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Framework for City Climate Risk Assessment

Buenos Aires, Delhi, Lagos, and New York

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**World Bank
Commissioned Research**

Fifth Urban Research Symposium
Cities and Climate Change:
Responding to an Urgent Agenda

Marseille, France
June 2009

FRAMEWORK FOR CITY CLIMATE RISK ASSESSMENT

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Abstract

Estimation of spatially and temporally disaggregated climate risks is a critical prerequisite for the assessment of effective and efficient adaptation and mitigation climate change strategies and policies in complex urban areas. This interdisciplinary research reviews current literature and practices, identifies knowledge gaps, and defines future research directions for creating a risk-based climate change adaptation framework for climate and cities programs. The focus is on cities in developing and emerging economies. The framework unpacks risk into three vectors—hazards, vulnerabilities, and adaptive capacity. These vectors consist of a combination of physical science, geographical, and socioeconomic elements that can be used by municipal governments to create and carry out climate change action plans. Some of

¹ During the initial research phase, the author was based at the Office of the Minister of Railways, Government of India, New Delhi.

these elements include climate indicators, global climate change scenarios, downscaled regional scenarios, change anticipated in extreme events, qualitative assessment of high-impact and low-probability events, associated vulnerabilities, and the ability and willingness to respond. The gap between existing responses and the flexible mitigation and adaptation pathways needed is also explored. To enhance robustness, the framework components have been developed and tested in several case study cities: Buenos Aires, Delhi, Lagos, and New York. The focus is on articulating differential impacts on poor and non-poor urban residents as well as sectorally disaggregating implications for infrastructure and social well-being, including health. Finally, some practical lessons are drawn for successful policies and programs at the city level that aim to reduce systemic climate risks especially for the most vulnerable population. Additionally, a programmatic response is articulated with a four-track approach to risk assessment and crafting of adaptation mechanisms that leverages existing and planned investments in cities so that city governments can respond to climate change effectively, yet efficiently.

Key Words:

Urban, Climate Change, Risk Assessment, Buenos Aires, Delhi, Lagos, New York

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Abstract

Estimation of spatially and temporally disaggregated climate risks is a critical prerequisite for the assessment of effective and efficient adaptation and mitigation climate change strategies and policies in complex urban areas. This interdisciplinary research reviews current literature and practices, identifies knowledge gaps, and defines future

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research directions for creating a risk-based climate change adaptation framework for climate and cities programs. The focus is on cities in developing and emerging economies. The framework unpacks risk into three vectors—hazards, vulnerabilities, and adaptive capacity. These vectors consist of a combination of physical science, geographical, and socioeconomic elements that can be used by municipal governments to create and carry out climate change action plans. Some of these elements include climate indicators, global climate change scenarios, downscaled regional scenarios, change anticipated in extreme events, qualitative assessment of high-impact and low-probability events, associated vulnerabilities, and the ability and willingness to respond. The gap between existing responses and the flexible mitigation and adaptation pathways needed is also explored. To enhance robustness, the framework components have been developed and tested in several case study cities: Buenos Aires, Delhi, Lagos, and New York. The focus is on articulating differential impacts on poor and non-poor urban residents as well as sectorally disaggregating implications for infrastructure and social well-being, including health. Finally, some practical lessons are drawn for successful policies and programs at the city level that aim to reduce systemic climate risks especially for the most vulnerable population. Additionally, a programmatic response is articulated with a four-track approach to risk assessment and crafting of adaptation mechanisms that leverages existing and planned investments in cities so that city governments can respond to climate change effectively, yet efficiently.

1.0 INTRODUCTION

Local governments are beginning to put a greater focus on adapting their cities to the inevitable effects of climate change. This is a result of the lag between when reductions in greenhouse gas emissions will occur and the time it takes for those effects to be felt in the climate system. In its 2007 Fourth Assessment Report (AR4), the Intergovernmental Panel on Climate Change (IPCC, 2007a) concluded that there is a greater than 90 percent chance that the average global temperature increase over the last century is primarily caused by human activity. According to the IPCC (2007a), the main cause of this temperature increase has been increasing levels of greenhouse gases in the atmosphere associated with the burning of fossil-fuels, changes in land-use, and other human activities. Levels of the greenhouse gases—carbon dioxide (CO₂), methane (CH₄), ozone (O₃), and nitrous oxide (N₂O)—have all increased in atmospheric concentration with CO₂ levels almost one-third higher than at the onset of the Industrial Revolution. Measures to mitigate climate change through the reduction of greenhouse gas emissions have been in large part due to the United Nations Framework Convention on Climate Change (UNFCCC), which has led to the ratification of the Kyoto Protocol and its associated three market mechanisms—Emissions Trading, the Clean Development Mechanism, and Joint Implementation. A post-Kyoto policy framework is anticipated at the 15th Conference of the Parties to be held in Copenhagen, Denmark in December 2009. In addition to IPCC assessments (2007a, 2007b, 2007c), for further details of various sources of greenhouse gas emission data disaggregated by various sectors and its implications on ‘international climate policy’ see studies by the World Resource Institute (Baumert et al., 2005; Bradley et al., 2007).

However in the context of cities, several climate-induced challenges remain neglected. In urban areas, inequities will become more apparent as certain populations

are less able to relocate away from highly-vulnerable locations, especially due to sea-level rise and enhanced flooding in cities by the coasts, leading to changes in the spatial distribution and density of both formal and informal settlements. Degradation of building and infrastructure materials is also projected to occur. As warmer temperatures extend into higher latitudes, diseases that have long been considered eradicated may re-emerge; new diseases may also be experienced. The health ramifications that this could have in cities, especially densely-populated informal settlements, could be serious. The gap between water supply and demand is projected to increase as drought-affected areas expand and floods intensify. While precipitation is expected to increase in some areas, water availability is projected to eventually decrease in many regions, including those areas where water is supplied by meltwater from mountain snow and glaciers.

Overall, climate change and increased climate variability will alter the environmental baselines of urban locales, such as the temperature regimes and precipitation patterns. Shifts in climate and increased frequency of extreme events have direct impacts on water availability and quality, flooding and drought periodicity, and water demand amongst a host of conditions. These dynamic changes will affect system processes within multiple sectors in cities interactively, increasing the uncertainty under which urban managers and decision-makers must operate.

In response, this paper focuses on developing a framework for urban risk assessment, thus laying emphasis on how cities are affected by climate change as opposed to the impact of cities on climate change through greenhouse gas emissions. Thus, this paper focuses on adaptation aspects of climate change and not mitigation, particularly because adaptation has been neglected until recently both in developed and developing-country cities alike (IPCC, 2007a). Further, adaptation remains a critical concern in most developing country cities where *per capita* emissions are already at relatively low levels⁸. The purpose of this paper is to fill this critical gap by crafting a risk assessment framework for cities that synthesizes existing local information, testing the framework on four geographically-diverse large cities, and identifying a programmatic response to the development of climate change risk assessment and adaptation planning pathways, which are effective, efficient, and necessary responses to climate change at the city-level.

Understanding how cities craft institutional mechanisms to respond is an important complement to this risk assessment framework. This has been briefly explored where relevant, for detailed case studies on Quito and Durban (see Carmin & Roberts, 2009) and the eight-stage Risk, Uncertainty and Decision-Making Framework

⁸ Large cities in seventeen major economies account for most GHG emissions: Australia, Brazil, Canada, China, the European Union, France, Germany, India, Indonesia, Italy, Japan, Korea, Mexico, Russia, South Africa, the United Kingdom, and the United States.

developed by UK Climate Impacts Programme (2009), which aims ‘to help decision-makers identify and manage their climate risks in the face of uncertainty.’

For the purposes of policy-makers, this framework looks at the projected impacts of climate change through the end of the twenty-first century. Climate projections for the twenty-second century have even larger uncertainties and lie beyond the likely planning horizons for most urban development and thus are not addressed here. Despite the uneven availability of data for developing-country cities, research done for this paper suggests that time-series of observed climate parameters are readily available for hundreds of cities and that gaps in data do not limit use of climate models for projections. Further, we find that relatively straightforward downscaling of global climate model simulations provides ample information for assessing urban-scale vulnerability and risks, at least in initial stages. Finally, data on city characteristics through the global urban observatory of UN-Habitat are also available. By complementing these metrics with city-specific analysis by local experts and existing studies, we find that it is feasible to conduct substantive climate change vulnerability and risk assessments for cities around the world, as demonstrated in this paper.

2.0 LITERATURE REVIEW

This review articulates the implications of climate risks as they pertain to cities with a focus on differential impacts on the poor and the non-poor as well as on a range of urban sectors—transport, water and sanitation, energy, and health. Highlights from the relevant climate change studies are discussed in the section on case studies. The emphasis is on the enhanced vulnerability of the poor in most future scenarios, and the lack of capacity to mitigate and adapt to short and long-term climate risks is articulated. From the literature review, we identify useful attributes of a climate risk framework, some of which are addressed in the research.

At the global-level, the IPCC Working Group I identified four major aspects of climate change relevant to cities in its synthesis report (IPCC, 2007a). First, heat waves are very likely to increase in frequency over most land areas. Second, heavy precipitation events are very likely to increase in frequency over most areas; available data suggest that a significant current increase in heavy rainfall events is already occurring in many regions. The resulting risk poses challenges to urban society, physical infrastructure, and water quantity and quality. Third, the area affected by drought is likely to increase. There is high confidence that many semi-arid areas will suffer a decrease in water resources due to climate change. Drought-affected areas are projected to increase in extent, with the potential for adverse impacts on multiple sectors, including food production, water supply, energy supply and health. Fourth, it is likely that intense tropical cyclone activity will increase. It is also likely that there will be increased incidence of extreme high sea level (excluding tsunamis).

Further, the IPCC (2007b) Working Group II lays emphasis on conceptual issues regarding urban climate change with a focus on economic and social sectors in Chapter 7 on Industry, Settlements, and Society. The review identifies four key findings with *very high* or *high* confidence. First, climate-change effects can amplify the risks that cities face from non-climate stresses. These non-climate stresses include large slum populations that live in low-quality housing lacking access to basic social services, city-wide lack of access to effective and efficient physical infrastructure, often-poor quality of urban air, water, and waste disposal systems, lack of land-use planning and other urban governance systems among others. Further, the climate-change associated risks for cities stem primarily from extreme events—implying that cities need to assess risk for droughts, floods, storms, and heat waves, in order to plan and implement adaptation strategies. However, gradual changes such as rise in mean temperature do affect cities in at least two significant ways: by increasing the frequency and intensity of extreme events and burdening the existing infrastructure.

Second, vulnerability of a city depends on ‘geographic, sectoral, and social’ attributes. For instance, the risk to a city’s infrastructure, firms, and households is greater in coastal and other flood-prone areas or in economic sectors that are vulnerable to climate variability, like tourism. Likewise, in developing countries, an increasing proportion of the urban population and local economies are at risk as cities are rapidly growing on susceptible land. Poor households in cities are particularly vulnerable because they tend to occupy ‘high-risk areas’ (such as riverbeds, and flood plains), their communities lack resources to adapt, and they rely extensively ‘on local climate-sensitive resources such as water and food supplies.’

Third, disaster management—prevention, preparedness, and response—are intrinsically related to climate change management because in cities where climate-induced extreme events become more frequent and intense, the costs can range from a small fraction of the regional economy in large regions with big economies to as much as a quarter in small regions with small economies. Further, through organic linkages, the impacts from climate change can spread across urban regions and sectors, posing systemic risks.

Fourth, cities have a certain degree of resilience to climate change and embody adaptive capacities, although within limits. And while adaptation responses for cities are locally grounded, regional, national, and global linkages can enhance adaptive capacities through resource transfers and knowledge exchange.

The impacts of climate change will vary across cities as well as among households and sectors within cities. In this regard, scholars and practitioners concerned with urban development argue for the need to focus on the poor as they are more vulnerable due to their lack of access to infrastructure and their relative inability to hedge against risks. UN-Habitat (2008a, 2008b), the United Nations’ agency for human settlements as well as the International Institute for Environment and

Development (Satterthwaite et al., 2007), among others, have articulated the need to focus attention on developing country cities due to several interrelated factors. Half the world's population is urban, and cities, which are the engines of economic growth, are extremely vulnerable to climate change. This is particularly so in developing countries as most coastal mega-cities are located there and are home to rapidly growing population centers of the world (UN-Habitat, 2008a). The challenge posed by climate change for African cities is particularly alarming (UN-Habitat, 2008b).

Developing country cities face more risks of economic and social catastrophes due to their relative lack of resources to adapt and mitigate. These cities also offer opportunities to address the needs of some of the most vulnerable urban populations of the world—essentially about a billion slum dwellers, a section of the urban population that is projected to grow to two billion by 2020. As poverty has often been primarily associated with rural areas, this population has received relatively lesser attention. However, there is increasingly recognition of the 'urbanization of poverty' (UN-Habitat, 2003).

There is a critical need for sectorally-tailored analysis of climate hazards, sector-specific vulnerabilities, and location-specific adaptive capacities, as has been highlighted in the most recent IPCC Working Group III AR4 (2007c), which focuses on sectorally-disaggregated mitigation strategies, and the World Resource Institute (Baumert et al., 2005; Bradley et al., 2007). OECD, in a literature review on climate impacts on cities also identifies such gaps, concluding, for example, that most analysis on climate impact assessments and cities has neglected non-coastal cities and that uncertainties in assessing the economic impacts need to be incorporated, particularly for developing-country cities where variances are likely to be higher (Hunt & Watkiss, 2007, and Hallegatte, et al., 2008). Further, there is a need for city-specific efforts to graduate from awareness-raising to impact assessments—including costing impacts and identifying co-benefits-and-costs—and adaptation analysis so that 'no-regret adaptation options' can be adopted to increase resilience of cities to climate change. Economic costs of climate change in cities need to 'bracket' for uncertainty and assess both intra-and-inter sectoral and systemic risks to address direct and indirect economic impacts.

Risk frameworks tend to fall broadly into three categories or groups. The first group of risk frameworks stems from the work of climate scientists associated with the IPCC and focuses primarily on climate hazards—variances in mean and extreme climate parameters, collectively referred to as climate hazards. The second group emerges from the work of planners and policy-makers, such as those associated with UN-Habitat's *The Cities in Climate Change Initiative* (CCCI) or the World Bank, East Asia Unit's recent analysis summarized in the *Climate Resilient Cities: A Primer on Reducing Vulnerabilities to Disasters*, focus on vulnerabilities—essentially city characteristics that determine the susceptibility a city has to climate change. The third group of risk frameworks focuses on economic analysis of climate impacts, such as the OECD reports

(Hunt & Watkiss, 2007 and Hallegatte et al., 2008) or the Stern Review on the Economics of Climate Change (Stern, 2007). These cost-accounting exercises define risk as the cost of catastrophe weighted by the probability of extreme events.

In sum, the literature points to the pressing need for understanding risks associated with climate change as they pertain to different types of cities—coastal versus non-coastal and developed versus developing; different sectors—physical infrastructure such as energy, transport, water supply, as well as social services such as health and environmental management (and the complex interactions among these sectors); and differential impacts on the poor or the young and old, who are more vulnerable than the rest of the urban population. The goal of this paper is to develop and test a climate change risk framework that captures the complexities resulting from the interactions of these factors, thus filling a critical gap in research as well as practice.

3.0 FRAMEWORK FOR RISK ASSESSMENT

Initial climate change adaptation strategies have developed from international and national efforts in response to increased awareness of the potential threat of climate change and enhanced climate variability. In the past two decades, government and international organizations have begun to assess how climate change could have a wide variety of primary and secondary impacts. The foundation for emerging climate change and adaptation policy has been science-based studies and assessments. Prime examples of such efforts are the four major assessment reports of the Intergovernmental Panel on Climate Change, which have been produced since 1990. These reports, along with a host of regional and national scientific reports, serve as the current basis for policy-makers. However, there is a lack of such studies with a city-based focus, and the administrative response to the emerging pressure of climate change impacts and associated scientific assessment in cities remains largely diffuse and uneven.

On the other hand, urban theorist and practitioners with their emphasis on rational comprehensive planning with master plans as the primary tool to regulate city development, over the last few decades has evolved into a more bottom-up community-oriented approach of advocacy planning widely used in urban governance (Campbell & Fainstein, 1996). Here as well, most city managers do not yet address climate change in their management strategies largely because city-specific risks remain undefined and more short-term problems such as lack of basic services or aging infrastructure take precedence.

Further, where climate change concerns are being recognized by policy-makers at the local level, climate risks assessment literature looks predominantly at hazards—temperature, precipitation, and sea-level trends and projections. This emphasis can be explained by the fact that in the near future most climate change impacts are likely to be in the form of enhanced climate variability, i.e., increased frequency and intensity of extreme events. While the observed and projected trends in climate parameters are a

prerequisite to any climate risk assessment, in the context of cities two additional vectors are critical and often neglected—namely vulnerability and adaptive capacity. Vulnerability of a city is determined by a host of internal characteristics of the city. Adaptive capacity is a function of the ability and willingness of the city stakeholders to respond to and prepare for future climate-induced stresses.

To address this critical gap, the aim of the proposed framework for urban climate risk assessment is to unpack or deconstruct risk into three elements: *hazards*, *vulnerability*, and *adaptive capacity*. Similar, frameworks have evolved in disaster risk reduction, however they use different indicators (for instance see Shook, 1997). However, these conceptual frameworks owe their roots to the evolution of concepts of development economics from the Rawlsian notions of development (1971) to that of Sen's (1999) capability-based approach which accounts for both internal constraints and degrees of agency in addition to constraints due to external conditions.

The challenge is to translate information from climate science into knowledge that triggers a realistic assessment of the vulnerability of the city and its systems so as to facilitate the development of pragmatic adaptation strategies. The overall purpose of this Urban Climate Risk Framework is to assist policy-makers in assessing and responding to the risks associated with climate change in cities. The specific objectives of the framework are three-fold:

1. Characterize the hazards associated with climate change at the city-level;
2. Identify the most vulnerable segments (people, locations, sectors) of the city; and
3. Assess the city's ability to adapt to anticipated changes in climate.

Risk is defined as the product of the three vectors: hazards, vulnerability, and adaptive capacity (Figure 1, Framework adapted from Mehrotra, 2003; Rosenzweig & Hillel, 2008).

Hazards: These are defined as the climate-induced stresses on the city and are identified through observed trends and projections derived from global climate models (GCMs) and regional downscaling (see Table 1). Extreme events affected by climate change include heat waves, droughts, inland floods, accelerated sea level rise, and floods for coastal cities. The variables examined to track these hazards are temperature, precipitation, and sea level (see Figures 2–11). In essence, the hazard element of the framework structures the array of climate-change information into the key stresses that potentially have the greatest consequence for the specific city under consideration. In this regard, it is critical to draw attention to both the variation in climate means and the change in frequency and intensity of extreme events. The latter offers opportunities for linkages with disaster risk reduction programs and has received perhaps more attention, while the former has critical long-term implications for city infrastructure and development, and tends to receive lesser attention because the mean changes are gradual.

Vulnerability: These are physical attributes of the city and its socio-economic composition that determine the degree of its susceptibility. The variables affecting vulnerability include flood-proneness (proximity to coast or river), land area, elevation, population density, percentage of poor, and quality of infrastructure. OECD's work on city vulnerability in the context of climate change points to such variables as location, economy, and size as well (Hunt & Watkiss, 2007). More detailed indicators such as composition of the poor population—age, gender, labor force composition and the like—need to be taken into consideration when in-depth city vulnerability analysis is conducted, but for the purpose of this study a more restricted set of variables that are readily available for most cities are utilized, essentially to illustrate that such physical and socio-economic characteristics affect a city's risk.

Adaptive Capacity: These are institutional attributes of the city and its actors that determine the degree of its capability to respond to potential climate change impacts. Thus they provide measures of the ability (institutional structure, caliber, resources, information, analysis), and willingness (of actors—local governments, their constituent departments, private sector, civil society—NGOs, academics) to adapt to climate change. Variables that can determine the extent of a city's ability to adapt include the structure and capacity of institutions, presence of adaptation and mitigation programs, and motivation of change agents. Here it is critical to draw a distinction with the term 'resilience'⁹ that the IPCC (2001b) Working Group II assessment defined as "amount of change a system can undergo without changing state." In contrast, adaptive capacity does not assume a steady state of a city and its integrated systems; rather it measures the ability and willingness to not only cope but to respond positively to the stresses that climate change imposes.

3.1 Measuring Hazards through Climate Change Scenarios

Analysis of hazards specific to a particular city should include observed and projected data on key climate parameters—temperature, precipitation, sea-level rise, among others. Further, each hazard¹⁰ needs to be analyzed for variance in climate parameter

⁹ *Coping Range* and *Exposure* are two related concepts that climate change scientists often include within vulnerability that are germane to the framework described here. IPCC (2007) defines coping range as 'variation in climatic stimuli that a system can absorb without producing significant impacts' while exposure is "nature and degree to which a system is exposed to significant climatic variations."

¹⁰ *Defining Climate Risk Factors:* Climate change (or climate variability) affects hazard, vulnerability and adaptive capacity through a variety of direct and indirect relationships, although the most direct, well-understood effect is on hazard. Climate change manifests itself in changing temperatures and changing temporal and spatial atmospheric circulation patterns. Increasing temperatures are very likely to result in continuing sea level rise, which increases the likelihood of flooding of coastal regions. Rising sea levels also increase storm surge, wave damage, and coastal erosion—particularly significant effects considering that population and other assets are becoming ever-more concentrated in coastal regions. Changes in rainfall will mean increased flooding and water shortages, in some cases for the same region. Changing

over the short and long-term and where relevant for frequency as well as intensity of extreme events. Climate change scenarios provide a reasonable understanding of potential future climate conditions (Parsons, et al., 2007). It is not expected that a single climate model will project exactly what will happen in the future but by using a range of climate model simulations along with scenarios incorporating different atmospheric concentrations of greenhouse gases a range of possible climate outcomes are produced and can be presented as projections that demonstrate the current expert knowledge.

Local climate change information is derived from the scenarios of greenhouse gas emissions and global climate model simulations described above. Quantitative projections are made for key climate variables such as the change in mean temperature that reflect a model-based range of values for the model grid boxes covering Buenos Aires, Delhi, Lagos, and New York City, (see Table 2–5). Further, there is a need for a nuanced understanding of the complex interactions between hazards and the city. This is because the city can be both a producer as well as a receiver of these hazards. For instance New York City alone contributes to about 0.25 percent of global greenhouse gas emissions (The City of New York, 2007). On the other hand, increase in sea level also increases the city's susceptibility to flooding. In addition, while both urban heat island and global warming increase the ambient temperature of the city, one is internally generated while the other is externally induced.

3.2 Measuring Vulnerability

Vulnerability is defined as the extent to which a city is predisposed to “adverse effects of *climate change*, including *climate variability* and extremes.” (IPCC, 2007d). However, unlike the IPCC definition of vulnerability that includes adaptive capacity we decouple the two and address them individually considering vulnerability to be determined by the physical and underlying social conditions of the city while adaptive capacity is determined predominantly by the change agents. In turn, vulnerability is a function of a host of city characteristics, including but not limited to the location of a city, particularly its proximity to the sea, topography or any other physical attributes of the landscape or physical geography that make the city susceptible to climate variations.

Social factors that determine the degree of vulnerability of a city include its population size and composition, density, size of city, quality of infrastructure, type and quality of its built environment and its regulation, land use, governance structure and the like. A critical factor determining the vulnerability of the poor as opposed to the non-poor population of the city is the percentage of the population living in slums. These are households that lack access to one or more of the following: improved water supply, improved sanitation, sufficient living-space, structurally sound dwellings, and

patterns of tropical storms are likely to bring higher winds and more intense rainfall affecting buildings and infrastructure not designed for these impacts.

security of tenure (UN-Habitat, 2003). The contrast between the formally planned part of the city and the slums is stark and is a key determinant of the differential vulnerability of the poor as opposed to the non-poor (UN-Habitat, 2008a).

3.3 Measuring Adaptive Capacity

Adaptive capacity is the ability and willingness of the city's key stakeholders to cope with the adverse impacts of climate change and depend on the awareness, capacity, and willingness to the change agents. A quick measure of institutional awareness is the presence of a comprehensive analysis of climate risks for the city and corresponding adaptation and mitigation initiatives. Capacity here refers to the quality of institutions at various levels of governments—local, regional, and national—and within local government, across various departments. Further, the capacity of the private sector, non-governmental organizations, and community groups to respond also matters. Finally, the willingness to act is of essence. In this regarding identifying in substantial detail the leading actors for climate response—government, private sector, and civil society—and mapping their initiatives is essential in estimating adaptive capacity of a city.

