Climate Change and Cities

First Assessment Report of the Urban Climate Change Research Network

Executive Summary

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Cities[1] are home to over half of the world's people and are at the forefront of the climate change issue. Climate change exerts added stress on urban areas through increased numbers of heat waves threatening the health of the elderly, the infirm, and the very young; more frequent and intense droughts and inland floods compromising water supplies; and for coastal cities, enhanced sea level rise and storm surges affecting inhabitants and essential infrastructure, property, and ecosystems. At the same time, cities are responsible for no less than 40% of global greenhouse gas emissions, and given current demographic trends, this level will likely only increase over time. These challenges highlight the need for cities to rethink how assets are deployed and people protected, how infrastructure investments are prioritized, and how climate will affect long-term growth and development plans.

Work on the *First Assessment Report on Climate Change and Cities* (ARC3) was launched by the Urban Climate Change Research Network (UCCRN) in November 2008 at a major workshop in New York City with the goal of building the scientific basis for city action on climate change. Eventually more than 100 lead and contributing authors from over 50 cities around the world contributed to the report, including experts from cities in both the developing and developed world, representing a wide range of disciplines. The book focuses on how to use climate science and socio-economic research to map a city's vulnerability to climate hazards, and how cities can enhance their adaptive and mitigative capacity to deal with climate change over different timescales.

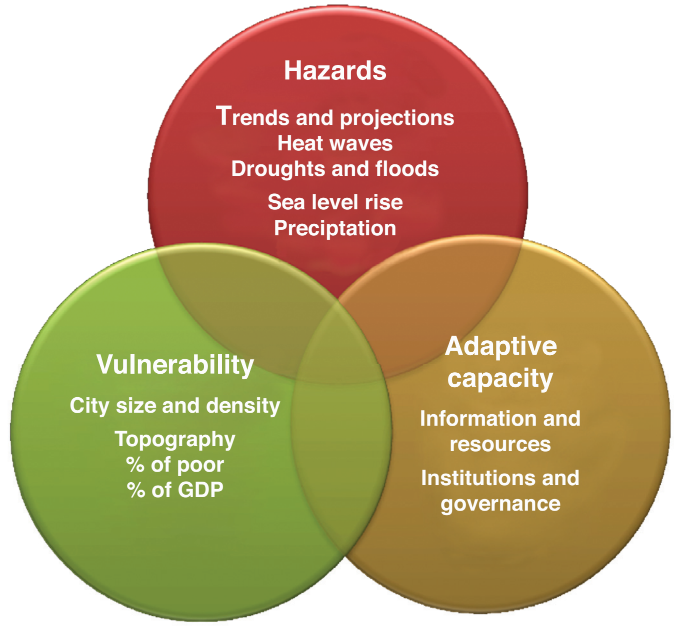

Figure 1: *Urban climate change vulnerability and risk assessment framework.*

Source: Mehrotra et al. (2009).

Key findings

Defining the risk framework

A new vulnerability and risk management paradigm is emerging as a useful framework for city decision-makers to analyze how their city should seek to adapt to the anticipated impacts of climate change. The UCCRN climate change vulnerability and risk assessment framework (Figure 1) is composed of three sets of indicators:

- *Climate hazards* facing the city, such as more frequent and longer duration heat waves, greater incidence of heavy downpours, and increased and expanded coastal or riverine flooding;
- *Vulnerabilities* due to a city's social, economic, or physical attributes such as its population size and density, topography, the percentage of its population in poverty, and the percentage of national GDP that it generates;
- *Adaptive capacity aspects*, factors that relate to the ability of a city to act, such as availability of climate change information, resources to apply to mitigation and adaptation efforts, and the presence of effective institutions, governance, and change agents.

In most cities, readily available data exist about climate hazards (trends and projections), population and geographic features, and institutional capacity that can serve as a foundation for adaptation planning efforts. In other cities that are still in the early stages of efforts to assess local vulnerabilities and climate risks, work can nonetheless begin by using generalized climate risks and information from similar urban areas as a starting point for local climate planning efforts.

