Urbanization and Global Environmental Change

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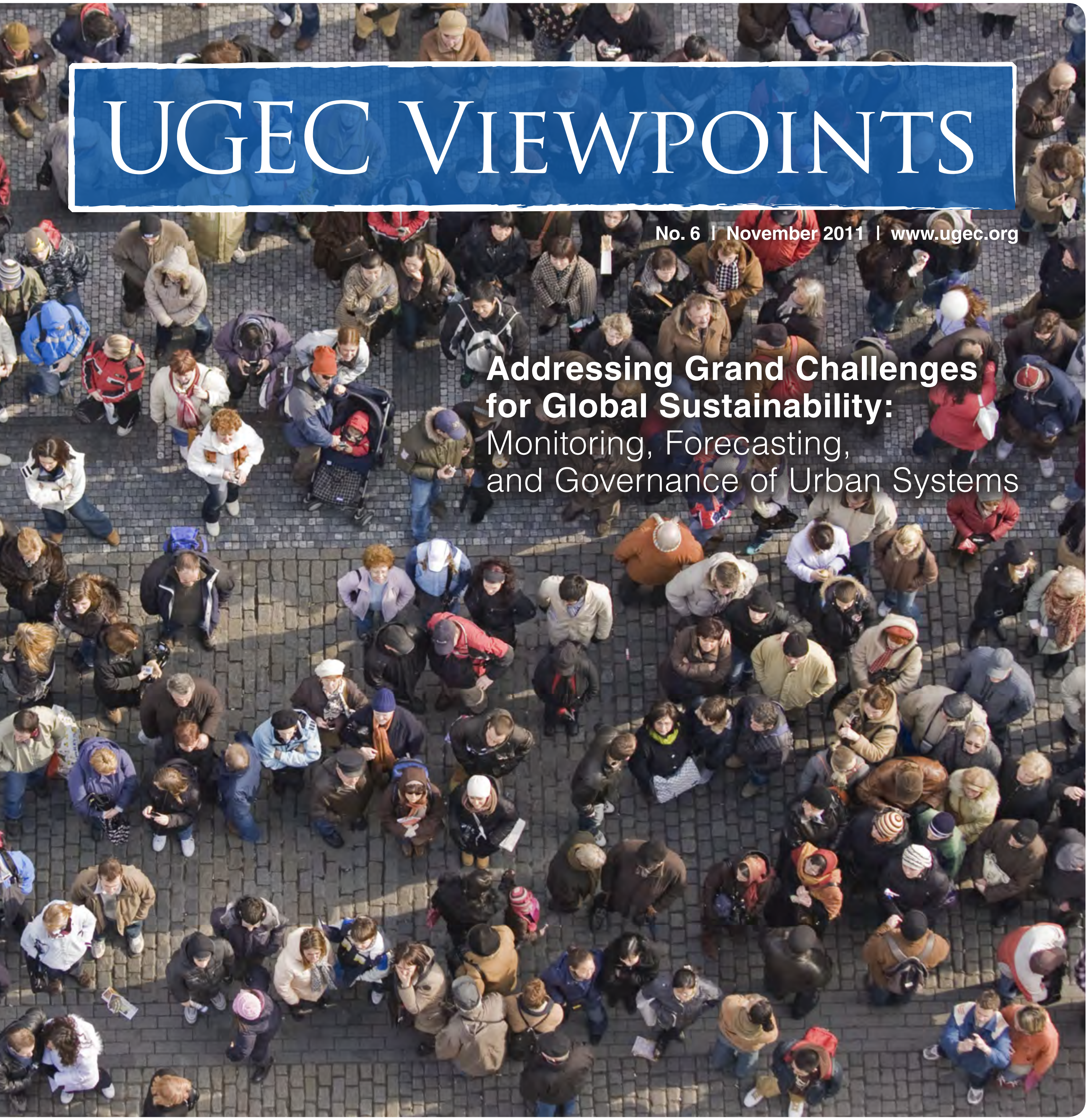

UGEC Viewpoints

No. 6 | November 2011 | www.ugec.org

Addressing Grand Challenges for Global Sustainability:

Monitoring, Forecasting, and Governance of Urban Systems

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Editorial

Dear friends of the UGEC project,

Urbanization is one of the most powerful, irreversible, and visible anthropogenic forces on Earth driving transformations of landscapes and ecosystems and global environmental problems. The UGEC project is committed to promoting new scientific understanding of the interactions between urban areas and global environmental change and this new understanding has begun to take shape in local governance structures. Our publications serve as important communication tools as we continue to pursue the exchange of experiences and knowledge towards sustainability pathways for urban areas. The goal of *UGEC Viewpoints*, in particular, is to communicate and facilitate the development of new directions in research and practice on urbanization and global environmental change, fostering international collaborations across disciplines and scholars/practitioners.

Notwithstanding this progress, a significant amount of work lies ahead for researchers and practitioners exploring the theme of global sustainability in an urbanizing world. The establishment of the new ICSU-supported Earth System Sustainability Initiative (ESSI) provides an opportunity for an added boost to the process of knowledge creation and application. The founding document of ESSI, 'Earth System Science for Global Sustainability: The Grand Challenges' (http://www.icsu-visioning.org/other/grand-challenges/) states that "[t]he international scientific community holds the promise of delivering the knowledge necessary for answering these crucial questions. But realizing that promise will require a refocusing of research priorities and a reorientation towards new research frontiers." This refocusing of research priorities led ESSI to identify five Grand Challenges in which scientific advancement and practical application needs speeding up. These challenges centrally focus on the themes of *forecasting* ("improving the usefulness of forecasts of future environmental conditions and their consequences for people"), *observing* ("developing, enhancing and integrating the observation systems needed to manage global and regional environmental change"), *confining* ("determining how to anticipate, avoid and manage disruptive global environmental change"), *responding* ("determining what institutional, economic and behavioral changes can enable effective steps toward global sustainability") and *innovating* ("encouraging innovation […] in developing technological, policy, and social responses to achieve global sustainability").

As strong supporters of the vision of the ESSI, we highlight in this issue how the dimension of urbanization and global change fits into the envisaged objectives and scientific agenda of the ESSI Grand Challenges. The challenges posed by ESSI are areas to which UGEC project researchers and practitioners are increasingly turning their attention – the current isse of the *UGEC Viewpoints* showcases several examples. In particular, we include articles that are representative of the work occurring within the UGEC network, address three of the five major challenges posed by the ESSI, and apply them to urban systems. The authors address questions of *monitoring/observing* (Javed Mallick, Atiqur Rahman, Maik Netzband and Sunil Bhaskaran; Lucy Hutyra, Steve Raciti, Nathan Phillips and J. William Munger; Xiangrong Wang, Shixiong Wang, Yuan Wang, Huanran Ling and Zhengqiu Fan), *forecasting* (Burak Güneralp; Helber López Covaleda and Tyler Frazier) and *responding* (Anna Brown and Sam Kernaghan; JoAnn Carmin, David Dodman and Eric Chu; Mauricio Domínguez-Aguilar and Federico Dickinson Bannack; Peter Elias; B.K Singh and Shiraz Wajih). The overview article by Libby Wentz, Karen Seto, Soe Myint, Maik Netzband and Michail Fragkias, which introduces a special section of articles authored by workshop participants, summarizes the findings of the two recent jointly-held UGEC-sponsored workshops and addresses the issue of the synthesis of research on monitoring, forecasting and governance in urban systems.

We hope you enjoy reading the 6th issue of the *UGEC Viewpoints*. We greatly enjoyed putting it together!

Michail Fragkias

Michail Fragkias
UGEC Executive Officer

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Old Town, Hoi An, Vietnam

Beyond Climate-Proofing: Taking an Integrated Approach to Building Climate Resilience in Asian Cities

Anna Brown and Sam Kernaghan

Cities across the developing world are struggling to meet rising demands for safe and respectable housing, transportation, water, waste treatment and other infrastructure and services necessary to foster healthy and productive places to live and work. As the understanding grows around how climate change will affect urban areas, 'climate proofing' and 'climate risk screening' are increasingly becoming part of the arsenal of donors and governments, reflecting a desire for infrastructure investments to be protected from climate-related shocks and stresses. The underlying logic to this is sound, given the massive potential losses projected from flooding, storms, heat waves, and sea level rise. However, if not linked to a more comprehensive resilience strategy for the city, drawing upon land use planning, policy, and institutional strengthening, the resulting conditions may weaken – not strengthen – the capacity of the city as a whole to respond to the spectrum of changes happening now and on the horizon.

Anachronistic planning: predict and prevent

The past no longer serves as an instructive predictor of what the future will bring. Historical climate data – rainfall, extreme heat days, frequency and intensity of storm events – have formed the basis on which cities have been designed and planned to date. The 'predict and prevent' paradigm, used by planners and engineers to design cities, infrastructure, and neighborhoods, is based on forecasts that assume a degree of linearity in pursuit of a high degree of perceived certainty. These rigid assumptions translate into design specifications for infrastructure like levees, roads, and water supply systems, which in turn result in hard and fixed construction.

Today, *uncertainty*, including that which arises from climate change, characterizes the context in which cities are growing. Approaches to urban development and planning that rely on precise data projections as design inputs have lost relevance given the complexity and unpredictability of possible climate-related impacts – and how these impacts will interact with one another. According to engineers themselves, "engineers tend to design and provide rigid systems with fixed performance characteristics, but are obliged to place and maintain them within an environmental context which is highly dynamic and unpredictable" (da Silva et al., 2010). Now more than ever, such fixed designs risk failure given the extreme flux and uncertainty presented by climate change and climate vulnerability. It's prudent to reflect on painful lessons from the developed world. While the Dutch may have successfully 'kept nature out' to date, residents of New Orleans have learned that this is not a failsafe approach – but rather a set-up for catastrophic failure. In fact, in an era of complexity and uncertainty, the inverse, 'safe failure', is exactly one of the principles on which approaches to infrastructure should be founded.

To account for new realities, concepts like 'climate proofing' have gained purchase among donors, governments and private firms. In some instances, such as United Nations Development Programme (UNDP) training manuals, climate-proofing refers to a holistic approach to climate adaptation and mitigation challenges in development programs. More often the term is applied to suggest modifications to pre-existing project plans, most specifically infrastructure investments. By climate-proofing, infrastructure is made more robust in the face of challenges like storm surges, increased flooding intensity, or extreme heat. This suggests a fairly linear and narrow business-as-usual pathway whereby infrastructure designs are adjusted, accounting for new climate projections, but which may fail to situate the proposed structure into the city as a whole. The ability of the city to maintain economic functions and keep inhabitants safe in a changing and variable climate, relies on the ability to 'get it right' when planning and constructing infrastructure.

To date, nature is yet to be tamed and certainty remains elusive. Thus, in taking a narrow approach to climate-proofing, it risks advancing mal-adaptive measures. On a project-by-project basis, it is possible to make infrastructure projects more durable in the face of projected changes in climate. Considered en mass, however, these investments can collectively *decrease* the resilience of the city by reducing the flexibility of urban systems to handle surprise and multiple interacting impacts, transferring risk to other sectors, people, or geographies, and removing redundancies, which serve as essential back-ups when one part of the system fails.

Quy Nhon in 2009, a city of 350,000 people on the coast of central Vietnam, experienced intensive rains that inundated areas never before flooded. The immediate response: build higher roads and develop houses on raised mounds, sometimes two meters above the surrounding land (see Figure 1). At the household or project level, each piece of infrastructure may better endure higher water levels, but the system as a whole suffers. Higher roads block natural drainage channels, which may cause flooding in new areas. The projected climate trends for Quy Nhon, longer dry spells and more intense rain events in the wet season, suggest that flash flooding events will likely increase in the future. Specific measures, such as those taken immediately after the flood, reflect mal-adaptive steps, which may over the longer run generate more damage and losses.

Figure 1 | Elevated road constructed in floodplain of Quy Nhon, Vietnam

Source: Brown, A. Elevated Road in Quy Nhon, Vietnam. May 2011.

Experience from ten cities in Asia reveals the importance of integrative assessments and resilience planning to identify appropriate measures for urban areas to equip themselves for a range of climate-related effects. In these cities, participants in the Asian Cities Climate Change Resilience Network (ACCCRN)[1], local institutions have used multi-stakeholder processes to develop an understanding of the local dynamics among urban growth, climate change, and the effects on vulnerable sectors and communities. Through these processes and assessments, city stakeholders have identified how collections of measures, which pertain to land use planning, ecosystem protection, institutional coordination, knowledge sharing , and physical infrastructure, can add up to an influential set of actions that help the city better manage anticipated and unanticipated surprises, shocks, and slow-onset changes.