3.4 Data Sources and Uncertainties

The indicators (see Table 6) are based on comparable data compiled in readily accessible databases like the United Nations Population Statistics, UN-Habitat's Global Urban Observatory databases, the World Development Indicators of the World Bank and other international data sets. For a comprehensive review of available and planned urban indicators see Hoornweg, et al. (2007).

The aim is to create straightforward indicators and communication tools that will provide timely and ongoing assessments of climate risks to inform the adoption of appropriate adaptation programs and policies in urban areas. An uncertainty rating similar to that employed by the IPCC (IPCC, 2007a) has been utilized for the climate projections, and is based on the correspondence between the observations and model projections (either existing or modified), the agreement among models, and expert judgment. However, as the framework is applied to cities, higher-quality locally available data will often allow for further analysis as illustrated through the case study cities. While sensitivity analysis to capture uncertainty is a useful concept to apply to vulnerability and adaptive capacity indicators as well, it is beyond the scope of this paper.

4.0 METHODOLOGY: FRAMEWORK APPLIED TO FOUR CITIES

To test the proposed climate-risk framework, case studies were conducted for the

metropolitan areas of several cities¹¹—Buenos Aires, Delhi, Lagos, and New York. The primary criterion for selecting these cities is that all four have leadership that is committed to addressing the issue of climate change¹² and thus the risk analysis is expected to inform policymakers as well as yield response through the creation of programmatic responses needed to create flexible climate adaptation pathways. Further, these cities are located in four different continents and have a range of socioeconomic conditions and vulnerability to climate hazards. As these are all megacities and important national urban centers in their respective countries, not only do they constitute a significant share of the national GDP but also help to shape the direction of national urban development policies. See Table 7 for demographic parameters for the case study cities.

Most aspects of the risk framework articulated in this paper are equally applicable to smaller cities, as in many cases time-series data on climate parameters are available. Smaller cities may have fewer resources to apply to the development of climate risk responses and thus may have additional needs for national and international guidance and support. However, the diverse urban conditions in the case study cities allow for some generalized lessons to be drawn regarding effective and efficient urban responses to climate change. The combination of city cases allows for a comparison among developing countries as well as contrasts between developed and developing country cities, their challenges and responses.

For each city, available knowledge is analyzed for various aspects of climate risks (including uncertainty). Background information from the case study cities has been evaluated and selected variables have been assigned to the framework components. The case studies allow for preliminary tests of the transferability of the climate risk framework to a variety of cities and to explore what ‘climate services’ of data analysis, access, and processing need to be provided at the international level.

To provide concrete examples of how climate risk information can be communicated, current trends in key climate variables (including temperature, precipitation, and the incidence of extreme events) for each of the case study cities have been determined, and recent IPCC 2007 projections (up to sixteen models and three emissions scenarios) have been used to create city-focused downscaled climate model projections. The degree to which these models are able to replicate observed climate and climate trends in the past several decades is described. We also explore discrepancies, if any, between the identified risks and vulnerabilities and the current

¹¹ The unit of analysis for this paper is the city. The city is defined as the urban agglomeration that constitutes the broader metropolitan area and has overlapping jurisdictions. While every effort has been made to maintain consistency across the four cities, due to varying legal traditions and related local administrative differences the units are not strictly identical, but are broadly comparable.

¹² All cities are members of the C40 Large Cities, Climate Leadership Group, <http://www.c40cities.org/> and all co-authors are members of the Urban Climate Change Research Network <http://www.uccrn.org>

responses of cities to climate-related hazards. This addresses the important question of real-versus-perceived needs. Finally, how such information contributes to urban vulnerability assessments, quantification of the range of potential impacts, and formulation of practical, user-relevant adaptation strategies is explored.

4.1 Buenos Aires

Buenos Aires is the third largest city in Latin America, and is the political and financial capital of Argentina. The city is composed of several sub-jurisdictions that were added as the city expanded since its inception in the fifteenth century as a Spanish port. The Greater Buenos Aires Agglomeration (AGBA) is the largest in Argentina, with over 12 million inhabitants (National Population Census, 2001), with 77 percent of the population living in the surrounding provincial boroughs, and 23 percent in the central urban core of Buenos Aires City (Instituto Nacional de Estadística y Censos [INDEC], 2003). Table 8 summarizes the population, area, and density of the city and its administrative units (Figure 22). Buenos Aires City (CABA) is administered by an autonomous government elected directly by its citizens. With less than 10 percent of the Argentinean population, the CABA produces around 24 percent of the GDP. The Geographic Gross Product of the city in 2006 was about US \$50 billion (Directorate for Statistics and Census, 2007). Service sectors account for 80 percent of the local economy.

Hazards

Increases in sea and river levels, rising temperature and precipitation, along with increased frequency of extreme events like flooding caused by heavy (convective) rains and storm surges, as well as droughts are the primary climate-induced hazards for Buenos Aires. The city has a humid subtropical climate with long hot summers, and winters with low precipitation caused by the central semi-permanent high pressure center in the South Atlantic. This pressure system can cause strong south-southeast winds in the autumn and summer causing floods along the shores (Camillioni & Barros, 2008). For an overview of the seasons and basic climate parameters of the city see Tables 9 and 10 (Servicio Meteorológico Nacional, 2008).

Since the 1900s, the mean temperature has steadily increased on average by 0.2°C per decade. Likewise, over the last century, the precipitation in Buenos Aires has increased on average by 22.8 millimeter per decade. For details on observed and projected temperature and precipitation trends for Buenos Aires see Figures 2, 6, 12 and 16. In regard to extreme events, there is an increase in frequency of extreme precipitation and associated city floods, see Table 11. Further, occurrences of precipitation events of more than 100 millimeters within 24 hours have nearly doubled—from 19 times between 1911 and 1970 to 32 times between 1980 and 2000. Such observed increases in the quantity and frequency of extreme precipitation not only

adversely affects urban infrastructure, but also damages private property and disrupts the economic and social functioning of the city.

Moreover, floods have become more frequent in the low-lying coastal zones since 1960 when the south Atlantic anticyclone was displaced southward bringing an increased frequency of easterly winds over the La Plata River. Storms with southeasterly winds, locally known as *sudestadas*, cause the River to swell, and result in the flooding of coastal zones that lie up to 2.8–5 meters above mean sea level, see Table 12.

Additionally contributing to flood proneness, over the last century the average water level of the La Plata River has increased by 1.7 millimeters per year. If this trend continues, the coastal areas in and around the metropolitan agglomeration will experience more frequent flood frequency as well as erosion along the coast (Camillioni & Barros, 2008). A less likely, yet catastrophic climate-associated hazard is the salinization of the inner waters of the La Plata River, and the consequent contamination of the aquifers (Menéndez, 2005).

Box 1. Coast of the La Plata River

The La Plata River, an estuary, widens gradually from 50 kilometers at its source to 200 kilometers at its mouth; the river also increases salinity along its exterior boundary towards the Atlantic Ocean. The riverbed has a gradual gradient (0.01 meter per kilometer), which favors maritime-type dynamics, with both lunar and wind-induced tides from the ocean. The “sudestadas” are local storms that can last from a few hours up to two or three days with strong winds from the southeast that push waters towards the interior of the river and cause floods along the low Argentinean bank.

Source: Assessment of Impacts and Adaptation to Climate Change, 2005

Droughts caused by long dry spells in the La Plata River basin occasionally occur. However, these droughts affect cities located in the centre and northwestern areas of the Basin more than Buenos Aires. This is because the section of the river along Buenos Aires has an average annual flow rate of 22,000 meter cube per second. Therefore, droughts were not considered a hazard for the city until 2008 when a surprising environmental problem with dry conditions emerged. In autumn, smoke from forest fires covered the city with soot for several weeks, posing a health hazard for the people of Buenos Aires.

Vulnerabilities

The city is located along the shores of the La Plata River and spreads over the *pampa*, a wide fertile plain, and adjoining the Paraná river delta. As a result the entire metropolitan area is less than 30 meters above mean sea level. As the city grew, several

rivulets that formed the natural drainage system were replaced with a system of underground storm water drains (Falczuk, 2008).

Spatial Distribution of Poor Versus Non-poor: Over the 1990s the city has experienced sprawl with developers building gated communities on the periphery of the metropolitan area, extending the city over an area one and a half times the size of the CABA (Pírez, 2002). With disparity on the rise and migration of the non-poor from the city center to the periphery, the city has been further spatially segregated by income groups. This condition was further intensified with the economic crisis of 2001, which created the 'new poor' consisting of the middle class that now lacked incomes.

The precise distribution and enumeration of the slums is complicated by two additional factors. First is the process of 'urban invasions' whereby squatter settlements crop up sporadically across the city. Second, like all other urban data for AGBA, information on the poor is parsed into 30 administrative units. For this research, data for slums and other dilapidated housing in the CABA were derived from an Ombudsman survey in 2006 (see Table 13 for quantification of low-income housing), which found that about 20 percent of all households in the urban core of the AGBA live in poor housing conditions.

Additionally, the survey identified 24 new settlements with 13,000 inhabitants located under bridges or simply 'under the sky' (Defensoría del Pueblo de la Ciudad de Buenos Aires, 2006). However, unlike developing-country slums, most households have land tenure and property rights related to their homes due to a well-established public housing program in Argentina. Mapping the spatial distribution of differential vulnerability of the poor and non-poor to floods and other hazards is critical to crafting a climate-risk assessment of Buenos Aires (see Figures 23 and 24).

Low elevation urban areas: In its present configuration, a quarter of the metropolitan area is susceptible to floods (Clichevsky, 2002; Menéndez, 2005). Urban expansion continues over the basins of the Matanza-Riachuelo, Reconquista, and Luján rivers, as well as the estuary of the La Plata River (see Figure 25). These areas consist of a combination of new gated communities, real estate speculation sites, as well as illegal plots in the flood plain targeted toward the housing needs of the poor. With a lack of regulation governing such urban development and the creation of unprotected infrastructure in the flood plain, the vulnerability of this part of the city is increasing (Ríos & González, 2005).

To assess the vulnerability of the low-elevation areas of the city a review of past urban floods was undertaken. As reported in newspapers and official assessments, floods impaired all modes of public and private transportation, including domestic flights, road, and rail; disrupted energy supplies, telephone lines and traffic lights; flooded buildings; and created an overall disruption of city life. Streets and cellars were waterlogged and people living in low-elevation neighborhoods in the suburbs were evacuated (González, 2005). In sum, the economic costs were high. Unlike urban

disasters in other developing countries, the death toll in Buenos Aires related to flooding disasters tends to be low. The primary costs are the disruption of the economic activity of the city and damage to public and private property.

As the metropolitan area has been expanding into the flood plains, a simulation to quantify the population vulnerable to sea level rise was conducted. Barros et al. (2008) observed that “Assuming little change in population density and distribution, under the scenario of maximum sea-level rise during the 2070 decade (...) the number of people living in areas at flood risk with a return period of 100 years is expected to be about 900,000, almost double the present at-risk population”. The potential damage to public and private assets can be assessed from a recent survey that estimated that 125 public offices, 17 social security offices, 205 health centers, 928 educational buildings, 306 recreational areas and 1,046 private industrial complexes are currently at risk to floods.

A conservative estimate by Barros et al. (2008) states that at present the damage to real estate from floods is about US\$30 million per year. Assuming a business-as-usual scenario, which includes a 1.5 percent annual growth in infrastructure and construction and no adoption of flood-protection measures, the projected annual cost of damages is US\$80 and US\$300 million by 2030 and 2070 respectively. These estimates do not include the losses to gated communities of the non-poor being built in the coastal area, largely located less than 4.4 meters above mean sea-level. Nor does this account for the loss in productivity of the labor force, which can be significant given the size of the population likely to be affected. Thus, the costs of not responding to climate change in the course of urban development are projected to be significant and disruptive.

Adaptive Capacity

The Argentinean government's response to global climate change has been dominated by mitigation efforts related to policies and programs to reduce greenhouse gas emissions (Pochat et al., 2006), with relatively little attention to adaptation. The lead national agency to address climate issues is the Secretariat for Environmental and Sustainable Development.

In 1993 Argentina became a signatory to the United Nations Framework Convention on Climate Change. In response, the federal government established the office for Joint Implementation, but in 1998 this was renamed the Office for Clean Development Mechanisms. Further, in 1999 Argentina adopted the objectives of the Greenhouse Gases Reduction Programme, and in 2001 signed on to the Kyoto Protocol. To institutionalize the response to climate change, in 2003 a Climate Change Unit was established within the Secretariat for Environmental and Sustainable Development. In 2007, this evolved into the Climate Change Office. In addition, the government has been supporting a range of research programmes, such as the National Programme on Climate Scenarios, which was initiated in 2005. Through these institutional

arrangements, first and second national reports were prepared in 1997 and 2006 respectively. The third version is under preparation (Pochat et al., 2006).

However, the roles and responsibilities of governmental agencies in regard to climate change remain fragmented, while adaptation responses, specifically at the city level, remain to be addressed. In addition, four Ministries with a dozen departments and institutions are involved in flood monitoring and broader disaster management systems (Natenzon & Viand, 2008). Gradually, lower levels of government such as the states and local authorities are taking an interest in addressing climate change mitigation and adaptation, and a range of stakeholders such as NGOs, the media, and citizen groups are participating.

Emerging Issues

Conflicting plans and multiple jurisdictions reduce the efficacy of climate change response plans at the city level as well (Murgida & González, 2005). For example, in 2007 an office for Climatic Protection and Energy Efficiency was established within the Ministry for Environment of Buenos Aires City. With the arrival of a new administration in December 2007 this ministry was restructured into the Ministry of Environment and Public Space, with a new Environmental Protection Agency. The Office of Climate Protection and Energy Efficiency was dismantled despite the fact that previously initiated programs and projects like “Clean Production” and “Air Quality” continue to be implemented (Murgida, 2007).

The primary obstacles to institutional action at the metropolitan level are lack of actionable climate information, as well as vertical and horizontal fragmentation of jurisdictions with divergent interests and responses. Administrative units within the AGBA address flood management but lack an integrated strategy. For example, within Buenos Aires City two different plans—the Urban Environmental Plan and the Buenos Aires 2015 Strategic Plan—are being implemented simultaneously but with a lack of effective coordination. Further, in practice there are two critical legislative instruments to regulate urban development in the city—namely the Building Code enacted in 1944 and the Urban Planning Code enacted in 1977. These are complemented by additional measures like the Flood Control Plan, and post-2001 flood tax rebates for affected communities. However, these plans, codes and norms are inconsistent. For instance, the Urban Planning Code incentivizes the occupation of vulnerable low-lying areas within the city contradicting the flood prevention plans (González 2005).

Moreover, constantly changing organizational roles and responsibilities of government agencies tasked to address climate change pose a challenge. For instance, in 2005, the Buenos Aires State Government created a unit to address climate change within the provincial Ministry for Environmental Policy. This office continues to be operational under the new local government that was elected in 2007, but the unit has been moved to the Ministry of Social Development and has a reduced mandate. This

lack of action orientation is compounded by a general lack of public awareness of the risks associated with climate change (Assessment of Impacts and Adaptation to Climate Change, 2005).

Additionally, there is a mismatch in terms and scales. While the climate adaptation strategies like flood prevention and management need to take a long-term view and plan for the metropolitan region as a whole, most planning interventions address short-term needs and do not take a city-wide view (Murgida & Natenzon, 2007). “By analyzing who participated in the planning process and in which areas they did so, it becomes evident that the vast majority of interventions were partial, some were very specific, and a few encompass different areas and spheres” (Pírez, 2008). These issues become further complicated for the metropolitan region due to the overlap and aggregation of administrative units that lack a central governing authority.

The community of scientists and researchers has taken on an unusual task of coordinating climate-related programs and policies. A leading example of this effort was the launch of the Global Climate Change Research Program at Buenos Aires University (PIUBACC) in May 2007. The objective of this program is to map and link all research as well as city development projects within the metropolitan area so as to provide the government, civil society, and more-specifically interested groups directly involved in climate change programs a holistic and scientific assessment of climate change risks. Additionally, the scientists are drawing transferable lessons from community knowledge on flood management along the La Plata River coast with a dual focus on the vulnerability of the poor and on adaptation to storm-surge floods (Barros et al., 2005).

4.2 Delhi¹³

Delhi has a population of 16 million inhabitants, and is rapidly urbanizing with a 3.85 percent annual growth rate over the 1990s amounting to half a million migrants each year. In 1901 Delhi had 400,000 inhabitants. Furthermore, rising per capita incomes are increasing energy consumption, and over-stretching its infrastructure. Delhi is a city of contrasts—in 2000, 1.15 million people were living below the National Poverty line. On the other hand, Delhi’s Gross State Domestic Product at current prices was about US \$27 billion during 2007 (Department of Planning, 2008). At its widest dimensions, Delhi stretches 50 kilometers and occupies an area of 1,400 square kilometers. To compound

¹³ This response is primarily based on feedback and documents provided by the Department of Environment, Government of National Capital Territory of Delhi, India. In particular, summarized here are some pivotal actions taken by the government of Delhi under the leadership of the Chief Minister of Delhi including issues raised during her participation at the C40 Large City Climate Summit in New York in 2007.

the challenges of rapid urban expansion and associated environmental risks, Delhi—like many Indian cities—faces several climate-related challenges and opportunities.¹⁴

Delhi has three distinct seasons—summer, winter, and monsoons with extreme temperatures and concentrated precipitation. Summers begin in mid-March lasting for three months and are dry and hot with temperatures peaking at about 40°C in the months of May and June. Monsoons are between mid-June and September during which period Delhi receives most of its 600 millimeters of annual rainfall with July and August getting as much as 225 millimeters each, see Figure 26 for seasonal variation in temperature and precipitation. Winters are dry and last from November to mid-March with December and January being the coldest months with temperatures as low as 7°C (Delhi, 2009).

Hazards

The National Action Plan for Climate Change and related analysis provides an overview of climate change issues confronting India as recognized by the federal government (see Government of India, 2002, 2008). Revi (2007) provides an overview of direct and derived climate-induced hazards in the context of urban India. Through a review of research on climate science, policy papers, and practitioner notes five hazards are identified. First, although there are uncertainties with scaling down global models such that they reflect regional climate conditions like the Indian monsoon, temperature, precipitation, and sea-level are likely to rise (see Table 14). Mean extreme temperature, as well as maxima and minima, are expected to increase by 2 to 4°C, likely to result in an average surface warming of 3.5 to 5°C within this century.

Second, average mean rainfall is projected to increase by 7 to 20 percent due to the increase in mean temperature and its impact on the Indian monsoon cycles within the latter half of this century. However, some drought-prone areas are expected to get dryer and flood-prone areas will very likely experience more intense periods of precipitation. Third, 0.8 meters is the projected centennial rise in mean sea level. Fourth, extreme events like the Mumbai flood of 2005 are expected to be more frequent in western and central India. A combination of these hazards expose the cities in this region to a range of other climate-induced extreme events like droughts, temporary and permanent flooding, both inland and in coastal areas, and cyclones.

For a summary of observed and projected temperature and precipitation for Delhi see Figures 3, 7, 13, and 17. Extreme minimum and maximum temperature events

¹⁴ To address similar issues in a global context, in February 2008 Delhi hosted the Delhi Sustainable Development Summit, which was attended by several world leaders. The summit explored links between sustainable development and climate change. Similarly, in 2002 Delhi hosted the United Nations Conference on Climate Change. The Delhi Declaration of 2002 was signed by representatives of 185 countries.

appear to be increasing. In December of 2006, Delhi had the lowest temperature since 1935 (0.2°C), and the media reported the death toll from the cold wave in north India to be over a 100 people in and around the region. The following summer in June 2007, Delhi had a maximum temperature of 44.9°C, once again taking a toll on the people of the city. While these extreme temperatures cannot be directly linked to climate change, the challenge facing Delhi is variability in weather patterns and the potential for exacerbated extreme events due to climate change. Table 15 summarizes some of the months when temperature and precipitation were greater than 1.5 standard deviation from the mean, the hottest summer was in 1944, the coldest winter in 1935 and the wettest monsoon in 1958 (see Table 16), however recent years have seen similar extremes in temperature in 1978, 1988 and 1996 and precipitation in 1994, 1995, and 2003.

Vulnerabilities

Delhi's physical infrastructure, social services, and slum populations make the city highly vulnerable. Demand for basic infrastructure services like water, electricity, and public transport far exceeds supply (Delhi Development Authority, 2005). To add to the existing conditions, climate change-induced variability in rains could worsen the severe shortage of drinking water in summers and aggravate the floods in the monsoon season, thus making the existing energy shortage more challenging to address. With regard to transportation, Delhi has the highest per capita vehicular population in India—5.4 million automobiles for 15 million people. This poses a challenge for a city with mixed land use and varying urban densities within the metropolitan region to introduce effective modes of public transport. Carbon emissions from vehicles, traffic congestion, and increasing particulate matter all pose challenges. These and other challenges pose widespread public health risks to the inhabitants of Delhi. For example, lack of adequate sanitation facilities for the poor poses a problem for a rapidly growing city where a large proportion of population lives in slums.

The hyper-dense nature of the slums, despite Delhi's relatively low population density and the centrality of the poor in provision of services—from household help to a range of labor-intensive and low-wage tasks—poses an enormous challenge. The access to basic services is uneven across the city. While many parts of Delhi have high-quality infrastructure compared to other Indian cities, the slum dwellers lack access to many of these services. The extent of the vulnerability of the poor within the city is captured in the statistics offered by the Yamuna Action Plan, a river revitalization effort of the Government of India. They observe that about 45 percent of the city's population live in a combination of unregulated settlements, including unauthorized colonies, villages, slums, and the like. Further, three million people live along the Yamuna River, which is prone to flooding, where 600,000 dwellings are classified as slums. Further, they observe that:

“ . . . nearly 62,000 units are estimated to be located in the river bed of Yamuna on both sides of its stretch along Delhi and on the embankments of a few major storm water drains such as Najafgarh drain, Barapulla drain etc. During dry weather these slum dwellers use open areas around their units for defecation. In this way, the entire human waste generated from these 62,000 units along with the additional wastewater generated from their household is discharged untreated into the river Yamuna.”

Moreover, increasing competition for scarce basic services caused by the rapidly growing population of Delhi poses public health as well as quality-of-life challenges. For example, some poor settlements lack basic amenities resulting in open defecation. Although the extent of the impacts remains to be assessed, potential climate change impacts added to current local environmental stresses are likely to intensify this crisis. Moreover, the low quality of housing in slums and their proximity to environmentally degraded land and flood-prone areas further exacerbate the vulnerability of the poor. Within the slums, climate-induced stress is likely to affect certain social groups more than others, particularly the elderly, women, and children.

Adaptive Capacity

The government of Delhi has made many efforts towards climate change mitigation, but there is lesser emphasis on adaptation. In addition to the issues of energy, water, transportation, mitigation projects also encompass public health and other social and economic development efforts. Climate change mitigation efforts by the Government of Delhi were introduced first in the government departments and are being gradually expanded to include other stakeholders—schools, households, and firms. As seen below, most initiatives remain project-oriented (Department of Environment, 2008). Some projects, such as the Bhagidari program, seek participation from neighborhood groups, private-sector associations, schools, and non-governmental organizations to enhance civil society engagement in environmental management, creating an expanded policy space for addressing climate change. Such collaboration holds the potential to address broader issues of climate adaptation by building awareness as well as capacity of stakeholders to respond. However, the most striking of all climate mitigation initiatives in Delhi so far is the establishment of the world's largest fleet of compressed natural gas (CNG)-fueled public transport in response to a Supreme Court order.

This has resulted in 130,000 CNG-powered vehicles, 145 CNG fuel stations, as well as improved vehicular emission standards like those adopted in the European Union. The fuel quality has been improved with respect to benzene, sulphur, and lead content. Yet, the greatest lesson from this initiative is in recognizing the diverse set of triggers and actors that can initiate adaptation and mitigation programs (see Box 2).

Box 2: Change agents for CNG-operated public transport in Delhi

In 1995 a World Bank study found that poor air quality posed health hazards for households in Delhi. The study estimated that air pollution caused 1 death every 70 minutes in Delhi, and branded Delhi as one of the most polluted cities in the world (Brandon and Hommann, 1995). Subsequently, Cropper et al. also a World Bank study, argued that these death tolls may have been overestimated (1997), however the initial report generated public outrage in the city, and the Centre for Science and Environment (CSE, 2009) started a campaign demanding clean air. The health impacts of suspended particles matter (SPM) on lungs became apparent, and emissions from poorly managed polluting public transport were identified as one of the main causes of poor air quality.

