy precipitation events in most areas of the world.[29]

Precipitation changes have been variable at the regional level. In the tropics, eastern North America, Northern Europe, and Northern and Central Asia, precipitation increases have been documented in summer and winter, while summer precipitation decreases have been observed in mid-latitude regions. Severe decreases in both precipitation intensity and volume have been documented in countries such as Kenya, Ethiopia and Thailand.[30] Likewise, the number of days during which more than 10mm of precipitation occurs has significantly increased over the 20th century across these countries and also in parts of Europe.[31] General precipitation trends are expected to continue throughout the 21st century, with average precipitation increases very likely in the high latitudes and average decreases likely in the subtropical regions.[32] More frequent heavy precipitation events will have far-reaching economic and social implications throughout the urban environment, especially through flooding and landslides.

The concentration of future exposure to sea-level rise… will be in the rapidly growing cities of developing countries in Asia, Africa and, to a lesser extent, Latin America

Flooding

Floods are among the most costly and damaging disasters posing a critical problem to city planners as they increase in frequency and severity. The frequency and severity of flooding has generally increased during the last decade (compared to 1950–1980 flood data), along with the frequency of floods that exceed levels that only typically occur once every 100 years. Although there is variation in regional predictions, it is generally accepted that both trends will continue, especially in Asia, Africa and Latin America. Flood risk is also projected to increase throughout Europe, particularly in eastern and northern regions and along the Atlantic coast. Assessments of vulnerability in Germany show that seaport cities Bremen and Hamburg may experience increased probabilities of flood risk from storms as climate change progresses, exposing billions of dollars of economic capital to potential damage.[33] The Netherlands is one of the most exposed countries in Europe, with nearly one third of the country located below average sea level in 2008.[34] Densely packed Amsterdam and Rotterdam are two out of ten cities that currently have the highest value of assets exposed to coastal flooding.[35]

A recent ranking of cities based on vulnerability to flooding found that the top ten cities in terms of exposed population were Mumbai (India), Guangzhou (China), Shanghai (China), Miami (US), Ho Chi Minh City (Viet Nam), Kolkata (India), Greater New York (US), Osaka-Kobe (Japan), Alexandria (Egypt) and New Orleans (US) (see Table 4.2).[36] The study also predicts that by 2070 almost all cities in the top ten exposure risk category will be located in developing countries (particularly in China, India and Thailand) because of the rapid population growth occurring in these areas. On a national scale, the study predicts that the concentration of future exposure to sea-level rise and storm surges will be in the rapidly growing cities of developing countries in Asia, Africa and, to a lesser extent, Latin America. It is anticipated that the majority of high-exposure coastal land area (90 per cent) will be located in only eight countries: China, US, India, Japan, The Netherlands, Thailand, Viet Nam and Bangladesh.

In addition to the evident structural damage and loss of life that they cause, floods can short-circuit transformers and disrupt energy transmission and distribution; paralyse transportation; contaminate clean water supplies and treatment facilities; mobilize trash, debris and pollutants; and accelerate the spread of waterborne diseases.[37] Poorly planned informal settlements are especially vulnerable to the impacts of flooding, as illustrated by the case of Mexico City where flash flooding has increased dramatically over the past decade (see Box 4.1).

Box 4.1 Increased incidence of flash flooding in Mexico City

The greater metropolitan area of Mexico City is one of the largest and most densely populated urban settlements in the world, containing an estimated 19.5 million residents at a population density of 3584 persons per square kilometre in 2010. The city and its residents have become increasingly vulnerable to flooding and related impacts of climate change over the past century. Annual rainfall in Mexico City increased from 600mm during the early 20th century to over 900mm towards the end of the century. Likewise, the annual incidence of flash flooding has increased from one to two annual floods, to six to seven annual floods over the same time period. On 2 August 2006, for example, a rainfall of 50.4mm in only 36 minutes caused severe flooding in the southern and western parts of the city. The incidence of flash flooding is expected to continue to rise due to climate change-related increases in the frequency of heavy precipitation.

Higher precipitation is associated with an increased frequency of flash flooding, which encompasses a wide range of conditions that threaten life and property, including submerged roads, overflowing rivers and mud- or rock-slides. Flooding damage including injury, death, property loss and water contamination are exacerbated by the infrastructure and development patterns in Mexico City. Informal settlements are often located in areas prone to flooding and landslides and, thus, particularly vulnerable. Inadequate drainage in these areas results in the accumulation of trash and debris that poses serious hazards to human health when flooding occurs. Poorly maintained and aging water drainage and sanitation systems throughout the city worsen the impacts of heavy rains and flash flooding, and make it more difficult for communities to recover.

Source: Ibarrarán, 2011

Landslides

A landslide refers to a mass of material (e.g. rock, earth or debris) that slips down a slope by gravity. The movement is often rapid and assisted by water when the material is saturated.[38] Vegetative cover, precipitation patterns, slope angle, slope stability and slope-forming material all influence the vulnerability of an area to landslides.[39] Furthermore, the spatial distribution of landslides suggests a correlation between rapid land-use change and areas affected by landslides and mudflows.[40] Urban expansion and the clearing of vegetation for building and road construction can lead to soil erosion and weathering, and thereafter to loss of soil stability and the increased likelihood of landslides. Clearing vegetation interferes with the capacity for absorption of rainfall, which results in runoff and gully erosion. Also, as settlements develop, vegetation is replaced with paved or hard pack areas and rainwater is channelled through preferential flow channels instead of natural pathways, which increases the water's erosive power.

The risk from landslides is also likely to increase as urban development continues on marginal and dangerous lands. With rapid urbanization, populations, especially the urban poor, increasingly settle in areas that are prone to hazardous landslides and are unsuited for residential development.[41] City growth, chronic poverty, urban land speculation, insecure tenure, inadequate urban infrastructure investment, and poor urban planning policies contribute to continued development in vulnerable areas.[42]

Faulty construction methods and missing or inadequate infrastructure design prevalent throughout informal settlements further contribute to slope degradation, increasing the risks of landslides. Construction practices, such as cut and fill, which move soil from one part of a site to another, increase the risk of a landslide, which, in turn, has been shown to weaken slope stability and increase the likelihood of a further landslide.[43] Recent estimates suggest that 32.7 per cent of the world's population live in slums,[44] which are often situated in marginal and dangerous areas (i.e. steep slopes, floodplains and industrial areas).[45] In cities such as Dhaka (Bangladesh), residents of informal settlements inhabit slopes surrounding the urban core, putting themselves at risk from flash floods and landslides.[46] Similarly, in Mexico City, landslides often adversely affect slum residents.[47] However, wealthy urban residents also occupy areas vulnerable to landslides primarily for aesthetic reasons, as illustrated by the case of Los Angeles, US.[48]

An increasing frequency of landslides will have a variety of direct and indirect impacts in urban areas. Damage to infrastructure can be substantial, resulting in high maintenance and repair costs. Indirect impacts as a result of this damage, such as constrained movement of goods and services, drive costs higher.

Extreme heat events

Heat waves are typically defined as extended periods of hotter than average temperatures, although the precise timing and temperature differential varies regionally.[49] The lack of specificity in the definition of an extreme heat event or heat wave is due to the importance of local acclimatization to climate, which varies geographically. Previous research shows that populations in different locations have varying abilities to deal with temperature extremes. For example, studies in Phoenix (US) have found no statistically significant relationship between mortality rates and high temperatures below 43°C, while in Boston (US), an increase in the rates of mortality is observed at 32°C.[50] Several explanations exist for this phenomenon in Boston, including behavioural factors. Extremely high temperatures occur infrequently and, as a result, residents do not have the proper level of preparedness for heat waves. Also, Boston has extremely cold winters so a large percentage of homes are built from heat-retaining red brick and few homes have central air conditioning.[51] Consequently, during extreme heat events, ambient air temperature inside Boston homes can be dangerously high.

As a result of climate change, extreme heat events are predicted to become more frequent, intense and longer lasting over most land areas (see Box 4.2).[52] Some of the regions where more severe heat waves are expected in the future, due to increasing concentrations of atmospheric GHGs, include North America (particularly in the southern and north-western parts of the US) and Europe.[53]

Communities dependent upon glacial melt water also stand to be negatively affected by changes in the distribution of extreme heat. As air and ocean temperatures rise and the increasing frequency of heat waves changes stream flows, glaciers around the world will continue to shrink, threatening the one sixth of the world's population dependent upon glacial melt water.[54] In a number of South American countries with communities dependent upon glacial melt water, water stress[55] could increase as small glaciers disappear due to warmer temperatures and less snowfall. Changes in precipitation and the rapid loss of glacial mass in this region will significantly affect water availability for cities across the region – for example, Quito (Ecuador), Lima (Peru) and Bogotá (Colombia) – both for human consumption and electricity generation. Communities dependent upon glacial melt water in China and Pakistan could also be negatively affected by shrinking glaciers.[56]

While physical climate changes can impact upon both rural and urban areas, urban settlements generate unique local conditions that interact with heat events. Compared to rural areas, cities tend to have higher air and surface temperatures due to the urban heat-island effect: the tendency of cities to retain heat more than their surrounding rural areas.[57] For the average developed country city of 1 million people, this phenomenon can cause air temperatures that are 1°C to 3°C higher than the city's surrounding area. At night, when urban heat-island effects are strongest, temperature differences can reach 12°C.[58] By increasing temperatures, urban heat-island effects can aggravate the heat-related negative implications of climate change and impose costly energy demands on urban systems as they attempt to adapt to higher temperatures.[59] The degree of these effects is not uniform across cities. The physical layout of a city, its population size and density, and structural features of the built environment all influence the strength of the urban heat-island effect. For example, the tendency

Urban settlements generate unique local conditions that interact with heat events

Box 4.2 Extreme heat event trends in the US and Europe

Around the world, extreme heat events are predicted to become more intense, more frequent and longer lasting. In general, the increasing frequency of extreme heat events is likely to affect cities in colder regions because of a lower saturation of cooling technologies, heat retention design of the existing building stock and cultures underprepared for extreme heat events:[a]

- On average in Chicago, 1.09 to 2.14 heat waves occur per year, whereas by 2080 to 2099 the region could see heat wave frequency increasing to 1.65 to 2.44 per year. Also, the duration of heat waves may increase from 5.39 to 8.85 days today, to 8.47 to 9.24 days by the same time.[b]
- Today, Paris averages 1.18 to 2.17 heat waves per year, which is expected to increase to 1.70 to 2.38 per year by the end of the century. The average duration of a heat wave is expected to increase from 8.33 to 12.69 days, to 11.39 to 17.04 days within this timeframe.[b]
- In the north-eastern US, cities typically experience 10 to 15 days with temperatures above 32°C and 1 or 2 days with temperatures above 38°C. However, by the end of the century, cities such as Philadelphia, Boston and New York can expect between 30 and 60 days each year with temperatures over 32°C, and between 3 and 9 days with temperatures over 38°C, depending on the emissions scenario.[c]
- In some parts of Switzerland, the average monthly temperatures were as much as 6°C above monthly averages in June and August 2003, when Europe experienced a major heat wave. It is likely that future climate conditions will resemble the summer of 2003 more than current conditions. Basel (Switzerland) could experience as many as 40 days above 30°C, as compared to 8 days today.[d]

Sources: a Basu and Samet, 2002; b Meehl and Tebaldi, 2004; c UCS, 2006; d Beniston and Diaz, 2004 for French, Italian and Spanish cities to have stronger heat-island effects has been linked to their compactness and limited area of green space compared to other European cities.[60]

Extreme heat events negatively impact upon human health and social stability, increase energy demand and affect water supply. The costs of water treatment are likely to increase as high temperatures increase water demand. At the same time, water quality could decline as water pollution becomes increasingly concentrated.[61] Heat waves are more likely to impact upon vulnerable populations, including the elderly, very young, individuals with pre-existing health conditions and the urban poor. The urban poor in developed countries are especially at an increased risk from extreme heat events because of their low adaptive capacity.[62]

The amount of land area under extreme drought conditions is expected to increase further in the future as a result of changes in precipitation

Drought

Drought can be defined as a phenomenon in which precipitation is significantly below normal levels, which leads to hydrological imbalances that negatively affect land resources and production systems. It can refer to moisture deficits in the topmost metre of soil (i.e. agricultural drought), prolonged deficits of precipitation (i.e. meteorological drought), below-normal water levels in a body of water (i.e. hydrological drought) or any combination of these.[63] Droughts can result from a number of different factors. In the western parts of the US, drought conditions have emerged largely as a result of decreases in snow pack, while areas in Australia and Europe have seen drought conditions due to extremely high temperatures associated with heat waves.[64] In Asia, increasing frequencies of droughts are likely to result from increasing temperatures.[65]

Substantial damage to residential and commercial structures is expected with the increasing occurrence of climate change-related hazards and disasters

The IPCC concluded that not only have droughts become more common in the tropics and subtropics since 1970 but, more likely than not, humans have contributed to this trend.[66] Since the 1950s, significant drying trends have been observed across the Northern Hemisphere in portions of Eurasia, Northern Africa, Canada and Alaska. The Southern Hemisphere over the same time period has experienced slight drying trends. During the last century, mean precipitation in all four seasons of the year has tended to decrease in all of the world's main arid and semi-arid regions: northern Chile, the Brazilian northeast and northern Mexico, West Africa and Ethiopia, the drier parts of Southern Africa, and western China.[67] In Yemen, the capital city Sanaa is expected to run out of water by the year 2020, spurring mass migration and potential conflicts.[68]

The amount of land area under extreme drought conditions[69] is expected to increase further in the future as a result of changes in precipitation.[70] Currently, as much as 1 per cent of all land area is considered as being under extreme drought conditions.[71] By 2100, this could increase to as much as 30 per cent.[72] Drying is likely to occur in continental interiors during summer periods, especially in the subtropics, low and mid-latitudes.[73] More intense and multiannual droughts have occurred in sub-humid regions, including Australia, western US and southern Canada.[74] In Africa, one third of all people already live in drought-prone areas and, by 2050, as many as 350 to 600 million could be affected by drought.