Early engagement with 'softer measures' like integrated planning and policy is critical to avoid a trajectory of mal-adaptive urban development. Within a resilience planning framework, possible infrastructure investments are identified in the context of how they support and service the needs of the broader urban system and its inhabitants. This process enables the development of flexible and integrated infrastructure systems that advance more

1 For further information go to http://www.rockefellerfoundation.org/what-we-do/current-work/developing-climate-change-resilience/asian-cities-climate-change-resilience

Key Messages

The traditional modes of urban governance and infrastructure decision-making, founded on the 'predict and prevent' paradigm, are no longer relevant. Dynamic factors in cities across Asia, including rapid urbanization, climate change impacts and rising vulnerability of populations, mean that land-use decisions and infrastructure investments need to reduce vulnerability and enhance opportunities for urban populations despite these challenges.

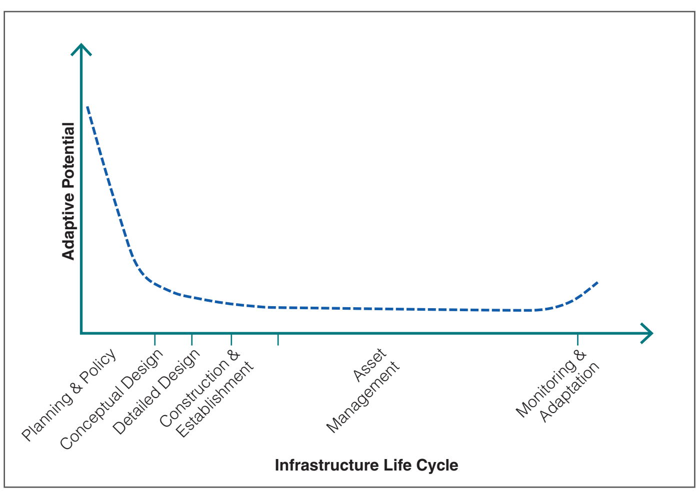
From research and experience we see that adaptation actions are best positioned to advance urban climate change resilience when considered from the policy and planning stages rather than design, implementation, and construction.

The Asian Cities Climate Change Resilience Network is testing a range of approaches that enable decision makers, and other key urban governance actors, to develop a strategy which, informed by the local context and relevant climate, growth and environmental data, provides a pathway for the city to recognize what it is doing well, and build resilience to the most immediate and longer-term shocks and stresses that the city is facing.

Through this process, cities have recognized that any local strategy or plan needs to be informed by multiple stakeholders, and must set out not what infrastructure to build, but how to strengthen capacities of decision makers so that infrastructure and land-use choices are not mal-adaptive, but contribute to the long-term urban resilience to climate change and other dynamic factors.

than one aim. The greatest opportunity to influence the adaptive potential of infrastructure occurs in this early phase. Once conceptual designs begin, the prospects for incorporating effective adaptation and resilience building measures dips dramatically (see Figure 2). Attempts to 'climate proof' later, such as at the point of conceptual or detailed design, forecloses the chance to more fundamentally influence the resilience of that project – and more importantly, the urban system as a whole.

Figure 2 | Adaptive potential of infrastructure



Source: Adapted from *UNDP 2010 Climate-Proofing Infrastructure: Conceptual Considerations and Recommended Actions*, www.adaptationlearning.net

Context matters

In the early period of ACCCRN, many cities gravitated toward a 'predict and prevent' approach to prepare for climate change impacts, identifying major infrastructure projects to provide defenses against the changing elements. Having undertaken a series of multi-stakeholder participatory dialogues with the intention of introducing and sharing new information around potential climate change impacts, each of the ten ACCCRN cities has now developed a city resilience strategy (CRS), creating a framework for integrated resilience planning. The CRS includes a set of measures – both 'soft' and 'hard'—to strengthen the capacity of the city to anticipate, cope with, and restore stability from immediate and slower onset impacts associated with climate change and climate variability. In examples from Vietnam and India, as the understanding deepened around the local dynamics of urbanization, climate change, and vulnerability, it triggered decisions to revisit current urban development plans and to consider the potential resilience benefits from strengthening institutional capacity and coordination within the city.

As a result of the severe flooding in 2009 and through engagement with ACCCRN, Quy Nhon paused development plans for peri-urban lands located in a floodplain. This part of the city, despite its exposure, has been steadily urbanizing since the mid-1980s. With Rockefeller Foundation support, Quy Nhon initiated a study in early 2011 to identify and assess the impacts of flooding from extreme storm events and climate change on this urban growth corridor. The analysis, currently underway, aims to inform long-term urban development and infrastructure plans for the city. Quy Nhon also established a climate change coordination office to facilitate integration of resilience building policy, planning, and investment across different agencies and institutions within the city and to influence socio-economic development planning and future donor projects.

The city of Surat in the western Indian state of Gujarat, with a population of four million and growing, is built on the banks of the River Tapti (see Figure 3). Through the ACCCRN process, climate projections suggesting more intense and frequent rainfall and data on the impacts of sea level rise on tidal river flows were introduced into stakeholder meetings, leading to discussion of future climate risks and response options available to the city. A Rockefeller Foundation funded intervention, under implementation by the City, saw the opportunity to better link the institutional bodies responsible for upstream dam management (under federal jurisdiction), downstream disaster management (under state authority), and the municipal corporation and development authorities with catchment managers and rainfall forecasting units at an inter-governmental early warning facility. Through this low-cost and flexible communication and data sharing effort across key agencies, combined with better forecasting, it creates strong potential benefits for vulnerable urban populations, and the businesses, services, and governments on which they rely.

Figure 3 | Informal settlements along Tapti River in Surat, India

Source: Kernaghan, S. Informal Settlements in Surat, India. 2008.

Both the Quy Nhon and Surat examples show that, far from replacing infrastructure, softer measures augment the performance of existing and planned investments, and place each specific infrastructure project in the context of the wider urban system. These positive disruptions pivot from business-as-usual to an integrated approach to reducing vulnerability and building resilience.

Policy and planning implications

As climate change adaptation finance increases toward the projected $100 billion (World Bank, 2010) needed per annum, governments and donors alike will need to identify ways to prioritize decisions about what measures to support.

Infrastructure offers an obviously compelling entry point to help prepare cities for climate change impacts given the level of investment that will flow in this direction. As donors and national governments consider investments to address the huge infrastructure and service deficits in the rapidly urbanizing developing world, some development banks and governments are beginning to understand the critical importance of incorporating integrated climate resilience planning to inform their infrastructure investments. This understanding needs to be deepened so that expensive investments to climate-proof infrastructure are not done in isolation and rendered prematurely inappropriate, or indeed mal-adaptive, generating new risks and vulnerabilities.

Uncertainty around how to deal with shocks and stresses requires an approach that enables cities to address the resilience of the entire urban system (ecosystems, institutions, communities, knowledge networks and infrastructure) to reduce vulnerability and contribute to well being. In ACCCRN, cities are attempting to embrace these newer approaches, far more suitable for the 21st Century, and more likely to foster resilient cities in the future.

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Traditional floating market near Bangkok, Thailand

Engaging Stakeholders in Urban Climate Adaptation: Early Lessons from Early Adapters

JoAnn Carmin, David Dodman and Eric Chu

Given their density of populations and high investments in infrastructure and buildings, cities have the potential to suffer tremendous losses as a consequence of climate impacts. Already, some cities are coping with changes in temperature and precipitation patterns as well as increased natural hazards that are attributed to climate change. Over time, it is anticipated that these conditions will intensify, placing increased stress on natural systems, the built environment, and human populations in urban areas (IPCC, 2007). In response to the imperative that exists, climate adaptation agendas are beginning to take root in cities in both developed and developing countries. Although there is growing recognition of the need to promote adaptation, and efforts are being made to develop international, national, and local programs, many cities are finding this to be a challenging agenda to initiate and maintain.

One way cities are seeking to cope with the climate challenges they face is by promoting public participation and partnerships. A time-honored view is that local authorities will be most effective when the public is engaged and when partnerships with stakeholders are developed to support local activities. Stakeholder engagement can lead to a range of benefits, such as generating support for planning initiatives (Bickerstaff & Walker, 2001; Harpham & Boateng, 1997) and surfacing strategies that are suited to local realities (van Aalst et al., 2008; Fischer, 2000). Building on these views, many urban practitioners are seeking to involve stakeholders in adaptation planning and implementation (Kithiia & Dowling, 2010; Rosenzweig & Solecki, 2010).

Here, we summarize participatory measures that city representatives are using to advance their climate adaptation initiatives. These findings are derived from a three-day meeting where a small group of urban adaptation leaders from around the world gathered to reflect on their experiences and learn from each other.[1] While a wide range of topics were discussed, we focus on techniques cities are using to engage the public and partner with different stakeholders. We conclude by summarizing

1 The meeting of adaptation leaders was hosted at the Rockefeller Foundation Bellagio Study and Conference Center. Data collection and analysis were funded by the U.S. National Science Foundation (NSF) under Grant #0926349. Travel was funded by NSF, the Institute of International Education (IIE) and the International Institute for Environment and Development (IIED).

the challenges leading cities are encountering and discussing the implications of their experiences for social science research.

Approaches to stakeholder participation

Many cities represented at the meeting engaged community organizations and local residents in assessment and planning. For instance, cities participating in the Asian Cities Climate Change Resilience Network, such as Surat, involve the public in vulnerability analysis. Other cities tend to emphasize participation in planning. This was the case in London and Quito where consultations were held with the public on draft plans. In addition, some cities encourage participation in project and program implementation. London demonstrates to local residents how they can prepare themselves for flood events as a means to encourage them to take ownership of this process. Alternatively, Quito is working with civil society groups, including those working on cycling, sustainable transportation, and water management, to enlist their support in implementing the city's climate change strategy.

A technique being used by cities to support their adaptation efforts is the creation of expert committees and task forces. Boston provides an example where this has been effectively employed with the formation of a Leadership Committee. The composition of the committee, which was determined by the Mayor and city staff, includes academic scientists, business leaders, advocacy groups, planners, and property owners. The committee was divided into working groups that met over the course of the year in 2010 and gave their recommendation to the Mayor on how to advance the city's adaptation planning program, with specific input on adaptation measures for open space planning, zoning, water and sewer infrastructure, emergency preparedness, urban forestry, and transportation. As was the case in Boston, engaging experts and other stakeholders can provide the city with needed ideas, skills, and knowledge as well as lend legitimacy to decisions.

Partnerships between local governments and universities and research organizations have been particularly important in the production of climate projections, scenario development, and the provision of data. In London, for example, the development of climate scenarios by the UK Climate Impacts Programme supported adaptation planning by providing a scientific basis for action. In Seattle, the University of Washington mapped inundation, enabling the city to assess chronic aspects of sea level rise as well as episodic events such as storm surges. Partnerships such as these extend city adaptation capacity by ensuring the availability of data and analysis necessary for sound planning.

Urban adaptation initiatives also have the potential to be enhanced by partnerships between municipal governments and the private sector. Cities are finding that partnerships with insurance companies can be influential given the understanding these organizations have of emerging risks. Toronto had a successful experience working with the insurance industry to produce a risk assessment tool for urban flooding while Copenhagen worked with the Association of Insurance Companies to increase understanding of the assets at risk as a result of climate change. Partnerships with engineering firms are also proving valuable in assessing the vulnerability of urban assets. This was the case in Toronto where the city partnered with an engineering firm to catalogue risks on specific infrastructure assets, including a wastewater treatment plant, an office building, and three different types of culverts. As these examples suggest, private sector knowledge and experience can enhance urban decision making capacity. At the same time, there are benefits to the private sector since supporting decisions that cities make to build resilience reassures companies that their assets are protected and encourages further investment.

Challenges in stakeholder participation

Those gathered at the meeting noted that adaptation requires developing strategies specific to a particular location. As a result, this makes it difficult for them to import participatory processes and techniques from elsewhere without modification. Effective and sustainable participatory programs rely on sound pathways for information dissemination and mechanisms for community learning. Those assembled indicated that communicating the need for adaptation and educating the public is a challenge in all communities, but one they find particularly significant in disadvantaged neighborhoods and impoverished settlements where access to communication technologies is limited. Building strong participatory programs requires attachment to a community while knowledge of what actions are most appropriate stems from familiarity with a place. The leaders at the meeting noted that the lack of social capital and commitment in highly transient communities, which also tend to be those that are most vulnerable, makes it difficult to work on adaptation in these locations.

A further challenge is that meaningful adaptation requires a fundamental change in thinking about planning, institutions, and communities and achieving transformation is partially predicated on institutional support. The assumption is that planners can establish a program and that it will be sustained by participants.

However, since the goal of adaptation is widespread change, and the understanding of adaptation is constantly being refined, these leaders are finding that in addition to adequate levels of funding and information, there is a need for ongoing governmental support and management of participatory processes and partnerships.