The campaign mustered citizen support through involvement of professional associations, media, academics, and other stakeholders. The advocacy campaign involved bringing the message directly to the attention of the national political leadership. In response to the public outrage, the Supreme Court issued a judgment in 1998 requiring the government of Delhi to stem air pollution by introducing CNG-operated public transport, and to augment the supply of mass transit within a prescribed timeframe of 3 years, as well as required adoption of stringent emission standards within 5 years.

Automobile firms resisted the change and found some support within the government that raised safety and viability concerns. In response, the Supreme Court issued stringent directives including appointing a CNG czar to ensure compliance of new regulations, instituted large penalties for defaulters—including state and federal agencies—and increased funding of research and development. The Supreme Court, by now the principal driver of change, followed up with further directives. Both supply and demand for CNG and safety regulations were addressed through institutional mechanisms.

In about five years (1998-2002) all public transport in Delhi was converted to CNG-operated retrofitted buses. Further, this effort triggered several projects to increase supply of efficient and clean public transport systems like the Delhi metro and the Bus Rapid Transport all contributing to emission reductions as part of climate change mitigation efforts within the city. However, the key lesson illustrated here is that change agents are diverse—like in this case researchers, civil society, and the supreme court—and require creative and persistent efforts as well as the willingness to learn by doing.

Source: Adapted from Centre for Science and Environment (www.cseindia.org), and C40 Cities (www.c40cities.org)

Some mitigation measures have co-benefits for adaptation as well. For instance, adoption of green building technology that is mandatory for the Public Works Department and the Airport Authority was introduced to address mitigation, but has adaptation benefits as well. Building guidelines include: (a) optimum energy efficiency in lighting, air-conditioning, and water systems; (b) eco-friendly heating, ventilation, and air-conditioning systems; (c) green screens for east and west building walls as well as for the roof; (d) maximizing natural lighting in buildings and using energy-graded glass; (e) use of certified eco-friendly building materials; (f) efficient water-dispensing technologies for kitchenware, toilets, and irrigation systems; (g) construction material

from recycled products like fly ash bricks, recycled material in false ceilings, and recycled asphalt for roads; (h) landscape design to minimize soil erosion, reduce water usage, and ensure natural drainage systems. Expected greenhouse gas emissions reductions are 35 to 50 percent in general energy consumption and 100 percent in energy for water heating. Moreover, the New Delhi Municipal Council aims to reduce demand for energy by 15,000 kilowatts by 2009 and the Municipal Corporation of Delhi is making efforts to install compact fluorescent lamps, and capacitor banks to increase energy efficiency. Further, the government has a program that subsidizes electric vehicles and is encouraging the introduction of the Reva car, as well as battery-operated two and three-wheelers.

Delhi has expanded its forest cover over the past ten years. The cities greening program is considered to be one of the largest in the world. The forest cover has grown from 3 percent in 1998 to 19 percent in 2005. The city planted 1.7 million trees in 2007 and the forest cover grew to 300 square kilometers. To maintain the momentum, the city plans to plant 1.8 million samplings in the fiscal year 2009, increasing the greenery cover to a total of 326 square kilometers. The city also has a policy to plant ten trees for every tree chopped down. This project is done in collaboration with several stakeholders including school children, housewives, and neighborhood associations. The samplings are distributed gratis through a host of vendors. This afforestation effort is part of a CDM project proposal. To scale-up mitigation efforts, the Delhi government has established a program with the aim to raise awareness about carbon credits and clean development mechanisms among various departments. The objective is to develop a holistic approach towards reducing green house gas emission and developing projects that can redeem carbon credits. In essence, these mitigation projects can prove vital for adaptive capacity as well. For example, green roofs and walls, and tree-planting help to cool the urban environment and reduce heat island effects, as do many of the energy-efficiency projects related to buildings.

While the neglect of adaptation remains a concern, another co-benefit to mitigation efforts in Delhi is the climate change awareness and administrative capacity being built as a result of mitigation projects that may help as adaptation projects and policy measures are introduced. Not only is the government developing financial incentives to introduce programs and adopting a multi-sectoral approach that involves various departments within the city jurisdiction, they are also learning to utilize mechanisms like UNFCCC's Clean Development Mechanism (CDM) funds that are likely be equally relevant for adaptation. Illustrations of such efforts are the CDM projects and certified emission reductions (CERs) in the water, energy, and transport sectors.

Delhi Jal Board—the department in charge of Delhi's Water and Sanitation service—has energy-efficiency improvement programs in water supply, wastewater treatment, and methane recovery. Delhi Jal Board has proposed a project under the Clean Development Mechanism (CDM) with the objective to reduce greenhouse gas

emissions. The Municipal Corporation of Delhi also has an ongoing project, sanctioned by the World Bank, for methane recovery and reuse from three landfill sites. The project involves landfill gas extraction, gas testing, a feasibility study, and technical design of the project. Expected emission reduction from this project is three million tons of carbon dioxide equivalents. Further, electricity-generating companies are taking initiatives to enhance efficiency of power plants through improvement in heat rates. Renovation of 210 megawatt units under a proposed CDM project is expected to improve heat rates by 25 percent—from 200 to 250 kilocalories per kilowatt hour. The expected emissions reductions are 128,000 tonnes of carbon dioxide per unit.

Efforts by the electricity distribution companies include: (a) installation of electronic chokes and compact fluorescent lamps (CFL)—installing CFL in homes can earn 1.22 million tons of CERs annually; (b) mandatory installation of solar water heating systems in buildings that are 500 meter square and more; (c) installation of energy-efficient water pumps, power capacitors, as well as foot and reflex valves for farmers; (d) promotion of low energy light-emitting diodes (LEDs) at traffic lights; (e) performance ranking among power distribution companies. Likewise, the Municipal Corporation of Delhi's integrated waste-management project—waste to energy—proposes to convert 2050 million tons of municipal solid waste into 16 megawatts of power. The anticipated greenhouse gas emissions reductions from this project are substantial. The project is registered with UNFCCC to earn 2.6 million CERs over ten years.

In the transport sector, the Delhi Metro Rail Corporation has provided the city with a subway system. Its efforts to mitigate emissions include: (a) reduction in net energy consumption through introduction of regressive brakes that convert kinetic energy released during deceleration of the train and generate electricity that is supplied to the overhead electric supply lines. The expected emission reduction as registered with UNFCC is 400,000 CERs over ten years and is the world's first railroad project that includes carbon credits.

Finally, the government has several schemes through which it gives subsidies, low-interest loans, matching grants—like, buy one-get one free—to promote the use of less energy-intensive technologies. Although these instruments work well for capital investment like installing a solar heater or roof-top water harvesting system, these incentives often fail to sustain the projects overtime because operation and maintenance are ignored. Thus, the net impact of such program is often low.

Emerging Issues

While Delhi is making major efforts towards mitigation of climate change through carbon emission reductions and other environmental improvements, there is a significant lack of awareness about the need for adaptation to climate change. Therefore, the city has not yet planned for adaptation.

Further, Delhi's response to climate change is often less-than-effective as well as piecemeal because its efforts are primarily project-oriented. In the experience of the Delhi government, incentives—subsidies and grants—have been effective for initiating projects, but operation and management frequently remain neglected. For instance, subsidies to install rainwater-harvesting systems have created demand but subsequent maintenance is too-often ignored and many systems fall into disrepair. Such experiences hold the potential to inform adaptation efforts as well.

Gradually the city is developing a programmatic approach, but there is a need to coordinate between departments and among levels of government. For example, while the Prime Minister of India has recently released the National Action Plan for Climate Change, Delhi's local efforts will need to be reconciled with regional and national priorities.

4.3 Lagos

Lagos is Africa's second most populous city, which grew explosively, from 300,000 in 1950 to an expected 18 million by 2010, when it will be ranked as one of the world's ten largest cities. The metropolitan area, an estimated 1,000 square kilometers, is a group of islands surrounded by creeks and lagoons and bordered by the Atlantic Ocean. With a GDP triple that of any other West African country, Lagos is the commercial and industrial hub of Nigeria. Lagos is home to many industries and much large commercial infrastructure, and has greatly benefited from Nigeria's natural resources of oil, natural gas, coal, fuel wood and water. For an overview of the state of Nigerian cities see UN-Habitat (2004).

The climate of Lagos is affected by ocean and atmospheric interactions both within and outside its environment, in which the Inter-Tropical Convergence Zone (ITCZ) plays a controlling factor. The movement of the ITCZ is associated with the warm humid maritime Tropical air mass with its southwestern winds and the hot and dry continental air mass with its dry northeasterly winds. Maximum temperatures recorded during the dry season are high and range from 28–33°C when the region is dominated by the dry northeast trade winds. Minimum temperature of about 24–26°C is experienced during the wet season of May to September.

The city of Lagos experiences relatively high to very high temperatures throughout the year. The mean annual temperature is about 28°C and the maximum and minimum temperature is 33°C and 26°C respectively. High to very high monthly rainfall is also experienced between May and November, although significant variations in monthly rainfall peak values are experienced. For example, between 1950 and 2006, more than 10 instances were recorded with a maximum rainfall of over 700 millimeters. Minimum monthly rainfall of less than 50 millimeters is experienced between December and March. Occasionally, extreme precipitation events are experienced in June. On June 17, 2004, for example, 243 millimeters of rain was experienced in Victoria Island

and the Lagos environs. This resulted in flooding of streets and homes, collapsing of bridges, and massive erosion of the main road linking Lekki to Lagos Island. About 78 percent of the total rainfall amount for the month was experienced in one day in June. The city was ill-prepared for that amount of rainfall.

Hazards

This trans-administration megacity is bounded in the south by the Atlantic Ocean (Bight of Benin), in the east by the Lagos Lagoon and the southwest by the Badagry Creek. The west and northern limits merge into the gently undulating agricultural lands of Ado Odo, Ota local government area, and the north-central edge of the city is located in the Ogun River flood plain (see Figure 27 for built-up area along the coast and Figure 28 for topography identifying low lying areas prone to flooding).

The study by Ekanade et al. (2008) is one study that has localized the nature and magnitude of the climate change hazards for the city level using different (GHG) emission scenario models. The IPCC (2001a) Special Report on Emission Scenarios A2 and B1 climate change scenarios were utilized to project 30-year time-slices for temperature and rainfall values for the City of Lagos and Port-Harcourt and the coastal areas of Nigeria. This study did not, however, project sea level rise.

Temperature: Records from the two stations (Ikeja and Lagos) used in this analysis show that monthly maximum temperature is increasing at about 0.1°C per decade from 1952 to 2006, while monthly minimums are decreasing at about 0.5°C per decade; since the 1900s average temperature has increased 0.07°C per decade (Figures 4 and 14). At the extremes, monthly maximum temperatures for Lagos have reached above 34°C during seven of the last twenty years. The number of heat waves in Lagos has also increased since the 1980s (see Table 17). There are very few incidences of unusually cold months of less than 20°C since 1995. Projected temperature for Lagos for 2050s anticipates a 1 to 2°C warming (see Table 4 and Figure 14).

Precipitation: According to historical records, the total annual precipitation in Lagos has decreased by 8 millimeter per decade since 1900 (see Figure 8). In keeping with the overall precipitation trends, most of Lagos has experienced decreases in rainfall amounts during the rainy season. For example, between 1950 and 1989 more than 20 months experienced rainfall amounts of over 400 millimeters. In the recent period between 1990 and 2006 however, very few (4) rainy months recorded over 400 millimeters of rain. In the 21st century, precipitation in Lagos is expected to be less frequent but more intense, projected precipitation for Lagos for 2050s anticipates an uncertain 5 percent change in mean precipitation (see Table 4).

Storm surge is a concern. Lagos as well as the entire Nigerian coast is projected to experience more storm surges in the months of April to June and September to October annually. This increase in storminess is projected to be accompanied by greater extreme wave heights along the coasts. According to Folorunsho & Awosika (1995) the

months of April and August are usually associated with the development of low pressure systems far out in the Atlantic Ocean (in the region known as the 'roaring forties'). Normal wave heights along the Victoria beach range from 0.9m to 2m. However, during these swells, wave heights can exceed 4m. The average high high-water (HHW) level for Victoria Island is about 0.9m above the zero tide gauge with tidal range of about 1m. However, high water that occurs as surges during these swells has been observed to reach well over 2m above the zero tide gauge. These oceanographic conditions are aggravated when the swells coincide with high tides and spring tide.

An extreme event, which can be considered a case study for future threats, was observed between August 16 and 17, 1995, when a series of violent swells in the form of surges were unleashed on the whole of Victoria Beach in Lagos. The most devastating of these swells occurred on August 17, 1995 between 06.00 to 10.00 GMT. The surge coincided with high tide thus producing waves over 4 meters high flooding large parts of Victoria Island. Large volumes of water topped the beach and the Kuramo waters, a small lagoon separated from the ocean by a narrow—fifty meters wide—strip of beach, was virtually joined to the Atlantic Ocean. Many of the streets and drainage channels were flooded resulting in an abrupt dislocation of socio-economic activities in Victoria and Ikoyi Islands for the period of the flood.

Sea Level Rise: Coastal erosion is very prevalent along the Lagos coast. The Bar beach in Lagos has an annual erosion rate of 25 to 30m. Earlier IPCC scenarios have been used to estimate the effects of 0.2, 0.5, 1 and 2.0m sea level rise for Lagos. Along with coastal flooding, and erosion, another adverse effect of sea level rise on the Lagos coastal zone as earlier assessed by Awosika et al. (1992, 1993a, 1993b) is increased salinization of both ground and surface water. The intrusion of saline water into groundwater supplies is likely to adversely affect water quality, which could impose enormous costs on water treatment infrastructure.

Vulnerability

As a group of islands, Lagos is bordered by mainland Nigeria to the north and west, other islands to the east and the Atlantic Ocean to the south. Lagos has an extremely dense slum population, many of whom live in floating slums. These are neighborhoods that extend out into the lagoons scattered throughout the city. The Barrier Lagoon system in Lagos, which comprises Lagos, Ikoyi, Victoria and Lekki, will be adversely affected through the estimated displacement of between 0.6 to 6 million people for sea level rise of between 0.2 to 2m (Awosika et al., 1993a).

In their study of the impacts and consequences of sea level rise in Nigeria, French et al. (1995) recommended that buffer zones be created between the shoreline and the new coastal developments. A more generalized multi-sectoral survey of Nigeria's vulnerability and adaptation to climate change was funded by the Canadian

International Development Agency (CIDA) through its Climate Change Capacity Development Fund (CCCCDF). This study has served to create awareness of climate change issues and of the need for manpower development.

Even more worrisome is the general sensitivity of the megacity to climate change due to its flat topography and low elevation location, high population, widespread poverty and weak institutional structures. Many more vulnerabilities stem from these characteristics including the high potential for backing up of water in drainage channels, inundation of roadways, and severe erosion. The barrier lagoon coastline in the western extremity, including the high-value real estate at Victoria Island and Lekki in Lagos, could lose well over 584 and 602 square kilometers of land respectively from erosion, while inundation could completely submerge the entire Lekki barrier system (Awosika et al., 1993a, 1993b), (see Figure 31). Moreover, flooding poses greater threats to the urban poor in several African cities (Douglas & Alam, 2006).

Intense episodes of heatwaves will likely severely strain urban systems in Lagos, by inflicting environmental health hazards on the more vulnerable segments of the population, imposing extraordinary consumptions of energy for heating and air conditioning where available, and disrupting ordinary urban activities.

It is very likely that heat-related morbidity and mortality will increase over the coming decades; however net changes in mortality are difficult to estimate because, in part, much depends on complexities in the relationships among mortality, heat, and other stresses. High temperatures tend to exacerbate chronic health conditions. An increased frequency and severity of heat waves is expected, leading to more illness and death, particularly among the young, elderly, frail, and poor. In many cases, the urban heat island effect may increase heat-related mortality. High temperatures and exacerbated air pollution can interact to result in additional health impacts.

Impacts are projected to be widespread as urban economic activities will be likely affected by the physical damages caused to infrastructure, services and businesses, with repercussions on overall productivity, trade, tourism and on the provision of public services.

Built-up Area and Population Density: As mapped from the SPOT5 2.5 meter image of 2004 (Figure 27), the contiguously built-up area of Lagos megacity is about 872 square kilometers. This is located within 17 local government areas in Lagos State with a total of 642.22 square kilometers (73.6 percent) and 4 local government areas in Ogun State with 229.8 square kilometers (26.4 percent). The distribution of the built-up area by local government jurisdictions is presented in Table 20. Alimosho local government area has the largest built-up area of about 144 square kilometers while Lagos Island, also in the Lagos State sector has the smallest built-up area of about five square kilometers. Most of the local government areas in Lagos are almost completely built with virtually no further space to grow (see Figure 27).

Lagos megacity is one of the world's fastest growing urban centers. The UN-Habitat (2006) estimated the city's population to be about 15 million in 2006 with 600,000 additional migrants added each year and projected its population to reach 20.2 million by 2010.

The city's high aggregate population is an indication of its enhanced sensitivity to hazards. Thus, the effects of any negative consequences of climate change and climate variability extremes are likely to be felt by a large number of people, most especially the urban poor living on the marginal flood-prone areas of the city (see Table 19 and Figure 28). The built-up area breakdown shows that the Lagos State side of the megacity, which is made up of about 74 percent of the built-up area, has about 85 percent of the megacity's population, while Ogun state, with 26 percent of the built-up area, accounts for about 15 percent of the megacity's population. The elevation of the built-up area of the city ranges between 1m in the coastal areas to about 75 meters above sea level at its northern fringes (Ogun State Government, 2005).

The average population density of the city's constituting local government areas is about 2094 per square kilometer with the minimum of 164 per square kilometer in Owoode Obafemi local government area of Ogun State and a maximum of 55,939 per square kilometer in Ajeromi Ifelodun local government area in Lagos State. A better picture of the city's high population density can be inferred by a breakdown of each local government area's population density by the built-up areas. The local government areas in the Lagos State side have an average density of 13,194 per square kilometer. Ajeromi, Ifelodun local government area has a staggering density of 60,204 per square kilometer.

Lagos City, Urban Form, and Poverty: In 1983, 42 slums or blighted areas covering 1,622 hectares were officially documented by Lagos State. The number rose to about 62 out of the 2,600 communities in the state in 1995 (UN-Habitat, 2006). Due to the lack of secure land tenure slum communities are vulnerable to the threat of eviction (Morka, 2007). More recently, the Report of the Presidential Committee Redevelopment of Lagos Mega-City (Federal Republic of Nigeria, 2006) put the number of slum or blighted areas at over 100 in the Lagos portion with another 31 areas in the Ogun State portion of the megacity. The growth of the slums was also described in the report as a testimony to the city's difficulties in producing affordable housing for the urban poor. A 2002 survey in the megacity by Nubi and Omirin (2006) similarly revealed that over 70 percent of the built-up area of the metropolis is blighted. Most of the slums are located on marginal lands that are mainly flood-prone with virtually no physical and social infrastructure (see Figure 28). Lagos State government has, however, been making attempts at the inventory, management and upgrade of some of the slums through the Lagos State Urban Renewal Authority (LASURA) and the World Bank (IDA)-assisted Lagos Metropolitan Development and Governance Project (LMDGP).

Some of the planned and affluent neighborhoods in many parts of the city still experience flooding during “normal” rainfall. This may be attributed to the little-to-no attention often given to the provision and maintenance of sewer and storm drains in these supposedly “planned” affluent neighborhoods. For instance, Ikoyi, one of the most highly-priced neighborhoods in the city, was actually developed from an area originally covered by about 60 percent wetland. Also, Victoria Island and Lekki neighborhoods were formally low-lying barrier lagoon systems interspersed by wetlands and tidal flats with an elevation of about 0-3 meters before they were developed (see Figure 28).

Urban poverty has been described as one of the most daunting challenges currently facing the city’s administrators (UN-Habitat, 2006). The average monthly household income for the 1.1 million inhabitants of the 158,000 households in the LMDGP project was about US\$170 (Abosede, 2006, 2008). Also, despite the city contributing more than 60 percent of Nigeria’s Gross Domestic Product, 65 percent of national investments and 65 percent of the nation’s Value Added Tax (VAT), about 65 percent of the residents are estimated to live below the poverty level. The deplorable state of the urban form and poverty is indicative of the expected low resilience of most of the inhabitants of the city to external hazard stressors such as those often associated with climate extreme events.

Adaptive Capacity

Even with active membership in the C40 Large Cities Climate Leadership network, Lagos megacity still does not have a comprehensive analysis of the possible climate risks facing it. The Goethe Institute and the Heirich Boll Stiftung Foundation, Lagos were NGOs at the fore of raising the alarm specifically on the vulnerability of the city to inundation due to the sea level rise associated with climate change.

It would be untrue to say that there are no activities on climate change in Nigeria, most especially by the scientific community, but there is a disconnect between the scientists, the people and the political class. The implication is that there is an urgent need to address the obvious lack of awareness of the vulnerability of Lagos to climate change and the need to begin to plan adaptation strategies. Recently, tackling the problem of flooding and coastal erosion has been given more attention by the Lagos State government in the form of a sea wall along Bar Beach in Victoria Island. This activity, however, is evidence that local awareness appears to be lacking of the full scope of the city’s vulnerability to climate change.

Although the attention of the city managers is more focused on filling its long physical infrastructural gap due to years of neglect, the lack of concern or awareness of likely sea level rise in Lagos is worrisome. There continues to be sand-filling of both the Lagos lagoon and the Ogun River flood plain in the Kosofe local government area to

about 2 meters above sea level for housing developments. Such activities need to be done with projections of sea level rise due to climate change as part of the planning process.

Emerging issues

Currently, the leading actor on climate change issues in the city is the Lagos State government, which has been influenced by its membership of the C40 Large Cities Climate Summit. Some of the mitigation actions being pursued by the Lagos State government in the city include:

1. Improvement of the solid waste dump sites that are notable point sources of methane—a greenhouse gas—emissions in the city.
2. The new bus rapid transport (BRT) mass transit system is already shopping for green technology to power vehicles in its fleet.
3. Commencement of tree planting and city greening projects around the city.
4. Proposed provision of 3 air quality monitoring sites for the city.

The full picture of the nature of climate change and variability, its magnitude and how it will affect the city is yet to be analyzed to support any informed adaptation actions. Thus, the climate risk reduction adaptation actions presently taken in the city are primarily spin-offs from the renewed interest of the city's management in reducing other risks and taking care of developmental and infrastructural lapses, rather than being climate change-driven. Some of these adaptation activities include:

1. The sea wall protection at Bar Beach on Victoria Island to protect the coastal flooding and erosion due to storm surges.
2. Primary and secondary drainage channel construction and improvement to alleviate flooding in many parts of the city.
3. Cleaning of open drains and gutters to permit easy flow of water and reduce flooding by the Lagos State Ministry of Environment Task Force locally referred to as "Drain Ducks."
4. Slum upgrade projects by the LMDGP project.
5. Awareness and education campaigns such as the formation of Climate Clubs in Primary and Secondary Schools in Lagos, and organisation of training sessions and workshops on climate change issues.

Due to the increasing activity in the Ogun State sector of the city, a regional master plan for the years 2005–2025 (Ogun State Government, 2005) has been developed for its management. However, the issue of climate change risks to infrastructures and the different sectors such water and wastewater (Iwugo et al., 2003), health, energy and the like is not yet reflected in the report.

"Normal" rainfalls are known to generate extensive flooding in the city largely because of inadequacies in the provision of sewers, drains and wastewater management even in government-approved developed areas. Consequently, an increase in the

intensity of storms and storm surges is likely to worsen the city's flood risks. Since the local governments are very close to the people and the communities threatened by climate risks, there is the need to create the awareness at the local government level. There is an urgent need to empower them intellectually, technically and financially to identify, formulate and manage the climate-related emergencies and disasters, as well as longer-term risks more proactively.

4.4 New York

With 8.2 million people, a \$1.1 trillion GDP (Bureau of Economic Analysis, 2008) and an operating budget of over \$40 billion, New York City is the largest city in the United States both in population and economic productivity (The City of New York, 2007, 2009). The distribution of wealth within the City, however, has been described as an "hourglass economy" where there is a shrinking of the middle class and growth in both the upper and lower-income populations (Rosenzweig & Solecki, 2001).

New York City is an archipelago with five boroughs spread out over three islands—Long Island, Manhattan and Staten Island—and the mainland of the United States (see Figure 32). Once a major manufacturing center, New York is now one of the world's most important international financial hubs. As a coastal city, most of New York City sits at a relatively low elevation with approximately 1 percent of the city below 3 meters (10 feet) (Rosenzweig & Solecki, 2001). Much of Manhattan's very low-lying land is home to some of the most important economic infrastructure in the world. Lower Manhattan, including the Wall Street financial district, and portions of both LaGuardia and John F. Kennedy airports sit at this low elevation.