Drought affects urban areas in numerous ways. It can compromise water quality and increase the operating costs of water systems while reducing their reliability.[75] Water stress is likely to increase as a result of changes in precipitation and the consequent decline in water supply and quality and increased demand for water.

IMPACTS UPON PHYSICAL INFRASTRUCTURE

This section describes the physical damage caused by climate change and their implications for urban areas. Climate change has direct effects on the physical infrastructure of a city – its network of buildings, roads, drainage and energy systems – which, in turn, affects the welfare and livelihoods of its residents. The severe weather events and related hazards outlined above can decimate roads, homes and places of business. These impacts will be particularly severe in low-elevation coastal zones where many of the world's largest cities are located. Although they account for only 2 per cent of the world's total land area, approximately 13 per cent of the world's urban population live in these zones.[76]

Residential and commercial structures

Substantial damage to residential and commercial structures is expected with the increasing occurrence of climate change-related hazards and disasters. In this regard, flooding is one of the most costly and destructive natural hazards, and, as indicated earlier, one that is likely to increase in many regions of the world as precipitation intensity increases. In the absence of adaptive infrastructure changes, vast increases in spending on flood damage in cities are expected due to climate change.[77] In Boston (US), for example, river flooding could cause up to US$57 billion in damage by 2100 without adaptive measures, an estimated US$26 billion greater cost than would occur in the absence of climate change. Many of the homes likely to be affected are low-value houses that may not be insured against predicted damage. As in other areas of the world, the distributional nature of these impacts remains a challenge.[78]

The terms '100-year flood' and '500-year flood' are sometimes used to describe the flood risk to residents living in particular areas. These terms refer to the probability with which the flood occurs. For example, if there is a 1/100 chance of a given city experiencing a flood at a rate of 425 cubic metres per second, this level of flooding will occur, on average, once every 100 years. Likewise, a flood rate that occurs with a probability of 1/500 is referred to as a 500-year flood.[79] The terms 100-year floodplain and 500-year floodplain refer to the geographic areas that are affected during 100-year and 500-year floods, respectively.

Today, around 40 million people live in a 100-year floodplain. By 2070, the population living at this risk level

Ranking by population exposure	Ranking by value of property and infrastructure assets exposure
Kolkata (India)	Miami (US)
Mumbai (India)	Guangzhou (China)
Dhaka (Bangladesh)	New York (US)
Guangzhou (China)	Kolkata (India)
Ho Chi Minh City (Viet Nam)	Shanghai (China)
Shanghai (China)	Mumbai (India)
Bangkok (Thailand)	Tianjin (China)
Rangoon (Myanmar)	Tokyo (Japan)
Miami (US)	Hong Kong (China)
Hai Phong (Viet Nam)	Bangkok (Thailand)

Source: Nicholls et al, 2008

Table 4.2

Exposure to floods in cities

could rise to 150 million people. The estimated financial impact of a 100-year flood would also rise from US$3 trillion in 1999 to US$38 trillion by this time. Miami (US) is the most exposed city today and will remain so in 2070, with exposed assets rising from approximately US$400 billion today to over US$3.5 trillion. Over the coming decades, the unprecedented growth and development of Asian megacities will be a key factor driving the increase in coastal flood risk globally. By 2070, eight of the most exposed cities will be in Asia (see Table 4.2).

Damage to residential and commercial structures is not limited to large-scale disasters. Slow-onset climate-change physical risks such as sea-level rise can also affect the built environment in a number of ways. Coastal erosion is likely to affect cities around the world particularly in the mega-deltas of South, East and Southeast Asia, Europe and the North American Atlantic coast.[80] In the US, a 0.3m sea-level rise[81] would erode approximately 15m to 30m of shoreline in New Jersey and Maryland, 30m to 60m in South Carolina and 60m to 120m in California.[82] Parts of Louisiana and Mississippi along the Gulf Coast of the US are physically susceptible to loss of land from the combined effects of erosion and sea-level rise, whereas some areas of Florida and Texas are susceptible due to social and economic factors of vulnerability.[83] Coastal erosion and saltwater intrusion can ruin buildings and render some areas of land uninhabitable, which is a particular problem for coastal cities that rely on tourism as a major part of their economies. Mombasa (Kenya), for instance, could lose approximately 17 per cent of its land from a 0.3m rise in sea level, causing the loss of hotels, cultural monuments and beaches that draw tourists.[84]

Subsidence, or the downward shift of the Earth's surface, is another 'slow-onset' factor that poses a risk to residential and commercial structures in cities. Subsidence can be caused or exacerbated by overexploitation of groundwater resources during hot, dry periods which are likely to occur more frequently with climate change. Subsidence can be as rapid as 1m per decade, resulting in significant damage to pipelines, building foundations and other infrastructure.[85] In England, increased subsidence caused by drier, hotter summers led to significantly greater homeowner insurance claims throughout the late 1990s.[86] Subsidence has been noted in several megacities throughout the world, including Tokyo (Japan), Dhaka (Bangladesh), Jakarta (Indonesia), Kolkata (India), Metro Manila (the Philippines), Shanghai (China), Los Angeles (US), Osaka (Japan) and Bangkok (Thailand).[87] During the late 1980s, Tianjin (China) experienced as much as 11cm of subsidence per year.[88] Portions of the Osaka-Tokyo metropolitan region would be under water as a result of subsidence if it were not for coastal defences and extensive flood-control systems.[89]

Accumulating damage to residential and commercial buildings due to sun exposure and low-intensity wind and precipitation may increase in some areas of the world as regional weather patterns change. In London (UK), more frequent heavy rains and higher peak wind speeds (predicted for the 2050s and 2080s) are expected to damage buildings, particularly those that are aging. Wind and rain damage can cause hazards to people in the vicinity of affected buildings and may lead to additional economic losses if commercial buildings need to close for repairs.[90] Studies on New Zealand indicate that commercial buildings throughout the country will experience increased damage in the face of wind damage, coastal flooding and extreme temperatures.[91] In the Arctic region, human settlements are expected to face serious challenges with the melting of permafrost, which is essential for the stability of buildings and infrastructure.[92]

Unprecedented growth and development of Asian megacities will be a key factor driving the increase in coastal flood risk globally

Transportation systems

Climate change impacts frequently disrupt transportation systems through weather conditions that have immediate consequences for travel and damage, causing lasting service interruptions. In coastal cities, in particular, sea-level rise can inundate highways and cause erosion of road bases and bridge supports. For example, along the Gulf Coast of the US an estimated 3862km of roadway and nearly 402km of rail tracks may become permanently submerged during the next 50 to 100 years due to the combined impacts of subsidence and sea-level rise. Total economic impacts resulting from this loss could reach hundreds of billions of dollars when considering the commercial and industrial activities that take place in the gulf's many seaports, highways and railroads.[93] For instance, weather-related highway accidents translate into annual losses of at least US$1 billion annually in Canada, while more than one quarter of air travel delays in the US are weather related.[94] In India, landslides in July 2000 resulted in 14 days without train service, leading to estimated losses of US$2.2 million.[95]

Climate change impacts frequently disrupt transportation systems

Destruction or damage of transportation systems and lasting service disruptions greatly affect nearly all aspects of urban life

Climate change is likely to affect both energy demand and supply

Heavy precipitation and its effects in the form of flooding and landslides can cause lasting damage to transportation infrastructure, such as highways, seaports and bridges. In 1993, flood damage to transport systems in Midwestern US resulted in major traffic disruption from Missouri to Chicago for nearly six weeks.[96] Delays in public transportation including rail and air services often occur during heavy rains and storms. A study of the Konkan railway network in western India that facilitates trade and energy services between Mumbai and Mangalore revealed that 20 per cent of major repairs were due to climatic factors. Each year, US$1.1 million is spent to reduce the number of locations on the network that are vulnerable to heavy rains.[97] Heavy rains also affect the long-term functional capacity of airport runways, which will lead to the need for increased maintenance considerations in those areas where precipitation is likely to increase.

Increasingly higher temperatures, particularly long periods of drought and higher daily temperatures, compromise the integrity of paved roadways and necessitate more frequent repairs. For instance, by 2080, road buckling, rutting and speed restrictions are anticipated to increase in London (UK) as average temperature increases melt asphalt and accentuate subsidence.[98] Extreme heat also leads to joint expansion on bridges and rail deformation, which require costly maintenance and, in worst-case scenarios, could cause major accidents. Drier conditions can further cause lower water levels in rivers and interrupt trade and transportation via inland water routes.

Besides potentially endangering lives, the destruction or damage of transportation systems and lasting service disruptions greatly affect nearly all aspects of urban life. Disruptions in public transportation can limit the ability of residents to get to work, leading to declines in economic productivity. By 2100, as a result of increases in climatic change-related delays, motorists in Boston (US) could spend 80 per cent more time on roadways and 82 per cent more trips could be cancelled.[99] Interruptions in the transport of fuel for energy production can also lead to service disruptions in the electricity sector.

Energy systems

By their very nature, cities are centres of high demand for energy and related resources. Climate change is likely to affect both energy demand and supply. The combination of urban population growth, changing local weather conditions, urban heat-island impacts and economic growth has the potential to substantially increase demand for energy (see Box 4.3). Although the relationship between energy demand and local weather fluctuations has long been confirmed, relatively few studies have taken on the task of examining how longer-term climate changes affect the energy sector.

Energy demand increases will depend upon regional climate differences. Higher winter temperatures can lead to decreased heating use, while increased summer temperatures can lead to increased need for cooling. In turn, greater use of air conditioning due to rising temperatures can worsen the urban heat-island effect and further increase the cooling demand in urban areas.[100] Studies indicate that there is high regional variation in energy demand sensitivity to climate change even in similar climates. In the US, for example, neighbouring states Florida and Louisiana have different patterns of industrial and residential energy use.[101] Likewise, an assessment of several US regions reveals unique demand sensitivities among four cities (Seattle, Minneapolis, Phoenix and Shreveport) and different directions of demand change between states with differing average local weather conditions.[102] The use of aggregate data, however, may be misleading because even if there is no net increase in regional demand, great increases in local demand for cooling may still require infrastructure investment, reconsideration of energy portfolios and energy conservation mechanisms.

Climate change will also affect energy generation and distribution. Across Africa, hydroelectric power generation is likely to be restricted with the more frequent occurrence of drought periods. For instance, climate change simulations suggest that the planned Batoka Gorge Hydroelectric Project on the Zambezi River, a joint project between Zambia and Zimbabwe, will be negatively affected if the mean monthly river flow significantly declines.[103] However, the worldwide impacts of climate change upon hydroelectricity production are variable. For example, electricity output from hydroelectric projects in Scandinavia and northern Russia is predicted to increase due to trends in future precipitation patterns and temperature.[104]

Reduced stream flows due to climate change may further reduce the availability of cooling water for thermal and nuclear power plants.[105] In Europe, the 2003 heat wave was accompanied by annual rainfall deficits of as much as 300mm.[106] Drought conditions had impacts upon power generation and several power plants were unable to physically or legally divert water because of extremely low stream flow, resulting in reductions in power generation. For instance, nuclear power plants in parts of France were forced to shut down as stream levels became too low or water temperatures exceeded environmental standards. Six nuclear reactors, as well as a number of conventional power plants, were given exemptions to continue operating in spite of exceeding legal limits.[107] In terms of energy distribution, electricity transmission infrastructure may become increasingly vulnerable to damage and interference as storms and flooding become more frequent and intense.[108]

Box 4.3 Global changes in energy demand

- Between 2010 and 2055 in the US, energy demand may increase capacity requirements for the electricity sector by 14 to 23 per cent over demand trends in the absence of climate change.[a]
- Daily peak energy loads for New York City (US) could increase by 7 to 13 per cent by the 2020s, 8 to 15 per cent by the 2050s and 11 to 17 per cent by the 2080s.[b]
- By 2080, a 30 per cent increase in energy demand is forecast for Athens (Greece), largely as a result of increasing air-conditioning use.[c]
- In Toronto (Canada), a 3°C increase in temperatures would result in increases in peak electricity demand of 7 per cent and an increase of 22 per cent in the variability of peak demand.[d]

Sources: a Linder, 1990; b Rosenzweig and Solecki, 2001; c Giannakopoulos and Psiloglou, 2006; d Colombo et al, 1999

Water and sanitation systems

The availability, treatment and distribution of water could be affected by climate change as temperatures increase and precipitation patterns change.[109] On the one hand, climate change is expected to compromise water supplies, particularly in areas where water stress is expected to increase. In developing regions such as Africa, water stress is expected to increase as a result of population growth and is likely to be exacerbated by climate change. However, the impacts will not be uniform across the continent as populations in the north and south are expected to experience increases in water stress, while those in the east and west are likely to see a reduction in water stress.[110]

Water supplies can be reduced or increased through changes in precipitation patterns, reductions in river flows, falling groundwater tables and, in coastal areas, saline intrusion in rivers and groundwater.[111] For example, detected declines in glacier volumes in parts of Asia and Latin America are already reducing river flows at key times of the year. For cities located in the Andean valleys and in the Himalaya-Hindu-Kush region, this has substantial impacts upon water flows and affects multiple human uses of water in these areas, including reducing hydroelectric power generation.[112] The expected changes in runoff and water availability are, however, projected to be regionally differentiated by 2050: increases by 10 to 20 per cent at higher latitudes and in some areas in the wet tropics (e.g. populous areas in tropical East and Southeast Asia), and decreases by 10 to 30 per cent over areas in the mid-latitudes and dry tropics, some of which are currently water stressed.