Many commonalities exist, but the discussions also surfaced differences in participation challenges facing cities in developed and developing countries. For instance, since there are relatively fewer universities in African cities, some are finding it difficult to partner with local researchers. In contrast, cities in developed countries are finding that academics are eager to partner, but these relationships require nurturing, as researchers may have different priorities than practitioners. In both developed and developing countries, cities have limited national and international support. However, at this time, the sources of support seem to vary. In a number of instances, national-level agencies in developed countries are sponsoring research programs that not only provide data, but engage an array of stakeholders to ensure that the research agendas are salient and partnerships are developed at the local level. Alternatively, while many national agencies in developing countries are conducting assessments and providing data and input, they appear to be dedicating fewer resources overall to cities and placing less emphasis on establishing mechanisms that foster citizen engagement and promote formal partnerships in the urban context. Nonetheless, cities in developing countries are receiving greater levels of funding and training for adaptation from international organizations, development banks, and foundations, much of which emphasizes public participation.

Research gaps on participation and partnerships

The cities represented at the meeting have promoted public participation and stakeholder partnerships, working to establish a variety of forums and ensure representation of diverse groups in their initiatives. The complexity and multi-dimensional nature of climate adaptation has led them to pursue stakeholder engagement as a means to extend their capacity while promoting democratic forms of governance. The efforts of these cities illustrate techniques being used by urban practitioners and, at the same time, point to areas ripe for additional research.

One issue discussed at the meeting is the local nature of adaptation and the difficulty practitioners have in adopting processes from other locations. This suggests the need for comparative assessments to determine whether patterns exist in the types of participatory processes and partnerships that are most effective in particular city contexts. Stakeholder engagement in the realm of adaptation requires the exchange of scientific, financial, and commercial information. While this raises questions about managing proprietary information, it also underscores the need for studies of how information shapes power differentials and how co-dependence alters government autonomy and authority. Furthermore, most of the processes noted by those assembled were initiated by government actors. The reliance on government highlights the importance of investigations that examine how community-based adaptation is viewed by local government officials and the role it can play in the urban context.

The leaders at the meeting emphasized that preparing cities for the impacts of climate change requires new approaches to planning and transformational thinking when designing and implementing programs. While some of their efforts are innovative, many of the participatory techniques they are employing are rooted in approaches traditionally used in urban planning. This raises important theoretical questions about institutional inertia and change, most notably, what is enabling some cities to experiment and take on a leadership role while others are maintaining the status quo rather than adopting adaptation policies and programs. Urban climate adaptation is an emerging and rapidly changing policy domain. As the issues and questions noted suggest, learning from the efforts of early adapting cities will advance our understanding of how to effectively foster participation in climate adaptation initiatives while furthering our general knowledge of the dynamics of urban planning and local governance.

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View of the urban landscape from the Boston University rooftop CO_2 observatory

Exploring Space-Time Variation in Urban Carbon Metabolism

Lucy R. Hutyra, Steve Raciti, Nathan G. Phillips and J. William Munger

Carbon dioxide is a well-mixed greenhouse gas, but how, where, and when it is exchanged with Earth's surface is a complex spatio-temporal, coupled natural-human problem. Nowhere is this challenge more pronounced than in the urban environment. Fixed objects like buildings and trees, and mobile elements like cars and people, exchange carbon (C) across a wide range of spatial and temporal scales with a dynamic set of driving variables. As cities, states, and nations undertake efforts to reduce and regulate greenhouse gas emissions, we must understand these space-time variations and the underlying drivers of biogenic and anthropogenic exchange in order to develop robust monitoring, reporting, and verification systems. Within urban areas, the concept of urban metabolism provides a framework for monitoring, reporting, and verification that allows us to account for imports, exports, and transformations of carbon within urban areas.

Carbon dynamics of urbanizing areas

Carbon dioxide (CO_2) and methane (CH_4) are the two most important greenhouse gases (GHGs). At first glance, the monitoring of atmospheric GHGs is routine; we have an extensive international network of observations – National Aeronautics and Space Administration's (NASA) FLUXNET: http://www.fluxnet.ornl.gov/; National Oceanic and Atmospheric Administration/Climate Monitoring and Diagnostics Laboratory (NOAA/CMDL): http://www.esrl.noaa.gov/gmd/. However, the atmospheric mixing ratios of these gases are continually changing through a combination of anthropogenic emissions, biogenic exchange, and atmospheric transport. While 71% of anthropogenic CO_2 emissions are estimated to being attributable to urban areas (IEA, 2008), most efforts to study both atmospheric and terrestrial carbon dynamics have avoided areas heavily influenced by urbanization (Baldocchi, 2008). While more observations and studies are beginning to explore carbon cycling within urban and urbanizing areas, extraordinarily large uncertainties and knowledge gaps remain. Carbon emissions inventories are often at very coarse temporal and spatial resolutions (annual and national or 1° x 1°).

Attribution to smaller scales is very challenging (Kennedy et al., 2007) and prone to double counting and leakage given that most of the energy consumed within urban areas is generated elsewhere. This spatial mismatch between generation and consumption results in significant attribution challenges (Cannell et al., 1999). We do not yet have a sufficient understanding, the requisite measurement network, or the analytical modeling techniques necessary to adequately characterize the space-time variation in terrestrial sources or sinks within urbanizing areas that are required for future carbon regulation.

The current paucity of data about the biogeochemistry and carbon dynamics of urbanizing areas is in part a byproduct of the perception that urban ecosystems have limited ecological value because they are heavily modified by humans and are relatively small in size. However, urban areas are rapidly evolving in their spatial configurations and are growing in spatial extent (Schneider & Woodcock, 2008; UNFPA, 2007) and can contain significant pools of vegetation and soil carbon (Hutyra et al., 2011a). As urban areas grow, the ecology of cities will become ever more germane to both people's lives and the development of local to regional carbon mitigation strategies (Dhakal, 2010).

Over the last several years through a National Science Foundation (NSF) Urban Long-Term Research Area – Exploratory Award (ULTRA-Ex), we have begun exploring the spatio-temporal variation in CO_2 exchange across an urban-to-rural gradient in metropolitan Boston. Our results paint a picture of tremendous variation, but with some surprisingly clear signals of human activity and biotic response. Our atmospheric CO_2 mixing ratio measurements show the clear urban CO_2 hotspot observed in other studies, but also indicate seasonal vegetation metabolism signals as well as human metabolism signals in the heating and traffic patterns. Urban ecosystem structure also changes significantly across the Boston study area, with clear gradients in vegetation density, development intensity, traffic volumes, and energy use that are reflected in the CO_2 concentrations. Thus far, our early results raise more questions about scaling and attribution than they answer, but addressing these questions will be crucial to ultimately understanding the full complexity of urban metabolism.

Terrestrial carbon pools

There is conflicting evidence about the importance of soils and vegetation in the urban carbon metabolism that is caused, in part, by inconsistent definitions of 'urban' land use. In Massachusetts, the US census estimates that 36% of the state is 'urban', yet remote sensing observations reveal that 50% of this urban area is forest or forested wetlands (see Figure 1). While both of these estimates can be correct, the importance of soils and vegetation on the carbon metabolism is clearly dependent on whether municipal, physical, or social definitions of urban are applied.

Figure 1 I A fusion of remote sensing imagery from Quickbird (4-band, 2.4m image from August 4, 2007) and Light Detection and Ranging (LiDAR, 50cm horizontal resolution from the summer of 2005) observations highlights the distribution of vegetation taller than 1 m in the City of Boston, MA. The location of the CO_2 observation tower at Boston University is denoted with the red point (BU: 42.350N, 71.104W).

We quantified urban ecosystem contributions to terrestrial carbon pools in the Boston Metropolitan Statistical Area (MSA) using several alternative urban definitions. Aboveground biomass (DBH ≥ 5 cm) for the MSA was 7.2 ± 0.4 kg C/m^2, reflecting the high proportion of forest cover. Vegetation carbon was highest in forested land uses (11.6 ± 0.5 kg C/m^2) followed by residential

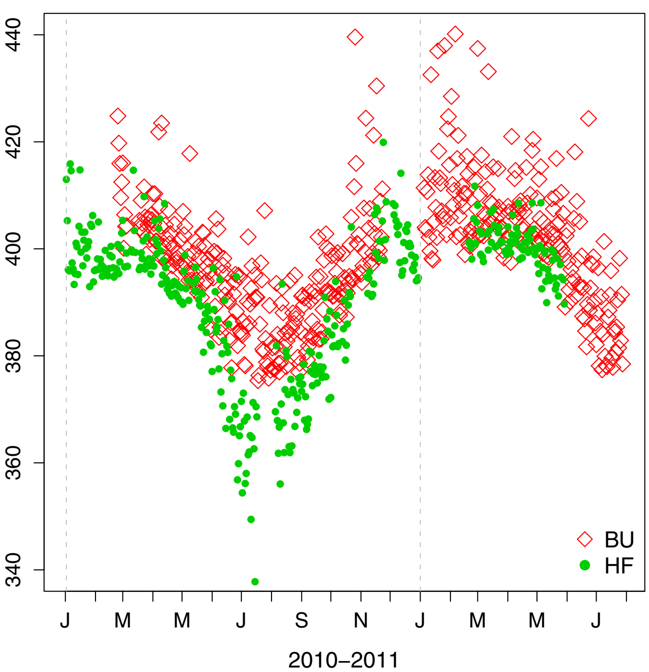
(4.6 ± 0.5 kg C/m²) and then other developed (2.0 ± 0.4 kg C/m²) land uses. Soil carbon (0 to 10 cm) followed the same pattern of decreasing carbon concentration from forest, to residential, to other developed land uses (4.1 ± 0.1, 4.0 ± 0.2, and 3.3 ± 0.2 kg C/m², respectively). Soil nitrogen concentrations were higher in urban areas than non-urban areas of the same land use type, except for residential areas, which had similarly high soil nitrogen concentrations. Enhanced soil carbon and nitrogen concentrations in residential areas may reflect human amendments to the system, including water and nitrogen fertilizer. When we extrapolate our estimates of soil (to a 1 m depth) and vegetation carbon pools to the Boston MSA, our estimates span a very wide range, from 1.4 to 54.5 Tg C and 4.2 to 27.3 Tg C, respectively, depending on the urban definition that was used. Conclusions about the importance of soils and vegetation in urban ecosystems are very sensitive to the definition of 'urban' used by the investigators. The development of consistent, empirical definitions of urban land use would facilitate comparative studies.

While we have found the Boston MSA holds large pools of vegetative and soil carbon, the exchange of carbon by urban vegetation is dwarfed by the local CO_2 emissions. Nonetheless, there is evidence that urban vegetation can provide important ecosystem services beyond carbon sequestration, including decreased storm water runoff (Xiao & McPherson, 2002), reduced airborne particulates (Nowak et al., 2006), reductions in seasonal heating/cooling demands (McPherson et al., 2005), reduction of the urban heat island through evaporative cooling (Huang et al., 2011), and provide aesthetic value and recreation space (Millward & Sabir, 2011). Unfortunately, new development may be outpacing the forest recovery that New England has enjoyed for the past 200 years (Foster et al., 2010). Depending on the trajectories and patterns of development in the region, the large carbon pools that we have found may be significantly diminished as some of the region's carbon stocks (and active C sinks) may become sources of carbon emissions (Stein et al., 2005). A recent analysis in Seattle, WA found that urban expansion resulted in a loss of 3.6 Kg C/m² between 1986 and 2007 (0.12 Kg C/m²/yr) in vegetative carbon pools (Hutyra et al., 2011b). The loss of forests to urban development is compounded by other threats, including outbreaks of native and invasive pests and pathogens (Lovett & Mitchell, 2004), changes in climate, and associated shifts in the frequency of fires, storms, droughts, and other disturbances (IPCC, 2007).

Atmospheric CO_2

Carbon dioxide is a well-mixed gas with a long atmospheric residence time, but we find significantly enhanced concentrations at our Boston University measurement site relative to observations at the rural Harvard Forest Long-Term Ecological Research site (~100 km distance, see Figure 2). During the summer of 2010, when CO_2 near the surface is depleted in the daytime by photosynthesis, the mean concentration at Boston University was 15.9 ppm higher than its rural counterpart (387.5 ± 0.4 and 371.6 ± 0.7 ppm, respectively). During the winter of 2010, when ecosystem respiration and heating of urban buildings release large amounts of carbon, the mean concentration at Boston University was only 11.2 ppm greater than the rural forested site (412.5 ± 1.0 and 401.3 ± 0.4 ppm, respectively). In Boston we also observed enhanced mid-day CO_2 concentration on weekdays relative to weekends due to traffic and commuting patterns (3.4 ppm during the summer and 1.7 ppm during the winter). The differences across this urban-to-rural gradient depend not only on the season and the relative magnitudes of uptake and emissions, but also on strength of horizontal and vertical mixing in the atmosphere. Atmospheric mixing and transport complicate direct interpretation of urban and rural concentration differences as an indicator of carbon metabolism. However, by coupling concentration data with high-resolution weather and atmospheric

Figure 2 | Mid-day mean CO_2 concentrations for 2010-2011 at Boston University and Harvard Forest showing the seasonal cycles and urban enhancement.



transport models it is possible to assess the spatial and temporal differences in carbon flux across urban-to-rural gradients.