New York City has a temperate, continental climate characterized by hot and humid summers as well as cold winters and consistent precipitation year round. Tables 5, 9, and 11 show the historic, observed weather conditions for temperature, precipitation, and sea level in New York City for the period 1900–2005. Using a baseline period of 1971–2000, these records show an average temperature of 12.7°C with precipitation averaging 109 to 127 centimeters per year. Recent climate trends show an increase in average temperature of 1.4°C since 1900 and a slight increase in mean annual precipitation (New York City Panel on Climate Change [NPCC], 2009).

As with other cities, climate change risks in New York City are a function of the hazards that the city faces, the vulnerability of its population and infrastructure to those hazards, and the adaptive capacity of the city to address climate change mitigation and adaptation needs. Hazards come in the form of increasing incidence of heatwaves, droughts and floods, and sea-level rise and associated storm surges. Adaptive capacity in New York City has been bolstered by the high-level adoption at the Mayoral and the State levels of the need to develop climate change adaptation strategies. Agencies, departments and public authorities are now developing and being provided with the tools necessary to undertake climate change mitigation and adaptation strategies.

Hazards

Each year New York City is susceptible to mid-latitude cyclones and nor'easters, which peak from November to April. These storms contribute greatly to coastal erosion of vital wetlands that help defend areas of the city from coastal flooding. Tropical cyclones (hurricanes) also have the potential to reach New York City usually during the months of August to September. There is some indication that intense hurricanes will occur more frequently in the future, but this is an area of active scientific research.

Based on climate model projections and local conditions, sea level is expected to increase by 4 to 12 centimeters by the 2020s and 30 to 56 centimeters by the 2080s (see Figure 21); when the potential for rapid polar icemelt is taken into account based on current trends and paleoclimate studies, sea level rise projections increase to between 104 to 140 centimeters (NPCC, 2009). With some of the world's most valuable and important economic activity taking place on Wall Street, the economy of the City, the United States, and arguably the world is vulnerable to the effects of enhanced coastal flooding due to sea level rise. The New York Stock Exchange is the largest stock exchange in the world (NYSE Euronext, 2009) and sits at an elevation of less than three meters (Rosenzweig & Solecki, 2001). The possibility of inundation during coastal storms is greatly enhanced with the projected effects of sea level rise.

Another hazard to New York City as a result of climate change is rising mean temperature, along with the associated increase in heat waves. The annual mean temperature in New York City has increased nearly 2°C since 1900 as seen in Figure 5 (NPCC, 2009). Climate models predict that the average temperature will increase between 1 to 1.5°C by 2020 and 2 to 4°C by the 2080s as seen in Figure 15 (NPCC, 2009). As defined by the New York Climate Change Task Force, a heat wave is any period of three straight days with a temperature over 32°C. The frequency of heat waves is projected to increase as the number of days over 32°C increases. These higher temperatures will also intensify the urban heat island in New York City, since urban materials absorb radiation throughout the daytime and release it during the night causing minimum temperatures to rise (Rosenzweig & Solecki, 2001; Kinney et al., 2008). These sustained, higher temperatures exacerbate the effects of heat on humans (Basu & Samet, 2002).

Inland floods and droughts are two more hazards that confront New York City. Climate models indicate that precipitation in New York City is likely to increase up to 5 percent by the 2020s and between 5 and 10 percent by the 2080s as seen in Figure 19 (NPCC, 2009). These increases are projected to come in the form of more intense rain events. This means more days without precipitation between larger and more intense storms. As extreme rain events are expected to increase in intensity while decreasing in frequency, many of the rivers and tributaries that flow through New York City and feed

into the bodies of water that surround the city may breach their banks more frequently as they will likely be unable to handle the volume of water flowing into them as runoff.

Droughts may also prove to be a hazard as a result of climate change if the period between rain events increases. A major concern is the New York City water supply, which is drawn from up to 100 miles north of the City. The higher levels of precipitation associated with climate change are expected to be offset by the greater rates of evaporation associated with temperature increase, thus increasing the likelihood of drought (NPCC, 2009).

Vulnerability

The impacts of these climate hazards are interconnected and affect many systems in New York City differently but simultaneously. Roadways and subways, as well as ferry ports, industries located along the coast, and wastewater treatment facilities are susceptible to inundation. More hot days will increase electricity demand to run cooling systems, thereby increasing CO₂ emissions. The erosion of natural defenses like coastal wetlands increases the likelihood of flooding of nearby neighborhoods and industries.

Different populations are more vulnerable than others and these vulnerabilities are frequently differentiated along the lines of inland vs. proximity to coast, young vs. old, and rich vs. poor. One key climate change vulnerability is related to air quality and human health, since degradation of air quality is linked with warmer temperatures. The production of ozone (O₃) and particulate matter with diameters below 2.5 micrometers (PM_{2.5}) in the atmosphere is highly dependent on temperature (Rosenzweig & Solecki, 2001). Therefore, increased temperatures are likely to make managing these pollutants more difficult. Both of these pollutants affect lung functioning with higher ozone levels being associated with increased hospital admissions for asthma (Figure 33). Further, the elderly and those suffering from heart and lung-related diseases have been shown to be more susceptible to the effects of heat, often resulting in death from heat stroke and heat-related causes (Knowlton et al., 2007).

New York City is vulnerable to heat waves and, as an archipelago, is particularly vulnerable to the effects of storm surge as a result of sea level rise. Projected sea level rise of 30 to 58 centimeters—or 104 to 140 centimeters, if rapid polar ice melt is considered—is not expected to inundate the city extensively; rather, the problem emerges when larger storms such as the 1-in-100 year storm, which are expected to become more frequent, produce a greater storm surge that will likely cause damaging floods (NPCC, 2009).

Certain populations are more vulnerable to the effects of heat and higher sea levels. Approximately 967,022 people in New York City are 65 or older and of those it is estimated that 43 percent are living with some sort of disability (US Census Bureau,

2008). These two factors contribute to the extreme vulnerability to heat of the elderly (Basu & Samet, 2002). According to the Department of Health for the City of New York, during the heatwave of 2006 over half of those who died in New York City were over age 65 and all but five people were known to have suffered from some type of medical condition (Department of Health and Mental Hygiene [DOHMH], 2006).

New York City is a densely city with approximately 10,380 people in each of its 305 square miles or 790 square kilometers (Department of City Planning, 2009). Within this area there are clear pockets of wealth and poverty. The majority of high per capita income households are concentrated along the eastern border of Central Park with other areas of high per capita income households located along the western edge of the Park and the western shore along the southern part of Manhattan (see Figure 34). The shore areas are primarily vulnerable to coastal flooding caused by the storm surge associated with the combined effects of an increased sea level and an extreme rain event.

The areas of low per capita income are in northern Manhattan, above Central Park, the borough of the Bronx and parts of Brooklyn. Sea level rise and coastal flooding are concerns for certain parts of these areas including Coney Island, Brighton Beach, and Jamaica Bay. One of the more recurring vulnerabilities for these populations is extreme heat and the diminished air quality that accompanies the heating trend that New York City has seen over the last 100 years and that is projected to continue. The US Census Bureau has estimated that for the period 2005–2007 about twenty percent of those in New York City were living below the poverty line as established by the US Government (US Census Bureau, 2008). During the heat wave of 2006, thirty-eight of those who died of heat stroke did not have a functioning air conditioning in their apartment (DOHMH, 2006).

Adaptive Capacity

The environment in which New York City makes climate change adaptation and mitigation decisions is highly complex. Due to shared regional transportation, water, and energy systems, the stakeholders in any decision include numerous local governments, multiple state governments, businesses and public authorities.

The foundation for tackling the challenges of climate change in New York City began in the mid-90s when the New York Academies of Science published, *"The Baked Apple? Metropolitan New York in the Greenhouse"* in 1996. Shortly thereafter, The Earth Institute at Columbia University, through the Center for Climate Systems Research (CCSR) released *"Climate Change and a Global City: The Potential Consequences of Climate Variability and Change"*, (Rosenzweig & Solecki, 2001). This report covered the Metro-East Coast Region and served as the first assessment of climate change and cities in the United States. In 2008, CCSR worked with the New York City Department of Environmental Protection to develop a sector specific climate assessment and action

plan for New York City's water system (New York City Department of Environmental Protection, 2008).

The New York City administration through its Office of Long-Term Planning and Sustainability created the NYC Climate Change Adaptation Task Force in 2008, which is now working with local experts, city departments and stakeholders to develop a comprehensive, integrated climate change risk assessment and adaptation plan for the critical infrastructure of the metropolitan region. The NYC Climate Change Adaptation Task Force is made up of representatives from over 30 city and regional departments and industries. The City administration also convened the New York Panel on Climate Change (NPCC) to provide expert information about climate change risks and adaptation. The NPCC is made up of climate change scientists, and experts from the legal field, insurance, telecommunications and transportation, and has provided the climate risk information needed to create actionable guidelines and plans for adapting the city's critical infrastructure for the projected effects of climate change (NPCC, 2009). The NPCC has also worked with the NYC Climate Change Adaptation Task Force to develop a common set of definitions for adaptation assessment.

The next step is to begin planning and making specific adaptation investments across the city. In the past in New York City, this has tended to be on a project basis and so has been less coordinated across sectors. Having brought decision-makers from all key departments in the city and from numerous sectors, the New York City climate change adaptation process is helping to facilitate more open avenues of communication and coordination within and among departments.

4.5 Across-City Findings

As the various scholars applied the risk framework to their cities, a combination of local factors revealed very specific climate risks confronting each city; however, there are some common threads as well (see Table 22). This summary table also provides the basis for developing a city climate risk assessment index. First, a multidimensional approach to risk assessment is essential as was observed in all four cities. Second, despite lack of data, climate risks can be articulated as especially demonstrated by the cases of Lagos and Delhi. Third, there are substantial mismatches between needs and responses—who mitigates, how much adaptation, and why, remain serious concerns. For instance Delhi, despite its extremely high risk due to its large vulnerable population is now focusing primarily on mitigation, as does Buenos Aires. Fourth, as observed in all cities vertical and horizontal fragmentation of urban governance is a challenge. As in the case of Delhi, however, such distributed jurisdictions may offers an opportunity. In Delhi, the Environment Ministry is an early adopter of pro-active climate change responses and is thus providing an entry point for systemic change. Finally, there are the oft-noted challenges for the climate scientists to provide credible downscaled risk

information on regionally-crucial climate dynamics such as potential changes in the Indian Monsoon. We also found, however, that effective adaptation planning can start with the climate risk information available now. For a programmatic approach for risk assessment and adaptation planning where an institutional structure is articulated see Annex 4 (Mehrotra, 2009).

5.0 LESSONS FOR DEVELOPING COUNTRIES AND KNOWLEDGE GAPS

Three initial lessons are summarized. *First, a multidimensional approach to risk assessment is a prerequisite to effective urban development programs that incorporate climate change responses.* At present most climate risk assessment is dominated by an over-emphasis on climate hazards. The application of the climate risk framework developed in this paper provides more nuanced and more actionable insights into the differential risks depending on the exposure to hazards on the spectrum of vulnerabilities of urban households, neighborhoods, and firms—for instance, from the most vulnerable slums in flood plains where infrastructure is lacking—and the adaptive capacity of local governments. However, a critical issue that requires further research is identifying when strategic retreat may be more cost-effective than adaptation and under what socio-economic conditions is it desirable and feasible.

Second, mismatches between needs and responses are occurring in regard to who should mitigate, how much to adapt, and why. Cities need climate change risk assessment in order to decide for themselves what is the right mix between mitigation and adaptation. Climate change risk frameworks, such as those described in this paper, can help cities to address the issue of mismatches, that is, the difference between the city's response to climate change as opposed to the actual needs. For example, it appears that some developing countries may be over-focusing on mitigation when they could be focusing more on adaptation due to the presence of critical climate risks in the near-term as well as in future decades. The seventeen largest economies account for most of the greenhouse gas emissions, the root cause of climate change (US Department of State, 2009). And while many cities within these major economies have a significant role in mitigation, it may be prudent for cities in low-income countries with large populations of poor households to incorporate climate risk into ongoing and planned investments as a first step (Mehrotra, 2009). However, since cities play an important role in greenhouse gas emissions in both developed and developing countries, there is also motivation for cities to lead on mitigation activities as well. Emissions from cities everywhere burden the environment, which is a global public good, and thus can be regulated through a combination of market and non-market incentives at the urban scale.

Third, the vertically and horizontally fragmented structure of urban governance is as much an opportunity as an obstacle to introducing responses to climate change. While much has been researched about the need for an integrated and coordinated

approach, the fragmented governance structure of cities is unlikely to change in the short term and offers the opportunity to have multiple agents of change. Examples in the case study cities show that early adopters on climate change solutions play an important role. The broad spectrum of governmental, civil society, and private sector actors in cities encourages a broader ownership of climate change adaptation programs.

Further, gaps and future research for scaled-down regional and local climate models were identified. In addition to the difficulties global climate models have with simulating the climate at regional scales, especially for locations with distinct elevational or land-sea contrasts, they also continue to have difficulty simulating monsoonal climates. Such is this case for climate projections for some of the case study cities in this paper, especially related to projected changes in precipitation. This is because simulation of seasonal periods of precipitation is challenging in terms of both timing and amount; in some cases the baseline values used for the projection of future changes are extreme—either too high or too low. Therefore, the percentage change calculated, vary greatly and can, on occasions, have distorted values. Especially for precipitation projections, the future trends may appear to be inconsistent compared to observed data, because the averages from the baseline period to which the projected changes were added onto are inaccurate, either due to a lack of data or extreme values within the time period that are skewing the averages. The inability of the global models to simulate the climate of individual cities raises the need for further research on regional climate modeling.

However, what is important to focus on in these future climate projections is the general trends of the projected changes and their ranges of uncertainty. These refers to attributes such as increasing, decreasing, or stable trends, and information about the uncertainty of projections in particular due to climate sensitivity or greenhouse gas emission pathways through time. Information on climate model projections regarding the extreme values and the central ranges both provide useful information to city decision-makers.

5.1 Other Concerns, What Next

Even as climate risk assessment frameworks as described in this paper are developed and implemented, a multitude of further concerns and questions immediately arise regarding climate change challenges for cities, pointing the way towards further research and policy development. These include:

- Ethical questions about what levels of government and what combination of stakeholders should (and in practice will) prioritize the actions on climate-related concerns where uncertainty at the local level remains high and the awareness among the poor and vulnerable sub-groups is low. How can cities address the specific needs of the most vulnerable sections of its inhabitants—the urban poor? Especially, as these sub-groups lack access to basic services and live in

vulnerable shelters, and on disaster prone land—flood plains and the like—further environmental stress can be catastrophic for the slum dwellers.

- How can mega-cities in developing countries do a holistic assessment of the potential risk due to climate-change, plan complementary mitigation strategies and adaptive resilience that do not remain mere recommendations in reports but lead to action? The lack of a climate-change strategy for the city increases the risk of the already vulnerable urban poor—how can this neglect of the poor be addressed in the broader climate and city debate? As Delhi has introduced CNG-fueled public transportation as a mitigation measure, what are the strategic interventions—short-gestation, low-cost, high-impact—that facilitate large-scale adaptation to reduce the economic, social, and environmental risk to cities, particularly the poor?
- How can city infrastructure—public transport, water, electricity—and social institutions for public health or disaster management be retrofitted to adapt to climate change? How can a city craft a flexible and calibrated approach towards adaptive resilience?
- How can cities develop an institutional response to climate change with complementary strategies for mitigation and adaptation that result in action on the ground? What strategies work for vertical coordination among national, regional, and local policy efforts? Moreover, how can horizontal co-operation be fostered resulting in collaborative action across stakeholders and between departments and agencies at the city level, and across cities nationally and internationally?

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Annex 1: Tables

Table 1. Scaling down climate risk models

Scale	Models and Data
Global Climate Scenarios	<ul style="list-style-type: none"> • SRES greenhouse gas emission pathways • GCM simulations
Local Climate Change Information	<ul style="list-style-type: none"> • Observed data • Quantitative GSM-based projections • Qualitative GCM-based projections
Climate Risk Factors	<ul style="list-style-type: none"> • Hazards, vulnerabilities, and adaptive capacities

Source: Authors' compilation

Table 2: Buenos Aires Baseline and Projected Air Temperature and Precipitation

	Baseline 1971-2000	2020s	2050s	2080s
Air Temperature Central Range ¹⁵	17.8° C	+ 1 to 1.5° C	+ 1.5 to 3° C	+ 2 to 4° C
Precipitation Central Range	1120 mm	- 5 to + 10 percent	+ 0 to 15 percent	+ 5 to 20 percent

Source: Center for Climate Systems Research, Columbia University

Table 3: Delhi Baseline and Projected Air Temperature and Precipitation

	Baseline 1971-2000	2020s	2050s	2080s
Air Temperature Central Range	25.0° C	+ 1 to 1.5° C	+ 1.5 to 2.5° C	+ 2.5 to 4.5° C
Precipitation Central Range	760 mm	-10 to + 20 percent	- 15 to + 35 percent	- 15 to + 35 percent

Source: Center for Climate Systems Research, Columbia University

Table 4: Lagos Baseline and Projected Air Temperature and Precipitation

	Baseline 1971-2000	2020s	2050s	2080s
Air Temperature Central Range	27.3° C	+ 0.5 to 1° C	+ 1 to 2° C	+ 2 to 3° C
Precipitation Central Range	1690 mm	- 5 to + 5 percent	- 5 to + 5 percent	-10 to +10 percent

Source: Center for Climate Systems Research, Columbia University

¹⁵ Central range = middle 67 percent of values from model-based probabilities; temperature ranges are rounded to the nearest half-degree, precipitation to the nearest 5 percent, and sea level rise to the nearest inch.

Table 5: New York City Baseline and Projected Air Temperature and Precipitation

	Baseline	1971-2000 ¹⁶	2020s	2050s	2080s
Air Temperature Central Range ¹⁷		12.8° C	+ 1 to 1.5° C	+ 1.5 to 3° C	+ 2 to 4° C
Precipitation Central Range ²		1180 mm	+ 0 to 5 percent	+ 0 to 10 percent	+ 5 to 10 percent
Sea Level Rise¹⁸ Central Range ²		NA	+ 4 to 12 cm	+ 15 to 29 cm	+ 30 to 56 cm

Source: Center for Climate Systems Research, Columbia University

Table 6: Three Vectors of Urban Climate Risk

Hazards	Vulnerability	Adaptive Capacity
1. Temperature 2. Precipitation 3. Sea-level 4. Tropical cyclone 5. Drought 6. Heat waves	1. Population 2. Density 3. percent slum population 4. percent of urban area susceptible to flooding	<i>Institutions and Governance</i> 1. Urban governance (corruption index ranking for city) 2. City leadership is willing to address climate change <i>Information and Resources</i> 3. Comprehensive analysis of climate risks for the city 4. Administrative unit assigned to address climate change

Source: Authors' compilation

Table 7: Demographics for the Case Study Cities (Metropolitan Area)

Metropolitan area	Population	Area	Population density	Slum population as a percentage of national urban population
Buenos Aires	12.0 million	3,833 km ²	3,131 people per km ²	26.2 percent
Lagos	7.9 million	1,000 km ²	7,941 people per km ²	65.8 percent
New Delhi	12.9 million	9,745 km ²	1,324 people per km ²	34.8 percent
New York	8.2 million	790 km ²	10,380 people per km ²	N.A.

Sources: Authors' compilation from city, state, and national statistics and census bureaus of Argentina, India, Nigeria, and United States; slum data from UN Habitat, 2008.

¹⁶ Data from National Weather Service (NWS) and National Oceanic and Atmospheric Administration (NOAA). Temperature data are from Central Park; precipitation data are the mean of the Central Park and LaGuardia Airport values; and sea level data is from the Battery at the southern tip of Manhattan (the only location in NYC for which comprehensive historic sea level rise data are available).

¹⁷ Central range = middle 67 percent of values from model-based probabilities; temperature ranges are rounded to the nearest half-degree, precipitation to the nearest 5 percent, and sea level rise to the nearest inch.

¹⁸ The model-based sea level rise projections may represent the range of possible outcomes less completely than the temperature and precipitation projections.

Table 8: Greater Buenos Aires Agglomeration¹⁹ (AGBA)

	Population* (2001)	Area** (square kilometer)	Total Area** (square kilometer)	Density (people/ square kilometer)
Metropolitan Area (AGBA, including Buenos Aires City)	12.045.921		6.078	1.982
Buenos Aires Autonomous Region, Ciudad Autónoma de Buenos Aires (CABA)	2.768.772	202		13.707
30 Administrative units within AGBA (partidos)	9.277.149		5.876	
14 units with all population and area within AGBA	4.611.266		827	5.576
Lomas de Zamora	590.677	89		6.637
Quilmes	518.723	125		4.150
Lanús	452.512	45		10.056
General San Martín	405.122	56		7.234
Tres de Febrero	335.578	46		7.295
Avellaneda	329.638	55		5.993
Morón	309.086	56		5.519
San Isidro	293.212	48		6.109
Malvinas Argentinas	290.530	63		4.612
Vicente López	273.802	39		7.021
San Miguel	253.133	80		3.164
José C. Paz	229.760	50		4.595
Hurlingham	171.724	36		4.770
Ituzaingó	157.769	39		4.045
10 units with partial population and area within AGBA and administrative GBA	4.051.805		2.800	1.447
La Matanza	1.253.858	323		3.882
Almirante Brown	513.777	122		4.211
Merlo	468.724	170		2.757
Moreno	379.801	180		2.110
Florencio Varela	343.238	190		1.807
Tigre	295.561	360		821
Berazategui	287.642	188		1.530
Esteban Echeverría	243.715	120		2.031
San Fernando	147.409	924		160

¹⁹ Agglomerado Gran Buenos Aires (Greater Buenos Aires Agglomeration, AGBA) is defined by the National Statistical Office (INDEC) as the metropolitan region that includes all surrounding urban population as far as the contiguous urban agglomeration sprawls. These include the CABA plus 30 partidos (administrative units) of the Buenos Aires Province, that are entirely or partially included in urban expanse. Furthermore, there are additional fringe administrative unites that are yet to be included in the AGBA), for example La Plata and Cañuelas. Finally, the Great Buenos Aires (GBA) includes 24 administrative units—the "partidos"—of Buenos Aires Province, as defined by INDEC in the 2001 Census.

Ezeiza	118.080	223		530
6 units with partial population and area within AGBA	605.047		2.249	269
Pilar	228.724	355		644
Escobar	172.494	277		623
General Rodríguez	64.017	360		178
Presidente Perón	59.592	121		492
San Vicente	40.801	666		61
Marcos Paz	39.419	470		84

Source: Instituto Nacional de Estadística y Censos, 2003, (*); Censo Nacional de Población 2001; (**)

<http://www.ec.gba.gov.ar/estadistica/ftp/Bs.As2001-2005/pobla.htm>

Table 9: Climate parameters for the metropolitan area of Buenos Aires

Annual temperature	Mean	Annual thermal range	Relative humidity	Average precipitation
17 to 18°C		13.1°C-14.2°C	72 percent	1,200 mm; (E-NE winds in summer; SW in winter)

Source: Servicio Meteorológico Nacional, 2008

Table 10: Seasonal climate parameters for Argentina

Season	Mean temperature	Twentieth Century thermal extremes	Relative humidity	Average precipitation
Winter	11.5°C	-5.4°C/ 33.7°C	80 percent	198.7 mm
Spring	17.3°C	-2.4°C/36.8°C	66 to 70 percent.	300.9 mm; (frequent hail storms)
Summer	23.6°C	3.7°C/43.3°C	63 percent - 68 percent; occasionally over 80 percent	341.6 mm; ("heat wave" lasting 2 to 8 days, and NE winds NE at 14 km/hr)
Autumn	17.8°C	-4.0°C/ 37.9°C	72 percent to 77 percent	304.7 mm (NE and N winds) 13 km/hr

Source: Servicio Meteorológico Nacional, 2008

Table 11: Extreme events in Buenos Aires

City	Extreme temperatures	Extreme precipitation
Buenos Aires	January & February 1987; December & January 1988; December & January 1996–97; January & February 2001; January 2002; January 2003; January 2004; December 2004	March 1988; May 2000; February 2003

Source: Center for Climate Systems Research, Columbia University

Table 12: Frequency of water levels above mean sea level at the Buenos Aires port

Frequency (years)	Height (meters)
2.5	2.50
5	2.80
11	3.10
27.5	3.40
79	3.70
366	4.00

Source: Barros et al., 2008.