On the other hand, with rising temperatures, more frequent extreme heat events and population growth in the future, demand for water in cities is expected to increase.[113] Many areas of the world have been getting drier across all seasons; if the trend continues, water resource limitations will become more severe.[114] By 2030, summer water use in Washington, DC (US), is expected to increase between 13 and 19 per cent relative to an increase from 1990 levels without climate change.[115] In Cape Town (South Africa), water demand is simultaneously projected to increase with temperature increases.[116] In Nagoya (Japan), temperature increases could induce an increase of 10 per cent in water use.[117] In Latin America, 12 to 81 million residents could experience increased water stress by the 2020s. By the 2050s, this number could rise to 79 to 178 million.[118] Stream flow supplying Melbourne (Australia) is likely to decline by 3 to 11 per cent by 2020 and 7 to 20 per cent by 2050, compared to 1961 to 1990 averages, thereby affecting water supplies. Concerns about drought and water demand increases have also been raised in other cities such as Auckland, Adelaide, Canberra, Perth, Brisbane and Sydney.[119]

Climate change-related changes in precipitation and sea levels can also affect the quality and treatment of water in cities. Saltwater intrusion can occur more frequently in communities experiencing sea-level rise and contaminate ground and surface water, thus reducing the supply of potable water and spreading harmful pollutants throughout urban water systems. Cases of saltwater intrusion due to sea-level rise have already been documented among most coastal cities across diverse environments, including eastern US (e.g. New Orleans), Latin America (e.g. Buenos Aires, Argentina), as well as both in the Yangtze River Delta in China and the deltas of Viet Nam.[120] Reduced precipitation and, thus, water supply can also cause saltwater intrusion. The city of Kochi (India) is located at 2m above sea level and is compromised by a network of rivers and canals. Saltwater intrusion into these rivers is worsened during hot, dry periods when evaporation increases the concentration of salts in the water, leading to economic losses and drinking water shortages.[121]

Furthermore, excess heat from buildings and roads due to the urban heat-island effect can be transferred to storm water, thereby increasing the temperature of water that is released into streams, rivers, ponds and lakes. Higher water temperatures, in conjunction with increased precipitation intensity and low flows, are predicted to exacerbate water pollution, including through thermal pollution, which can promote algal blooms and increase bacterial and fungal content.[122] Once they have been contaminated, it is, in most cases, expensive to clean drinking water supplies.

The availability, treatment and distribution of water could be affected by climate change

Water supply infrastructure is capable of adapting to small changes in mean temperatures and precipitation amounts as water systems have been designed with spare capacity for future growth.[123] Still, many systems will need improvements, such as building new reservoirs or extension of water intake pipes to handle increasingly variable precipitation levels. In addition, water supply infrastructure is vulnerable to damage from extreme climate events such as floods and storm surges, especially if it is adjacent to rivers.[124] In New York City (US), pumping stations and water treatment facilities, including intake and outflow sites, are vulnerable to storm surges.[125] Damage to water supply infrastructure, especially if electronics are damaged, can take weeks to fix and can cost as much to repair as their initial construction costs, as was the case during flooding in Mozambique during 2000.[126]

Climate change-related disasters can also affect sanitation systems in urban areas… especially in developing countries

Climate change-related disasters can also affect sanitation systems in urban areas which already face serious challenges, especially in developing countries. Although access to improved water supply and sanitation has been increasing since 1990 in many areas of the world, there are still large proportions of the population living in unsanitary conditions.[127] In 2006, 38 per cent of the world's population and nearly half of the developing world's population lacked access to improved sanitation facilities, including flush toilets, pit latrines or composting toilets.[128] Access to sanitation infrastructure and services is likely to decline further due to climate change-related risks, as in the case of Hurricane Mitch, which destroyed 20,000 latrines in 1998.[129]

ECONOMIC IMPACTS

The increasing frequency and intensity of extreme climatic events and slow-onset changes will increase the vulnerability of urban economic assets and, subsequently, the costs of doing business.[130] Studies suggest that developing countries typically suffer low economic losses but high human losses as a result of climate change-related risks, while developed countries suffer high economic costs and low human losses. However, recent events show that developed countries can suffer high human costs as well, especially amongst the urban poor. Also, when economic impacts are expressed as a share of the value of total assets or gross domestic product (GDP), economic costs incurred by developing countries may also be high and can result in increasing fiscal imbalances and current account deficits due to increased borrowing and spending to finance recovery.[131] This section explores the economic impacts of climate change within urban areas, including those related to economic sectors, ecosystem services and livelihoods.

The increasing frequency and intensity of extreme climatic events and slow-onset changes will increase the vulnerability of urban economic assets

Sectoral economic impacts

Climate change will affect a broad range of economic activities, including trade, manufacturing, transport, energy supply and demand, mining, construction and related informal production activities, communications, real estate, and business activities.[132] Box 4.4 describes the cross-sectoral economic impacts of tropical cyclones in Dhaka (Bangladesh).

This section describes climate change impacts upon economic sectors – namely, retail and commercial services, industry, tourism and insurance – as these tend to operate in and around cities. Industrial infrastructure in coastal cities is particularly vulnerable to sea-level rise and coastal storms. The effects of climate change on tourism are also considered as it can be a part of the urban economy directly or dependent on it for services, including travel (e.g. airports, seaports, etc.) and supplies. Furthermore, climate impacts upon the tourism industry can induce migration from rural to urban areas, thus increasing the demand for goods and services within urban areas.[133]

Box 4.4 Cross-sectoral impacts of tropical cyclones: The case of Dhaka, Bangladesh

Given that the majority of its land area is less than 6m above sea level, the population of Bangladesh and its assets are highly vulnerable to the impacts of tropical cyclones. Rising sea levels and increased prevalence of cyclones have been documented over the past decade, along with increased frequency and intensity of sudden and severe floods. Between 1991 and 2000, the country experienced 93 major disasters, resulting in nearly 200,000 deaths and costing US$5.9 billion in damage to agriculture and infrastructure.

Storm surges cause massive damage to the city of Dhaka, which has experienced four major floods in the past two decades, including one that submerged 85 per cent of the city. In addition to endangering lives, these events have multi-sectoral impacts that cause lasting damage to the economic and social fabric of the city. Disruption of activity in textiles, timber, food and agro-based industries results in massive economic loss. In 1998, it was calculated that total industry loss was more than US$66 million. All utility services essentially cease during flooding events, and structural damage can cause lasting disruption of utility services such as water supply, sanitation, waste and sewage management, telecommunications, and electricity and gas supplies.

The city's adaptation efforts have been aimed at mitigating the impacts of extreme flooding events by expanding the Integrated Flood Protection Project, a programme funded by the Asian Development Bank to improve flood protection structures, drainage and sanitation, and to resettle residents of slums into safer areas. Improving the drainage system and reinforcing the water system is a priority since the city's water has become contaminated in the past, and acute drinking water crisis has been a major problem in post-flood efforts. There is also an initiative to involve non-governmental organizations (NGOs), the business community and community-based organizations to enhance aid in relief, recovery and rehabilitation programmes.

Source: Vaidya, 2010

Industry and commerce

Industrial activities can bear potentially high direct and indirect costs from climate change and extreme climate events. Whether industries are located in the heart of urban areas or in adjacent suburban or rural areas, they provide services and resources that are vital to city function. Damage to industries due to climate events thus has direct and indirect impacts upon cities and their residents.

The direct effects of climate change and extreme climate events on industry include damage to buildings, infrastructure and other assets. These effects are especially severe where industrial facilities are located in vulnerable areas, such as coastal zones and floodplains. For example, sea-level rise in coastal cities such as New Orleans (US) will potentially necessitate the relocation of refineries, natural gas plants and facilities, as well as supporting industries to less at-risk areas or further inland, at a substantial cost (see Box 4.5).[134] The indirect impacts of climate change upon industry include those resulting from delays and cancellations due to climate effects on transportation, communications and power infrastructure.[135]

Similarly, retail and commercial services are vulnerable because of supply chain, network and transportation disruptions, and changes in consumption patterns.[136] An increasing likelihood of flooding, coastal erosion and other extreme events will stress and damage transport infrastructure, as indicated earlier in this chapter, disrupt retail and commercial services, and subsequently increase the costs of doing business.[137] For example, in 2001, the Great Lakes–St Lawrence region of Canada experienced drought conditions that lowered river levels to such an extent that it slowed river traffic, which partially explains the reduction in volume of goods shipped through the Great Lakes that year.[138] Similarly, the 2003 heat wave and drought across Europe resulted in record low river levels, which negatively affected the transportation of goods along inland waterways.[139]

Changes in the regulatory environment, including climate change mitigation policies (e.g. carbon tax and emissions targets) could potentially raise the costs of business for industries, especially if they are energy intensive.[140] For instance, the iron and steel industry is heavily dependent upon burning fossil fuels, with 15 to 20 per cent of the production costs going towards energy. In the US, the pulp and paper industry is the second most energy-consuming industry.[141]

Industries dependent upon climate-sensitive inputs are also likely to experience changes in the reliability, availability and cost of major inputs as a result of changes in climate and climate mitigation policies. For instance, industries dependent upon timber and agricultural inputs rely on an increasingly fragile resource because of changes in the

Box 4.5 Economic impacts of Hurricane Katrina, US

The city of New Orleans is located on vulnerable lands at the mouth of the Mississippi River on the Gulf of Mexico. Due to its proximity to the Mississippi and the gulf, the area has strategic economic importance for the petrochemical industry, as well as international trade. New Orleans's longstanding infrastructure and population centres have become increasingly at risk from climate events; coastal defences and other land areas are subsiding as a result of groundwater withdrawal, man-made changes to the flow of the Mississippi River prevents silting and the build-up of new land, and the below sea-level elevation of much of the city requires continuous pumping of water.

In 2005, Hurricane Katrina caused extensive damage to physical infrastructure and the economies of the gulf coast region. The economic losses were in the hundreds of billions of US dollars. An estimated 1.75 million property claims were filed, totalling more than US$40 billion. Over 250,000 claims were filed as a result of flood damage, which would have bankrupted the National Flood Insurance Program were it not given the right to borrow an additional US$20.8 billion.

In the Gulf of Mexico, over 2100 oil and natural gas platforms and 15,000 miles (24,140km) of pipeline were affected. A total of 115 platforms were lost, with 52 suffering heavy damage; 90 per cent of total Gulf of Mexico oil production and 80 per cent of natural gas were idled, with lost production equalling over 28 per cent of annual production. The damage to the petrochemical corridor, which produces half of the US supply of gasoline, caused disruptions in economic markets worldwide, resulting in the largest spike in oil and gas prices since the Organization of the Petroleum Exporting Countries (OPEC) embargo of 1973. In the first two months following Hurricane Katrina, over 390,000 people lost their jobs, with over half coming from low-wage earning jobs. As of 2006, only 10 per cent of businesses in New Orleans had returned and reopened.

Before Hurricanes Katrina and Rita, which also happened in 2005, the port of New Orleans was the fourth largest port in the world in terms of transported tonnage. However, as a result of the damage from hurricanes, port operations were halted for a period of time, which forced a realignment of shipping destinations and functions that, because of the high cost of realignment, could become permanent.

Sources: Petterson et al, 2006; Wilbanks et al, 2007

incidence of pests and diseases. Climate change holds the potential to shift the habitat of economically important tree and crop species, as well as changing the behaviour and distribution of pests.[142] The changing distribution of climate-sensitive inputs could result in increasing costs to industry, as industrial plants and their raw material inputs become geographically separated.

Tourism and recreation

The tourism industry is highly dependent upon reliable transportation infrastructure, including airports, ports and roadways. Climate change has the potential to not only shift regional temperature distributions, but also increase the incidence of severe weather events, which would increase transportation delays and cancellations. Since recreational activities and tourism are often major sources of revenue for urban areas, when climate change impacts affect these activities, local urban economies will incur monetary and job losses (see Box 4.6).