For example, in Sorsogon City in the Philippines, the city government developed its local vulnerability assumptions using climate change projections and risk assessments from national government agencies and private research institutions.

Urban climate: processes, trends, and projections

Cities already face special climatic conditions that must be accounted for when preparing long-term climate change adaptation plans. These include:

- *Urban heat island.* Cities already tend to be hotter than surrounding suburban and rural areas due to the absorption of heat by concrete and other building materials and the removal of vegetation and loss of permeable surfaces, both of which provide evaporative cooling.
- *Air pollution.* The concentration of residential, commercial, industrial, electricity-generating, and transportation activities (including automobiles, railroads, etc.) contributes to air pollution, leading to acute and chronic health hazards for urban residents.
- *Climate extremes.* Major variability systems such as the El Niño-Southern Oscillation, the North Atlantic Oscillation, and

1 Cities are defined here in the broad sense to be urban areas, including metropolitan and suburban regions.

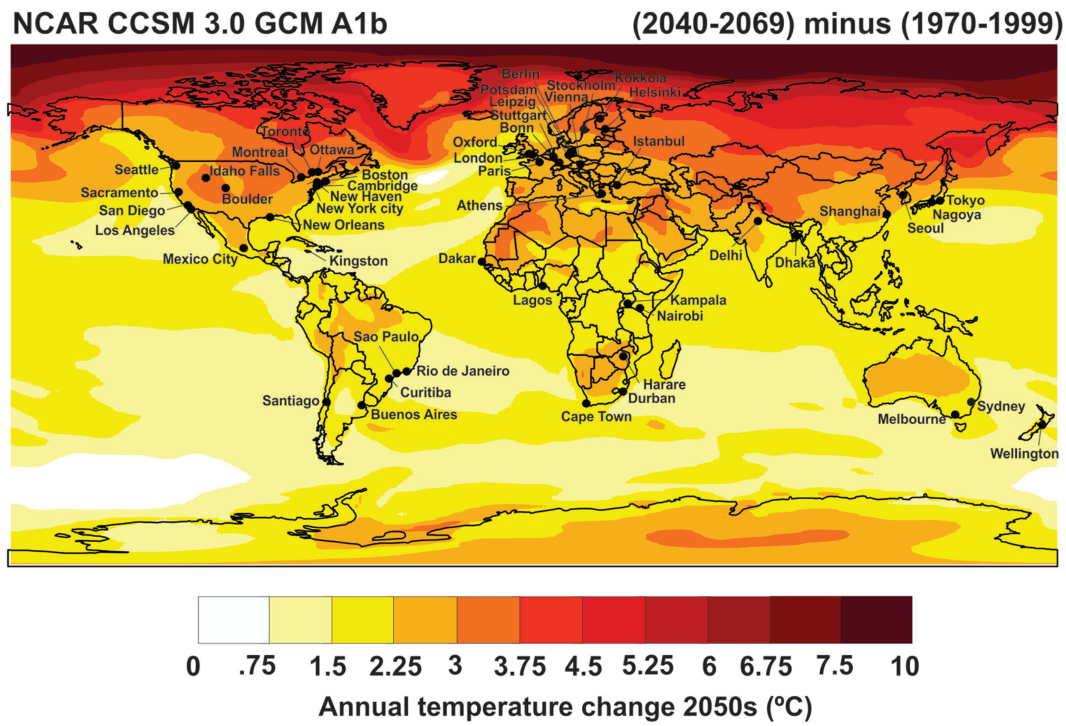

Figure 2: *Cities represented in ARC3 and 2050s temperature projections for the NCAR CCSM 3.0 GCM with greenhouse gas emissions scenario A1b.*

Source: NCAR CCSM 3.0 – Collins et al. (2006); Emissions Scenario A1b – Nakicenovic et al. (2000).

oceanic cyclonic storms (e.g., hurricanes and typhoons) affect climate extremes in cities. How these systems will interact with anthropogenic climate change is uncertain, but awareness of their effects can help urban areas to improve climate resilience.