Table 13: Slum population in Buenos Aires City (CABA)

Housing types by building quality	Number of units
Slums (villas miseria)	< 120,000
Properties of other people (inmuebles tomados)	200,000
Trenement house (casas de inquilinato)	70,000
Lodges	70,000
Rooms in relatives' houses, rental rooms, or overcrowded houses	120,000

Source: Office of the National Ombudsman, Buenos Aires, 2006

Table 14: Climate Change Projections for India

Year	Temperature Change (°C)			Precipitation Change (%)			Sea Level Rise (cm)
	Annual	Winter	Monsoon	Annual	Winter	Monsoon	
2020s	1.36±0.19 (1.06±0.14)	1.61±0.16 (1.19±0.44)	1.13±0.43 (0.97±0.27)	2.9±3.7 (1.05±3.7)	2.7±17.7 (-10.1±10.0)	2.9±3.7 (1.05±3.7)	4 to 8
2050s	2.69±0.41 (1.92±0.20)	3.25±0.36 (2.08±0.85)	2.19±0.88 (1.81±0.57)	6.7±8.9 (-2.36±7.1)	-2.9±26.3 (-14.8±18.9)	6.7±8.9 (-2.36±7.1)	15 to 38

Source: Aggarwal & Lal, 2001; also in Revi, 2007

Note: These statistics are based on an ensemble of four A-O GCM outputs. Numbers in bracket are for the GHG+aerosol forcing experiments while those outside are for GHG only forcing experiments.

Table 15: Past extreme events in Delhi

City	Extreme temperatures	Extreme precipitation
New Delhi	May 1978; April 1988; May 1996	July 1994; July 1995; June 2003

Source: Center for Climate Systems Research, Columbia University

Table 16: Extreme temperature and precipitation in Delhi

	Maximum recorded temperature	Lowest recorded temperature	Maximum rainfall in 24 hours
Delhi	47.2 °C May 29, 1944	-00.6 January, 16, 1935	266.2 mm July 21, 1958

Source: Indian Meteorological Department, Regional Meteorological Center, Delhi.

Retrieved January 10, 2009, from <http://121.241.116.157/dynamic/weather/metfact.html>

Table 17: Extreme Events in Lagos

City	Extreme temperatures	Extreme precipitation
Lagos	March 1988; March 1990; February 1998; March 1988; March 2001; March 2002; February 2003; March 2003; August 2004	May 1958; June 1962; July 1968; August 1998; November 1998

Source: Center for Climate Systems Research, Columbia University

Table 18: Projected Land Erosion and Inundation by Sea Level Rise (SLR) Scenarios in Lagos

	Low estimate (in meters)				High estimate (in meters)			
SLR	0.2m	0.5m	1.0m	2.0m	0.2m	0.5m	1.0m	2.0m
Shoreline types in square kilometers								
<i>Barrier</i>	177	284	584	1167	118	289	602	1204
<i>Mud</i>	403	1008	2016	3456	403	1008	2016	3456
<i>Delta</i>	2846	7453	15125	18398	2865	7500	15332	18803
<i>Strand</i>	79	197	395	575	85	212	446	677
<i>Total</i>	3445	8942	18120	23596	3471	9009	18396	24140

Source: Awosika et al., 1992

Table 19: Estimation of Internally Displaced People by Sea Level Rise Scenarios in Lagos

(in meters)				
Sea Level Rise Scenarios	0.2 m	0.5 m	1.0 m	2.0 m
By shoreline types, number of people displaced (in millions)				
<i>Barrier</i>	0.6	1.5	3.0	6.0
<i>Mud</i>	0.032	0.071	0.140	0.180
<i>Delta</i>	0.10	0.25	0.47	0.21
<i>Strand</i>	0.014	0.034	0.069	0.610
<i>Total</i>	0.75	1.86	3.68	10.00
<i>Percentage of Total Population</i>	0.07	1.61	3.20	8.70

Source: Awosika et al., 1992

Table 20: Population distribution of the constituting local government areas of the Lagos Megacity

Local Government Area	State	Census 2006	Total area	Built-up Area	Population Density	Population Density of Built-up Area
Agege	Lagos	459,939	11.10481	10.69055	41,418	43,023
Ajeromi/Ifelodun	Lagos	684,105	12.22944	11.36309	55,939	60,204
Alimosho	Lagos	1,277,714	183.61363	143.84956	6,959	8,882
Amuwo Odofin	Lagos	318,166	133.44068	41.54252	2,384	7,659
Apapa	Lagos	217,362	26.44117	13.90495	8,221	15,632
Eti Osa	Lagos	287,785	193.47395	84.07192	1,487	3,423
Ifako/Ijaye	Lagos	427,878	26.38935	25.27185	16,214	16,931
Ikeja	Lagos	313,196	45.78036	40.13424	6,841	7,804
Ikorodu	Lagos	535,619	390.96523	74.32418	1,370	7,207
Kosofe	Lagos	665,393	80.75072	33.64824	8,240	19,775
Lagos Island	Lagos	209,437	8.59056	5.28071	24,380	39,661
Lagos Mainland	Lagos	317,720	19.81438	11.28527	16,035	28,154
Mushin	Lagos	633,009	17.33567	17.21586	36,515	36,769
Ojo	Lagos	598,071	156.75289	63.22544	3,815	9,459
Oshodi/Isolo	Lagos	621,509	44.38370	34.57862	14,003	17,974
Shomolu	Lagos	402,673	11.45639	10.31107	35,148	39,053
Surulere	Lagos	503,975	22.80968	21.52606	22,095	23,412
Lagos State Side		8,473,551	1,385.33261	642.22412	6,117	13,194
Ado Odo/Ota	Ogun	526,565	869.58338	97.66340	606	ND
Ifo	Ogun	524,837	516.70853	86.82293	1,016	ND
Obafemi Owode	Ogun	228,851	1,398.73443	19.40536	164	ND
Shagamu	Ogun	253,412	609.32607	25.90021	416	ND
Ogun State Side		1,533,665	3,394.35241	229.79190	452	ND

Source: Census, Government of Nigeria, 2006

Table 21: Baseline Climate and Mean Annual Changes for New York City Relative to Baseline Years for New York City²⁰

	Baseline 1971-2000 ²¹	2020s	2050s	2080s
Air Temperature Central Range²²	12.8° C	+ 1 to 1.5° C	+ 1.5 to 3° C	+ 2 to 4° C

²⁰ Based on 16 GCMs (7 GCMs for sea Level Rise) and 3 emissions scenarios (low, medium, and high).

²¹ Data from National Weather Service and National Oceanic and Atmospheric Administration (NOAA). Temperature data are from Central Park; precipitation data are the mean of the Central Park and LaGuardia Airport values; and sea level data is from the Battery at the southern tip of Manhattan (the only location in NYC for which comprehensive historic sea level rise data are available).

²² Central range = middle 67 percent of values from model-based probabilities; temperature ranges are rounded to the nearest half-degree, precipitation to the nearest 5 percent, and sea level rise to the nearest inch.

Precipitation Central Range ⁸	1180 mm	+ 0 to 5 percent	+ 0 to 10 percent	+ 5 to 10 percent
Sea Level Rise ²³ Central Range ⁸	NA	+ 4 to 7 in	+ 9 to 14 in	+ 16 to 25 in

Source: Center for Climate Systems Research, Columbia University

Table 22. Risk-Response Summary of the Four Case Study Cities and the Kernels of a City Climate Risk Index

Hazards	Buenos Aires	Delhi	Lagos	New York City
Temperature observed trend and projections for 2050s	~2°C warming since 1900 (statistically significant at an alpha level of 0.05); 1°C to 1.5°C projected warming	Slight warming since 1900; 2006 0.2°C, lowest temp since 1935; 2007 44.9°C, highest recorded temp; 1.5°C to 2.5°C projected warming	About 1°C warming since 1900 (statistically significant at an alpha level of 0.05); Warmer period since 1990; 1°C to 2°C projected warming	Slight warming trend since 1900 (statistically significant at an alpha level of 0.05); 1.5°C to 3°C projected warming
Precipitation observed trend and projections for 2050s	22.8 millimeters per decade increase since 1900 (statistically significant at an alpha level of 0.05); projected change in precipitation uncertain: 0 to 15% increase	14 millimeters per decade increase since 1900 with large variability; projected change in precipitation uncertain: -15% to +35%	Slight decrease since 1900 with large variability; projected change in precipitation uncertain: -5% to 5%	17 millimeters per decade increase since 1900 with large variability (statistically significant at an alpha level of 0.05); projected change in precipitation uncertain: + 0 to 10%
Sea level rise observed trend and projections for 2050s	Since 1900 average water level of La Plata River increased 1.7 millimeters per year; since 1960 increased frequency of storms causing coastal flooding up to 2.8–5 m above mean sea level	Non-coastal city; experiences local flooding during monsoons	Oct 1992-Dec 1996 mean sea-level rise observed; Projected rise: 12 to 17 centimeters	3 centimeters per decade increase in mean sea level (statistically significant at an alpha level of 0.05); projected rise: 4 to 56 centimeters
Extreme events	Precipitation >100 mm/day increased from 19 times (1911–1970) to 32 times (1980–2000)	Extreme precipitation July 1994, July 1995, June 2003; extreme temperature May 1978, April 1988, May 1996; faces inland flooding due to intense precipitation during monsoons	Extreme precipitation May 1958, June 1962, July 1968, August 1998, November 1998; extreme temperature March 1988, March 1990, February 1998, March 1988, March 2001, March 2002, February 2003, March 2003, August 2004	Since 1900, seven of the ten years with most days over 32°C have occurred since 1980
Vulnerability				
Population	12 million (2001); ~10% of the Argentinean population	16 million; 500,000 added per year	18 million (2010); 600,000 added per year	8.2 million
Density	1,982/km ²	1,400/km ²	164/km ² to 60,204/ km ²	10,380/ km ²

²³ The model-based sea level rise projections may represent the range of possible outcomes less completely than the temperature and precipitation projections.

Percent poor or slum dweller	~20% of the greater Buenos Aires agglomeration	1.5 million live below poverty line; 45% live in unregulated settlements	70%; \$650 million annual budget; lacks basic infrastructure	18.9% below poverty line defined by US Government
Percent of urban area (or population) susceptible to flooding	450,000 people live in flood-prone areas; 25% of city is flood-prone; annual flood damage to property estimated at US\$30 million, projected to US\$300 million by 2070	~7% (Delhi Disaster Management Authority) 3 million people live along Yamuna River prone to floods	Significant proportion of the city is located on land that is less than 5 meters above mean sea level; 1m of sea level rise will displace 3.6 million people	1% of New York City land area is less than three meters above mean sea level (Rosenzweig & Solecki, 2001)
City % of national GDP	~50%; US\$245 billion (2005 PPP ²⁴ , Price Waterhouse Coopers, 2007 ²⁵); 2006 US\$494.5 billion (2006 PPP, CIA World Fact Book); CABA ~24%; 2006 Geographic Gross Product ~US\$50 billion; Service sectors is 80 percent of local economy	~3.3%, US\$ 93 Billion (2005 PPP Price Waterhouse Coopers, 2007) US\$2,812 billion (2006 PPP, CIA World Fact Book); >2% of 2007 GDP of India (2007 \$27 Billion Gross State Domestic Product)	~10%; US\$30 Billion (2005 PPP Price Waterhouse Coopers, 2007); US\$299.5 billion (2006 PPP, CIA World Fact Book)]	~8.2%; US\$1,133 billion (2005 PPP, Price Waterhouse Coopers, 2007) US\$13,830 billion (2006 PPP, CIA World Fact Book)]
Adaptive Capacity				
Institutions and governance measures affecting climate change actions²⁶	CPI Country Ranking ²⁷ 109; Score 2.9	CPI Country Ranking 85; Score 3.4; action oriented; fragmented jurisdictions	CPI Country Ranking 121; Score 2.7; fragmented jurisdictions; centralized decision-making; local needs neglected	CPI Country Ranking 18; Score 7.3; Office of Long-term Planning and Sustainability provides coordination; multiple (>1,000) jurisdictions in metropolitan area
Willingness of City leadership to address climate change	Member C40 Large Cities Climate Leadership Group	Member C40 Large Cities Climate Leadership Group; People action for right to clean air; Supreme Court judgment requiring fuel switch in public transport;	Member C40 Large Cities Climate Leadership Group;	Member C40 Large Cities Climate Leadership Group; Host of second C40 Summit, 2007; Mayoral endorsement and active

²⁴ Purchasing power parity (PPP) is “[a] method of measuring the relative purchasing power of different countries’ currencies over the same types of goods and services. Because goods and services may cost more in one country than in another, PPP allows us to make more accurate comparisons of standards of living across countries” (The World Bank Group, 2009).

²⁵ Source: City Mayor Statistics, <http://www.citymayors.com/statistics/richest-cities-2005.html>

²⁶ Urban Governance Index is presently under development by UN-Habitat. Transparency International’s country ranking of the National Corruption Perception Index (CPI) (2008) is used as a substitute for the purpose of illustration

²⁷ Country ranking of the National Corruption Perception Index (CPI) is measures where higher score implies less perceived corruption, the range of scores is between 1 and 10; about 180 countries are ranked in order of least corrupt to most, for details see

http://www.transparency.org/news_room/in_focus/2008/cpi2008/cpi_2008_table

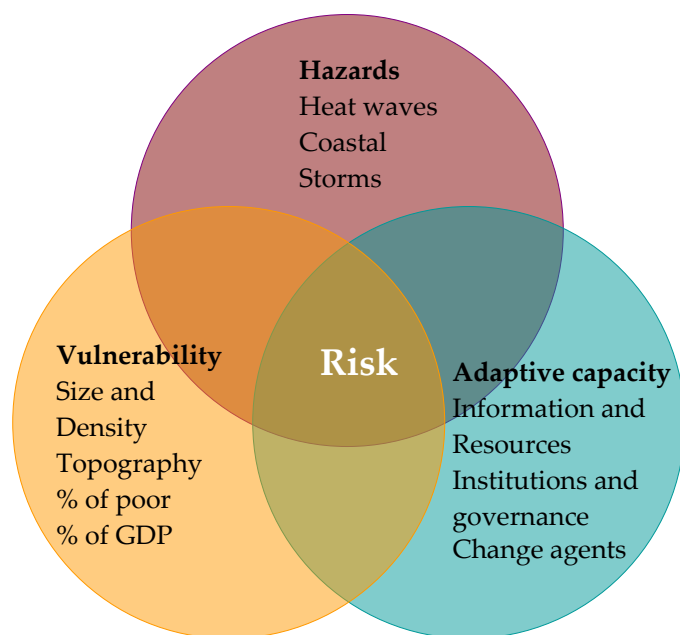
		Government of Delhi steps up to challenge—world's largest fleet of CNG-operated public transport; introduction of BRTS, and Delhi Metro		collaboration between city government and resident climate experts and institutions
Information and resources comprehensive analysis of climate risks for the city	Government supports range of research programs, such as National Program on Climate Scenarios, initiated in 2005; first and second national plans prepared in 1997 and 2006. Third version under preparation.	National action plan on climate change prepared in June 2008, but Delhi specific risk assessment lacking	Preliminary climate impact assessment (Ekanade et al., 2008) not linked to infrastructure investment; Information on sea level rise not linked to action	Comprehensive Risk Information has been prepared by New York Panel on Climate Change (NPCC). NPCC has conducted in-depth climate risk analysis for infrastructure for NYC Climate Change Adaptation Task Force
Administrative unit assigned to address climate change	In 2003 Climate Change Unit was established within the Ministry for Environmental and Sustainable Development; in 2007, this evolved into Climate Change Office.	Mitigation efforts led by the Ministry of Environment in close collaboration with Chief Minister of Delhi.	Lagos State Urban Renewal Authority (LASURA); World Bank.	Office of Long-term Planning and Sustainability established in September, 2006, and reports directly to Mayor
Balance between adaptation and mitigation	<i>Mitigation >> Adaptation</i> Dominated by mitigation efforts to reduce greenhouse gas emissions, neglect of adaptation despite high flood risk	<i>Mitigation >> Adaptation</i> Emphasis only on mitigation, (CDMs for landfills, electricity generation, <i>bhagidari</i> program for community participation, 1.7 million trees planted in 2007); adaptation needs neglected however implicit co-benefit from city greening for adaptation	<i>Mitigation > Adaptation</i> Primarily focused on mitigation like GHG emission reduction from solid waste, introduction of BRTS, a mass transit system, tree planting; adaptation not a focus, but co-benefits from other infrastructure investments	<i>Mitigation = Adaptation</i> City is proactively pursuing mitigation and adaptation responses
Risk	Medium	High	Very High	Low
	<i>Climate Hazards:</i> Sea-level rise and coastal flooding <i>Vulnerability:</i> Rapidly growing urban development with some encroachment onto the flood plain, lack adaptation planning and investments <i>Adaptive capacity:</i> lack of coordination and consistency in government initiatives	<i>Climate Hazards:</i> Heatwaves, inland flooding <i>Vulnerability:</i> large population of poor lacking basic services and land tenure living in unregulated settlements, lack adaptation planning and investments <i>Adaptive capacity:</i> active civil society and judiciary, and leadership by Chief Minister of Delhi	<i>Climate Hazards:</i> Sea-level rise and coastal flooding <i>Vulnerability:</i> very large population of slum dwellers living in coastal areas prone to storm surge and flooding; lack of adaptation planning and investment <i>Adaptive capacity:</i> lack of dedicated institutional support for climate risk reduction	<i>Climate Hazards:</i> Sea-level rise, coastal and inland flooding; heatwaves; <i>Vulnerability:</i> Resources, including insurance, available to plan and implement adaptations <i>Adaptive capacity:</i> Mayor actively leads efforts to address climate change with institutional support to the office of long-term planning
Response				
	Conflicting plans, multiple jurisdictions	Mitigation is focus; lack of awareness about need	Lagos State government is leading actor on	Climate Change Task Adaptation Task Force

	reduce efficacy; lack of consistent, coordinated response; primary obstacles: lack of actionable climate information, vertical and horizontal fragmentation; divergent interests and responses	for adaptation. Response is piecemeal because efforts are project-oriented. Incentives — subsidies and grants — have been effective for initiating projects, but operation and management remain neglected	climate change, which has been influenced by its membership in C40 Large Cities group; Initial studies of climate change risks but results have yet to inform ongoing and planned investments in infrastructure and slum upgrading	and its advisory body the New York City Panel on Climate Change are identifying mechanisms for leveraging planned and ongoing infrastructure investments to incorporate climate risk into decisions. PlaNYC set mitigation target of 30% reduction of CO ₂ emissions from 2005 levels by 2017
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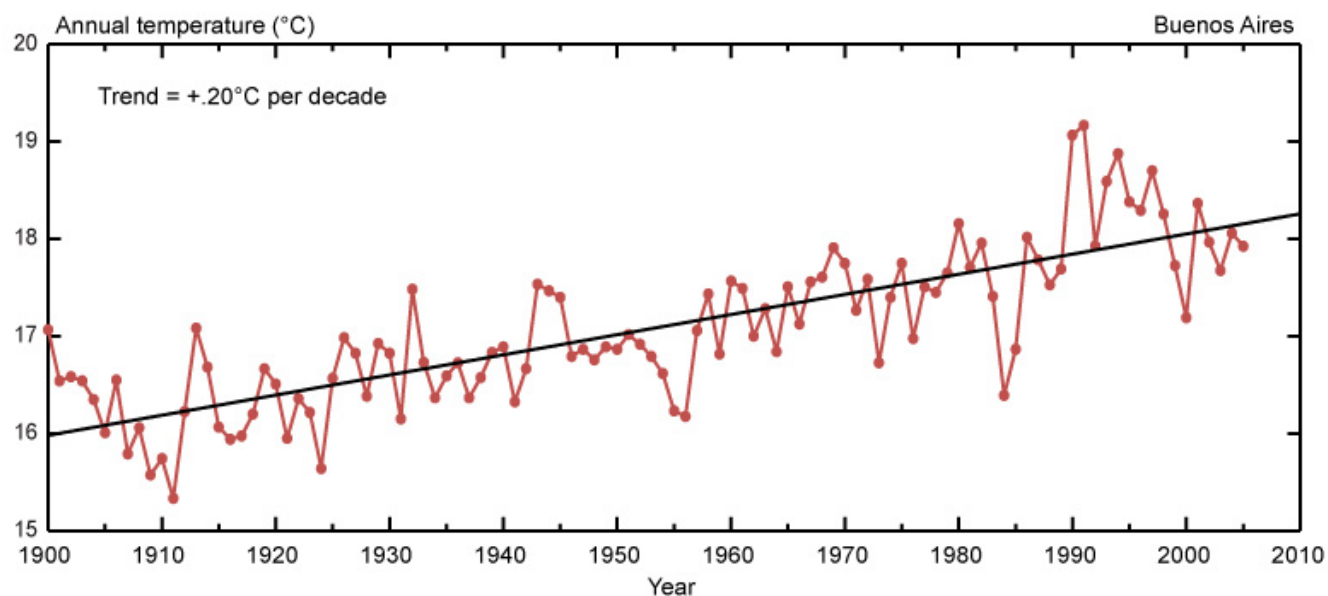
Source: Authors' analysis

Annex 2: Figures

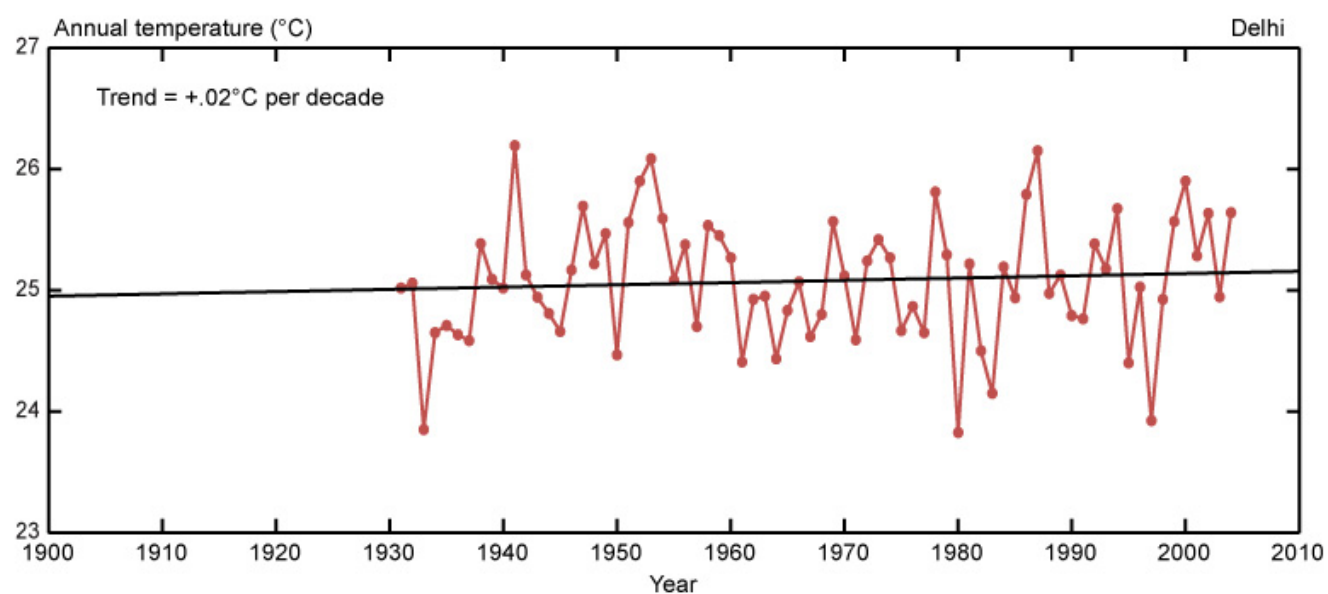
Figure 1: Framework for Urban Climate Risk Assessment