Conclusions

Globally, urban areas are growing in population, land area, and ecological significance which will have dramatic impacts on regional carbon pools, fluxes, and the overall metabolism of the system. As we move forward with the development of CO_2 emissions reduction plans and regulations, we will need integrated estimates of CO_2 sources and sinks from the surface coupled with direct atmospheric CO_2 measurements that are able to partition the local and background CO_2 dynamics in a robust manner. Meaningful city, regional, or national reductions in CO_2 emissions will require major economic changes and self-reporting of reductions will not be enough. The framework of urban metabolism provides a platform that can integrate CO_2 emissions, ecosystems, atmospheric transport, and atmospheric observations to provide an independent method for reporting, monitoring, and verification of carbon.

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Commuters on the Brooklyn Bridge, New York, USA

Urban Remote Sensing (URS) and Forecasting Urban Land-Use (FORE) Workshops: Common Ground and Targeted Opportunities

Elizabeth A. Wentz, Karen C. Seto, Soe Myint, Maik Netzband and Michail Fragkias

Cities offer opportunities unmatched by their rural counterparts in terms of being hubs for economic growth, community building, and cultural creativity and expression. Furthermore, by concentrating human activities in urban centers, there is also the opportunity to protect habitats in outlying areas and increase the efficiency of municipal services such as power, water, sanitation, and education. In contrast, cities can also result in increased poverty, crime, social detachment and pollution. And while it is idealistic to think that the environmental impact of cities is local, the footprints of cities are extensive and can lead to widespread environmental degradation. These opportunities and problems represent key challenges for investigators and planners who simultaneously intend to promote improved urban living but in a way that supports long-term growth and environmental and social sustainability (Seto et al., 2010).

Workshop motivation and organization

Two workshops focusing on urbanization and its impacts were held jointly at Arizona State University (ASU) in April 2011- a workshop on urban remote sensing (URS), funded by the U.S. National Science Foundation (NSF) and a workshop on forecasting urban land-use change (FORE), funded by the National Aeronautics and Space Administration (NASA) and organized by the Urbanization and Global Environmental Change (UGEC) project. The workshops were held jointly to address the common goal of understanding urbanization through four parallel themes running throughout both workshops: data, applications, scale and case studies. The application discussion involved identifying how remotely sensed data and land-use forecasting models could be widely used by decision-makers and other stakeholders. The aim of the scale discussion was to define what is meant by scale and yet to recognize that it is an unsolvable but manageable issue. The data discussion aimed to understand the kind of data that are available, which data are needed, and how they can be accessed. Finally, the case studies discussion focused on alternative ideas on generating more case studies or developing a theoretical framework for comparing cities.

The workshops hosted approximately 35 academics and practitioners from 13 countries and five continents. Participants were asked to prepare short or medium length summary documents on the current state-of-knowledge on one of the four themes. These white papers were compiled and disseminated prior to the workshop to facilitate conversations focused on moving forward rather than on what has been done. On site, we had minimal presentations and numerous active conversations with moderators to guide the discussion and rapporteurs to record key points. Each morning, we distributed highlights from the previous day to energize the day's discussion.

Workshop participants

The goal of this article is to sustain the momentum that emerged from the two workshops and extend opportunities to a larger researcher and practitioner community. Below we focus on how the dynamics between the two workshops emerged in common ground, diverging interests, and steps to move foreword.

Common ground

Common ground emerged between the two workshops in each of the four themes. In particular, four common questions and issues arose:

1. **The need to improve accessibility and usage by non-expert users.** URS participants hypothesized that uptake by users outside of the remote sensing community remains low because there is a view that accessing and using remotely sensed products is difficult and requires expert use of specialized software. FORE participants questioned the policy-relevance of models and discussed disconnect between spatial models of urban growth and economic models of urban development. Although both groups speculated on different causes, the common conclusion is that there is a need to facilitate wider use of data and models through open-source, web-based data and tools. Both groups agreed that communication becomes a central tool for moving forward.
2. **The need to explicitly examine the range of scales in analysis.** Both workshops defined scale broadly, converging on spatial, temporal, governance, and economic scales. Each context includes grain size and spatial extent. URS added spectral scale to this list, to include the range of spectral information in the electromagnetic spectrum with regards to remotely sensed data. Beyond the basic definitions, however, the problems associated with scale and the possible solutions to them varied between the two groups. These differences will be discussed in the 'Diverging interests' section below.
3. **The need to increase data availability and accessibility.** Gaps in knowledge on data availability and accessibility emerged frequently throughout the workshop. Both groups linked data availability to the prior discussion on scale, recognizing that data are not always available at all scales. Furthermore, there was consensus between the groups that data, which exist in 'silos' and only accessible with expert knowledge, is needed for decision-making purposes. The data needs are also consistent between the groups. Data archives that store longitudinal data are needed to provide temporal information at as-detailed-as-possible spatial scales. There was a shared sentiment that technology associated with preprocessing, geo-rectification, data fusion, standardization, networking, and validation provides key solutions to accessibility and therefore usability of needed data.
4. **The need to develop an urban typology and framework to facilitate comparative studies across cities.** As a research community, we need to continue to study regions in depth and to create conceptual demonstrations of modeling efforts, but there is also the need for a theoretical framework to tie case studies together. We need to build a typology of cities to capture their complexity but have this built around a more theoretical framework. Furthermore, participants suggested that we do not start from scratch but rather leverage existing work to move forward more efficiently. For example, Fink (2011) proposed modeling urban efforts after the human genome project.

Diverging interests

In addition to the common ground just described, notable differences emerged during the joint discussions. The mixture of academic and practitioners as well as the different overarching objectives led to different emphases. This diversity provided additional opportunities to move forward.

During the 'application' discussions, URS questioned why remotely sensed data are not widely used for planning and policy-making. They speculated that one problem is data and software

are perceived to be expensive to acquire and difficult to use. Participants pointed out that a non-solution would be to wait for a Google-like company or a NASA-type initiative to take the lead. Currently, such an effort is not part of the Google business model and is not a NASA mandate. Instead, this group suggested that a possible solution would be to develop and promote open-source web solutions to data access and interpretation. In contrast, the FORE group similarly questioned why planners and practitioners underutilize land-use forecasting models. They speculated that one reason is that there are unique problems faced by decision makers in different locations and therefore different solutions are needed for models.

These different conversations led both groups to discuss how more case studies are needed but within a unifying theoretical framework. Case studies could be developed to illustrate how data that are free to acquire and easy to manipulate can provide comparative information across temporal and spatial scales. The theoretical framework would be built around how policy can affect real-world outcomes. For example, vegetation data in the form of a Normalized Difference Vegetation Index (NDVI) can be quantified from medium resolution, free data over a span of multiple years. These data could be used to model and analyze the impact of landscaping policies and the urban heat island effect.

Steps to move forward

Four critical steps can move the urban research agenda forward with an overarching theme that involves broader engagement and increased communication.

1. There is a need for academic researchers, model developers, and decision-makers to work together on urban issues so that the data we acquire and the analyses we perform are policy relevant.

2. The study of urban areas is unique in that it offers opportunities for both theoretical and applied work. Yet, there is a noticeable gap between empirical research and theory development. How do the myriad of urban remote sensing and modeling studies contribute to advancing fundamental knowledge of urbanization, sustainability, and how the Earth works? As a research community, we need to move closer towards bridging the empirical with the theoretical. Otherwise, we risk the danger of diving too deeply into the nuances of our algorithms and models at the expense of progress on 'the big questions'.

3. There is a considerable amount of data and information widely and (often) freely available. Although sometimes the data are awkward to acquire, there is an opportunity to overcome the limitations imposed by scale and data costs. We need to overcome the inertia to tap into them, be it crowd sourcing data or epidemiological data.

4. Research foci are becoming increasingly narrow in scope, which may be limiting our ability to address our problems. It may be time for academics to re-assess: are we asking the most salient questions for human well-being?

This article described the planning strategy, the unifying challenges and solutions, and the final engagement and outcomes associated with the joint workshop event. Our goal was to host an event that made the two groups more than the sum of the individual parts. We aim for continued efforts among the group of workshop participants as well as inviting other researchers and practitioners in urban remote sensing and forecasting urban land-use change to join us.

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Delhi, India

Thermal Satellite Data for the Assessment and Monitoring of Surface Temperature Change and its Impact on the Micro-Climate of Delhi

Javed Mallick, Atiqur Rahman, Maik Netzband and Sunil Bhaskaran

Rapid urbanization in cities across the world causes significant land use/land cover (LULC) change on the Earth's surface and is recognized as one of the most important anthropogenic influences on climate (Kalnay and Cai, 2003). Many studies have focused on examining urban thermal patterns and their relationship to urban surface characteristics (Weng et al., 2004; Yue et al., 2007). One of the most well-known adverse effects induced by urbanization is the so-called "urban heat island" (UHI) effect (Oke, 1976). Due to the presence of impervious surfaces, urban areas generally have higher solar radiation absorption and a greater thermal capacity and conductivity so that heat is stored during the day and released by night. As such, urban areas tend to experience relatively higher temperatures when compared with surrounding rural areas. Given that there is a strong link between population, environment and development, land use and land cover analysis has environmental implications at both local and regional levels. LULC is also linked to global environmental processes, due to the interrelated relationship of elements within the natural environment, i.e., the direct effects on one element may cause indirect effects on others.

In Delhi, LULC has undergone fundamental changes due to natural and socio–economic factors over the last three decades. Massive amounts of agricultural land disappear each year, as it is converted to urban or related uses. The urban surface temperature or UHI effect is one of the factors influencing the weather, micro-climate, and environment over the urban and its suburban area. Remote sensing data and GIS have been widely applied and recognized as powerful and robust tools in detecting urban land use and land cover change and its relationship with micro-climate effects (Banzhaf & Netzband, 2011). To help guide efforts to cool cities in order to improve human comfort, conserve energy and resources and reduce air pollution in the NCR (National capital region) Delhi, we have attempted to evaluate the magnitude and pattern of Delhi's urban growth under the following objectives:

- assess the LULC changes in Delhi, over the last decade (1999-2009);

- estimate the surface temperature and its relationship with different types of LULC;
- analyse the impact of LULC change on surface temperature and micro-climate.

The study area: Delhi, India

The capital city of New Delhi is geographically situated between 28° 23' 17" – 28° 53' 00" North latitudes and 76° 50' 24" – 77° 20' 37" East longitudes. It lies at an altitude between 213 and 305 meters and covers an area of 1,483 km². The climate of Delhi is influenced by its remote inland position and the prevalence of continental air masses, bringing extreme summer heat in June (48°C) and alternatively cold winters in December (3°C). Only during the three monsoon months of July-September is rainfall experienced, but of meagre amount. This influences the gradual conversion of rural open area into built-up area and the consequent merger with urban area. If the present population trend continues, the total population of NCT Delhi by the year 2011 and 2021 will be 18.2 million and 22.5 million respectively.

Materials and methods

Satellite Data Sets Used for this Study				
Satellite/ Sensor	Date of Acquisition	Day/Night	Path/Row	Information Extraction
Landsat7 ETM+	October 22, 1999	Day Time	146/40	LULC map NDMI and Surface Temperature
Landsat TM	October 25, 2009	Day Time	146/40	LULC map NDMI and Surface Temperature

Satellite datasets of Landsat-7 ETM+ and TM level-1G over the Delhi area have been used to prepare LULC maps and estimations of surface temperature derivation. Digital Number (DN) values were converted to sensor radiance for the Landsat satellite data which has been explained in depth in Wubet (2003). The images have been geometrically rectified to a common Universal Transverse Mercator (UTM) WGS84 coordinate system.

In order to assess the LULC change in Delhi over the last decade, seven major classes were constructed as per the classification scheme developed in Anderson et al. (1976). Training sites were digitized based on ground truth data using GPS. Finally, the Maximum Likelihood Classification was run with original bands and texture images as inputs, producing two final LULC maps for 1999 and 2009 that were then compared. A cross-classification procedure is a fundamental pair-wise comparison technique used to compare two images of qualitative data (Eastman, 1995), hence, an assessment of land cover change and its implications based on cross-classification principles was carried out. Using the classified land cover maps of 1999 and 2009 as input parameters we attempted to identify the locations and magnitude of major land change and the transitions between land cover categories in Delhi.

To validate the classified LULC maps, field surveys were conducted from October 2-8, 2007 and October 18-22, 2009. About 55 sample points were selected in such a way that all major LULC classes could be covered and so that the accuracy of classified LULC could be improved in the event of any doubt about a particular LULC class.

Accurate broadband emissivity data is needed as model inputs to better simulate the land surface temperature. For the estimation of surface temperature, the derivation of surface emissivity gains is also an important component. Hence, emphasis has been put on the estimation of surface emissivity. In addition, the emissivity is largely dependent on surface-cover type, soil moisture content, organic composition of soil, vegetation density, and structure, etc. In this study we've attempted to derive emissivity by the Normalized Difference Moisture Index (NDMI).