Existing city-specific climate data and downscaled projections from global climate models can provide the scientific foundation for planning efforts by city decision-makers and other stakeholder groups (Figure 2). In twelve cities analyzed in depth in this report (Athens, Dakar, Delhi, Harare, Kingston, London, Melbourne, New York, São Paulo, Shanghai, Tokyo, and Toronto), average temperatures are projected to increase by between 1 °C and 4 °C by the 2050s. Most cities can expect more frequent, longer, and hotter heat waves than they have experienced in the past. Additionally, variations in precipitation are projected to cause more floods as the intensity of rainfall is expected to increase. In many cities, droughts are expected to become more frequent, more severe, and of longer duration.

Coastal cities should expect to experience more frequent and more damaging flooding related to storm events in the future due to sea level rise. In Buenos Aires, for example, damage to real estate from flooding is projected to total US$80 million per year by 2030, and US$300 million per year by 2050. This figure does not account for lost productivity by those displaced or injured by the flooding, meaning total economic losses could be significantly higher.

Sector-specific impacts, adaptation, and mitigation

Climate change is expected to have significant impacts on four sectors in most cities – the local energy system; water supply, demand, and wastewater treatment; transportation; and public health. It is critical that policymakers focus their attention on understanding the nature and scale of the impacts on each sector, developing adaptation and mitigation strategies, and determining policy alternatives.

Climate change and urban energy systems

Cities around the world have prioritized efforts to reduce energy consumption and the associated carbon emissions. This has been done both for localized efficiency reasons – to reduce the effects of high energy costs on household budgets, for example – as well as to respond to concerns that activities in cities are responsible for a large share of global greenhouse gas emissions. Emphasis is now being placed on urban energy system adaptation, as well, because climate change impacts such as the loss of key supply sources or transmission and distribution assets can jeopardize public health and the economic vitality of a city. For example, in New York City, power plants were historically sited on the waterfront to facilitate fuel supply delivery and to provide access to cooling waters. The majority of these facilities are at an elevation of less than 5m, making them susceptible to increased coastal flooding due to sea level rise (Figure 3).

Increases in the incidence or duration of summertime heat waves may result in higher rates of power system breakdown or failure, particularly if sustained high demand – driven by high rates of air conditioning use – stresses transmission and distribution assets beyond their rated design capacity. In Chinese cities, the number of households with air conditioners has increased dramatically in the past 15 years (Figure 4), although the extent to which usage is nearing a point where system vulnerabilities are heightened is still unclear. In cities heavily reliant on hydropower, changing precipitation patterns resulting from climate change may be problematic, if availability is reduced during summertime periods when demand is greatest.