Tourism in cities of high-latitude countries could benefit from a pole-ward shift[143] of warmer conditions, increasing the area available for tourism activities.[144] However, winter activities (i.e. skiing and snowmobiling) are likely to become increasingly vulnerable because of climate change-related declines in natural snowfall leading to fewer days of snow cover.[145] Across much of the north-eastern region of the US, climate change will result in fewer days of natural snow cover and, in spite of snow-making technology, ski areas will experience a decline in the length of their seasons. To continue operating will necessarily mean an increase in costs because manufacturing snow is both water and energy intensive. Climate change will further result in declining season length as reliable snow is pushed into upper latitudes and higher elevations. As a result, the average distance travelled to winter resources such as ski mountains is expected to increase dramatically.[146] The weakening of the ski industry would also affect related support industries such as hotels, restaurants and ski shops. The decline of winter recreational opportunities can thus result in great economic losses for those regions with economies heavily reliant on skiing and snowboarding.

The summer tourism industry across the temperate zone is thought to be resilient to increases in average temperatures because of the expectations of warm temperatures, as well as the availability of air conditioning.[147] However, changes in the frequency and intensity of extreme

Industries dependent upon climate-sensitive inputs are also likely to experience changes in the reliability, availability and cost of major inputs

Box 4.6 Climate change impacts upon the tourism industry

- The annual number of tourists visiting Canada and Russia is estimated to increase by 30 per cent as a result of a 1°C rise in temperatures.[a]
- The cost of climate change for Switzerland is estimated to be US$1.4 to $1.9 billion by 2050 – of this amount, US$1.1 billion is from tourism alone. In Switzerland, 85 per cent of ski areas are considered as snow-reliable today; however, under climate change scenarios, only 44 per cent will remain snow reliable in the future. A number of communities in Switzerland are heavily dependent upon winter tourism as it provides a significant portion of their income.[b]
- The Norwegian ski industry could be negatively affected by climate change as summertime ski destinations are expected to experience more rainy weather during the summer months.[c]
- For Australia, a 3°C to 4°C increase in temperatures would cause catastrophic mortality to a large percentage of the coral species that make up the Great Barrier Reef. Even with a 1°C to 2°C increase in temperatures, between 58 and 81 per cent of the coral would be bleached every year. And because of the importance of the reef to Australian tourism, a US$32 billion industry, declines in reef health would negatively impact the tourism industry.[d]

Sources a Hamilton et al, 2005; b Elsasser and Bürki, 2002; c O'Brien et al, 2004; d Preston and Jones, 2006 weather events could negatively affect the perception of safety in these locations, environmental quality and tourism infrastructure reliability. For example, in Southern Europe, along the Mediterranean coast, increasing water scarcity as a result of climate change could negatively impact upon the tourism industry.[148]

Coastal areas, including those in cities, have often been extensively developed for tourism, leaving substantial investments in buildings and infrastructure at risk from extreme climatic events, which would significantly affect the economies of small island states.[149] Erosion as a result of coastal storms can cause beaches to recede by as much as 5m, but can recover quickly through natural sand deposition. If sea-level rise is accompanied by stronger and more frequent coastal storms, the costs of maintaining shore space for tourist activities could rise and reduce beach tourism for cities.[150] The city of Rio de Janeiro (Brazil), for instance, popular, among other reasons, for its beaches, is vulnerable to sea-level rise and increased erosion. In the capital city of Estonia, Tallinn, beachside resorts are particularly vulnerable to sea-level rise and storm surges, which could lead to more erosion of the beaches and negatively affect tourism.[151] Furthermore, extreme climate events can damage many reefs and coastal ecosystems, resulting in declining tourism.[152] A 1°C rise in temperatures would result in more frequent coral bleaching, with the coral recovering slowly, while a 2°C rise in temperatures would result in the annual bleaching of coral in many areas that might never recover.[153]

Climate change could result in increasing demand for insurance while reducing insurability

Tourism is an essential component of the local economy of many island countries in the Caribbean and elsewhere. In the eastern Caribbean, tourism accounts for between 25 and 35 per cent of the regional economy, one quarter of foreign exchange earnings and one fifth of all jobs. Each year, the region receives approximately 20 million tourists. The economic dependence upon tourism has led to intensive development and siting of infrastructure (i.e. hotels, roads, etc.) that tend to be densely packed along coastlines. As a result of changes in sea level and wave action, the islands of the eastern Caribbean will experience submergence of low-lying areas, including population centres, erosion of soft shores, increasing salinity of estuaries and aquifers, and more severe coastal flooding and storm damage.[154]

■ Insurance

The insurance industry is vulnerable to climate change, particularly extreme climate events that can affect a large area.[155] Storms and flooding can cause significant amounts of damage and are often responsible for a large percentage of total losses, as illustrated in Box 4.7.[156]

Climate change could result in increasing demand for insurance while reducing insurability. Insurance industry catastrophe models forecast that annual insured claims and losses are likely to significantly increase over the next century as a result of the increasing intensity and frequency of extreme storms. The distribution of claims is unlikely to be even as construction quality, property values and insurance coverage vary widely worldwide. In response, the insurance industry could adapt by raising the cost of insurance through measures such as increasing premiums, restricting coverage, etc.[157] Indeed, the costs of insurance coverage are expected to increase significantly if infrequent but catastrophic events become more common in the future.

In addition, the uncertainty surrounding the probability of high-loss events in the future is likely to place upward pressure on insurance premiums.[158] The implications of this will be harshest on low- (and possibly middle-) income households in developed countries if they are no longer able to afford insurance to recover from climate change-related events. It is already the case in the insurance industry that individuals tend to be underinsured, especially against events with low probabilities of occurrence. Studies have

Box 4.7 Impacts of climate change upon the insurance industry

- In 1992, Hurricane Andrew hit southern Florida (US) and resulted in over US$45 billion in damage (2005 dollars). In the aftermath, 12 insurance companies dissolved.[a]
- The average annual damage from hurricanes in the US is estimated to increase by US$8 billion (2005 dollars) due to intensification, assuming a scenario in which CO_2 levels double.[b]
- By the 2080s, a severe hurricane season in the US would increase annual insured damage by 75 per cent, while in Japan, insured damage would increase by 65 per cent.[c]
- Insured damage in Europe are estimated to increase by 5 per cent as a result of extreme storms, with the costs of a 100-year storm doubling from US$25 billion to US$50 billion by the 2080s.[c]
- Miami (US) has over US$900 billion of capital stock at risk from severe coastal storms, and London (UK) has at least US$220 billion of assets located on a floodplain.[d]
- The gross regional product of the New York City region (US) is estimated to be nearly US$1 trillion annually and losses from a single large event could be in the range of 0.5 to 25 per cent, or as much as US$250 billion.[e]
- The full macroeconomic costs of Hurricane Katrina of 2005 are estimated at US$130 billion, while the gross state product for Louisiana (US) in the same year was US$168 billion.[f]
- In Russia, insurance costs along the Lena River have increased during recent years as a result of more frequent and severe flooding.[g]
- By 2100, flooding could cause over US$94 billion in property damage in metropolitan Boston (US) if no adaptive actions are taken, with homeowners on 100-year and 500-year floodplains sustaining an average of US$7000 to US$18,000 in flood damage per household.[h]

Sources: a Wilbanks et al, 2007, p369; b Nordhaus, 2006; c Hunt and Watkiss, 2007, p21; d Stern, 2006, p14; e Jacob et al, 2000; f Stern, 2006, p11; g Perelet et al, 2007; h Kirshen et al, 2006

Table 4.3

Impacts of urbanization upon ecosystem services

Impact of urbanization	Effects on ecosystem	Effects on ecosystem service
Reduced permeability of surfaces	Reduction of biodiversity Surface and groundwater pollution Alteration of surface and groundwater channels	Reduced capacity for natural pollutant filtration
'Patchy' land-use patterns that fragment the landscape and spread into natural environments such as forests	Reduction of biodiversity Loss of trees and soil	Reduction in CO_2 retention of nearby land Reduction in local oxygen supply
Excess emissions of nutrients (e.g. nitrogen, phosphorus), sediments, metals and other wastes into waterways	Mass death of aquatic species	Reduction of food sources and other economic activity (e.g. recreation, tourism)
Development on wetlands	Loss of wetland area Loss of biodiversity	Reduced capacity for natural pollutant filtration Reduction in local oxygen supply Reduction of natural storm buffer

found that, despite favourable premiums, individuals often fail to purchase insurance for low-probability but high-loss events in part because of the costs associated with finding a policy.[159]

Insurance coverage can vary widely within and among developed and developing countries, as there tends to be a correlation between economic growth and insurance coverage.[160] While it is expected that insurance coverage will increase with economic development in many developing countries, at-risk infrastructure and buildings – including government-owned properties – compound their vulnerability by not having insurance coverage.[161] As much as 29 per cent of total property losses are covered by some form of insurance in developed countries.[162] In developing countries, however, only about 1 per cent of total losses are insured.[163]

Private insurers in developed countries will often not provide insurance or will restrict it in areas that have suffered significant past losses from floods, which then necessitates government involvement in order to provide flood insurance.[164] The risk of loss then falls upon government programmes and individual homeowners because insurance out-payments rarely cover the entire cost of reconstruction.[165] Furthermore, it would appear that government programmes are increasingly vulnerable to climate change as a result of an increasing frequency and intensity of extreme climate events. For example, Hurricane Katrina damage in New Orleans (US) and the surrounding region almost bankrupted the National Flood Insurance Program.[166] Populations worldwide are growing within coastal areas and growth is expected to increase rapidly, suggesting an increase in the vulnerability of property but also insurance providers, including government programmes.[167]

Populations worldwide are growing within coastal areas … suggesting an increase in the vulnerability of property but also insurance providers

In some places, the availability of insurance in coastal and other vulnerable areas fails to discourage development in areas at risk of flooding from coastal storms.[168] In the eastern parts of the Caribbean, for instance, building quality and location are not typically factored into insurance availability or cost. Due to missing incentives to mitigate the impacts of extreme climatic events and given that only a small percentage of the risk is retained by local insurance companies, buildings are often ill-prepared targets for extreme weather events or climate change. Instead, insurance companies are encouraged by the system to underwrite as many policies as possible, regardless of their soundness.[169]

Ecosystem services

Natural environmental processes provide benefits that are vital to city function and human health. These ecosystem services include oxygen production, carbon storage, natural filtering of toxins and pollutants, and protection of coastal societies from flooding and wind during storms. Human activities (e.g. development, pollution and wetland destruction) can harm such ecosystem services. Increasing urbanization places greater demand on natural resources and imposes significant changes on the environmental processes that drive the benefits that societies derive from ecosystem services.[170] Table 4.3 illustrates some of these changes and their effects on ecosystem services.

The Millennium Ecosystem Assessment[171] indicates that climate change has been identified as a key factor behind the accelerated loss and degradation of ecosystem services. The assessment found that approximately 60 per cent of the ecosystem services evaluated were being degraded or used unsustainably.[172] Wetland health may be particularly threatened in the coming decades as the combined impacts of landscape modification and sea-level rise cause the Earth's deltas to sink below oceans levels.[173]

Loss of ecosystem services, besides potentially affecting food provision and human health, can significantly reduce the revenue of cities. In Durban (South Africa), for example, the replacement value of the ecosystem services (e.g. water provision, flood prevention) within the city's network of open space was estimated at US$418 million per year in a study published in 2003.[174] This was approximately 38 per cent of the city's total capital and operating budget at that time, illustrating the financial consequences of losing access to these services. A further significant point is that it is the poorest and most vulnerable people/communities who are most directly reliant on these services in order to meet their basic needs. They therefore stand to lose the most from the damage of ecosystems goods and services under projected climate change conditions.

Climate change has been identified as a key factor behind the accelerated loss and degradation of ecosystems services

Livelihood impacts

Extreme climate events can disrupt the ability of individuals and households in urban areas to sustain livelihoods.[175] Climate change-related disasters destroy livelihood assets or the means of production available to individuals, households or groups. These include stocks of natural resources (natural capital), social relationships (socio-political capital), skills and health (human capital), infrastructure (physical capital) and financial resources (financial capital), which are necessary to sustain a livelihood. By affecting such assets, climate change-related events can pose a serious threat to urban livelihoods.

The effects of climate change on livelihoods will also depend on their geographical location and, thus, exposure to the physical risks associated with climate change. Livelihood activities located in low-elevation coastal zones, for instance, will be vulnerable to the impacts of sea-level rise and cyclones. Livelihood impacts will also vary from one context to another depending on the vulnerability of existing assets and opportunities. For instance, the livelihoods of the urban poor are likely to be most at risk from climate change effects since their assets and livelihoods are already meagre and unreliable. In particular, individuals living in informal settlements are likely to have meagre savings and any disruption to their livelihood directly affects their ability to buy food and pay bills, including for their children's education and healthcare. Livelihood activities of the urban poor are also more severely affected by climate events than other social groups because of their presence in at-risk zones. For instance, flooding makes it difficult for residents of informal settlements to conduct small-scale commerce, petty trading and artisan trades, and thus can leave them undernourished for days while the area and local economy recovers. A one-day rain event in Maputo (Mozambique) might result in floods that linger for three days, and if rains persist, floodwaters might rise as much as 1m and take a month to recede.[176]

Extreme climate events can disrupt the ability of individuals and households in urban areas to sustain livelihoods

Where livelihoods are dependent on climate-sensitive inputs, the impacts of extreme as well as slow-onset climate changes will be further accentuated. This is so in the case of agriculture and tourism sectors of the economy. Flooding associated with sea-level rise has reduced the level of tourism in Venice (Italy), resulting in fewer jobs and economic losses for the city. The city's productivity is largely tied to its aquaculture industry and tourism. By 2030, flooding and sea-level rise are projected to cost the city €35 to €42 million in decreased tourism levels and €10 to €17 million in aquaculture revenues.[177] Studies have revealed that tourists are unlikely to return to vacation spots in some islands such as Bonaire and Barbados if coral bleaching (which has been linked to warming waters) occurs, resulting in loss of fish and coral species.[178]

Climate changes cause local weather conditions … that affect public health in urban areas

The agricultural sector is also vulnerable to climate variability; thus, individuals dependent on it for their livelihoods are at risk. Low-lying areas in Southeast Asia are particularly vulnerable to coastal erosion and flooding, which is likely to result in loss of cultivated land and fishery nurseries. In parts of Africa, livelihoods and national GDP are highly dependent upon the agricultural sector, which accounts for as much as 70 per cent of national GDP in some countries.[179] For urban centres, distant impacts upon tourism and agriculture can potentially result in increased migration from rural areas, which creates more demand for infrastructure and services, though this phenomenon is not well understood.[180]

PUBLIC HEALTH IMPACTS

Climate changes cause local weather conditions – including extreme heat and severe weather events – that affect public health in urban areas. This section describes these key health issues, focusing on impacts related to extreme temperatures, disasters, epidemics, health services and psychological illnesses. It also considers how poverty acts as a compounding factor which exacerbates the health impacts of climate change.