The NDMI is the normalization of the bands moisture difference response, between near infrared (NIR) band 4 and (SWIR) band 5:

$$\varepsilon_{(8-14)} = \frac{\varepsilon_v - \varepsilon_s}{i_v - i_s} NDMI + \frac{\varepsilon_s(i_v + di) - \varepsilon_v(i_s + di)}{i_v - i_s} + d\varepsilon$$

Where i_v is the pure vegetation NDMI, i_s is the pure soil NDMI and di is the error in NDMI. The ε_v is the vegetation canopy emissivity, ε_s is the bare soil emissivity. For the estimation of error in emissivity value the term ($d\varepsilon$) is the mean weighted value that takes into account the emissivity value of different surface types. The details have been explained in depth in Mallick et al. (2011).

Band 6L was used in the estimation of surface temperatures. The thermal radiance values were converted to surface temperatures using the pre-launch calibration constants (Schott & Volchok, 1985). If atmospheric effects (upwelling radiance and reflected downwelling irradiance) are separated, and emissivity is known, the temperature of a Lambertian reflector can be determined by reversing the equation of Planck's function. Therefore, the surface temperature for Landsat was estimated using this reverse equation.

The derived emissivity values over different features have been compared with those in the literature, (Salisbury & D'Aria, 1992; Rubio et al., 1997; Van de Griend & Owe, 1993) and were found to be in accordance (error of around 1-2%). In order to compare the estimated surface temperature values from satellite data with the field measurements (in-situ), a field survey was carried out from October 22-29, 2009. All of the temperature measurements were taken using TELETEMP infrared radiometer. The comparison shows consistency between the satellite driven temperature and field observed surface temperatures for the analysis of relative surface temperature with an error of (0.4-1.0 °C). The procedures for the conducted field survey have been detailed in Mallick et al. (2011).

Results and discussion

Figure 1 shows the state of LULC in both 1999 and 2009. The north-western part of the central region of the study area shows that agricultural land has been converted to built-up area. Here the agriculture land means agricultural cropland as well as fallow land; it will be sown some time later. Any increase in area of a particular class from another class has been termed 'gain', whereas any decrease in area of a particular class to another class has been termed 'loss' (see Table1). The maximum gain of 219.14 km^2 (32.04%) has been recorded in the high-density built-up category but at the same time it has lost 10.13 km^2 (1.48%) of total area to other classes. This transformation may be connected to change in the economic base of the city from agriculture to other commercial/industrial activity. The study shows that both low-density built-up area, 225.41 km^2 (32.95%) and agricultural land, 167.50 km^2 (24.49%) have been lost during the course of the last 10 years.

The study further shows that the increase in high-density built-up area is mainly occurring within the low-density built-up area. This is supported by field survey observations of the demolition of single story houses which are being replaced by newly-constructed five-story plus houses. The data indicates a 137.36 km^2 net change in low-density built-up area and a 69.59 km^2 change in agricultural land (see Table 1). This negative change reflects the addition of impervious surfaces, which often leads to the decrease in vegetative cover and an increase in surface runoff and land surface temperature. This, in turn, affects the change in micro-climate of the urban area.

An important aspect of detecting change is to understand it in terms of location and its temporal dynamics. This information will serve as a vital tool in micro-climate change analysis and

Figure 1 | LULC in Delhi (1999 and 2009)

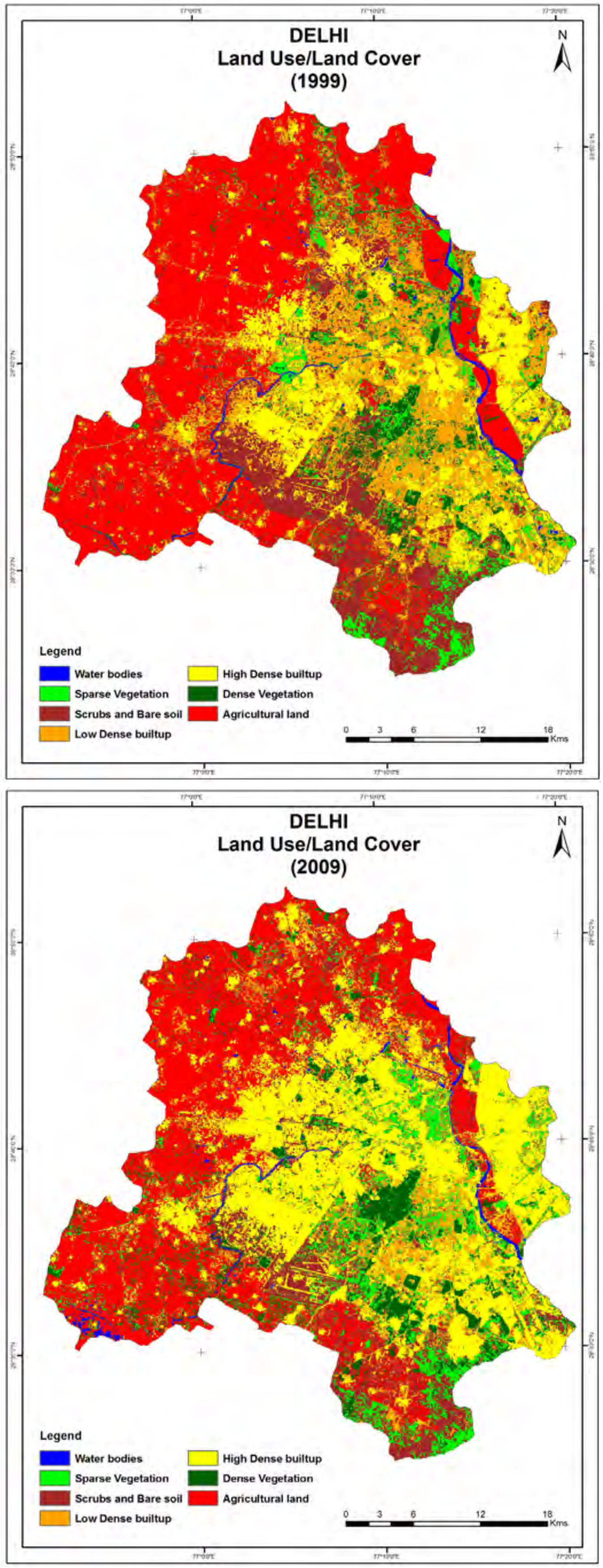


Table 1 I Gains and losses and net change (1999 – 2009)

LULC classes	Gain (Km^2)	Gain (%)	Loss (Km^2)	Loss (%)	Net change (Km^2)
Scrubs and bare soil	99.94	14.61	-111.00	23.23	-58.92
Sparse vegetation	108.52	15.86	-73.18	10.70	35.33
Dense vegetation	60.80	8.89	-39.31	5.75	21.49
Agricultural land	97.91	14.31	-167.50	24.49	-69.59
Water bodies	9.69	1.42	-9.64	1.41	0.05
Low-density built-up area	88.05	12.87	-225.41	32.95	-137.36
High-density built-up area	219.14	32.04	-10.13	1.48	209.01

Table 2 I Land use/land cover change (1999 - 2009)

Category-wise changes	Change/ Transformation (Km2)	Changes (%)
Low-density built-up area to High-density built-up area	129.57	42.18
Water bodies to High-density built-up area	2.25	0.73
Agricultural land to High-density built-up area	36.72	11.95
Dense vegetation to High-density built-up area	4.09	1.33
Sparse vegetation to High-density built-up area	9.65	3.14
Scrubs and bare soil to High-density built-up area	36.86	12.00
High-density built-up area to Low-density built-up area	4.02	1.31
Water bodies to Low-density built-up area	1.13	0.37
Agricultural land to Low-density built-up area	41.70	13.58
Dense vegetation to Low-density built-up area	6.68	2.17
Sparse vegetation to Low-density built-up area	11.03	3.59
Scrubs and bare soil to Low-density built-up area	23.49	7.65
Total	**307.19**	**100.00**

environmental management decision-making. This process involves pixel to pixel comparisons of the classified LULC maps and the overlaying of one map over the other in GIS software. Table 2 shows that the majority of changes have occurred from low-density built-up area to high-density built up area, which accounts for 42.18% of the total changes. This is followed by agricultural land which has changed to low-density built up area (13.58%) as a result of the high costs of land within the city and the relatively lower cost of agricultural land which has enabled the development of new high-rise residential communities.

Figure 2 shows the area where all land use changes have taken place. Major changes have occurred from low-density built-up to high-density built-up area mainly in the north-western and south-eastern parts of the city. The change of agricultural land into high/low-density built-up area can be seen in the northern and western parts of Delhi. All other areas where no change has occurred, mostly in the outskirts of the city with the exception of the eastern part, are shown in black.

In order to understand the impacts of LULC change on land surface temperature, the characteristics of the thermal signatures of each land cover type must first be studied. It is clear from Table 3 that for both years, bare soil exhibits the highest mean surface temperature followed by the urban or built-up land (32.9˚C in 1999 and 34.07˚C in 2009) and sparse vegetation (28.77˚C in 1999 and 29.51˚C in 2009). This implies that urban development does raise the surface radiant temperature by replacing natural vegetation and natural surface with non-evaporative and non-transpirational surfaces.

The minimum surface temperature in 1999 is recorded on water bodies (20.19˚C), followed by agricultural cropland (23.33˚C) and dense vegetation (24.39˚C) (see Table 3 and Figure 3). Similarly the minimum surface temperature in 2009 is observed on water bodies (22.02˚C), followed by agricultural cropland (26.39˚C) and dense vegetation (26.56˚C). The study further shows that the highest surface temperature is recorded on bare soil (41.78˚C) and (43.18˚C) in 1999 and 2009 respectively. When we compare the mean surface temperature of 1999 with 2009 it is observed that surface temperature is 1-2˚C higher over all the land use/land cover classes in 2009 compared to 1999 (see Figure 4). These differences may be due to the conversion of pervious surfaces to impervious surfaces together with some external factors, e.g., the increase in density of built up areas.

The relationship between surface temperature and land cover is influenced by land use, which means that changes in LULC can have a profound effect on the land surface temperature in the study area. The use of GIS with image processing software can help one to visualize the impact of land use and land cover change on surface temperature. The technique of image differencing (change analysis) is used to produce a surface temperature change image after the surface temperature of each year has been normalized. This image is then overlaid with the images of land use change. The result of GIS analysis shows that the urban development between 1999 and 2009 has given rise to an average increase of 1.84°C in surface temperature (see Table 4).

Table 4 further shows that highest mean surface temperature change (3.15°C) is recorded over the areas where dense vegetation has changed to high-density built-up area, followed by (2.92°C) where dense vegetation has changed to low-density built-up area. This clearly reveals that the increase in built-up area at the cost of vegetative cover is one of the main factors negatively impacting the micro-climate of Delhi.

Conclusion

For this study, an integrated approach of remote sensing and GIS was developed for the evaluation of land use change and its impact on surface temperature in Delhi, India. The results show that over the last decade (1999-2009) land use and land cover has significantly changed. There have been significant losses in agricultural area, scrubland and bare soil, but at the same time gains in high-density built-up area and low-density built-up area have been detected. During 1999 and 2009 the maximum gain of 219.14 km^2 (32.04%) was recorded in the high-density built-up category. This transformation may be connected to the change in the city's economic base from agriculture to other commercial/industrial activity. Urban land development was uneven in different parts of the study area.

Emissivity and surface temperature allow for a better understanding of the overall urban LULC classes. This provides an explanation of causes and effects, which is an important addition to conventional methods of monitoring the urban environment. Since the derived surface temperature values were found to be in concert with the field-measured values, this indicates that the methodology can be adopted for the study of urban areas. The results of this study show that urban land development has raised surface temperatures in Delhi by 1.84°C and demonstrates that the direct effect of urban land use/cover change on one environmental element can cause indirect effects on others. The methodology employed in this study provides an alternative to traditional observation and analysis using in situ field data for environmental studies in order to examine the environmental impact of urban expansion, land use change and its impact on the micro-climate.