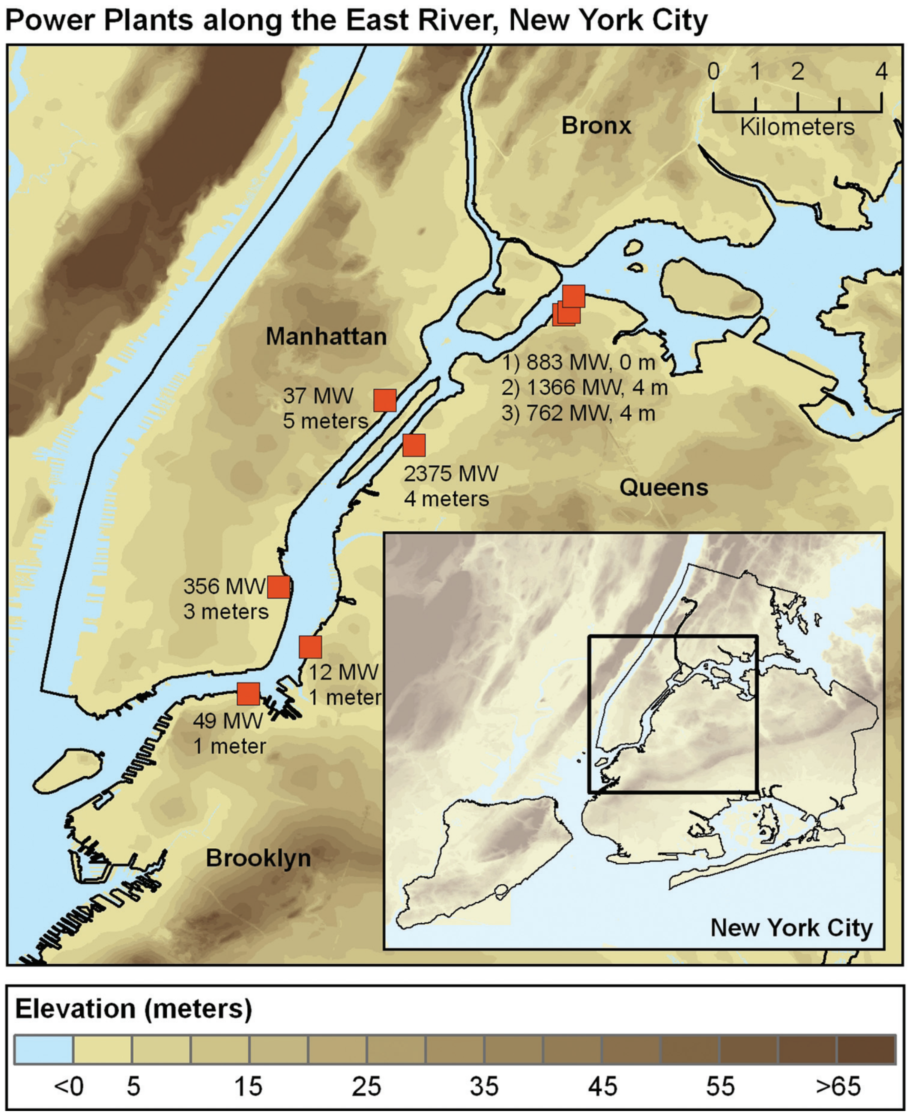

Figure 3: *Location and elevation of power plants along the East River in New York City.*

Source: Power plant data for 2000 from eGRID (US EPA, 2002) to reflect with recently retired plants deleted. New York City digital elevation model is from the USGS (1999), which has a vertical error of approximately +/–4 feet.

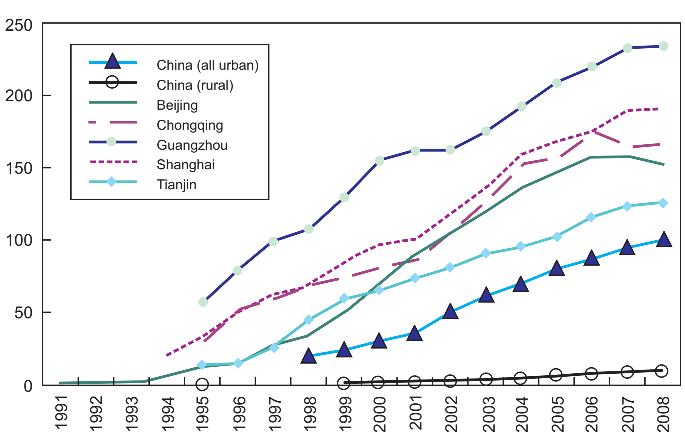

Figure 4: *Number of air conditioners per 100 households in selected Chinese cities.*

Source: CEIC (2010).

For any given city, local analyses are necessary to determine the overall impact of climate change on energy demand, as it may increase *or* decrease depending on which of the seasonal effects of climate change (i.e., reduction in energy demand in cooler seasons and increased demand in warmer seasons) are most significant.

Cities can take robust steps to reduce their energy demand and thus their carbon emissions, and it is increasingly clear that many of these steps also provide significant adaptation benefits. These steps include:

- Develop demand management programs to cut peak load, reducing carbon emission levels and simultaneously lessening stress on the system during times of heightened vulnerability.

- Capitalize on the natural replacement cycle to update power plants and energy networks to reduce their carbon intensity and simultaneously increase their resilience to flooding, storm, and temperature-related risks.