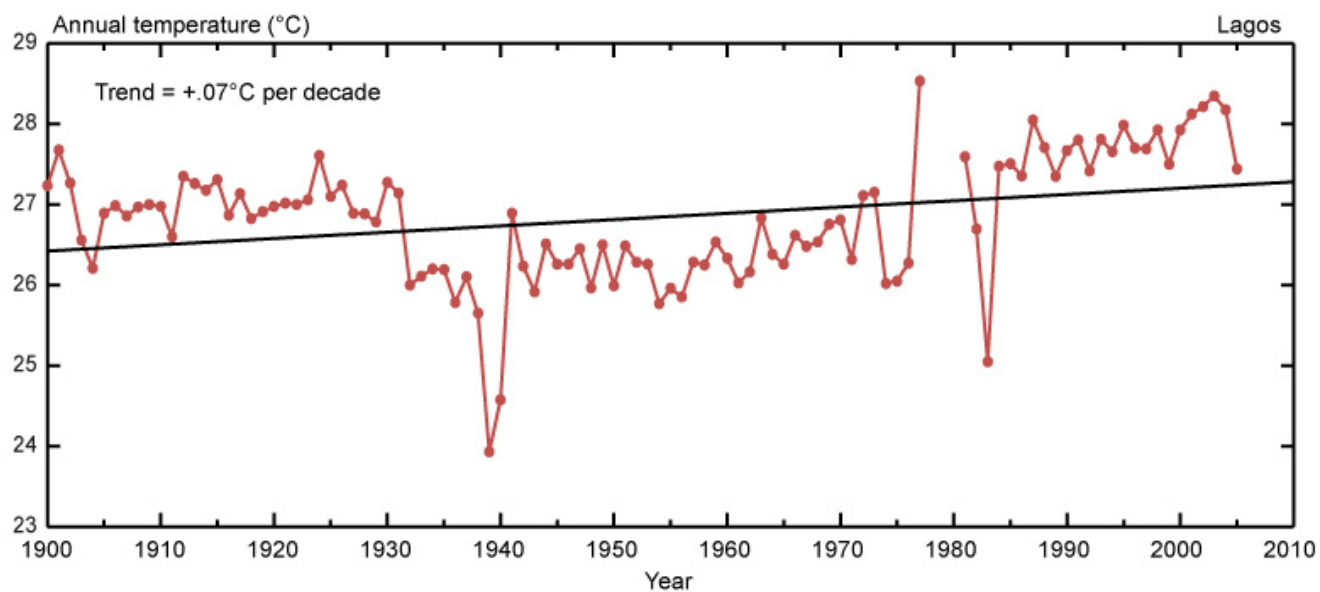
Source: Adapted from Mehrotra (2003) and Rosenzweig and Hillel (2008)

Figure 2: Observed Temperatures Buenos Aires

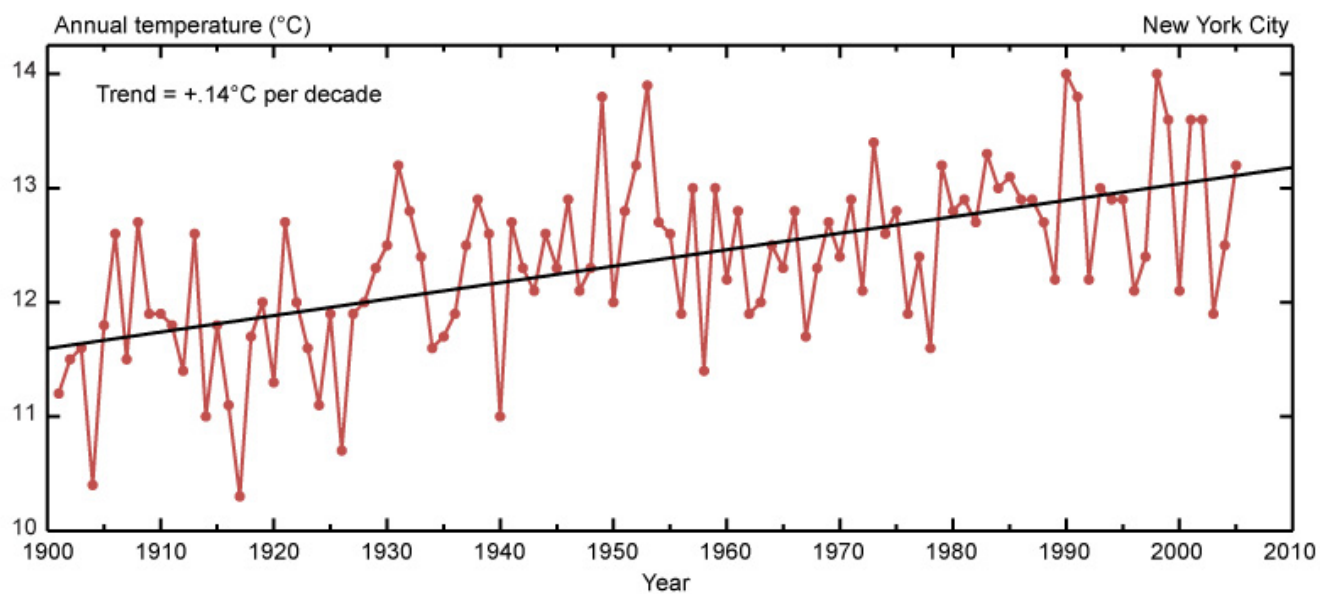
Source: Center for Climate Systems Research, Columbia University

Figure 3: Observed Temperatures Delhi

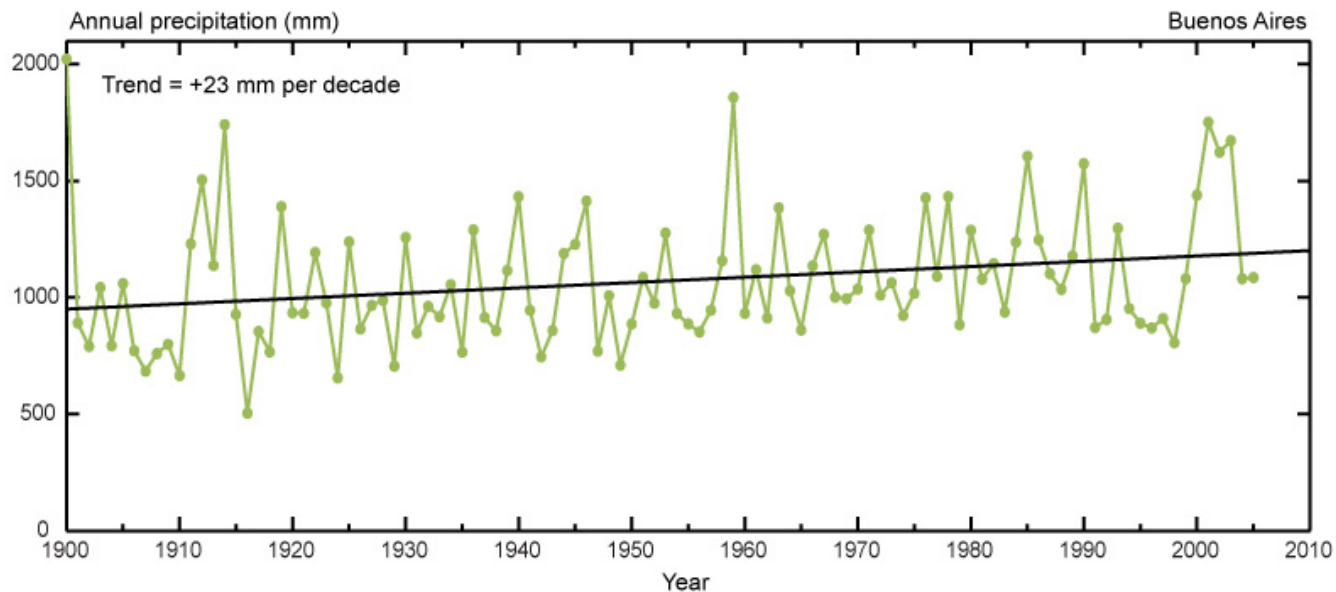
Source: Center for Climate Systems Research, Columbia University

Figure 4: Observed Temperatures Lagos

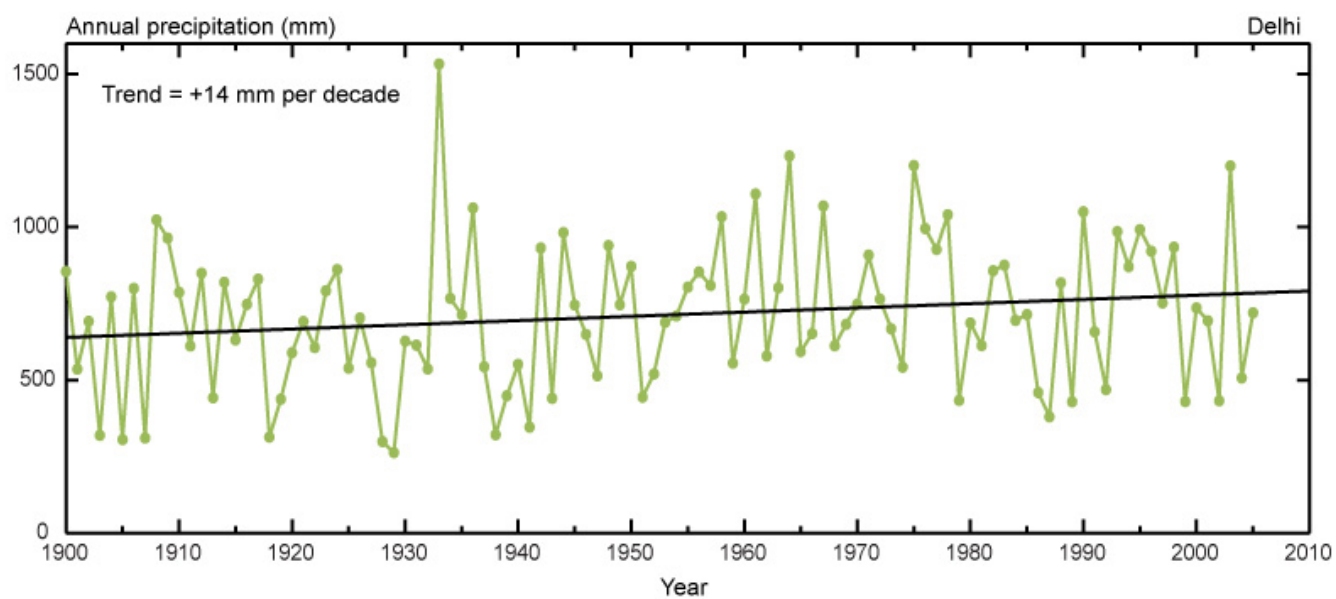
Source: Center for Climate Systems Research, Columbia University

Figure 5: Observed Temperatures New York City

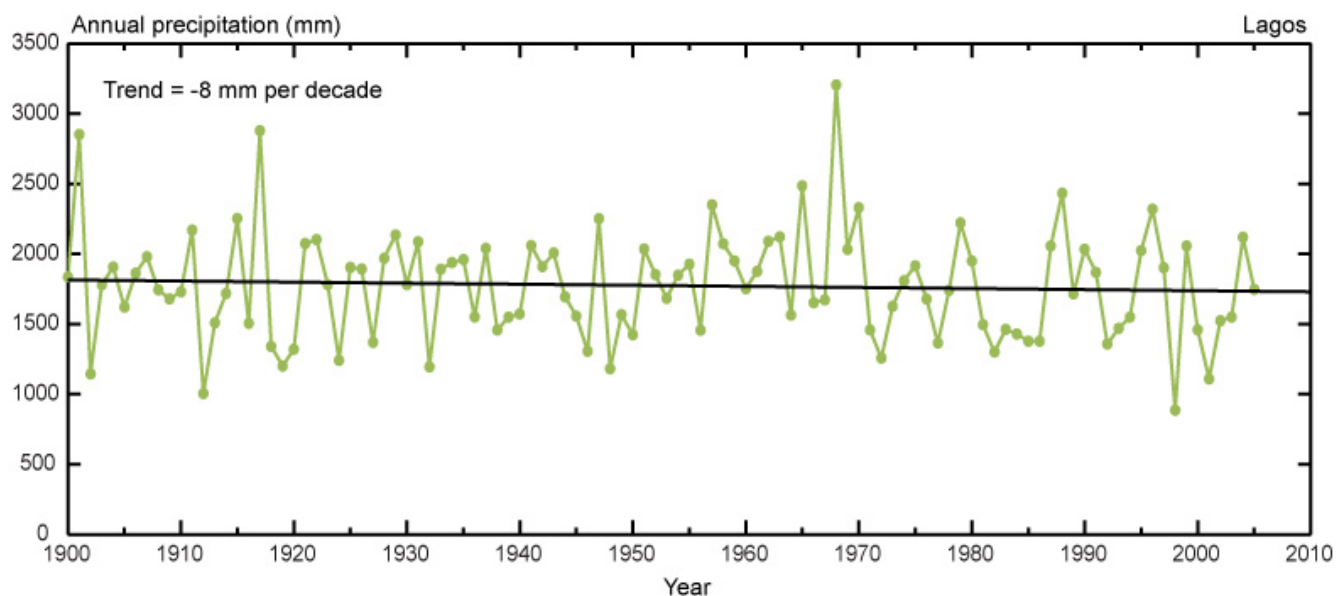
Source: Center for Climate Systems Research, Columbia University

Figure 6: Observed Precipitation Buenos Aires

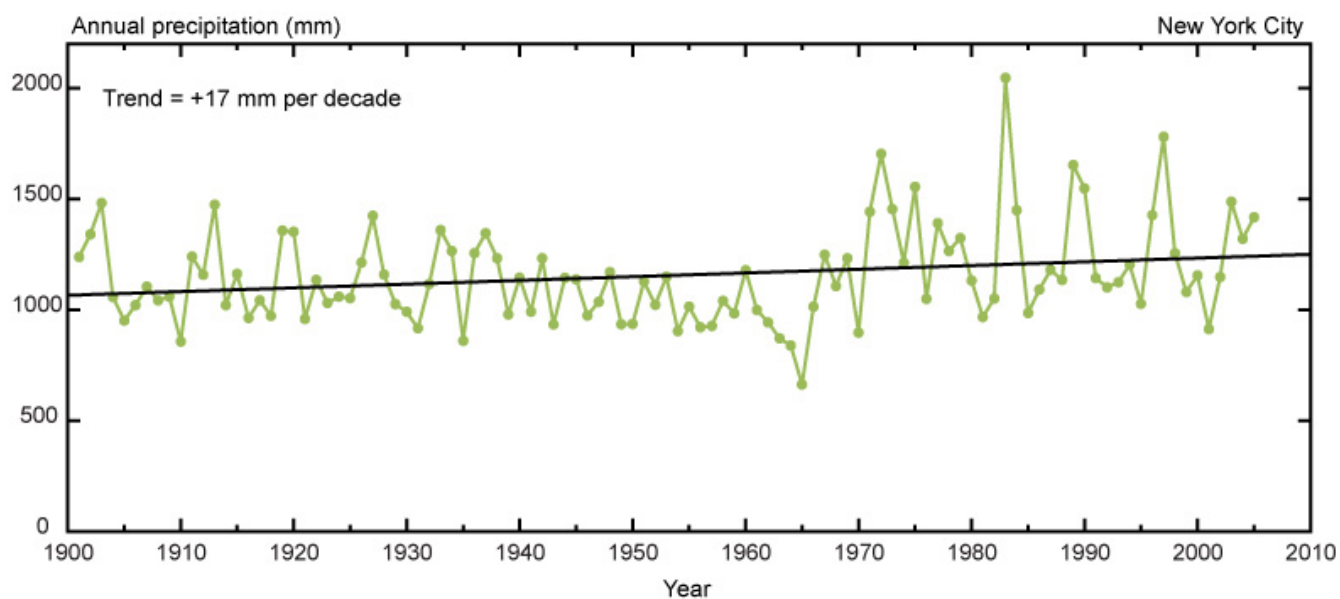
Source: Center for Climate Systems Research, Columbia University

Figure 7: Observed Precipitation Delhi

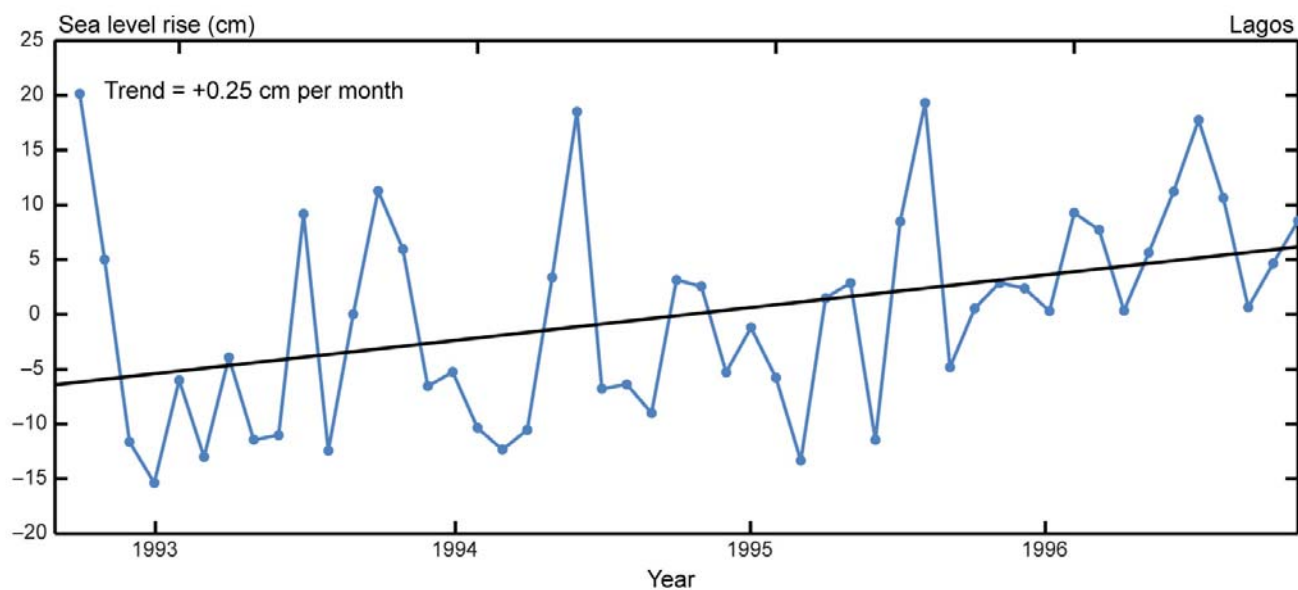
Source: Center for Climate Systems Research, Columbia University

Figure 8: Observed Precipitation Lagos

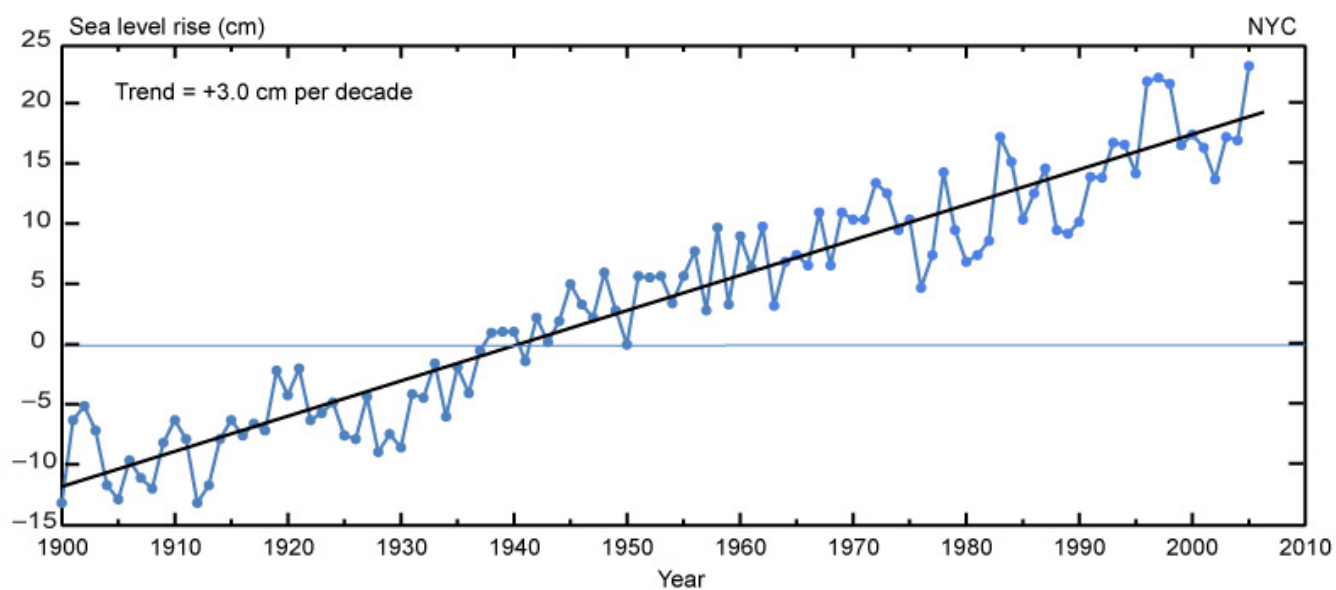
Source: Center for Climate Systems Research, Columbia University

Figure 9: Observed Precipitation New York City

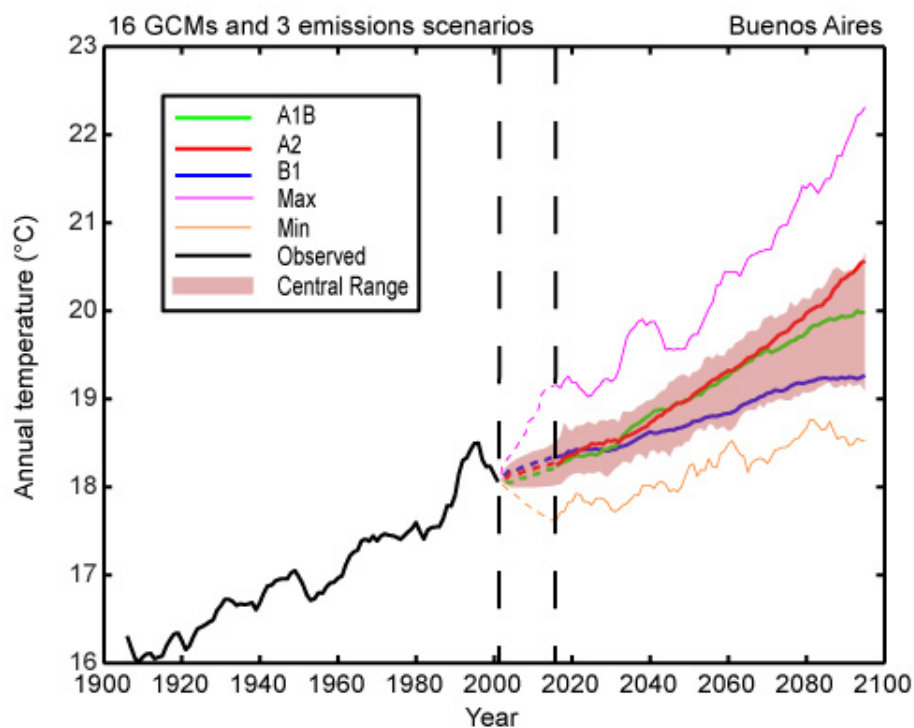
Source: Center for Climate Systems Research, Columbia University

Figure 10: Observed Sea Level Rise Lagos

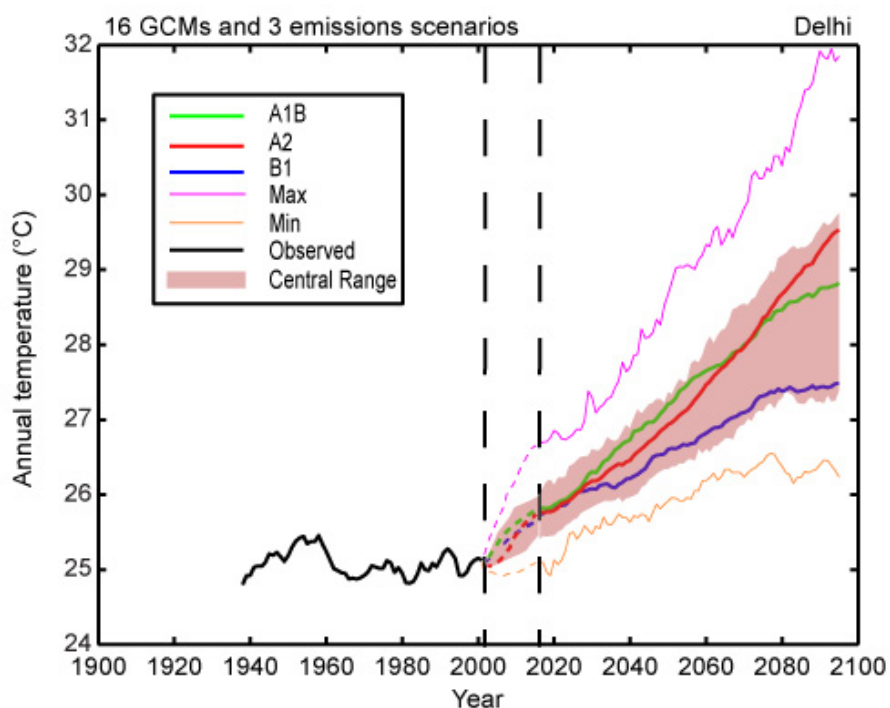
Source: Center for Climate Systems Research, Columbia University