Figure 2 I LULC change map of Delhi (1999-2009)

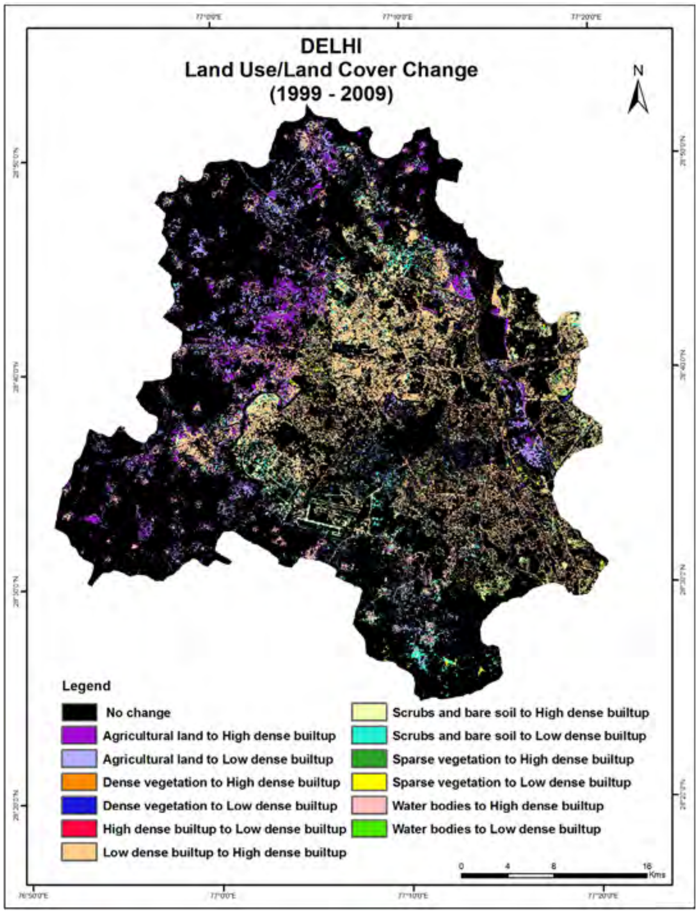
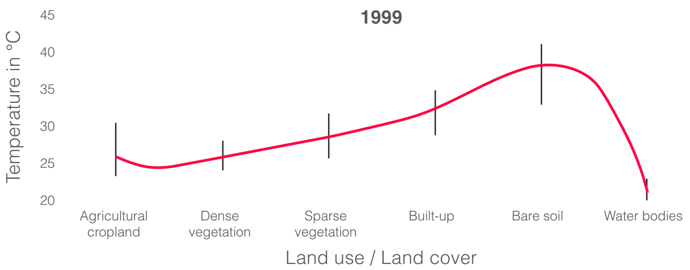


Figure 3 I Surface temperature profiles over different LULC (1999 and 2009)



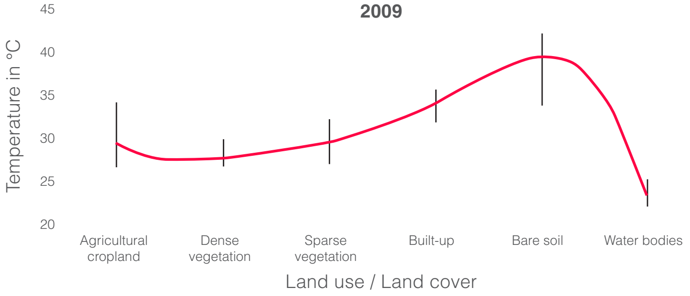


Table 3 | Surface temperature of different LULC (1999 and 2009)

Land use/land cover	Surface temperature October 22, 1999				Surface temperature October 25, 2009			
	Min. temp (°C)	Max. temp (°C)	Mean (°C)	Std. Deviation (SD)	Min. temp (°C)	Max. temp (°C)	Mean (°C)	Std. Deviation (SD)
Agricultural cropland	23.33	30.48	26.17	1.034	26.39	34.21	29.31	1.497
Dense vegetation	24.39	28.38	26.00	0.742	26.56	29.79	27.75	0.509
Sparse vegetation	25.95	31.94	28.77	1.403	26.91	32.23	29.51	1.219
Built-up area	29.17	35.40	32.90	0.743	31.61	35.74	34.07	0.516
Bare soil	33.34	41.78	38.65	2.142	33.78	43.18	39.59	1.968
Water bodies	20.19	22.94	21.78	0.552	22.02	25.08	22.92	0.782

Figure 4 | Mean surface temperature of different LULC (1999-2009)

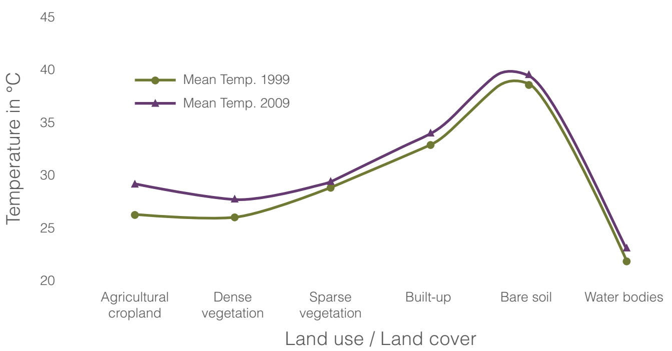


Table 4 | Surface temperature of different LULC (1999 and 2009)

LULC change	Area change (%)	Mean surface temperature change (°C) during 1999-2009
Low-density built-up area to High-density built-up area	42.18	1.23
Water bodies to High-density built-up area	0.73	1.84
Agricultural land to High-density built-up area	11.95	1.23
Dense vegetation to High-density built-up area	1.33	3.15
Sparse vegetation to High-density built-up area	3.14	2.16
Scrubs and bare soil to High-density built-up area	12	1.00
Water bodies to Low-density built-up area	0.37	2.57
Agricultural land to Low-density built-up area	13.58	1.62
Dense vegetation to Low-density built-up area	2.17	2.92
Sparse vegetation to Low-density built-up area	3.59	2.42
Scrubs and bare soil to Low-density built-up area	7.65	0.84
Average surface temperature change		**1.84**

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Playground in Hannover, Germany

The Impact of Demographic Change on the Accessibility to Public Services for the Elderly and Children of Hannover, Germany

Helber Y. López Covaleda and Tyler J. Frazier

Late in 2009, the German government conducted an exercise to determine population trends for the next 50 years. This study indicated that the German population, which is approximately 82 million, is expected to decrease by 12 to 17 million people as well as experience a significant shift in its demographic profile (Statitistisches Bundesamt, 2009). The most significant finding from this exercise is the projection for a shift in the share of senior citizens and children with respect to the economically active population; children and seniors are expected to account for half of the entire population of Germany, whereas they currently only represent 40%. Additionally, the ratio of senior citizens to children is expected to increase to 2:1 by the year 2040, indicating a trend towards an ageing population. With this expected declining population and changes in the age pyramid, a renewed focus on planning for future investments has been initiated with an eye on effective and efficient resource allocation of social services.

Improving the method for forecasting likely choices of location, migration patterns, and land development scenarios by using state-of-the-art urban simulation systems, such as UrbanSim, can foster improved planning for public services. This article presents the results of an urban simulation system developed to forecast the impact demographic change will have on the accessibility to public services for the elderly and children residing in Hannover, Germany.[1]

Demographic change and urban development

Hannover, a city of about 0.5 million people located in Niedersachsen, a region comprised of nearly 1.5 million, is attracting new inhabitants every day through increased urbanization. This trend of increased immigration from the rural environs is having a counterbalancing effect upon its existing declining and ageing population. In the long-term though, the phenomenon of rural to urban migration can only counterbalance the expected demographic change for ten to 15 years at most (Bertelsmann Stiftung, 2006). The impact from demographic change is expected to affect nearly every aspect of daily life, including labor and housing markets, social security, infrastructure, urban and regional planning, and education. A decrease in population will reduce the demand for goods and services, as well as disrupt general economic stability in the private sector. In the public sector a declining population can subsequently lead to reduced tax revenue for infrastructure maintenance, as well as capital improvements. As a result, the per capita burden will increase whenever services that continue to serve the public interest cannot be dissolved (CEMR & DIFU, 2006).

Demographic changes can have pervasive, substantial and widespread consequences for urban development. In regions where the population is in decline, the "growth allocation" planning paradigm[2] serves as the foundation for developing spatial reconfiguration strategies for maximum resource allocation and efficiency (CEMR and DIFU, 2006). In order to achieve this goal, Integrated Urban Models (IUMs) are becoming important tools for planners, as they have the capability to estimate the future locations of agents such as people and households as well as of employers (job locations), industries and real estate developments in a highly detailed, disaggregated manner. IUMs have been in use by urban planners for 50 years, but only in recent years have they begun to be considered as part of the planning process, moving away from a more singular focus on model development itself (Timmermans, 2003). These models involve accessibility, demographics, economics, regulations, global macroeconomic variables and others, in order to forecast the most probable agent location choices. UrbanSim is an IUM developed at the Center for Urban Simulation and Policy Analysis (CUSPA) in the University of Washington with the objective of providing a scalable, modular, robust, open source modeling platform (CUSPA, 2009). One advantage of UrbanSim is its ability to enable academics and programmers to collaborate and modify the core application, while at the same time users can process data, develop model scenarios, and generate forecast outputs which can be used in support of their land use planning processes.

Model development

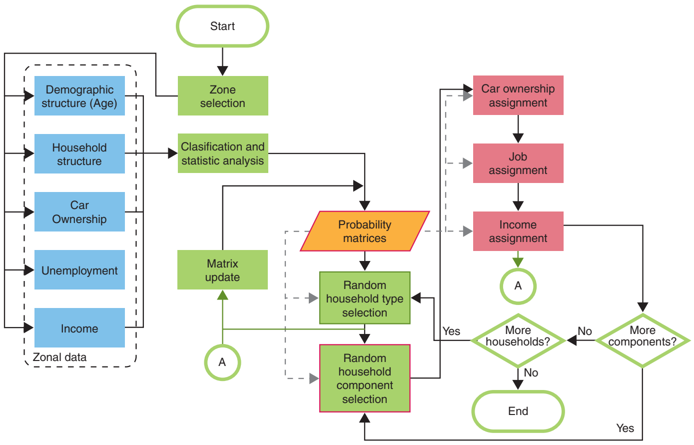
Configuring an urban simulation can be very challenging for most cities, as data is generally not standardized. There are no universal models or 'one size fits all' approaches, but instead each individual case must develop its own uniquely tailored approach. The Hannover Region transport planning department provided data for the transport model at the scale of the traffic analysis zone, which included a georeferenced job database and estimation of land value per area. Data processing was also an important first step in developing the base data for the urban simulation, which included writing a household synthesizer consistent with the available data structure at a higher level of aggregation. This synthetic households table was generated from the transport data which contained the age distribution and the statistic information about the specific household structure of each county. With this information a synthetic household generator was programmed in Visual Basic to randomly select one type of household within a given zone and then assign representative household data for each individual member. Once these synthetic households were generated, each one was assigned to one building, taking into account relationships such as income vs. rent/m^2 or household size vs. habitable area. Statistics calculated for the resulting households and the original data show almost identical results, with only minor differences which are attributed to inherent characteristics from the two sources (see Figure1).

Increased services for the elderly may become necessary due to an ageing population in Hannover, Germany

1 This is part of original work prepared for the Technische Universität München with the collaboration of the planning department of the Hannover Region.

2 When the general belief is that available resources are endless or that the limit of the given consumption rate would be difficult to reach, policies are created assuming that the preceding growth will prevail in the future. Analysis of the complex behavior of systems where planning has some relevance, has challenged those assumptions.

Figure 1 I Flowchart of the household synthesizer written to generate individual households from statistical data



A series of household forecasting models were developed which used the synthetic households table as their primary data input. The Household Transition Model (HTM) was programmed and specified to forecast the number and size of new households moving to the region, while the Household Relocation Model (HRM) used applicable variables to determine the probability that an existing household would chose to relocate within a given simulation year. Finally, the Household Location Choice Model (HLCM) aggregated new households moving to the region as well as existing households which had decided to relocate and employed several variables in order to predict the actual location where each household would move. Four sceneries were designed to predict potential regional development within the context of demographic change during the period between 2010 and 2040. The first two sceneries (1-W1 and 1-W2) represented the most likely limits to development in Niedersachsen and provide an illustration of what could potentially happen if the city fails to stem the impact from demographic change. The third scenario (BS-1-W2) was designed in accordance with the Bertelsmann Foundation estimations to 2025 (which exhibit a relatively stable population) and then slowly adapts to the general trend of Niedersachsen after 2025 until 2040. The fourth scenario (named FLAT after its horizontal shape when it is plotted) used a constant population to simulate stable conditions and was used as a reference case in order to evaluate the real impact of the long term mobility rate within the dynamics of the city.

Results

The results of the performed simulations provide a snapshot with clear tendencies of potential household preferences over the next 30 years. The first identified forecasted trend is the remarkable population decline in the more sparsely populated areas, with decreases of at least 22%. Another trend is the population increase in most urban cores, which is particularly noticeable in the second tier, smaller cities found throughout the region. Simulation runs for the city of Hannover were relatively consistent with the central boroughs revealing small positive variations, while some places in the outskirts exhibited moderate declines in population. On average, the urban simulation for Hannover predicts that the city will most likely maintain its population during the next 30 years, while other smaller urban centers in the region may witness a population increase through the in-migration of rural inhabitants. Nevertheless, this rural-to-urban migration will only dramatize the effect of demographic change outside of the urban cores. The Hannover urban simulation also reveals further concentration of households in the existing urban centers which is consistent with historical trends and concurs with previous estimations. Overall, migration to the cities will likely compensate for a deficit of newborns and increased deaths in the urban areas, but will accentuate the effect of the demographic changes within the rural fringe (see Figure 2).