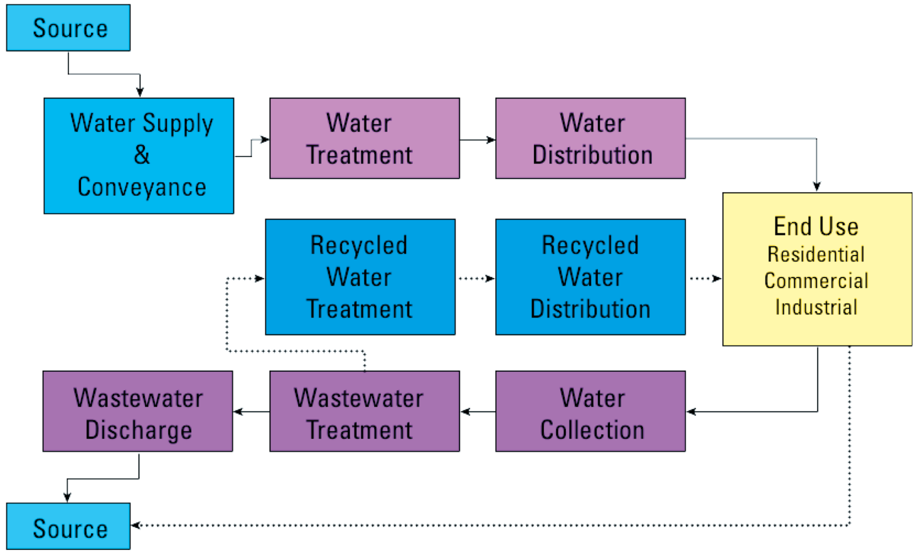

Figure 5: *Typical water-use cycle for cities and other developed supplies; dotted arrows indicate pathways that sometimes occur.*

Source: Modified from Klein et al. (2005).

- Diversify local power supply sources to increase the share of renewables, thereby enhancing system resiliency and reducing carbon emissions.

Climate change, water, and wastewater in cities

Urban water systems include water supply sources, conveyance, distribution, reuse, treatment, and disposal elements, all of which may be vulnerable to a changing climate (Figure 5).

Within cities, impervious surfaces and increased precipitation intensity can overwhelm current drainage systems. In Mexico City, the city's 27 treatment facilities currently handle only a fraction of the total sewage generated citywide, and as the local population increases, the ability of the system to accommodate runoff has become compromised, raising the risk of flooding around the city.

In many cities, the quantity and quality of the water supply will be significantly affected by the projected increases in both flooding and droughts, amplifying the need for cities to focus on upgrading their supply networks to maximize the availability of existing supplies. For example, in developed country cities, leakage from the supply distribution system can be severe, resulting in system losses of between approximately 5% and more than 30%. In developing country cities, the supply problem is often different, as significant numbers of people rely on informal water supply systems. In Lagos, for instance, 60% of the population uses informal distribution systems (Figure 6), which are far more vulnerable to drought-induced stoppages.

A range of adaptation measures will be required to ensure water supplies of adequate quantity and quality, especially in coastal regions where water sources and infrastructure are subject to the impacts of rising sea level, higher storm surge, salt-water intrusion, and land subsidence. Cities are pursuing a range of strategies to address these water and wastewater challenges, including:

- Reduce non-revenue water, which constitutes a significant fraction of supply in many urban areas, through leak detection and repair and reduction in unauthorized withdrawals;

- Review and modify surface water and groundwater sources, storage facilities, and intakes where appropriate to make supplies less vulnerable to climate-induced risks such as floods and droughts;

- Implement innovative local supply augmentations where feasible through techniques such as rainwater harvesting and water reuse, as well as through improved water accounting from better observation networks and holistic modeling;

- Practice demand management through appropriate pricing (including social, environmental and economic objectives), public education on water use and conservation, improved toilet and shower codes, updated drought management plans, and targeted land-use strategies; and

- Encourage the use of water-efficient processes in domestic, industrial, and agricultural uses.