Figure 11: Observed Sea Level Rise New York City

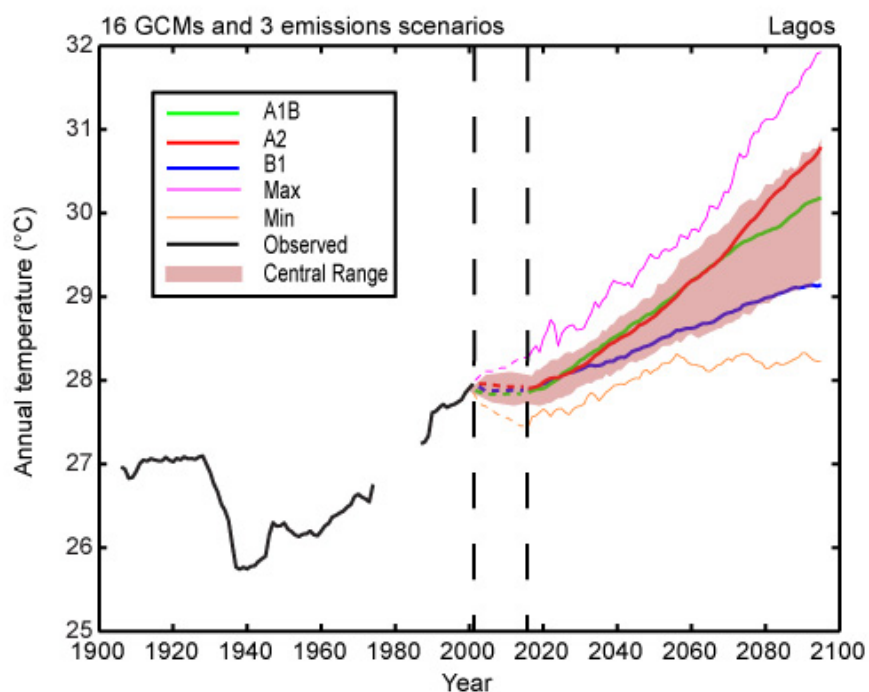
Source: Center for Climate Systems Research, Columbia University

Figure 12: Projected Temperatures Buenos Aires

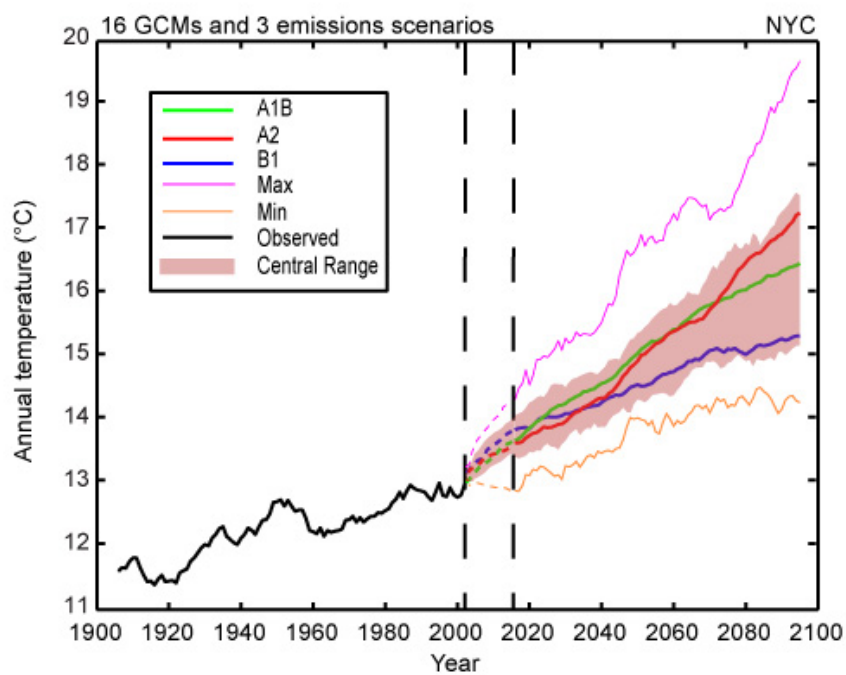
Source: Center for Climate Systems Research, Columbia University

Figure 13: Projected Temperatures Delhi

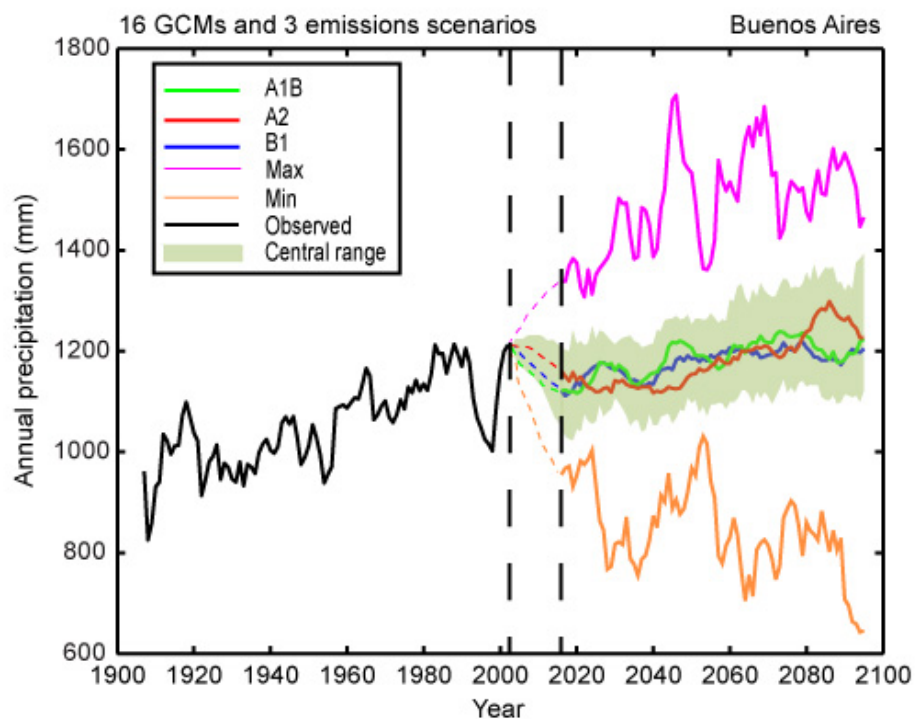
Source: Center for Climate Systems Research, Columbia University

Figure 14: Projected Temperatures Lagos

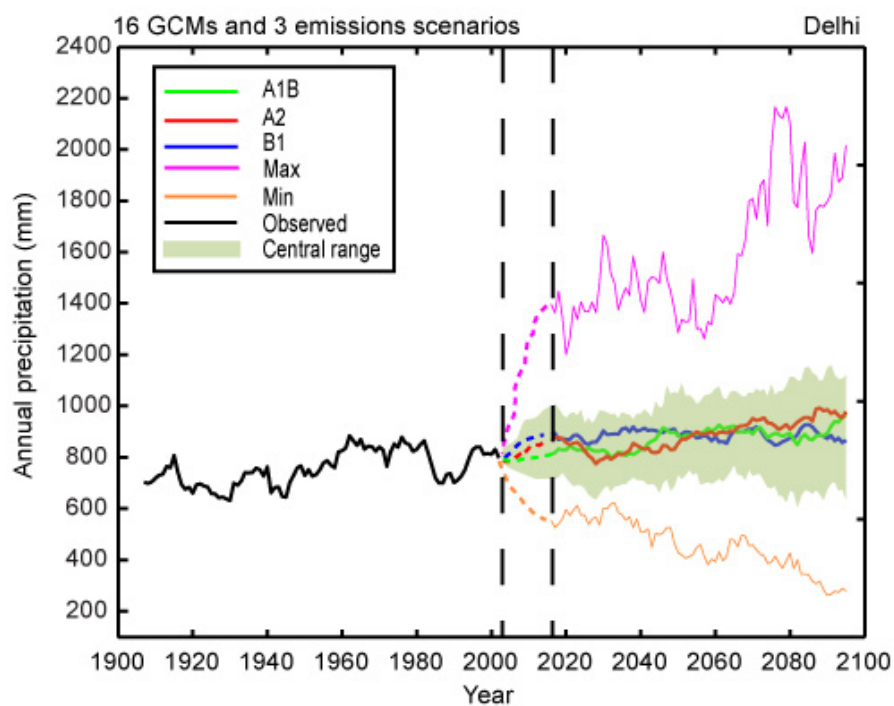
Source: Center for Climate Systems Research, Columbia University

Figure 15: Projected Temperatures New York City

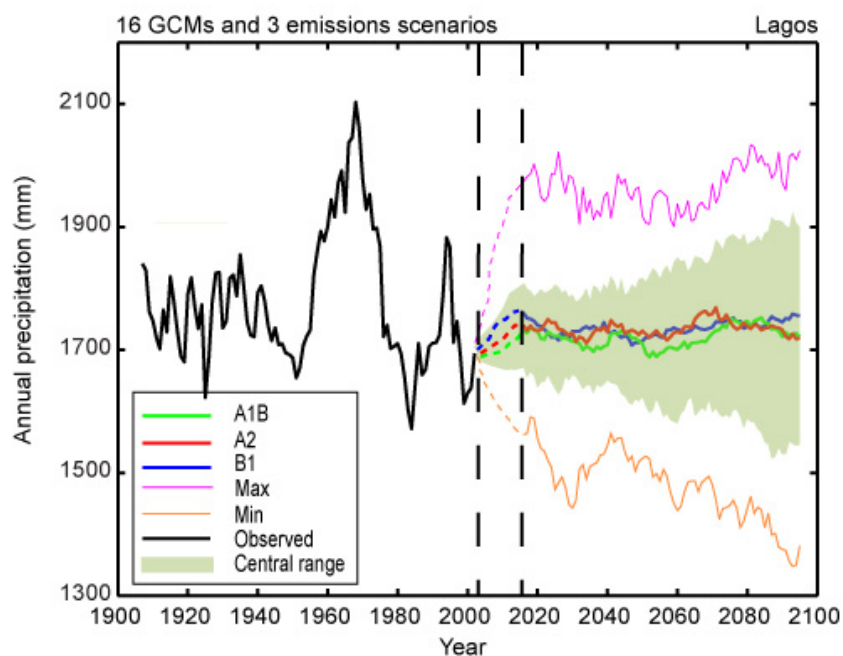
Source: Center for Climate Systems Research, Columbia University

Figure 16: Projected Precipitation Buenos Aires

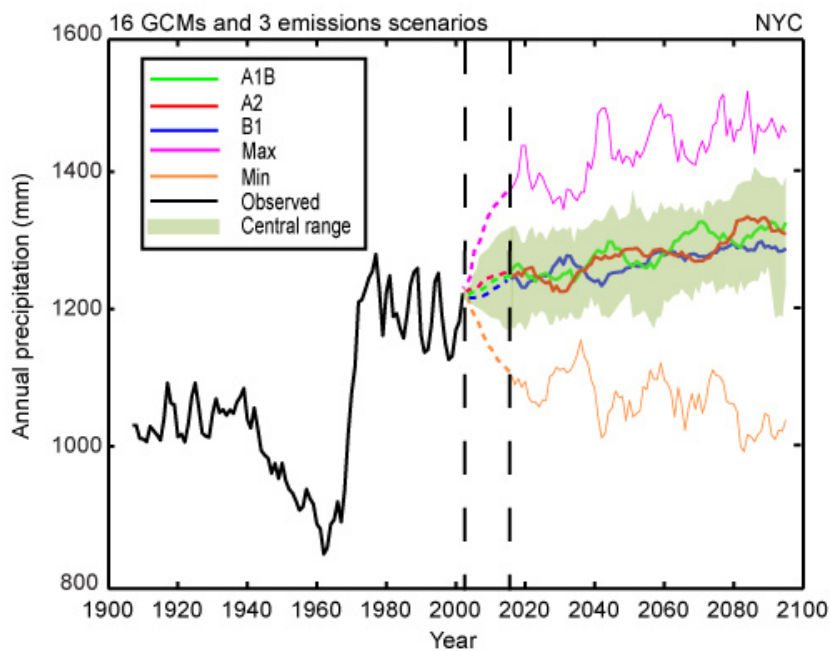
Source: Center for Climate Systems Research, Columbia University

Figure 17: Projected Precipitation Delhi

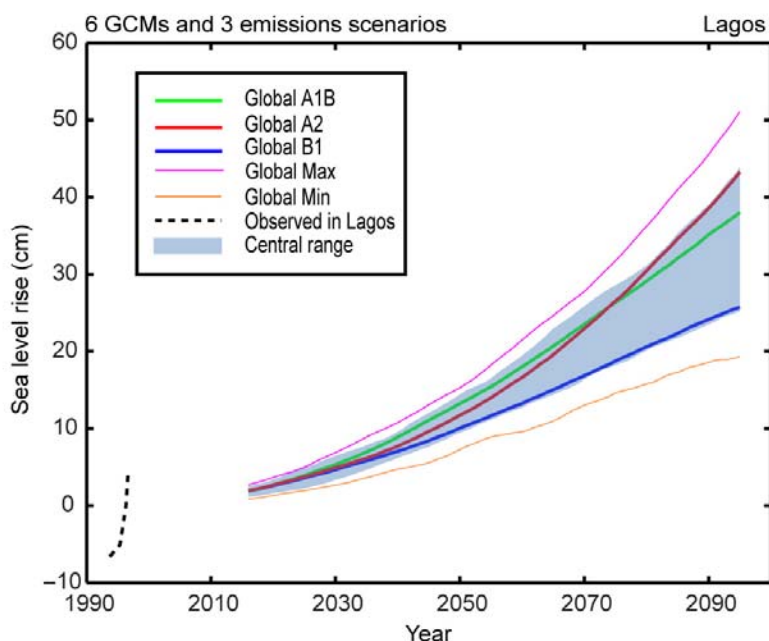
Source: Center for Climate Systems Research, Columbia University

Figure 18: Projected Precipitation Lagos

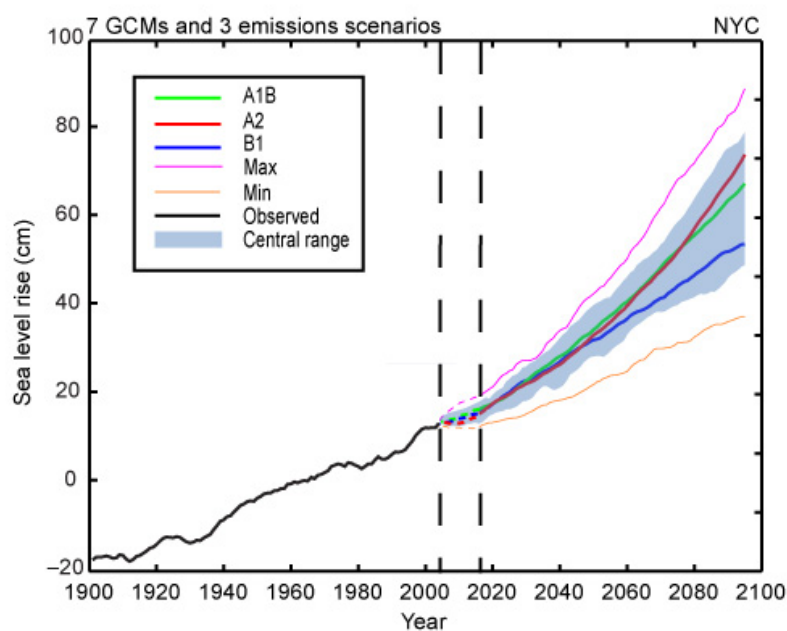
Source: Center for Climate Systems Research, Columbia University

Figure 19: Projected Precipitation New York City

Source: Center for Climate Systems Research, Columbia University

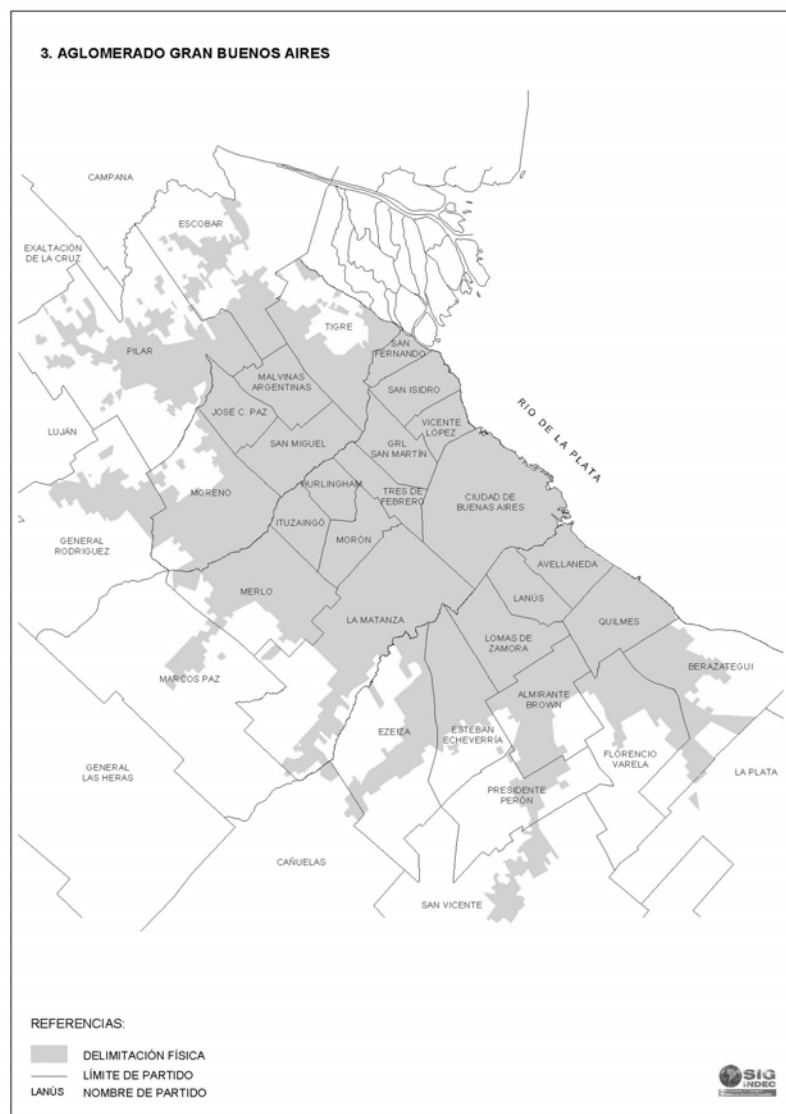
Figure 20: Projected Sea Level Rise Lagos²⁸

Source: Center for Climate Systems Research, Columbia University

Figure 21: Projected Sea Level Rise New York City

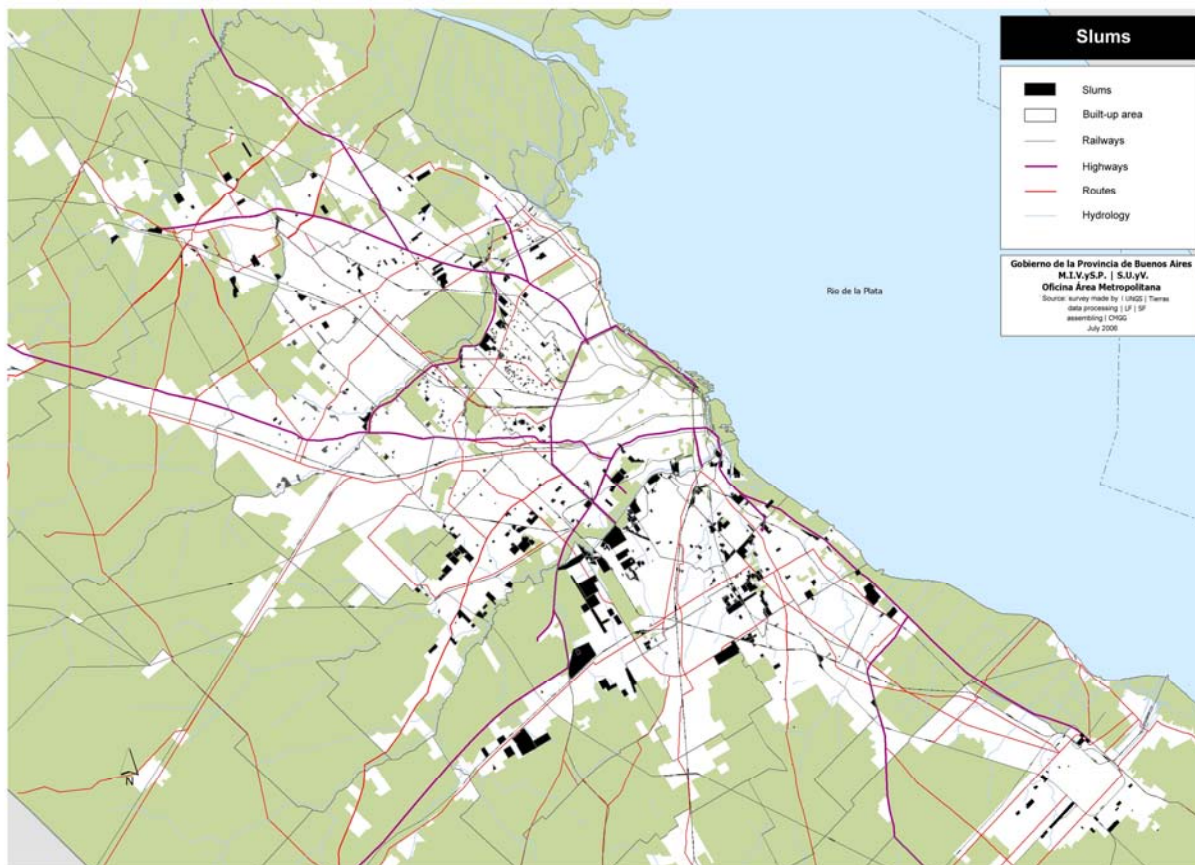
Source: Center for Climate Systems Research, Columbia University

²⁸ Plotted are the global sea level rise projections. These projections do not take into consideration the local terms for Lagos. Also on the plot is the observed trend (non-smoothed) for the available data for sea level rise from Lagos. The observed trend was adjusted to the base period of 2000 - 2004 using the global trend for sea level rise from 1993 to 2003 (IPCC,2007).