Simulation results generated new household tables which revealed relocation patterns. The resulting distribution of new households was then processed using the projected demographic structure, in order to determine the future location of senior citizens and children. The scenario BS-1-W2 forecasted the smallest differences from other estimations and was selected to be used as part of the accessibility analysis. While scenario

Figure 2 I Long-term household mobilizations in the Hannover Region (color intensity represents the relative increase or decline of population, represented by green and orange colors respectively)

BS-1-W2 was considered to be the most realistic, in fact all of the simulation scenarios identified probable patterns of long-term household mobility as well as other trends. The model consistently predicts household concentrations centering on and around the consolidated urban centers. However, in comparison with previous projections made by the planning department of Hannover, the urban simulation predicts a more substantial and pervasive mobilization than had previously been considered. Simulation results indicate a significant number of households are likely to relocate closer to existing schools and hospitals, and that access to services will likely increase for the majority of inhabitants throughout the region. For this reason, a decrease in potential demand for medical and educational services is not expected in the urban centers; however, it may become necessary to increase capacity at some facilities. Accessibility to education and health services for people in rural locations will be more difficult since current facilities in those areas are likely to become even more underutilized. Additional public services implicit to educational and health care add an additional burden in the more rural environs as well, as public transportation systems in these areas often have low ridership and generate less revenue (see Figure 3a & b).

Future work

This work provides an advanced starting point towards building a comprehensive and complete model of the region. The next step in the improvement of the urban simulation will be to implement a real estate model which evaluates new prices and balances them with the possibility of excessive migration. Since job market dynamics in the region have not changed significantly in recent years, nor are they expected to in the near future (Fuchs & Zika, 2010), it would be useful as a next step to implement the Employment Relocation Choice Model (ERCM) in support of the real estate model and an updated HRCM. Finally, coupled with detailed multimodal networks that enable isochrone-based catchment area estimations[3], a more detailed urban model fosters more precise accessibility

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Abandoned settlement in Hannover, Germany

Figure 3a I Spatial distribution of children and elderly in the Hannover Region

Figure 3b I Coverage of schools and hospitals in the Hannover Region

calculations and the implementation of refined indicators, such as the Land Use and Public Transport Accessibility Indicator (LUPTAI). This indicator seeks to measure how easy it is to access common destinations (e.g. health and education) by walking and/or public transport. This is in contrast to the traditional method of measuring accessibility only by road or Euclidean distance (Pitot et. al., 2006).

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3 Since access to any location is enabled by transportation networks, "closeness" is better assessed by measuring the travel time across the network (including delays, waiting and transfer times), than measuring the distance between origin and destination. In this way catchment areas are better estimated by defining acceptable travel times to a given facility, than defining traditional buffer zones.

Istanbul , Turkey

Urban Growth Models in a Fast-Urbanizing World

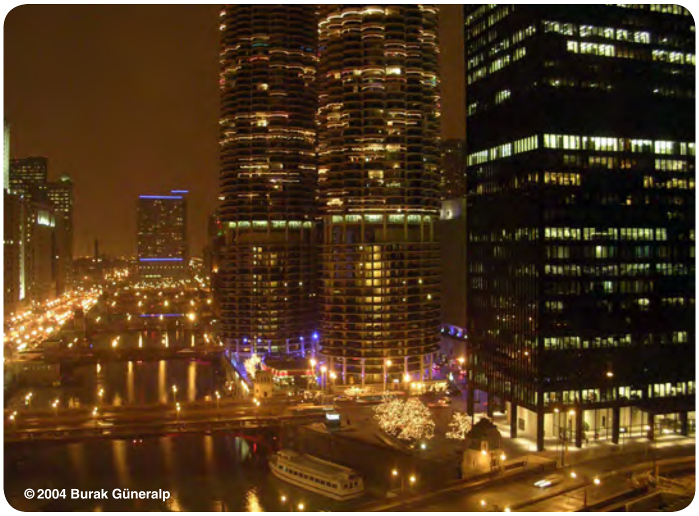
Burak Güneralp

Over the past few decades, there has been significant progress in urban growth modeling, which has the potential to contribute immensely to addressing the challenges of urbanization as well as realizing the opportunities it presents for sustainability. However, certain issues regarding modeling theory and practice, which I summarize in this article, must be resolved for this potential to be fully realized. First, the policy-relevance of the models must be scrutinized more forcefully. Secondly, there is an ongoing need to go beyond modeling the drivers of urban growth towards formulating the underlying urban processes informed by theory. The third important issue addresses modeling the dynamics of spatial configuration and composition of urban areas. Fourth, more comparative studies are needed to better understand urban dynamics across different geographies. Finally, more willingness is needed to incorporate uncertainty in the models as well as novel approaches to evaluate potential future paths. Improving modeling theory and practice in these five areas offers possibilities for maximizing the utility of urban growth models in addressing real-world problems facing urban areas.[1]

Democratization of model building and analysis

In the academic world of urban growth modelers, there are two competing agendas: building ever more-sophisticated models and making models relevant to decision-makers' concerns. Models that satisfy the expectations of the academic community do not necessarily serve the needs of the policy and stakeholder community. Consequently, most models remain to be academic exercises and inaccessible to a wider audience. Improving the accessibility and comprehensibility of models to stakeholders will facilitate the proper incorporation of their perspectives into the modeling process. There are several well-established approaches, i.e., 'community modeling', 'mediated modeling' and so on, to involve stakeholders not only in model analysis but also in model building process (van den Belt, 2004). Urban growth modelers can also experiment with integrating their models with

1 This contribution in part builds upon ideas discussed during the NASA-sponsored UGEC workshop "Forecasting urban land-use change" convened in Arizona State University, USA in April 2011. Many thanks to the participants of the workshop for their viewpoints and comments that inspired and informed this article.



Chicago, Illinois, USA

novel data visualization techniques to increase transparency of model structure and results (Kwartler & Longo, 2008). Open-source modeling initiatives, provided that the source-codes of the models are accompanied with sufficiently detailed metadata, can help address concerns about lack of transparency on how models work and who makes them work.

The aspects of reality that decision-makers will want to include in a model and how they are represented in the form of variables and relationships almost always differs from what modelers think should be included and how they should be represented in the model. This creates the crucial challenge of ensuring that the modeling process results in a model that is theoretically and mathematically valid and at the same time, serves the needs of the decision-makers. Thus, collaborative model building and analysis becomes as much a political process as a scientific one and the resulting model is more often than not a product of compromise. Even if the compromise is a useful and valid model, this is no guarantee for equitable outcomes for all stakeholders (Edmunds & Wollenberg, 2001). Moreover, various political forces at large may always prevent successful implementation. Closer cooperation with social scientists can help overcome some of these challenges towards purposeful, scientifically-valid as well as equitable implementation of models.

Representation of processes

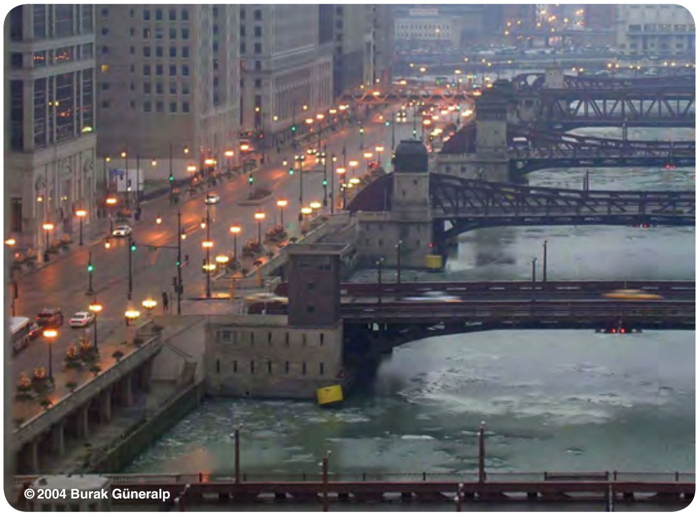
While it is important to integrate process-based approaches such as urban metabolism into the models of land change in order to track resource flows and accumulation due to urbanization, it is also important not to neglect the social and economic processes that interact with these physical flows and accumulations. Beyond relatively well-understood demographic dynamics, there is a gap in models of urban land change in terms of the representation of economic activity and how urban processes work within an ecosystem context (Grimm et al., 2000; Irwin, 2010). A focus on processes should include the ability to track the indirect impacts of urban land change both in terms of resource use and land change caused elsewhere due to urban change in a particular location. The trade networks of production and consumption result in the transportation of large numbers of manufactured goods and produce. These networks connect cities to diverse geographies thereby juxtaposing and increasing the size of the hinterlands of cities across the world (DeFries et al., 2010). Presently, there are no land change models that can simulate indirect land use change by tracking the actual resource flows as in urban metabolism or life-cycle analysis. SLEUTH, a popular urban growth model, can simulate indirect land change impacts of urbanization; however, it employs an empirical Markov Chain approach (Clarke et al., 2007) and thus is not process-based. In addition, it may be desirable to ensure model relevance to processes of environmental change and ecosystem-service provisioning at appropriate spatial and temporal scales. The coupling of different approaches to address some of the challenges of modeling the relevant processes could be a potentially fruitful course to take in this regard.

Dynamic modeling of urban spatial form

There are various implications of the amount of urban land cover and its form in terms of energy and materials consumption, conversion of natural and agricultural lands, local and regional climate, hydrological dynamics, and other ecosystem services (Seto et al., 2010). The ability of an urban land change model to predict the amount and spatial complexity of urban land cover should also be evaluated in consideration of these implications. For example, accurate prediction of urban patterns is important because urban form plays a significant role in determining energy demand and greenhouse gas emissions from transportation (Anderson et al., 1996). Yet, there are relatively few models that specifically focus on replicating urban spatial patterns by explicitly incorporating the processes underlying these patterns (Makse et al., 1995). In general, predicting urban land change patterns, typically defined as two-dimensional constructs, is more challenging than predicting the overall amount of change. Nevertheless, an accurate evaluation of environmental performance of cities including the urban heat island effect requires consideration of the vertical component of urban form (Adolphe, 2001). It is also important for a more accurate prediction of material and energy demands resulting from future urban land growth. Unfortunately, a common drawback in the overwhelming majority of urban land change models is the lack of representation of this vertical dimension. One way to incorporate this element is to include building height information (Benguigui et al., 2008) or, as a proxy, population density as an additional input image. However, obtaining such information at sufficiently fine resolution is costly even for most developed country cities.

Emphasis on comparative studies

Notwithstanding the significance of study findings on a particular urban area, comparisons are more likely to generate essential insights than stand-alone studies. Therefore, more concerted efforts by scholars to compare the findings of modeling studies from different cities must be made to crystallize the similarities and differences between disparate urbanization dynamics in different regions and countries. There are only few examples of such comparative assessments of different modeling studies or of the same modeling approach in different urban settings (Gazulis & Clarke, 2006; Pontius et al., 2008). Yet, such approaches can be very valuable to gain insight into the strengths and weaknesses of different modeling approaches as well as the similarities and differences among urban regions. A typology of urban areas may serve as an organizing framework to make sense out of the similarities and differences between cities in a comparative study. Indeed, the fundamental makeup of urban areas has been repeatedly likened to DNA by various researchers (Gazulis & Clarke, 2006; Wilson, 2010; Fink, 2011) with the implication that urban areas across the world share some fundamental traits.



Chicago, Illinois, USA

Urban growth models can help to uncover these traits and their multitude of expressions across the world. Nonetheless, the idiosyncrasies of cities belie simple generalizations and modelers must also be cognizant of the unique characteristics of each place.

Envisioning possible futures

Despite decades of theoretical and methodological improvements, land change models are still poor in predicting future growth patterns (Pontius et al., 2008). The fundamental limit on any model's predictive performance is the fact that the set of assumptions that undergirds a model constitutes a reflection of what we know about the past and present dynamics. The past and the present –even if perfectly known– can inform but cannot dictate a single future (Allen, 1988). Models, however steadfastly process-based, should account for the uncertainty that the future holds and become less focused on single predictions. There are well-established approaches that allow for the proper incorporation of uncertainty into the process of envisioning probable or desirable futures. Monte Carlo approaches as well as multi-model ensemble simulations, though the latter not so much in urban growth modeling, are already well-established in accounting for various sources of uncertainty in dynamic models (Palmer et al., 2005; Clarke et al., 2007). On the other hand, foresight is an approach in which different futures (i.e., scenarios) can be envisioned depending on widely different assumptions as well as aspirations (Frame, 2008). It is imperative to know the kind of urban environment in which stakeholders want to live in order for them to discover how to reach that vision. Importantly, a foresight approach allows for the enmeshing of forecasting with envisioning. An additional strength of this approach is that it allows stakeholder participation in which certain elements can be input to a mathematical model to simulate processes that are thought to play significant roles in a specific scenario and generate quantitative results (Cole, 2001). Hence, within a foresight framework, models can act as vehicles for facilitating the formation of consensus on such future visions among the stakeholders.