Figure 6: *Informal urban water supply: a water vendor's cart in Lagos.*

Photo by Ademola Omojola.

Climate change and urban transportation systems

Globally, according to the IPCC 2007 report, the transport sector accounted for 23% of the world's greenhouse gas emissions related to energy in 2004, although in some cities, the percentage is much higher, a reflection of local land use and mobility patterns. Cities are adopting a range of strategies to reduce transport-related emissions, including promoting transit-oriented development, reclaiming roadways to provide more space for bicycles and pedestrian walkways, and increasing the amount of mass transit systems available around the city.

Regulatory and pricing instruments are also increasingly being deployed to reduce the volume, timing, or location of private vehicle use, often with significant impact. In London, a congestion pricing program resulted in a 12% decrease in traffic levels in the congestion pricing zone, while in Stockholm, there was a 22% reduction in vehicle passages in the congestion zone. Beijing, Bogota, and Mexico City have all pursued limits on the number of days vehicles can be driven, but this approach may penalize households in locations where public transportation is inadequate. Other cities have focused on promoting more efficient fuels and technology as a means of reducing transport-related carbon emissions. In Delhi, for instance, all public transport buses were converted to compressed natural gas (CNG)-operated systems, in response to public action and right-to-clean-air campaigns that brought the issue to the attention of the Supreme Court of India. The Court subsequently issued a series of judgments regulating public transport and air quality. A key lesson from this experience is that leadership for change in cities can arise from diverse stakeholders – be it citizen groups, the private sector, or the judiciary – as well as from city government itself (Figure. 7).

Some of these mitigation strategies will bring climate change adaptation co-benefits, such as new energy-efficient fuel technologies that provide better temperature control for passengers, but others are being undertaken specifically to maintain the integrity of essential transportation infrastructure assets under changing climate conditions, such as improved engineering and management. Maputo is one of four cities benefiting from a UN HABITAT-supported initiative focused on climate planning, with a specific goal of identifying the hard approaches (sea walls, engineered levees, pump stations) and soft, ecosystem-based approaches (wetlands, parks, and planted levees) designed to protect local transportation system assets from coastal flooding. Mitigation and adaptation strategies for city transportation systems include:

- Integrate land use and transportation planning to increase the density of the urbanized portion of developed land, plan for mixed-use development, and enhance the proximity of travelers to transit and/or to their destinations to reduce vehicle miles of travel;

Figure 7: *Compressed natural gas public bus, Delhi. Photo by Shagun Mehrotra.*

- Construct transport systems with materials that are more resilient to higher temperatures and the potentially corrosive effects of increased exposure to sea water due to sea level rise and coastal flooding;

- Consider the appropriateness of rezoning as an adaptation solution, retreating from the shoreline, and building new transportation facilities farther inland on higher ground;

- Protect transport systems from increased precipitation and flash flooding through the use of larger culverts and catch basins, and replacement of impermeable road surfaces with permeable material and impermeable roof surfaces with green roofs; and

- Introduce operational measures, including traffic closures during extreme weather events; moving rolling stock to flood-protected and/or wind-protected locations; closing traffic on tall bridges during high winds; and using media to indicate hazardous road conditions and safer alternate transportation routes and modes.

Climate change and human health in cities

Cities are subject to unique health risks since larger populations and higher population density amplify the potential for negative outcomes. Climate change is likely to exacerbate existing health risks in cities and to create new ones. Specific impacts include:

- Direct physical injuries and deaths from extreme weather events such as tropical cyclones, storm surges, intense rainfall that leads to flooding, or ice storms that damage trees and overhead structures and produce dangerous transport conditions;

- Illnesses resulting from the aftermath of extreme weather events that destroy housing, disrupt access to clean water and food, and increase exposure to biological and chemical contaminants;

- Water-borne diseases following extended or intense periods of rainfall, ground saturation and floods, and saline intrusion due to sea level rise; all of which compound existing deficiencies in local water services (Figure 8);

- Food-borne diseases resulting from bacterial growth in foods exposed to higher temperatures;

- Illnesses and deaths from an expanded range of vector-borne infectious diseases;

- Respiratory illnesses due to worsening air quality related to changes in temperature;

- Morbidity and mortality, especially among the elderly, small children, and people whose health is already compromised, as a result of stress from hotter and longer heat waves.