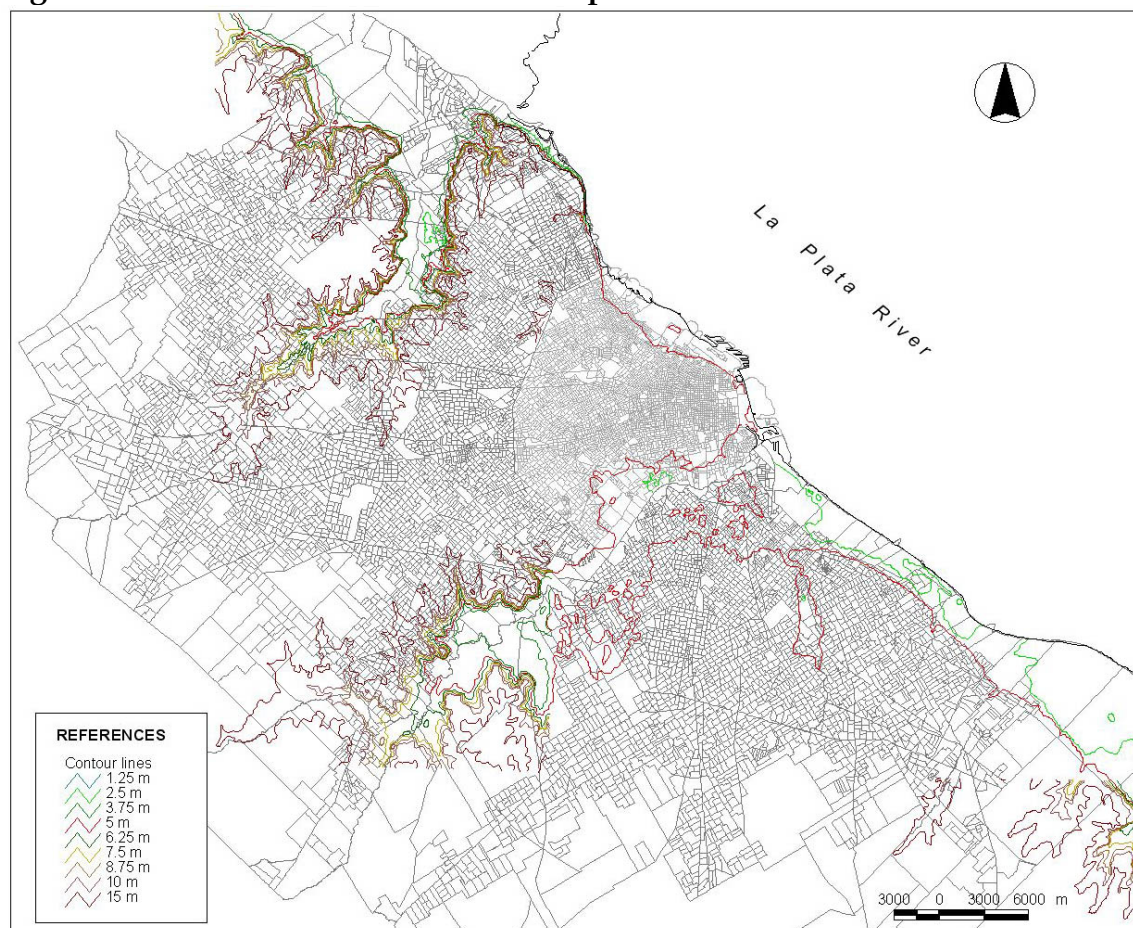
Figure 22: Administrative Units of Greater Buenos Aires Agglomeration

Source: Instituto Nacional de Estadística y Censos, 2003

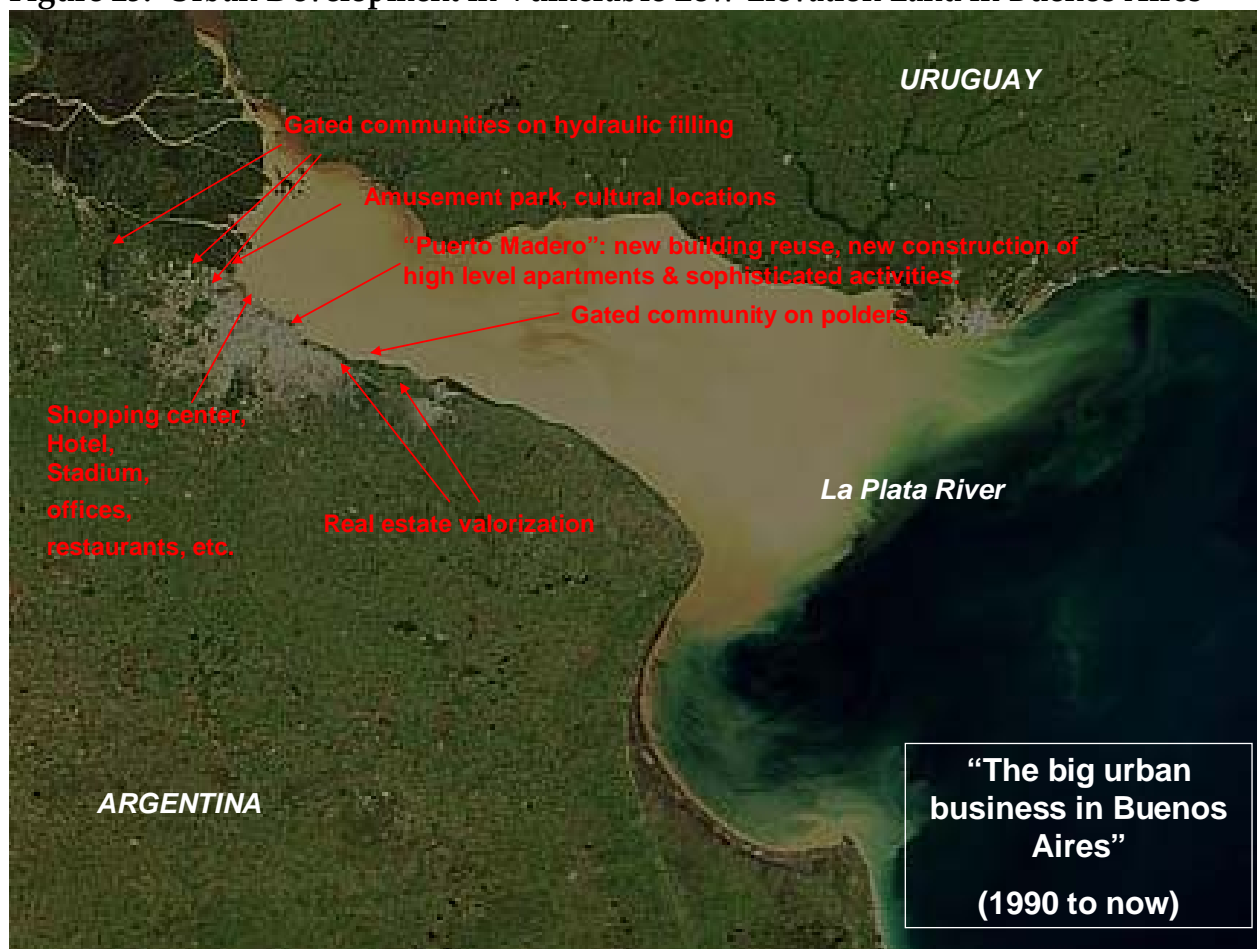
Figure 23: City plan with Slums (“barrios carenciados”) within the total built-up area of the Greater Buenos Aires Agglomeration (2007)



Source: Dirección Provincial de Ordenamiento Urbano y Territorial [Provincial Department of Urban and Land Management]

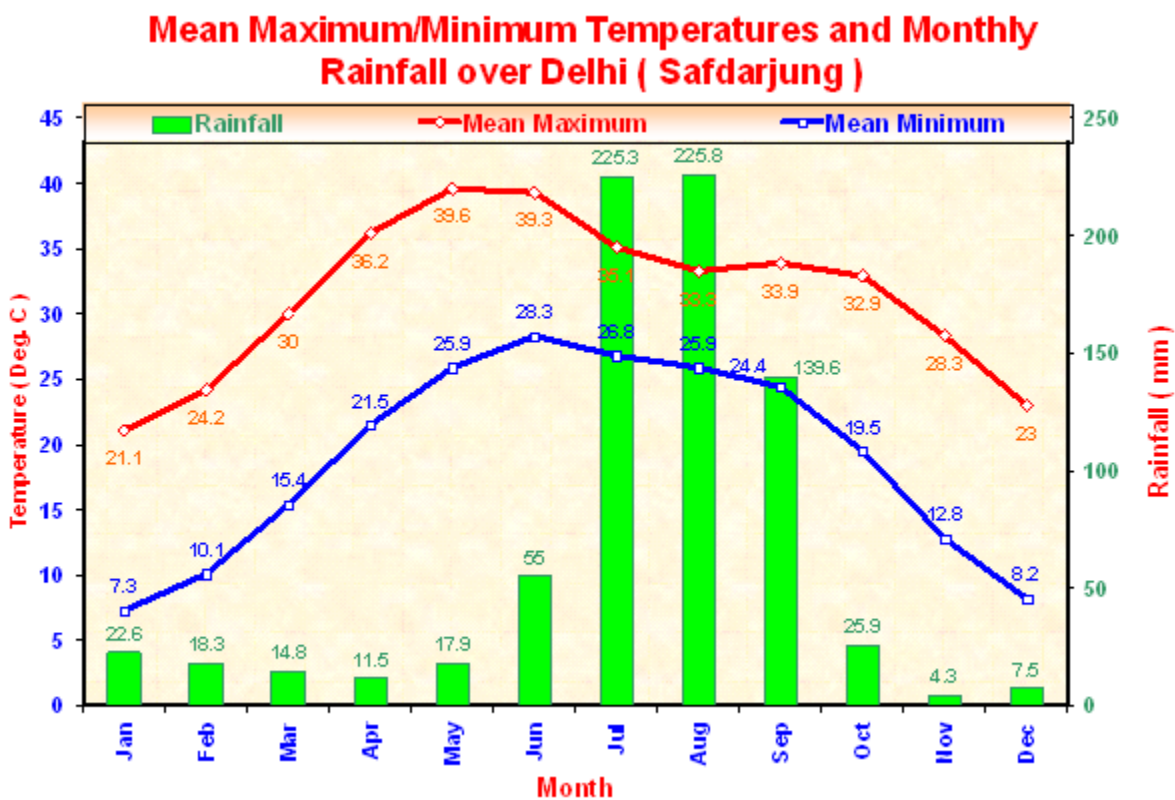
Figure 24: Low-elevation land and land parcels in Buenos Aires

Source: Silvia G. González adapted from Assessment of Impacts and Adaptation to Climate Change (2005)

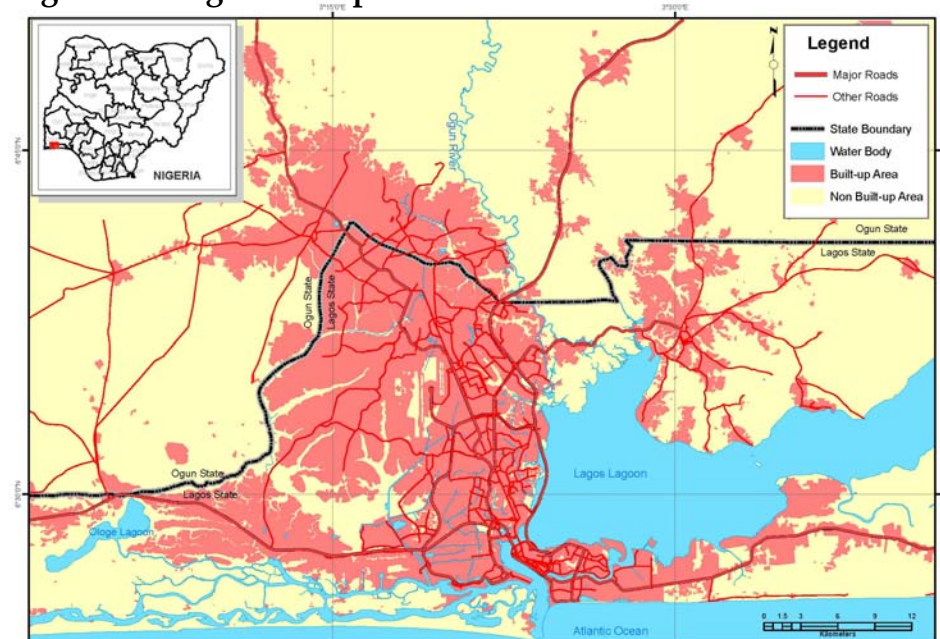
Figure 25: Urban Development in Vulnerable Low-Elevation Land in Buenos Aires

Source: Ríos, D., in Assessment of Impacts and Adaptation to Climate Change (2005)

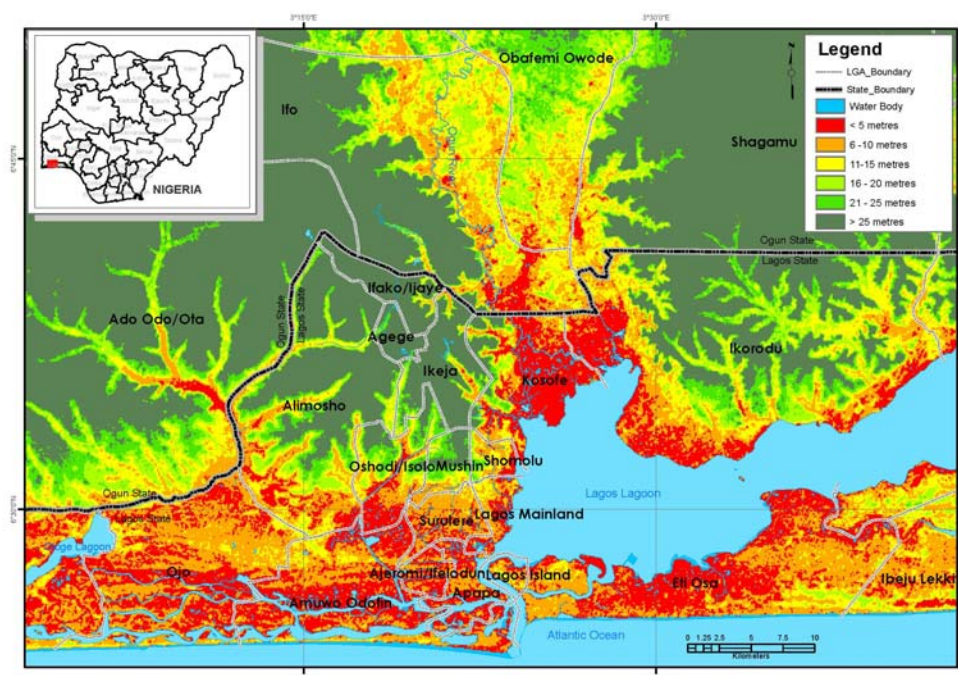
Figure 26: Seasonal variation in temperature and precipitation in Delhi



Source: Indian Meteorological Department, Regional Meteorological Center, Delhi.
 Retrieved on January 10, 2009, from <http://121.241.116.157/climatology/sfd1.htm>

Figure 27: Lagos Metropolitan Area

Source: Authors' analysis, identified built-up area using 2004 SPOT 5 2.5 meter, superimposed on the administrative map of Lagos State

Figure 28: Lagos Topography

Source: Authors' analysis, derived from the Shuttle Radar Topography Mission (SRTM) Digital Terrain Model (DTM) data. The DTM data was color-coded, clipped for the study area, and the administrative map superimposed.

Figure 29: Slum (Ajeromi, Ifelodun) beside an affluent neighborhood in Apapa, Lagos megacity



Source: IKONOS satellite imagery

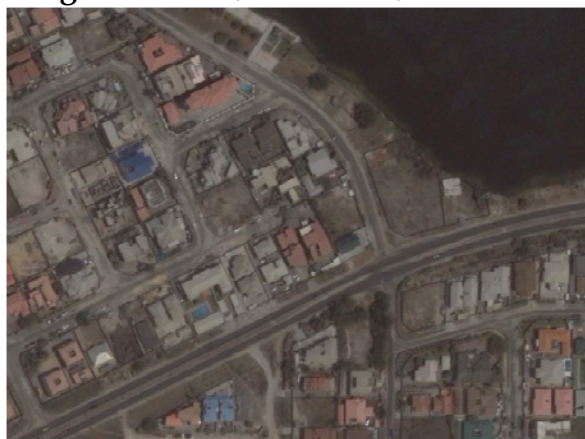
Note: the canal is their administrative boundary

Figure 30: Makoko Slum (stilt houses)



Source: IKONOS satellite imagery

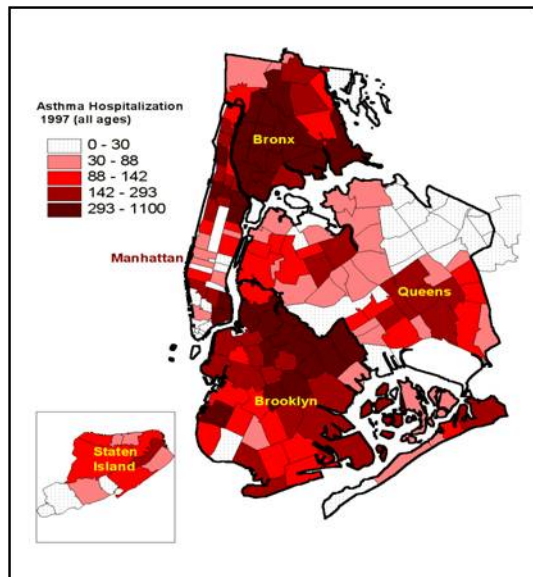
Figure 31: Lekki Phase I Affluent Neighborhood (sand filled)



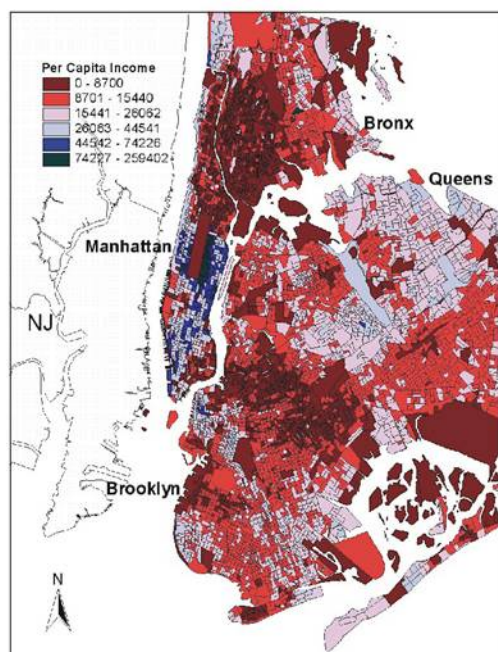
Source: IKONOS satellite imagery

Figure 32: New York City Map indicating five boroughs

Source: Office of Emergency Management, New York City

Figure 33: Asthma Hospitalizations in 1997 by age groups

Source: National Hospital Discharge Survey, National Center for Health Statistics, Center for Disease Control

Figure 34: Per Capita Income in New York City, 1999

Source: US Census Bureau

Annex 3

Methodological note on the criteria for selecting extreme events

Temperature extreme events (warm spells) were selected by finding the months that were over 1.5 standard deviations (2.0 for Lagos) from the full time series mean temperature for each city (the dataset was standardized). In case sufficient data is unavailable, a simple ranking procedure can be used to select the warmest months. This procedure would involve sorting and ranking the months and selecting the highest values.

The method used to select extreme precipitation events was similar to that used for temperature extremes. In this case, wet periods were selected by finding the months that were over 4 standard deviations from the 1900–2005 mean precipitation for each city. Lagos was the only city that had months that met the criteria for dry spells, which was greater than 1 standard deviation below the 1900–2005 mean. Again, a ranking procedure may be used for a quick assessment.

The thresholds selected for the cities were based upon a graphical analysis of the standard deviations for both variables. These values will be unique for each city. As the climate for cities varies dramatically across regions, a consistent value for all cities was avoided because using too low or high a threshold would result in either too many or too little observations—months with extreme temperature or precipitation.

The months selected are for the most recent years and it should be noted that others such observations exist over the entire period of the available observed data. The rationale for using more recent months is that it allows for an accurate literature search for these extreme events and there is an increased likelihood of the availability of daily climate data for these periods. An analysis of daily data can provide more details about the extreme events.

A preliminary analysis of the months when extreme events are occurring reveals that there is possibly a seasonal component. Ideally, when looking for the specific extreme events in the literature, other months within the same season should be examined.

Observed Temperatures and Precipitation

These figures show the observed trends in annual mean temperature (°C) and annual precipitation (in millimeters) for each of the cities. The annual temperature and precipitation values for each city were computed by averaging all the 12 months in each year. For each city's precipitation and temperature (excluding Delhi, which starts in 1931), the observed data plots over a hundred year period from 1900 to 2005. The months where data was missing were not used in the calculation and thus a gap in the annual temperature plot of Lagos is observed.

In addition to the observed trends, a linear trendline along with the calculated trend per decade is included for each of the plots. Over the course of the time period used, all cities saw increasing temperatures (at varying rates) and all cities but Lagos saw an increase in annual precipitation. The data set used for the temperature and precipitation values was the NCDC Global Historic Climate Network (GHCN) Monthly Version 2. <http://www.ncdc.noaa.gov/oa/climate/ghcn-monthly/index.php>

Annex 3

Global Institutional Structure for Risk Assessment And Adaptation Planning²⁹

Moving forward, there is a need for a programmatic science-based approach to addressing climate risk in cities of developing countries that are home to a billion slum dwellers, and quickly growing. These cities are most unprepared to tackle climate change-induced stresses that are likely to exacerbate the existing lack of basic urban services such as water supply, energy, security, health and education, as well as of disaster preparedness and response. Most climate change adaptation efforts until now have focused on lengthy descriptive papers or small experimental projects, each valuable in their own right, but insufficient to inform policymakers. Further, there is little recognition of the need for a flexible strategy to adaptation; instead there are sporadic medium and long-term project-oriented responses, often lacking analysis of basic climate parameters like temperature variability, precipitation shifts, and sea-level rise data. Three central elements of a comprehensive approach could include:

1. Establishment of a scientific body, which can verify as well as advise on technical matters of climate change science as it pertains to mitigation and impacts on cities.
2. A systematic approach to climate change adaptation
3. Ongoing assessment of climate change knowledge for cities.

The most pressing needs for developing-country cities in low-income countries is to focus on adaptation, outlined here, but similar measures are essential for mitigation efforts as well.

For adaptation, there is a requirement for assessing risk, evaluating response options, making some politically complex decisions on implementation choices and implementing projects, monitoring process and outcomes, and continuously reassessing for improvements as the science and practice evolve. Further, in order to maximize impact, there is a need to leverage ongoing and planned capital investments to reduce climate-risk exposure, rather than to neglect potential climate impacts. Practitioners and scholars agree that a primary reason why cities neglect climate change risks is due to lack of city-specific relevant and accessible scientific assessments. Thus to reduce climate risk in developing-country cities there is a demand for city-specific climate risk assessment as well as the crafting of flexible adaptation and mitigation strategies to leverage existing and planned public investments.

To inform action, the experience of the Climate Impacts Group at NASA's Goddard Institute for Space Studies and scholars at Columbia University and the City University of New York points to a need for at least a four-track approach.

²⁹ Annex 2 is an excerpt from a White Paper written by Shagun Mehrotra (April, 2009) and peer-reviewed by Cynthia Rosenzweig and William Solecki.

Track 1. Addressing the Need for a Mayors' IPCC. This is an across-city global assessment that captures the state-of-knowledge on climate and cities. The International Panel on Climate Change in Cities (IPCC3), First Assessment Report is one of the only ongoing efforts that addresses risk, adaptation, mitigation, and derives policy implications for the key city sectors — urban climate risks, health, water and sanitation, energy, transportation, land use, and governance. This assessment is an effort by more than 50 scholars located all over the world and offers sector-specific recommendations for cities to inform action. The aim is to continue assessments (on the order of every two years) and offer Technical Support after the UN Framework Convention on Climate Change COP15 is held in December, 2009 in Copenhagen. The first report is being prepared within a year to be launched by mayors of the world at the Mayors Summit in Copenhagen in December.

Track 2. Across-City Rapid Risk Assessment: Mainstreaming climate risk assessment into City Development Strategies as well as pro-poor programs like City Alliance's citywide and nationwide slum upgrading. This effort is critical to inform ongoing large-scale capital investments in cities that most often lack basic climate risk considerations (see map I). For most cities illustrated below, between 50 to 100 years of observed climate data are available but remain to be analyzed.

Track 3. City-Specific In-Depth Sectoral Assessment: General assessments are insufficient as most cities lack in-house expertise for technical analysis of city-specific climate impacts. To fill this gap, there is a requirement to craft city-specific risk and adaptation assessments for city departments (sector by sector) to redirect existing and planned investments. Cities like New York, London, and Mexico have initiated this demanding, yet essential task. Such risk analysis needs to disaggregate risk into hazards (external climate-induced forcing), vulnerability (city-specific characteristics, like location, and percentage of slum population), and agency (ability and willingness of the city to respond). The process will engage in-city experts and stakeholders in each city in the assessment process in order to develop local adaptive capacity.

Track 4. Learning from Experience: This task involves deriving adaptation lessons from the early climate change adopters like London, Mexico, and New York City. It focuses on answering such questions as How London, Mexico, and New York are crafting a response to climate change; What are the institutional arrangements? What are the roles of mayoral leadership, public demand, offices of long-term planning, and civil society initiatives? How assessments are financed—for example foundations, scientist-volunteered, tax dollars? And what are the positive externalities—such as establishment of the C40 Large Cities Climate Summit—of scaling-up both nationally and internationally? And what are transferable lessons? What can other cities learn from these experiences? Table I summarizes the four tracks along with their objectives and related outputs.

Estimation of spatially and temporally disaggregated climate risks is a critical prerequisite for the assessment of effective and efficient adaptation and mitigation climate change strategies and policies in complex urban areas. This interdisciplinary research reviews current literature and practices, identifies knowledge gaps, and defines future research directions for creating a risk-based climate change adaptation framework for climate and cities programs. The focus is on cities in developing and emerging economies. The framework unpacks risk into three vectors—hazards, vulnerabilities, and adaptive capacity. These vectors consist of a combination of physical science, geographical, and socioeconomic elements that can be used by municipal governments to create and carry out climate change action plans. Some of these elements include climate indicators, global climate change scenarios, downscaled regional scenarios, change anticipated in extreme events, qualitative assessment of high-impact and low-probability events, associated vulnerabilities, and the ability and willingness to respond. The gap between existing responses and the flexible mitigation and adaptation pathways needed is also explored.

To enhance robustness, the framework components have been developed and tested in several case study cities: Buenos Aires, Delhi, Lagos, and New York. The focus is on articulating differential impacts on poor and non-poor urban residents as well as sectorally disaggregating implications for infrastructure and social well-being, including health. Finally, some practical lessons are drawn for successful policies and programs at the city level that aim to reduce systemic climate risks especially for the most vulnerable population. Additionally, a programmatic response is articulated with a four-track approach to risk assessment and crafting of adaptation mechanisms that leverages existing and planned investments in cities so that city governments can respond to climate change effectively, yet efficiently.