Climate change can lead to extended periods of heat (i.e. heat waves) and drought. More heat waves have the potential to increase the incidence of heat stress and heat-related mortality.[181] Higher than average night-time temperatures compound heat stress by eliminating the typical period during which the human body can recover from heat stress accrued throughout the day.[182] In particular, several consecutive nights with temperatures above normal can negatively impact upon health, leading to heat-related illness and mortality.[183] For example, the heat wave of 2003 across much of Europe is believed to have caused the death of over 20,000 people. It was the warmest summer since 1540 and could become the norm by the end of the 21st century.[184] Sustained high temperatures in France raised mortality by an estimated 140 per cent compared to historical averages, while over 2000 excess deaths reportedly occurred in England and Wales.[185] In the US, high temperatures result in an average of 400 deaths and many more hospitalizations each year.[186] Projections of climate change impacts in New York City (US) further show significant increases in respiratory-related diseases and hospitalization.[187]

With more individuals moving to urban locations, higher temperatures and a rapidly aging society, the threat of heat-related mortality will become more severe in future.[188] Urban residents are especially at a higher risk of heat-related mortality as a result of the urban heat-island effect.[189] However, death from heat is significantly underreported, as widely accepted criteria in determining heat-related death do not exist. Often, a pre-existing condition is listed as the cause of death, while the role of environmental factors is not considered.[190]

Catastrophic events have both immediate and lasting impacts upon public health. For example, of 238 natural catastrophes occurring from 1950 to 2007, 66 per cent were climate related, most of which involved storms or flooding.[191] Recent flooding in Manila (the Philippines) and surrounding areas affected an estimated 1.9 million people and killed at least 240. Torrential downpours in cities and towns across north-eastern Brazil in 2010 caused floods that rendered at least 120,000 people homeless and killed at least 41 others.[192] As the intensity and frequency of precipitation increases, ever more urban residents will be at risk of injury and property loss.

Increasing intensity of storms and frequency of severe storms threaten to further impact upon urban areas and the health of their residents, as illustrated by recent floods in Pakistan which killed 1100 people.[193] Beyond causing immediate death and injuries, floods and storms can cause long-term damage to facilities that provide health-related services. Power outages can disrupt hospital services, as occurred in Dresden (Germany) in 2002 when floods from the River Elbe affected four out of the six major hospitals in the region.[194] Likewise, clean water provision can be compromised if treatment facilities are structurally damaged or lack power.

Physical climate changes, including temperature, precipitation, humidity and sea-level rise, can alter the range, life cycle and rate of transmission of certain infectious diseases. As indicated earlier, flooding can introduce contaminants and diseases into water supplies, which has been linked to increased incidence of diarrhoeal and respiratory illnesses in both developed and developing countries.[195] Psychological illnesses sometimes also increase following storms and other disasters. Post-traumatic stress disorder, anxiety, grief and depression are commonly observed among individuals following hurricanes and other disasters.[196] Declining local air quality is a further consequence of climate change which threatens health. The photochemical reactions of pollutants in the air which cause smog will intensify as temperatures rise. For example, in Los Angeles, California (US), a 1°C increase in temperatures above 22°C results in an increase in the incidence of smog by 5 per cent.[197]

While the complex relationship of disease incidence with both environmental and demographic factors makes the identification of cause–effect relationships difficult, it is likely that climate change will increase the global disease burden. The World Health Organization attributes at least 150,000 annual deaths to diseases associated with climate change that has occurred since the 1970s, and estimates that death rates from climate-induced disease risk may double by 2030.[198] Malaria may pose a particular problem for populations in developing countries, including those in sub-Saharan Africa. In contrast, precipitation decreases in some parts of Central America and the Amazon region may reduce the rate of malaria transmission.[199] Climate change is also likely to affect the transmission of a number of other diseases, including dengue fever, rodent-borne diseases and diarrhoeal illnesses.[200]

As discussed in a subsequent section of this chapter, diseases can weaken the defences of communities at large and of certain subgroups of a population in particular (e.g. low-income groups). Health impacts, both immediate and long term, tend to hit the poorest urban residents the hardest in part because they often lack mobility, resources and insurance. These residents also typically occupy the highest-risk areas of cities. These and other distributional impacts are discussed in the next section of this chapter.

SOCIAL IMPACTS

The degree to which human settlements are vulnerable to climate change depends not only on the nature and magnitude of physical changes, but also on the socio-economic characteristics of each city. Cities that experience the same category of hurricane, for example, may incur very different mortality levels and economic losses based on relative wealth and infrastructure. Within cities, too, different population groups are differentially affected by the same weather events and climatic conditions. Climate change differentially impacts upon groups of individuals, such as marginalized minorities, women and men, young and old. These impacts have, until recently, received relatively little attention compared to other distributional issues.

The distributional effects of climate change in urban areas within the context of existing vulnerabilities are reviewed below. In doing so, it is critical to acknowledge and confront compounding vulnerabilities for specific groups in urban areas. Individuals, households and communities who fall into more than one category of vulnerability can find the deck dramatically stacked against them in terms of their ability to prepare for and respond to the varied impacts that they already face and will face in the future. Climate change impacts magnify gender and racial inequalities, often affecting poor minorities and poor women more than any other groups. These impacts often exacerbate poverty as individuals lose their livelihoods and possessions. Sickness and injury, two of the most important factors attributable to increasing poverty, affect the poor more than other groups.[201] A vicious cycle then develops whereby marginalized groups bear the greatest burdens of climate change, thus preventing them from escaping poverty and leaving them continuously vulnerable to further change. Urban planners and policy-makers are thus often charged with confronting multiple social issues at once. Understanding the nature of group-specific climate change dynamics can enable decision-making that seeks to break this cycle – for instance, by promoting inclusion of typically marginalized groups in planning, anticipating the unique needs of groups during disasters and preparing accordingly.

Climate change will increase the global disease burden

Climate change differentially impacts upon groups of individuals, such as marginalized minorities, women and men, young and old

Poverty

Climate change is considered a distributional phenomenon because it differentially impacts upon individuals and groups based on wealth and access to resources. In general, low-income households in both developed and developing countries are most vulnerable to climate change impacts primarily due to the scale and nature of the assets that they possess or can draw upon (see Box 4.8). The interactions between climate change and income do not affect developing countries alone. There are many examples of poor communities in developed countries faring worse than the wealthier groups during the same disaster. During Hurricane Katrina in New Orleans (US), residents without cars and financial resources to evacuate were left behind. Some of the hardest hit low-lying neighbourhoods were also the poorest, leaving those with few resources to bear most of the devastation.[202]

It has been suggested that the assessment of vulnerability to climate change impacts and the ways in which it is socially distributed can perhaps best be understood by considering six key questions:[203]

1 Who lives or works in the locations most exposed to hazards related to the direct or indirect impacts of climate change (such as on sites at risk of flooding or landslides)?

Box 4.8 Poverty and climate change impacts in cities

Within any urban centre, it is common for poorer groups to be disproportionately at risk for a variety of reasons, including:

- greater exposure to hazards (e.g. through living on floodplains or unstable slopes);[a]
- lack of risk-reducing housing and infrastructure (e.g. poor-quality housing, lack of drainage systems);
- less adaptive capacity (e.g. lacking the income or assets that allow a move to better quality housing or less dangerous sites);
- less state provision for assistance in the event of a disaster (e.g. needed emergency responses and support for rebuilding or repairing homes and livelihoods; indeed, state action may increase exposure to hazards by limiting access to safe sites for housing);[b] and
- less legal and financial protection (e.g. a lack of legal tenure for housing sites; lack of insurance and disaster-proof assets).[c]

Sources: a Ruth and Ibarrarán, 2009, p56; b Syukrizal et al, 2009; c Bartlett et al, 2009; Hardoy and Pandiella, 2009

2 Who lives or works in locations lacking the infrastructure that reduces risk (e.g. drains that reduce flood risk)?
3 Who lacks information, capacity and opportunities to take immediate short-term measures to limit impacts (e.g. to move family and assets before a disaster event)?
4 Whose homes and neighbourhoods face the greatest risks when impacts occur (e.g. because of poorer quality buildings that provide less protection for inhabitants and their physical assets)?
5 Who is least able to cope with the impacts (including illness, injury, loss of property and loss of income)?
6 Who is least able to avoid impacts (e.g. by building better homes, agitating for improved infrastructure or moving to a safer place)?

The urban residents most vulnerable to climate change are the poor slum and squatter settlement dwellers

A large proportion of the urban population in developing countries live on sites ill suited to housing – for instance, floodplains or mountain slopes or areas prone to flooding or affected by seasonal storms, sea surges or other weather-related risks.[204] Most such sites are occupied by low-income households because other ‘safer’ sites are beyond their means. There is also the growing proportion of the world’s urban population living in the low-elevation coastal zone[205] – and many studies of particular coastal cities show that most of those most at risk are low-income groups.[206]

Access to insurance is generally more inclusive in cities in developed countries compared to those in developing countries

With regard to who lacks information, capacity and opportunity to take immediate short-term measures to limit impacts, the devastation caused in so many low-income settlements by extreme weather is not necessarily a matter of a lack of knowledge or capacities on the part of their residents, although this may be the case for some new arrivals.[207] Even if they know of an approaching storm that may threaten their homes, the residents of informal settlements are often reluctant to move even when advised to do so – for instance, for fear of losing valuables to looters, uncertainty about provisioning for their needs in the places they move to and the worry of not being allowed back if their house and settlement are damaged. For instance, in Santa Fe (Argentina), large-scale floods affecting large sections of the population have become common – but many of those living in informal settlements at high risk from flooding did not want to move because they had no confidence in the police that they would stop looting and were worried that because they had no legal tenure, they might not be allowed back.[208]

In terms of whose homes and neighbourhoods face greatest risks when impacts occur, studies of disaster impacts from extreme weather in urban areas suggest the majority of those who are killed or seriously injured and who lose most or all their assets are from low-income groups.[209] Many disasters only affect the inhabitants of particular informal settlements and other slums, and most such disasters are not registered in national or international records of disasters.[210] The reasons why most of the inhabitants of informal settlements are so much at risk is obvious: poor-quality housing with inadequate foundations, high levels of overcrowding, lack of infrastructure, etc. Most low-income groups live in housing without air conditioning or adequate insulation, and during heat waves, the very young, older persons and people in poor health are particularly at risk.[211] For instance, in regard to urban centres in India:

> *[T]he urban residents most vulnerable to climate change are the poor slum and squatter settlement dwellers and … they are multiply challenged by even small events that impact their livelihoods, income, property, assets and sometimes their lives. Because of systematic exclusion from the formal economy of the city – basic services and entitlements and the impossibly high entry barrier into legal land and housing markets – most poor people live in hazardous sites and are exposed to multiple environmental health risks via poor sanitation and water supply, little or no drainage and solid waste services, air and water pollution and the recurrent threat of being evicted.*[212]

Financial shocks from damage lasts months, even years, after a disaster occurs. Thus, the extent to which the population of a given city is protected by insurance will in large part determine the impact of disasters. Access to insurance is generally more inclusive in cities in developed countries compared to those in developing countries, where poor households typically lack access altogether.[213] Still, low-income households in developed countries can be excluded from insurance where public coverage is inadequate and the costs of private insurance are prohibitively high. Unlike their wealthy counterparts, low-income households often lack the resources to mitigate damages after they occur – for instance, through healthcare, structural repair, communication, food and water.[214] In the absence of adequate recovery assistance, the poor often sacrifice nutrition, children’s education or any remaining assets to meet their basic needs, thereby further limiting their chance of recovery and escape from poverty.[215]

Evidently, climate change disproportionately affects lower-income groups in both developed and developing countries. Although these distributional impacts are far from being adequately addressed on international or national levels, the nexus between poverty and climate change has steadily worked its way into the climate change discourse, emerging in focus groups, meetings and reports by many international organizations, including the Organisation for Economic Co-operation and Development (OECD) and the World Bank.[216]

Gender

In most urban centres, there are significant differences between women and men in terms of their exposure to climate-related hazards, and their capacity to avoid, cope with or adapt to them.[217] This is because men and women differ in their livelihoods, familial roles, production and consumption patterns and other behaviours, perceptions of risk, and are in some cases treated differently with respect to planning and relief efforts during and after disasters (see Table 4.4).