City health agencies can contribute to improvement of knowledge of the health effects of climate change on urban populations and work together with other responsible agencies to reduce the vulnerability of city dwellers to climate variability. Adaptation strategies, many linked to other sectors, land use planning, and governance, include:

Figure 8: *Potential health hazards in Kibera related to sanitation and water systems. Photo by Shagun Mehrotra.*

- Expand health surveillance and early warning systems utilizing both technology and social networks, especially for the elderly, very young, and the poor;

- Reduce the size of the urban heat island effect through passive approaches such as tree planting, green and reflective roofs, and permeable pavements, thereby minimizing heat stress on all citizens.

- Emphasize water and energy system climate resilience strategies, because of the key role they play in protecting the public during and after extreme weather events; and

- Regulate settlement in flood plains to minimize exposure to coastal storms and inland flooding.

Cross-cutting issues

A city's land use and governance practices are integrally bound up in the climate change issue. Past zoning and land use decisions are key factors because they create the essential circumstances from which climate-related vulnerabilities may arise. Local powers and the larger governance environment will influence what can actually be done, and at what pace. Progress in addressing climate change requires strategic management, science-based policies, efficient financing, jurisdictional coordination, and citizen participation.

The role of urban land in climate change

The built environment or structural aspects of cities, streets, buildings, and infrastructure systems contribute significantly to the emission of greenhouse gases, and can also amplify climate change impacts. The structure, orientation, and conditions of buildings and streetscapes can increase the need for cooling and heating buildings, which are associated with the level of energy use and greenhouse gas emissions in a city. Swaths of impervious surfaces can intensify flooding and are direct determinants of the heat island effect. The presence or lack of street trees and parks, and the extent of wastewater and drainage systems can either impede or enhance the natural processes of evapotranspiration, in addition to amplifying flooding and drought effects.

A city's natural setting, its urban form and built environments are relatively static factors, but they are subject to future modification through urban planning and management. For example, Shanghai has sought to increase the level of vegetation around the urban core to mitigate the urban heat island; since 1990, urban greenery per capita has increased from 1.0 m^2 to 12.5 m^2, resulting in decreasing temperatures. In Tokyo, the municipal government has similarly expanded its expenditures on tree planting, park development, and the use of paved surfaces that block heat and absorb moisture.

Stockholm is engaged in a long-term planning initiative to both mitigate and adapt to climate change. The Stockholm Royal Seaport is a new development district with strict environmental requirements on buildings. All buildings will be placed 2.5 m above the average sea level; building materials will be required to resist high humidity; and other requirements call for greenery on roofs, walls, and yards.

These examples represent a starting point for initiatives that local authorities can use to respond to climate change. These initiatives can be pursued through legal and political systems, planning departments, zoning regulations, infrastructure and urban services, real estate markets, and fiscal arrangements. Other specific adaptation and mitigation initiatives related to urban land use include:

- Reduce sprawl by increasing population and building densities, mixing land uses to reduce automobile traffic, and more frequent use of public transit;

- Change building codes to reduce energy use for heating and cooling;

- Restrict land use in areas subject to climate change impacts such as sea level rise and riverine flooding;

- Change building codes and land regulations to reduce damage from climate change hazards, e.g., elevating buildings in flood-prone areas;

- Increase urban tree coverage and vegetation to reduce the heat island effect;

Cities and climate change: The challenges for governance

Local governments face many challenges in their efforts to mitigate and adapt to climate change. For any city, climate is but one of many issues on the local agenda. Governments are also faced with the trade-offs between current priorities and long-term risks, a situation compounded by the uncertainties that may surround the timing and severity of climate-related impacts in a city.