In general, women, especially poor women, are more likely than men to suffer injuries or death when a natural disaster occurs, with more severe disasters correlating with wider gaps in relative risk. Poor women have been found to be more exposed to direct harm from flooding or hurricanes compared to other socio-economic groups.[218] In 1991, a cyclone in Bangladesh killed five times as many females as males.[219] Females comprised more than three-quarters of the deaths in four Indonesian villages hit by the 2005 tsunami, while in the village of Kuala Cangkoy, where the worst devastation occurred, females accounted for 80 per cent of the deaths.[220] Gendered impacts are evident in rich countries as well, particularly in poor communities. For example, in the French heat wave of 2003, about 70 per cent of fatalities were women, although this number may be artificially high since there are more women than men in older age groups.[221]

To some extent, the higher death rates for women in disasters can be explained by the fact that women comprise the majority of the world's poor population, who face vulnerability factors as previously discussed. This statistic, however, can obscure the many other important factors that place women at greater risk than men. In developing countries, women often experience unequal access to resources, credit, insurance, services and information. Women's socio-cultural roles and typical care-giving responsibilities often prevent them from migrating and seeking shelter before and after disaster events. In some cases, women may not be allowed to travel alone and may be prevented from learning skills that could aid their survival during a disaster. Also, women's lower economic status increases their vulnerability in the event of a disaster occurring. When homes are destroyed or damaged, this often affects women's incomes more than men's as they often engage in income-generating activities from home and therefore lose income when homes are destroyed.[222] Where access to resources and the social status of women are nearly equal to that of men, the mortality difference between the sexes is much smaller or, in fact, negligible, compared to societies with wide gender inequalities.[223]

Women, especially poor women, are more likely than men to suffer injuries or death when a natural disaster occurs

The method by which aid is distributed following disasters further contributes to gendered vulnerability. In both developing and developed countries, women may have limited capacity to secure relief aid, whether due to formal assistance policies or cultural norms.[224] In Bangladesh, for example, women have traditionally had difficulty receiving relief aid after disasters because it was difficult for them to wait in long lines at recovery centres when they needed to care for children at home. Expanded recovery systems that provide door-to-door service are helping to address this issue.[225]

Women's lower economic status increases their vulnerability in the event of a disaster occurring

Households that are headed by women do not always receive the assistance they need when disaster relief is tailored to reintegrate men into the workforce or when it privileges male-headed households for relief aid.[226] For example, relief checks following Hurricane Andrew in Miami (US) were distributed to men as traditional heads of household, ignoring the reality that many families were then headed by women.[227] If men leave their families, as frequently occurs following a natural disaster, women are rendered ineligible for public assistance or may go unrecognized by the system.

Aspect of vulnerability	Contribution to urban vulnerability	Contribution to climate vulnerability
Gendered division of labour and 'poverty of time'	Women have prime responsibility for 'reproductive' labour; lack of time to engage in 'productive' labour	Limited financial assets to build resilience and to cope with disaster events
Gender-ascribed social responsibilities	Women have prime responsibility for 'reproductive' labour; lack of time to engage in 'productive' labour	Additional domestic responsibilities when access to food, water and sanitation are disrupted; additional time required to care for young, sick and elderly
Cultural expectations of gender norms	Constraints on women's mobility and involvement in certain activities	Higher mortality from disaster events due to lack of skills and knowledge
Unequal entitlements to land and property	Limited access to productive resources	Limited ability to invest in more resilient land or shelter
Higher representation of women in informal sectors	Lower wages and lack of financial security	Damage to homes and neighbourhoods affects women's incomes more severely as income-earning activities are often undertaken at home
Safety and security in public spaces	Limited freedom to use public space	Particular problem in temporary accommodation/ relocation sites; high rates of sexual abuse and violence
Limited engagement of women in planning processes	Urban plans fail to meet particular needs of women and children	Climate adaptation plans fail to meet needs of women and children; failure to incorporate women's perspectives may result in higher levels of risk being accepted

Source: IFRC, 2010

Table 4.4

Gender and climate vulnerability

Likewise, trauma programmes are often not tailored to the specific, and, at times, unique needs of men and women. In the aftermath of storms, women often disproportionately experience sexual or domestic violence.[228] Disaster relief programmes are sometimes inadequate to meet the medical needs of women, especially those related to reproductive and psychological health. Women were 2.7 times more likely than men to exhibit clinical symptoms of post-traumatic stress disorder following Hurricane Katrina, and many went untreated for years after the event because of limited access to public assistance programmes and lack of health insurance.[229] In some cases, men may take greater risks following natural disasters and may not receive treatment for trauma because of gender roles and stereotypes.[230] The psychological needs of men may also be overlooked in disaster programmes; for example, men were not offered counselling following flooding of the Koshi River in 2008 that affected Bihar, India and Nepal.[231]

Women are often excluded from planning processes and discussions about climate change

Restrictions on women's livelihood also increase their vulnerability to climate change in both developing and developed countries. Women sometimes have less access to education compared to men and tend to earn lower wages than men as well, especially in developing countries (even for the same work). Similarly, in developed countries, gender differences in employment opportunities and pay are one of the greatest contributors to increased poverty rates among women.[232] In many developing countries, marriage customs may prevent women from working at all outside the home, and may remove women from social networks and extended family.[233] Women's ability to contribute to their own welfare and garner resources and investments that could help them recover from disasters is thus limited.

Young children are particularly vulnerable to climate change impacts, in part because of their physiological immaturity

Furthermore, women are often excluded from planning processes and discussions about climate change. As a result, the perspectives and needs of women are insufficiently incorporated within processes and mechanisms to address climate change, if they are included at all. There is little evidence of specific efforts to target women in adaptation activities funded by bilateral and multilateral programmes. In excluding them from planning processes, an opportunity is missed to gain the unique knowledge that women possess regarding mitigation strategies, natural resource use, and adaptation and coping strategies following disasters. For instance, as primary caregivers, women could provide vital information about storing and protecting food and valuables during a disaster, educating children about survival strategies, and reinforcing structures before and after a severe weather event.[234]

Age

Young children are particularly vulnerable to climate change impacts, in part because of their physiological immaturity (see Box 4.9). Due to their limited cognitive ability and behavioural experiences compared to adults, children are less equipped to handle disaster risks. They are more susceptible to diarrhoeal diseases and malaria – which, as mentioned earlier, are anticipated to increase with climate change in many regions. Furthermore, physical health damage can be more severe and long lasting in children than adults because their bodies and organs are still developing,[235] and higher metabolism in children makes their need for constant sustenance more pressing than it is for adults. Food and water scarcity thus has particularly rapid and serious consequences for children living in poverty.[236]

Children have limited ability to care for their basic needs and take actions to adjust their physical conditions to cope with external conditions. Adults are responsible for these and other needs of children, including providing information. In the absence of adult support, these and other issues – including reduced ability to communicate effectively and highly restricted mobility – leave children especially vulnerable to climate change impacts.

For some children in some places, the added challenges brought by climate change (including higher risks from under-nutrition, intestinal parasites, diarrhoeal diseases or malaria) could erode their opportunities for learning and growth – for instance, through lower cognitive capacity and performance. Learning is also dependent on supportive social and physical environments and the opportunities to master new skills. Disasters often result in the interruption of formal schooling for months at a time, and children are more likely to be withdrawn from school when households face shocks.

Levels of psychological vulnerability and resilience depend on children's health and internal strengths, as well as household dynamics and levels of social support. Poverty and social status can have an important role in this regard. The losses, hardships and uncertainties surrounding stressful events can have high costs for children. Increased levels of irritability, withdrawal and family conflict are not unusual after disasters. High stress for adults can have serious implications for children, contributing to higher levels of neglect. Increased rates of child abuse have long been associated with such factors as parental depression, increased poverty, loss of property or a breakdown in social support.

Displacement and life in emergency or transitional housing after disasters or evictions have been noted in many contexts to lead to an erosion of the social controls that normally regulate behaviour within households and communities. Overcrowding, chaotic conditions, lack of privacy and the collapse of regular routines can contribute to anger, frustration and violence. Adolescent girls especially report sexual harassment and abuse. The synergistic and cumulative effects of such physical and social stressors can affect children's development on all fronts. As the numbers of displaced people grow, these dysfunctional environments are likely to become the setting within which more and more children spend their early years.

Even less extreme events can create havoc in families' lives, deepening the level of poverty. When times are hard, children can become an asset that is drawn on to maintain the stability of the household. Children may be pulled from school to work or take care of siblings. Some children may be considered more 'expendable' than others. Many of the young prostitutes in Bombay (India) are from poor rural villages in Nepal, where inadequate crop yields lead families to sacrifice one child so that others may survive.

Box 4.9 Climate change risks for children

Drawing on studies on children and their vulnerabilities, it is possible to highlight the following risks associated with climate change that have clear impacts upon child health and survival:

- *Mortality in extreme events:* in most developing countries, the loss of life is disproportionately high among children – especially among the poor – during such extreme events as flooding, high winds and landslides. Children are 14 to 44 per cent more likely to die due to environmental variables, including extremes in temperature, flooding and severe weather events, than the total population at large.[a] For example, drowning incidents in floods are particularly high for children in Kampala (Uganda).[b] A study of flood-related mortalities in Nepal found that the death rate for children aged two to nine was more than double that of adults; and pre-school girls were five times more likely to die than adult men.[c] The average death rate for children was twice that of adults in flooding in Nepal, with poor children suffering the highest death rates.[d]
- *Water and sanitation-related illnesses:* children under five are the main victims (80 per cent globally) of sanitation-related illnesses (primarily diarrhoeal diseases)[e] because of their less developed immunity systems and because their behaviour can bring them into contact with pathogens. This also results in higher levels of malnutrition and increased vulnerability to other illnesses. Droughts, heavy or prolonged rains, flooding and conditions after disasters – as well as climate change-related constraints on freshwater supplies in many urban centres – all intensify the risks, which are already very high in informal settlements or other areas with concentrations of low-income groups.
- *Malaria, dengue and other tropical diseases:* warmer average temperatures are expanding the areas where many tropical diseases can occur, with children most often the victims. In many locations, the most threatening tropical disease is malaria. Up to 50 per cent of the world's population is now considered to be at risk. In Africa, 65 per cent of mortality is among children under five.[f] Malaria also increases the severity of other diseases, more than doubling overall mortality for young children. Climate change is also accelerating the comeback of dengue fever in many countries in the Americas.[g]
- *Heat stress:* young children, along with older persons, are at highest risk from heat stress. Research in São Paulo (Brazil) found that for every degree increase above 20°C, there was a 2.6 per cent increase in overall mortality in children under 15 (same as for those over 65).[h] Risks for younger children are higher. Those in poor urban areas may be at highest risk because of the urban heat-island effect, high levels of congestion and little open space and vegetation.[i]
- *Malnutrition:* malnutrition results from food shortages (e.g. as a result of reduced rainfall, other changes affecting agriculture, or interruptions in supplies during sudden acute events) and is also closely tied to unsanitary conditions and to children's general state of health. If children are already undernourished, they are less likely to withstand the stress of an extreme event. Malnutrition increases children's vulnerability on every front and can result in long-term physical and mental stunting.
- *Injury:* after extreme events, injury rates go up. Children, because of their size and developmental immaturity, are particularly susceptible and are more likely to experience serious and long-term effects (from burns, broken bones, head injuries, etc.) because of their size and physiological immaturity.[j]
- *Quality of care:* as conditions become more challenging to health, so do the burdens faced by caregivers. These problems are seldom faced one at a time – risk factors generally exist in clusters. Overstretched and exhausted caregivers are more likely to leave children unsupervised and to cut corners in all the chores that are necessary for healthy living.

Sources: a Bartlett, 2008; b Mabasi, 2009, p5; c Pradhan et al, 2007; d UN, 2007; e Murray and Lopez, 1996; f Breman et al, 2004; g World Bank, 2009c; h Gouveia et al, 2003; i Kovats and Akhtar, 2008; j Berger and Mohan, 1996

Older persons share similar physical and social vulnerabilities with children. Pre-existing illnesses and physical ailments limit their mobility and coping capacity, which may prevent them from evacuating or seeking shelter in emergency situations. Since their bodies adjust more slowly to physical conditions than younger populations, they may not perceive excessive heat quickly enough to prevent heat stroke. Empirical evidence indicates that the elderly display disproportionately higher injury rates after natural disasters and higher rates of heat wave mortality.[237] A recent study on climate change impacts in Oceania found that 1100 people aged over 65 die each year in ten Australian and two New Zealand cities as a result of heat waves.[238]

While adaptive measures do exist to help the elderly combat their physical vulnerability, these mechanisms are often solely accessible to wealthy populations. The elderly are more likely than younger people to require assisted transportation out of a dangerous situation; but poor individuals may not be able to afford private transportation. Lack of personal contacts and distrust of strangers decreases their access to volunteered assistance, and they are also less likely to accept financial assistance from public recovery and aid programmes.[239]

The vulnerability of the elderly is, thus, like other groups, dependent upon their economic status. Yet, all else being equal, the elderly show disproportionate rates of poverty, for the most part because they no longer maintain a source of income and tend to have low endowments of assets.[240] While rates and magnitude of poverty are greater in developing countries, poor older persons in developed countries are more likely to live alone and be socially isolated.

The elderly display disproportionately higher injury rates after natural disasters and higher rates of heat wave mortality

Ethnic and other minorities (including indigenous groups)

Racial and ethnic minorities also exhibit increased vulnerabilities to climate change in both developed and developing countries. Discriminatory practices often segregate groups of minorities into the highest-risk neighbourhoods, usually without access to insurance and loans as security against climate change impacts. The majority of flooding victims in Bihar (India) in 2007 were 'untouchable' low-caste groups who resided in floodplains and areas prone to landslides.[241] The most vulnerable low-lying communities in New Orleans (US) are comprised mostly of African-Americans. This group suffered the relatively most severe losses of life and assets during Hurricane Katrina.[242]

In both developed and developing countries, provision of government assistance following disasters is often less accessible to racial and ethnic minorities. Aid workers may not be properly educated regarding cultural norms, or important information regarding assistance may not be available in the right language.[243] Since aid is sometimes structured around the household as a single family unit, some ethnic minorities may not receive as much assistance as majority groups. For instance, in the US, the Federal Emergency Management Agency's assistance to Haitian residents of Florida following tropical storm damage has been found to be insufficient because several families tend to occupy a single household.[244] Outright exclusion of certain groups from disaster relief occurred during recent disasters in South Asia, including during the flooding of the Koshi River in 2008 in Bihar, India and Nepal, the 2005 Kashmir earthquake and the 2004 Indian Ocean tsunami. Assessments of the relief and reconstruction efforts following these disasters have revealed discriminatory practices and human rights abuses against women, the poor, indigenous groups and the disabled.[245] Furthermore, the knowledge of government views towards minority groups or previous examples of discrimination in some cases discourages minorities from seeking assistance.[246]

Racial and ethnic minorities also exhibit increased vulnerabilities to climate change in both developed and developing countries

Similarly, indigenous peoples in many areas have historically faced factors that can increase their relative vulnerability. Alienation from decision-making, education, healthcare and information regarding assistance and relief programmes are common among indigenous peoples. Moreover, indigenous peoples often lack security of land tenure and legally recognized property rights, which can force them to settle in hazardous areas if they are removed from their land.[247] Lack of legal property can also limit the ability of indigenous peoples to adapt to climate change, particularly when, for example, their adaptation strategies involve seasonal migration due to drought. If their traditional means of adapting are restricted by denial to move into new areas, they may not be able to cope with changing climatic conditions.[248]

As the world's climate changes, resulting environmental degradation, drought and sea-level rise may lead to … increased internal and international migration

DISPLACEMENT AND FORCED MIGRATION

Millions of people move each year, with over 5 million crossing international borders into developed countries and even greater numbers moving into or within developing countries.[249] The reasons why people move are complex and interrelated, and there is evidence that poor environmental conditions can contribute to the decision of groups or individuals to move. As the world's climate changes, resulting environmental degradation, drought and sea-level rise may lead to the permanent displacement of people and, consequently, increased internal and international migration. The term migrant does not imply that movement was forced, but refers to a person who has changed place of residence either by moving across international borders (international migrant) or moving within one's country of origin (internal migrant).[250] This section describes the observed role of the environment in migration, projections for future migration as a result of climate change, and the consequences of migration.

Migration has been documented around the world both as a response to sudden-onset natural disasters and slow-onset changing environmental conditions. In 2008, an estimated 20 million individuals were displaced due to sudden-onset natural disasters alone.[251] Flooding and severe storms have been linked to migration in the Philippines, Pakistan, China and the Democratic People's Republic of Korea.[252] Decades of drought and land degradation have contributed to the relocation of nearly 8 million inhabitants of north-eastern Brazil to the central and southern regions of the country since the 1960s.[253] In Ghana, studies have found evidence of drought-induced internal migration from north-western to central and southern regions. Northern Ghanaians relocate to Ghana's middle regions because of the combination of poor agro-ecological conditions at home and easy access to fertile lands in the more humid south. As such, 30.8 per cent of people born in north-western Ghana now live elsewhere.[254]

Still, figures for environment-related migration are contentious because it is difficult to ascribe a single cause to most migration events. Evaluation of historical migration events, both permanent and temporary, suggests that environmental decline can serve as an important 'push' factor in generating movement; but it is not typically the sole causative agent of migration. As a further complicating issue, environmental degradation itself may occur not only due to climate change impacts, but as a side effect of war, political instability, overpopulation or widespread poverty. Changing environmental conditions may exacerbate longstanding problems such as conflict or food shortages. Many factors that can be implicated in migration are difficult to entangle, and it is impossible to ascribe blame to a single starting factor.

The response of any particular community to environmental change depends on a variety of socio-economic and historical considerations. In the least developed countries where rural economic activities are disrupted by environmental conditions (e.g. drought), migration is usually temporary and internal.[255] If societies are able to adapt to slow-onset changes, they may only migrate seasonally or individuals may leave temporarily and send back resources to their remaining family. While sudden disasters often force people to move quickly to a safe location, the poor do not often have the resources to move, and loss of resources during disasters may only make it less likely that low-income households will eventually relocate.[256]

Projections for future climate change-related displacement average 200 million migrants by 2050; yet estimates depend greatly on the degree of climate change and how abruptly change occurs.[257] Despite difficulties in predicting global migration patterns, there are areas that may be particularly affected because of their vulnerability to risk factors. Populations located at low elevations are vulnerable to climate-induced migration, especially in areas where other vulnerability factors exist (e.g. overcrowding). Small island states, including the Bahamas, Marshall Islands and Kiribati, are located entirely below 3m or 4m above sea level, so their populations here may have to relocate entirely as sea-level rise and coastal subsidence continue.[258]

It is difficult to establish where displaced residents are likely to relocate to. In most historical cases, displaced residents move to other regions of their native country. Rural to urban migration has been a major component of urbanization across Africa and in Asia, though it should not be an assumed response to environmental degradation around the world. In regions with strong agriculture sectors, migrants may move from one rural area to another rather than from rural areas to cities. In rapidly urbanizing countries (e.g. in countries throughout the Latin American and Caribbean region), migration from one city to another is common. Rural to urban migration typically happens where economic growth is occurring or there is an expansive manufacturing or service economy.[259] However, it is also reasonable to expect that some international migration may occur where inland relocation is impossible or where cultural and historic relationships exist between countries.

Depending on the scale and nature of these events, migration can result in social disruption or conflict, especially if migratory events bring into contact peoples with pre-existing social or cultural tensions. New arrivals to cities may also be seen as competition for jobs or resources, generating distrust and possibly leading to conflict. Social disruption is particularly likely in developing countries where cities may be less able to absorb new residents. In addition, political instability common to many developing countries can at best fail to mitigate conflicts and can, at worst, facilitate them.[260]

Forced migrants can also find themselves vulnerable to a range of risks, climate related and otherwise. They often face threats to their health and personal security and, in some areas of the world, are at danger of human trafficking and sexual exploitation.[261] The nature and magnitude of these implications will depend on the location of events, number of people involved, and the time-scale over which migration occurs and preparations have been made.

A growing body of evidence suggests that threats to livelihoods, immigration and resource scarcity can become sources of violent conflict, and indicates that climate change can directly and indirectly influence these trends.[262] Indeed, the United Nations Security Council acknowledges climate change as a threat to human security as resource scarcity, water stress and migration potentially lead to competition and conflict.[263] Still, there is much uncertainty about the specific causal links between climate change, human insecurity and the risk of violent conflict. More research regarding conflict, especially at the regional level, would be useful in identifying where policy intervention may be necessary now and in future.[264]

IDENTIFYING CITIES VULNERABLE TO CLIMATE CHANGE

The concept of vulnerability in relation to climate change is also applicable to larger systems such as cities or city-regions or to resources and ecosystem services. This section of the chapter describes the key indicators of vulnerability in urban areas with regard to risk of exposure and adaptive capacity. Cities may not only serve as sources of particular vulnerability to climate change, but also as centres of concentration for resources, novel ideas and capacity for technological innovation. In this sense, although cities face interacting risk factors from climate change, they may have the ability to respond to climate change while providing tools and lessons for others.

Projections for future climate change-related displacement average 200 million migrants by 2050

Urbanization

As indicated in Chapter 1, levels of urbanization are increasing worldwide. Population growth in urban centres has the potential to significantly exacerbate climate change impacts. Increasing population means greater demand for resources – including energy, food and water – and greater volumes of waste products. Thus, for those regions of the world where resource scarcity is an existing problem, urbanization can be a significant vulnerability factor. Population growth can also cause stronger urban heat-island impacts, which can be a particular challenge for small compact cities such as those typical of Southern Europe.

Population growth in urban centres has the potential to significantly exacerbate climate change impacts

Where population growth occurs rapidly, demand for housing, infrastructure and services can grow much faster than supply. This can force development in hazardous areas or with inadequate construction materials and techniques. In many cases in developing countries, urban slum expansion results in part because population growth outpaces the construction of adequate affordable housing. Unplanned population growth can also result in sprawling urban settlements that encroach upon natural flood and storm buffers.

Rates of urbanization are higher in developing countries, which are less prepared than developed countries to deal with the resulting impacts. For these regions of the world, population growth can act as an acute threat multiplier, concentrating residents in high-risk areas without infrastructure or services, and accelerating environmental degradation. As cities continue to rapidly urbanize surrounding areas, they typically increase their exposure to climate events as development patterns expand into areas that are more vulnerable to climate change and extreme climatic events.[265]

Urban areas face a dichotomy with regard to their vulnerability and resilience to climate change. On the one hand, larger cities are more likely than other regions to be affected by climate events because of their larger size and populations.[266] On the other hand, larger cities tend to have a significant accumulation of human and financial capital that allows them to plan and respond more effectively to extreme events, as cities can draw on talents and financial resources from around the world to aid in rescue and recovery.[267] Also, adaptation can be expensive and, as a result, larger cities tend to be better protected, both by engineering works and early warning systems.[268] However, this generalization does not necessarily hold true in developing cities, where prevalence of slums, inadequate governance and limited resources can reduce resilience.[269]

Despite the inherent issues associated with growing urban populations, most problems can be mitigated with urban planning that diverts growth away from highly hazardous areas, enforces energy and water efficiency standards for buildings, and minimizes urban heat effects. Thus, the extent to which urbanization acts as an additional source of vulnerability often depends on the integration of future population projections within land-use and infrastructure planning at the city level.

Climate change impacts are not experienced in the same way by cities in developing and developed countries

Economic development

Climate change impacts are not experienced in the same way by cities in developing and developed countries. Risk is skewed towards developing countries such that more people are at risk of being affected by a natural disaster in a developing country compared to a similar disaster in a developed country.[270] Lack of economic strength, as is the case in many developing country cities, exacerbates vulnerability by limiting the ability to minimize and adapt to the impacts of climate-related hazards. Studies have linked the size of a city's coastal population and economy (e.g. GDP and GDP per capita) to its vulnerability to sea-level rise.[271] Other issues underlying the risk differential between cities in developing and developed countries include the integrity of infrastructure and urban planning, or lack thereof; the availability of resources and information; levels of risk awareness; presence of disease and malnourishment; and dependence on natural resources.

The level of vulnerability of an urban area to climate change risks depends … on how much of the city's population and economic assets are located in high-risk areas

Developing country cities often lack risk management plans, early warning systems and the ability or foresight to move residents to safer locations when disasters are inevitable. Their local authorities do not have the capacity to respond to natural disasters, and if laws or plans do exist for disaster response, they are rendered ineffective from lack of human or financial capital to enact them. For instance, the capacity of local authorities in developing countries to minimize the effects of flooding is restricted compared to developed countries, including through physical protection such as complex and modern water treatment and catchment systems, flood barriers and other risk buffers. Moreover, due to the unequal distribution or general lack of resources, political instability and corruption, many developing country cities lack the network of governmental and non-governmental institutions that aid recovery efforts in wealthier countries.[272] As a result, developing countries can experience great physical damage during flooding or severe weather events and often have difficulty rebuilding their infrastructure and economy. Furthermore, a recent study concludes that the National Adaptation Programmes of Action (NAPAs) which are intended to guide adaptation responses in least developed countries and small island states are inadequate to protect public health from climate change impacts.[273]

The diversity of local sources of income is a further important facet of the magnitude of climate change impacts in cities. Where cities are reliant upon few industries for the majority of local economic productivity, they can be seriously affected if those activities are affected by climate change both due to short-term monetary losses and longer-term economic decline. In those areas with low economic diversity, loss of a single industry leaves few other options for workers who lose their jobs. In Venice (Italy), for example, flood impacts on tourism and aquaculture leave the city's future uncertain.

An additional vulnerability factor for cities is the degree of disparity between high- and low-income groups. In both developing and developed country cities, the poorest are typically the hardest hit by natural disasters and least able to cope with a range of climate change impacts. Those cities with great income inequality and large populations of residents living in poverty have inherently high vulnerability.