Most cities undertaking climate plans find themselves constrained by fiscal and policymaking limitations. Jurisdictional conflicts over who can or must take action on a specific mitigation or adaptation initiative can make progress challenging. For example, in Mexico City, administrative boundaries do not align with the city's geographic boundaries and carbon-relevant functioning. Similar issues exist in Paris, where the *Plan Climat de Paris* is focused on the 105 km^2 area under the direct control of the *Mairie de Paris*, a fraction of the Paris metropolitan region which totals 700 km^2 and is under the jurisdiction of three other *départements*. In Durban, local officials are seeking to ensure that climate change does not get pigeonholed as simply an environmental issue, but instead is more appropriately seen as a development-related challenge.

Despite these difficulties, cities around the world are committing to action on climate change, entering into dialogues with state, provincial, and national governments to discuss their climate policy agendas. Cities are also increasingly focused on data gathering, both to improve internal management practices and to allow for comparison with other cities around the world.

In examining how cities are delivering effective action on climate change adaptation and mitigation, four key factors emerge:

- *Effective leadership* is critical for overcoming fragmentation across neighborhoods and sectors when building consensus on the climate change agenda in cities;

- *Efficient financing* is a core requirement for empowered governance in cities; success to date with efforts to confront climate change challenges has been hampered due to deficient financing;

- *Jurisdictional coordination* across city, state, and national governments is one of the most pressing challenges common to cities worldwide; and,

- *Citizen participation* can help in development of inclusive local government decision-making on climate change.

Cities act

Cities around the world are highly vulnerable to climate change, but have great potential to lead on both adaptation and mitigation efforts. Despite the economic and political constraints that many cities face, they are serving as important laboratories for climate change action.

These efforts have produced much helpful climate risk and response information. In order to effectively address the challenges presented by climate change, cities need to incorporate climate science, adaptation strategies, and mitigation actions into daily decision-making and long-term plans and investments. Many cities in both developing and developed country cities are also centers for research and house extensive research communities that are able and willing to help develop plans for assessing and acting on climate change.

Many cities are developing both near- and long-term climate action plans–but many more need to bring climate adaptation and mitigation into their everyday operations as well as their longer-term planning process. The *First Assessment Report on Climate Change and Cities* (ARC3) of the Urban Climate Change Research Network (UCCRN) provides knowledge to urban policy-makers for science-based city climate actions through an on-going information collection, review, and sharing process.

About the *First Assessment Report on Climate Change and Cities* (ARC3)

The First Assessment Report on Climate Change and Cities (ARC3) presents a comprehensive assessment of the most significant issues for cities as they face the climate change challenge. It was launched by the Urban Climate Change Research Network (UCCRN) in November 2008, with the goal of providing the scientific basis for city action in the mitigation of and adaptation to climate change. The ARC3 seeks to synthesize our current state of knowledge about how cities will be affected by climate change and the steps being taken to address climate change at the local level. It is specifically intended both to identify and to fill data gaps in the existing climate change literature, the majority of which has been compiled to analyze the information at a global, national, or regional scale.

To ensure that the information provided would be of use to urban decision-makers, UCCRN first conducted a needs assessment via a survey of city leaders in both developed and developing countries around the world. The content and structure of ARC3 reflects feedback received from respondents to this survey.

The report encompasses nine chapters which are divided into four sections: **Introduction** (Urban climate change in context), **Defining the risk framework** (Cities, disasters, and climate risk; and Urban climate: processes, trends, and projections), **Urban sectors** (Climate change and urban energy systems; Climate change, water, and wastewater in cities; Climate change and urban transportation systems; and Climate change and human health in cities), and **Cross-cutting issues** (The role of urban land in climate change; and Cities and climate change: The challenges for governance). The report represents the work of more than 100 lead and contributing authors from over 50 cities around the world. ARC3 authors are experts in climate change adaptation and mitigation, and include physical scientists, geographers, planners, engineers, social scientists, and policy experts. Each chapter of ARC3 has gone through a multi-stage expert review process.

Contact: www.uccrn.org

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