Some developing country cities may be unable to prepare for climate change or to cope with climate change because they are hampered by outbreaks of disease or chronic malnourishment. Unhealthy populations have reduced mobility and may be especially sensitive to water and food shortages. Prevalence of HIV (human immunodeficiency virus) and AIDS (acquired immune deficiency syndrome), for example, have been cited among the primary reasons that the population of Malawi has been increasingly vulnerable to the effects of regional drought.[274] The impacts of disease do not end with infected individuals, but rather weaken the defences of entire communities. As a greater proportion of the population becomes sick, food and economic productivity declines and contributes to higher rates of poverty and malnourishment.[275] It is clear that similar effects could occur not only in regions with AIDS epidemics, but those experiencing outbreaks of plague, flu and other infectious disease.

Physical exposure

The level of vulnerability of an urban area to climate change risks depends, in part, on how much of the city's population and economic assets are located in high-risk areas (i.e. exposure). In many cases, exposure level will be a function of the location of the city itself. Many of the world's largest cities are located in areas vulnerable to climate events, such as low-lying coastal areas. Though low-elevation coastal zones account for only 2 per cent of the world's total land area, this area accounts for approximately 13 per cent of the world's urban population.[276] Coastal cities in this zone have high levels of exposure – both of population and assets – to sea-level rise, storm surges and flooding simply as a function of being so near the ocean.

Exposure can also be linked to land-use planning within the city, including continued development in known hazardous zones, and the destruction of natural protective areas.[277] Coastal communities who encroach onto wetlands, sand dunes and forested areas increase the likelihood of flooding, together with all its associated impacts upon housing structures, transportation networks and water quality.[278]

Weak structural defence mechanisms and oversight of building codes further increase the vulnerability of cities in high-risk areas. Sea walls, levees, dykes and water pumps can reduce the chances and intensity of flooding from storm surges and heavy precipitation, while reinforcements on housing and transportation systems can limit damage when flooding does occur. Those cities with inadequate, aging structural defences and infrastructure in need of repairs or upgrades are often highly vulnerable to climate change risks. The system of structural defences throughout cities in Japan, for example, has resulted in fewer cyclone damages than in cities in the Philippines, even though exposure risk in Japan is generally higher.[279]

In particular, the physical infrastructure of slums increases the vulnerability of residents to climate change impacts. In 2010, nearly 32.7 per cent of the urban population in developing countries lived in slums,[280] which are especially vulnerable to climate change. The very defining characteristics of slums – namely, structures of substandard quality, lack of basic services, overcrowding and social exclusion – clearly suggest that residents are particularly vulnerable to climate change impacts.[281] Disaster risk is often high for slums because construction occurs in particularly hazardous areas, including steep slopes or in floodplains. In Nairobi (Kenya), for example, poor urban planning has resulted in residential and commercial development in floodplains that restricts water flow and increases the likelihood of flooding.[282] The lack of adequate drainage systems leaves such settlements open to rapid flash floods, as in the case of those that occurred near Caracas (Venezuela) in 1999 and Mumbai (India) in July 2005.[283] In Mozambique, politicized land distribution systems and high pricing forces urban residents to live in unregulated slums and informal settlements with inadequate drainage. As a result, severe flooding in 2000 disproportionately affected the urban poor living in a number of urban locations.[284] Box 4.10 further illustrates the challenge of flooding in the slums of Kampala (Uganda).

Box 4.10 Vulnerability of slums to climate change: The case of Kampala, Uganda

Kampala, the capital city of Uganda, has been experiencing rapid urbanization and slum expansion. Currently, over 50 per cent of the urban population live in informal settlements characterized by poor sanitary conditions, infrastructure deficiencies and lack of waste disposal services.

In these areas, even relatively small amounts of rain can cause flooding. The natural drainage capability of the land has been impaired because of the extensive amounts of construction, complex roadways and collection of trash and debris. Runoff is therefore six times that which would occur in a natural environment, leading to hazardous conditions during rains. Flood-related accidents result in deaths of slum residents each year, many of them children. Sewers are available to only a small proportion of the population, so flooding carries faeces and spreads diarrhoeal diseases such as cholera.

Increasing variability of rainfall and more intense storms have compounded the problems that already exist in the slums of Kampala. Climate change is likely to increase the incidence of flooding and accelerate the spread of diseases, including malaria and waterborne diseases. Climate change here has the potential to worsen poverty, especially among poor women, who have limited, if any, access to credit or property compared to men, and who are often excluded from decision-making processes.

Source: Mabasi, 2009

Urban governance and planning

The ability of urban centres to prepare for and respond to climate change is linked in large part to the quality of local governance and the strength of the institutional networks available to provide assistance to residents, as elaborated upon in greater detail in Chapters 5 and 6. Urban governance and planning can improve resilience to climate change impacts through targeted financing of adaptation, broad institutional strengthening and minimizing the drivers of vulnerability.[285] Urban areas with weak governance systems – as a result of political instability, exclusion of climate change from the political agenda or lack of governmental resources – are highly vulnerable to climate change impacts. In many cities throughout developing countries, populations continue to grow in the absence of effective urban planning, resulting in living conditions that exacerbate climate change impacts, and development in vulnerable areas such as coastal zones at risk from sea-level rise, flooding and coastal storms. Similarly, weak building codes and standards (or lack of enforcement) increase the vulnerability of individual households and entire communities.[286]

Civil society institutions – including community-based organizations, NGOs, faith-based organizations and organizations for minorities and women – can mitigate vulnerability by helping populations cope with and adapt to change. These may be especially powerful resources for underrepresented minorities, women and indigenous peoples whose unique needs are often overlooked even where climate change is a focus of political institutions. Cities where these resources are unavailable or discouraged may be particularly vulnerable to change.

The physical infrastructure of slums increases the vulnerability of residents to climate change impacts

Disaster preparedness

Natural and human-made disasters have been on the rise worldwide since the 1950s, coinciding with the rise in world urban population (see Figure 4.2).[287] As climate change continues to occur, disasters such as landslides, floods, windstorms and extreme temperatures may occur with greater frequency and intensity. Urban vulnerability to climate change will therefore depend upon disaster preparedness, defined by the International Strategy for Disaster Reduction Secretariat as 'activities and measures taken in advance to ensure effective response to the impact of hazards, including the issuance of timely and effective early warnings and the temporary evacuation of people and property from threatened locations'.[288]

Disaster preparedness may be linked to governance

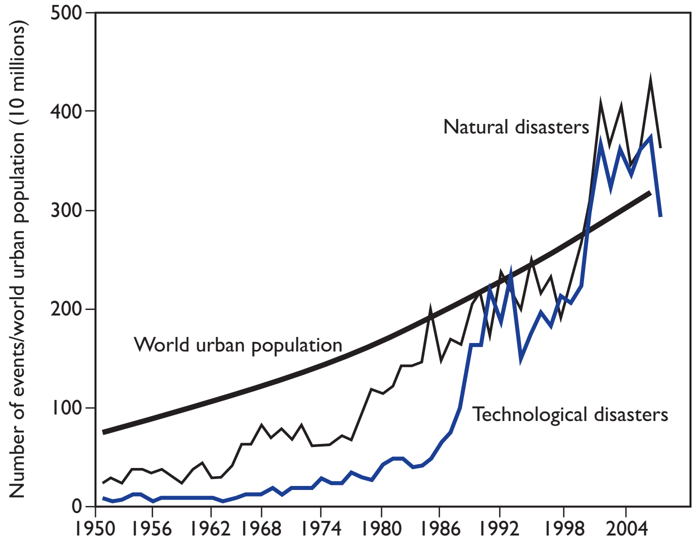

Figure 4.2

World population and recorded natural and technological disasters (e.g. industrial and transport accidents) (1950–2005)

Source: UN-Habitat, 2007, p170

and institutional capacity and the availability of information to residents; but it is not necessarily the case that poorer countries or cities will always be less prepared. For example, despite being a relatively poor country, Cuba has implemented effective disaster preparation mechanisms. On the other hand, although the US is a relatively rich country, it has sometimes proven to be ill prepared for disasters; for instance, emergency response was inadequate both before and after Hurricane Katrina struck the city of New Orleans.

CONCLUDING REMARKS AND LESSONS FOR POLICY

Climate change impacts have real implications in the urban environment, many of which will continue to exacerbate existing vulnerabilities and social issues in the future. While local climate change risks, vulnerabilities and adaptive capacity vary across cities, the global review undertaken in this chapter reveals several key common themes.

Urban vulnerability to climate change will therefore depend upon disaster preparedness

First, climate change impacts may have compounding effects across many sectors of city life. The specific nature of climate change risks is heterogeneous around the world; but these risks have compounding effects in nearly any context. For example, extremely high temperatures have direct impacts upon human health, placing individuals at risk of heat-related illness or mortality. At the same time, increasing temperatures in certain locations increase demand for energy, which can reinforce climate change by increasing greenhouse gas emissions and exacerbating the urban heat-island effect. Cities have inherent properties that can interact with climate change effects – including rapid population growth, high population density, urban heat-island impacts and the presence of poverty – such that impacts that may appear minor when considered individually may have serious effects when considered together in local context.

Second, climate change does not affect everyone within a city in the same way: gender, age, race and wealth have implications for the vulnerability of individuals and groups. Racial and ethnic minorities, indigenous peoples, poor populations and socially isolated individuals are highly vulnerable to climate change impacts. The poor are often least able to cope and adapt to climate change impacts because they have relatively few resources and tend to be located in the most hazardous areas. Indigenous peoples, minorities and women may be explicitly or tacitly removed from decision-making processes and, in some cases, have limited access to insurance, information and resources. As a result, these groups are both less prepared for physical hazards and less able to adapt. These effects tend to be particularly pronounced in cities in developing countries compared to developed countries, but are evident worldwide.

Third, planning within cities – including siting of residential areas, businesses and transportation infrastructure – often proceeds based on historic climate data, increasing the risk of various sectors to changing conditions. Because of low land prices and less resistance from residents, infrastructure (including ports, water sanitation facilities, power plants, roads and airports) tends to be constructed in vulnerable areas. These assets are long lived and will therefore be subjected to changing conditions such as sea-level rise, more variable precipitation and increased intensity of storms. Failure to adjust zoning and building codes and standards with an eye to the future may limit the prospect of infrastructure adaptation and place lives and assets at risk. Likewise, failure to consider the impacts of rising populations in city planning leads to conditions that exacerbate the vulnerability of residents to climate change, as illustrated by the case studies reviewed in this chapter. These conditions include water and other natural resource scarcity, environmental degradation and development of urban slums.

Fourth, climate change impacts can be long lasting and propagate worldwide. When disasters related to climate change occur, focus on the affected areas tends to be limited to a short period of time following the event. Yet, experience reveals that the social and economic impacts of these disasters can extend for months or years. Damage to transportation infrastructure can interfere with a city's ability to recover from extreme climate events. Lack of insurance coverage can make it very difficult for individuals to cope in the aftermath of disasters, particularly among the poor, who may not have savings or assets to use to repair damage to their homes or to purchase the necessities of recovery. Moreover, cities around the world, in particular large cities, are interconnected by capital and labour markets. Extreme climate events that result in economic losses in urban areas or interruption of trade routes can thus result in long-lasting rebounding global impacts.

Fifth, limitations on governance and planning increase the vulnerability of cities, especially in developing countries, to climate change. Poor planning resulting from scarce resources, limited information and/or political corruption limit the ability of cities to prepare for climate change as well as to recover when climate-related impacts occur. In developing countries, in particular, poor planning has encouraged the development of slums and informal settlements that are prone to damage from climate-related impacts. Slum expansion can be difficult to control because these settlements sometimes develop outside of the jurisdiction of local government. In both developed and developing countries, inadequate preparation for climate-related disasters has led to great losses of life and assets when individuals were not evacuated before a disaster or rapidly attended to afterwards.

Taken together, the themes discussed above suggest that the direct and indirect impacts of climate change will continue to threaten the very social and economic fabric of cities. International, national and local governments and institutions can benefit from the growing body of research on climate change impacts by adjusting their policy approaches with a mind to the future.

The many examples of climate change impacts reviewed in this chapter highlight the context-specific nature of impacts. Accordingly, policies ought to be designed to address local physical impacts and vulnerabilities to the greatest extent possible. This does not, however, preclude the importance of national government and international collaboration on the global challenge of climate change. In fact, security issues, migration and resource scarcity will often raise issues that cross local and national boundaries.

Likewise, policies and interventions should be developed with attention to the social and economic characteristics of resident populations in order to reduce, rather than reinforce, inequalities. Care should be taken to identify who bears the greatest burden of climate change in a given area and to develop policies with the goal of minimizing this burden. Increasing the participation of groups who have been typically marginalized – whether indigenous groups, low-income groups, women and/or racial minorities – can help to both reduce the distributional impacts of climate change and broaden the knowledge base used to tackle climate change.

The direct and indirect impacts of climate change will continue to threaten the very social and economic fabric of cities

Perhaps the most important lesson for policy-makers is that climate change should no longer be considered a solely environmental challenge, addressed in isolation from other social and economic issues. Climate change in urban areas interferes with a wide range of existing and emerging policy challenges, among them poverty eradication, water sanitation, scarcity of food and water, and population growth. When climate change is embraced as an integral part of these challenges, solutions can be designed to more adequately reflect and address its myriad impacts upon cities.

NOTES

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