Final remarks

Urban growth models, when used skillfully and judiciously, can be vehicles for organizing our knowledge on urban dynamics, platforms to facilitate communication among stakeholders, and a means by which we can make sense of what we know about the past and present when evaluating future potentialities. Progress on the issues around the real-world relevance of these models, some of which I have briefly touched upon here, will help to improve their utility for addressing the challenges of our urbanizing planet and take advantage of the opportunities it presents for sustainability.

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Gorakhpur, Uttar Pradesh, India

Environmental Change and Urban Resilience: The Experiences of Gorakhpur

B.K Singh and Shiraz Wajih

Over the last two decades, the resilience of urban areas with respect to environmental change has been considered an issue of great importance not only at the global level but also at the national, state and even local level, due to the complex interlinkages of urban systems. In many small- and medium-sized towns in India, these systems are not only comprised of physical infrastructure, but involve complex interrelationships between social, cultural, political, institutional, economic, geographic, organizational and environmental factors. These interrelationships influence the population, their activities and their response patterns under differing conditions.

In most of the small- and medium-sized towns in Uttar Pradesh, India (one of most economically impoverished states within the country), rapid urbanization is placing substantial pressure on natural resources. Consequently, these towns are experiencing serious problems which concern the environment, urban management, poverty and development.

This article assesses the development pattern of Gorakhpur city in light of recent climatic changes. It also presents the initiatives put forth by the Gorakhpur Environmental Action Group[1] under the guidance of the Asian Cities Climate Change Resilience Network (ACCCRN)[2] to develop urban resilience though community participation.

Urban growth in Gorakhpur

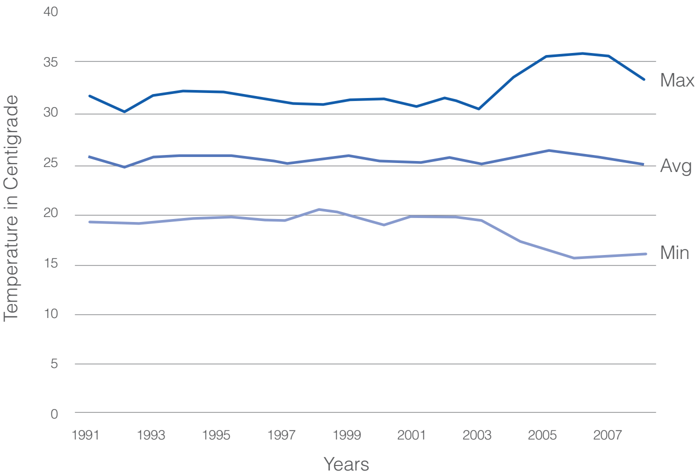
The city of Gorakhpur is one of the fastest growing cities in the Tarai[3] belt of the Mid-Gangetic Plains of Eastern Uttar Pradesh, India. It has seen unprecedented growth in the last

1 http://www.geagindia.org/

2 The ACCCRN is supported by The Rockefeller Foundation. More information about the Network can be accessed here: http://www.rockefellerfoundation.org/what-we-do/current-work/developing-climate-change-resilience/asian-cities-climate-change-resilience/

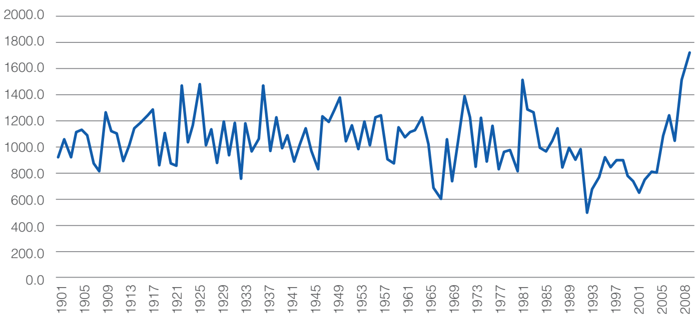
3 The Tarai is a belt of marshy grassland at the base of Himalaya range in India, Nepal and Bhutan.

Figure 1 I Gorakhpur City: Temperture scenario (1991-2008)



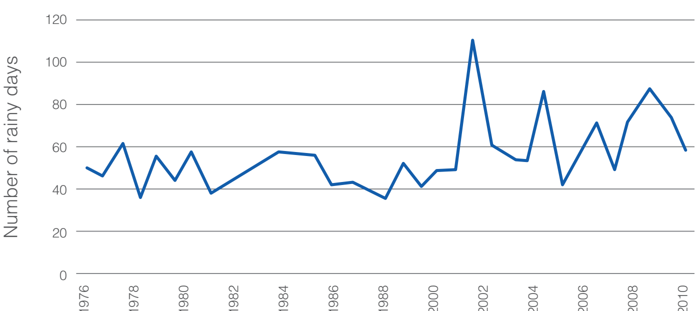
Source: Verma, S.S., 2009

Figure 2 I Gorakhpur City: Variations in annual rainfall (1901-2008)



Source: Opitz-Stapleton, 2009

Figure 3 I Gorakhpur City: Number of rainy days (1976-2010)



Source: Wajih et al., 2010

two decades, but this has come at the cost of unmanaged urban development characterized by poor environmental governance, traffic congestion, income disparities, poor delivery of basic services, social inequalities and lack of adequate capacity to manage the effects of climate change and resulting impacts (e.g., contaminated water and health pandemics) of natural disasters (e.g., flooding and water logging) (Wajih et al., 2010). The city needs massive investments in infrastructure, public services, institutional capacity and environmental programmes if basic security, health, safety and overall conditions are to improve for the majority of urban residents.

In 2001 the city of Gorakhpur had a population of 622,701[4] but it has now exceeded the four million mark[5] and has an average density of about 5,882 persons/km^2. During the last three decades, the population of the city has increased rapidly with record growth occurring between 1981-1991(64.1 %) due to the incorporation of adjacent rural areas into the municipal area. Besides natural population growth (2.3 % per annum), migration from nearby rural areas, as well as from outside the state to the city, has been a prominent factor influencing the ongoing rapid urban demographic growth and has exerted tremendous pressure on the land, water and varying infrastructural facilities. This has led to the development of numerous slums and informal sectors within the city, where inhabitants face living conditions that deteriorate further with each passing day. Currently, 33 percent of the city's population is concentrated in 110 slums located within the city boundary.

Changing climate

Global environmental change is a function of complex interwoven factors, but when analyzed at the micro level it is quite apparent that its varying impacts are very much localized. The rapid concentration of urban population and mercurial nature of the monsoon in south and southeast Gorakhpur have already made this region more vulnerable. The recent climate induced calamities have added a new layer of complexity, forcing policy makers and planners to retrospectively assess the development scenarios of these areas (Wajih et al., 2010). However, the lack of data availability on climate change within the public domain bottlenecks the formulization of any concrete planning to cope with its adverse impacts.

Historically, the climate of Gorakhpur and its surrounding areas has been mild (Nevill, 1909). However, in last few years there has been a rapid alteration and unexpected changes in the

4 http://www.censusindia.gov.in/towns/up_towns.pdf (Last accessed on August 4, 2011)

5 http://censusindia.gov.in/2011-prov-results/paper2/data_files/UP/datasheetpaper2.pdf (Last accessed on August 4, 2011

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temperature pattern, rainfall amount and moisture content in the air. The number of days above 40° Celsius/104° Fahrenheit is increasing each year and there has been a 9.51 percent increase in the maximum temperature during 2003 and 2008. However, at the opposite end, the annual minimum temperature has recorded a decreasing trend (Verma, 2009) (see Figure1). This aberration in temperature has raised several questions around whether these changes are attributable to the impact of global climatic change or the phenomenon of localized climatic altering. Despite the fact that there is no conclusive evidence that these shifts are the outcome of anthropogenic climatic change, the citizens of Gorakhpur are nevertheless feeling the effects of such changes (Opitz–Stapleton, 2010).

More rainfall in fewer days

The changing temperature has also affected the rainfall pattern and moisture content in the city's atmosphere creating considerable variation in annual rainfall. Since 2004, the trend shows a continual increase in rainfall (see Figure 2), however, while the rainfall amount is increasing, in Gorakhpur the number of rainfall days has decreased (see Figure 3). Due to low capacity of water storage and poor solid waste management and sanitation systems, this increased intensity of rainfall has exacerbated water logging and constricts the mobility within the city.

Water logging and flooding

There are many factors which contribute to the city's problems of flooding and water logging. The saucer shaped topography and gentle slope is less equipped to handle increasing water flows from Nepal into the rivers Rapti and Rohin. This along with other factors, such as the degradation of water bodies, unplanned development, poor infrastructure, localized underground sewerage and a lack of solid waste management further exasperate the problem (Wajih et al., 2009). During the last few decades, water logging has become chronic in many parts of the city and if development continues without modification, it can be easily predicted that the people of Gorakhpur will face serious consequences in terms of their health and livelihoods. At present, 18 percent of the city (see Figure 4), especially the southern, western and central areas, face acute water logging (Wajih et al., 2009). In these areas water remains stagnant for more than three to four months, creating serious health conditions and the increase of health hazards.

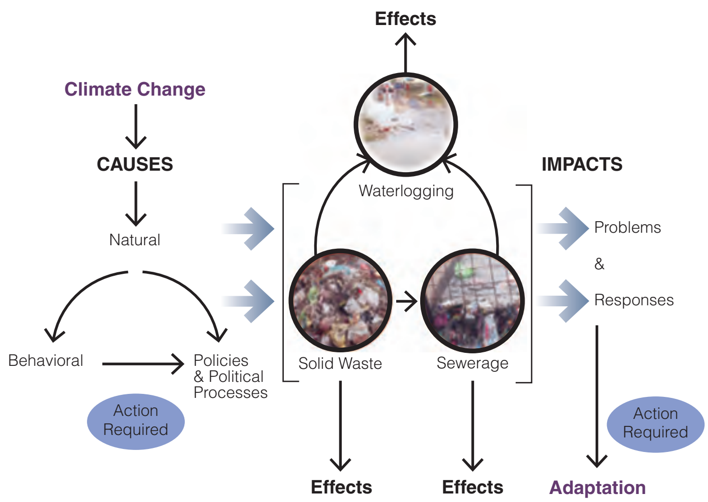
Sewerage and solid waste

The coverage of a sewage network in Gorakhpur is very poor. Presently, only 22 percent of the total area is covered by an underground sewer network (Wajih et al., 2009). The existing

Figure 4 I Gorakhpur City: Water logged area, 2008

Source: Wajih et al., 2010

Figure 5 I Gorakhpur City: The risk frame



Source: Wajih et al., 2009

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sewage networks cater primarily to the older areas of the city area. Since the city has no sewage treatment plant, sewage is directly released either into the river or into water reservoirs, leading to further pollution and increasing siltation of river beds. Due to improper maintenance, most of the open drains are badly damaged and choked with silt and garbage. Furthermore, a poor solid waste management system has perpetuated the problem of water logging. Due to a lack of formal dumping sites, all garbage is disposed of either along roads or used as land fill material within low-lying areas.

Vulnerability

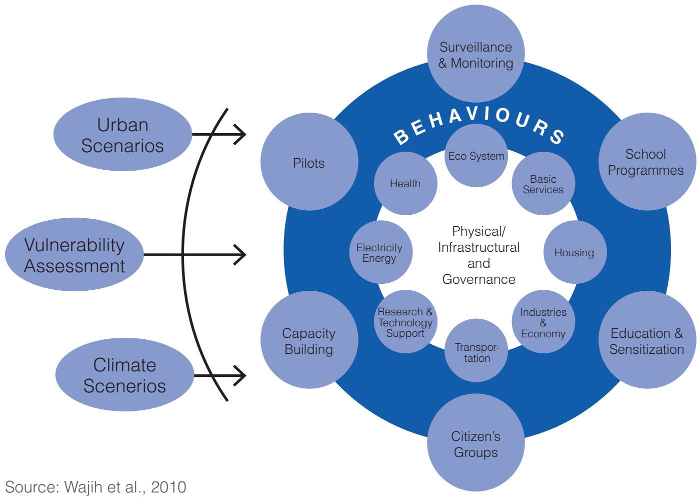
The perpetuation of water logging and flooding in the city cannot be attributed to any single factor, rather it is attributed to a combination of different risks (i.e., natural/topographical, behavioral and governance) (see Figure 5). While, the problem of solid waste management and localized sewage has its own negative effects in the form of disease and health risks, it also aggravates the situation of water logging. Thus, the causal factors are interdependent and interrelated in influencing the vulnerability of the city. The risk of water logging in Gorakhpur is increasing every year, damaging the infrastructure and affecting the society as a whole, particularly the underprivileged who are the city's most vulnerable, as they have neither the capacity to respond nor the option of moving to safer locations.

Resilience strategy approach

Practically speaking, resilience development within the city system and amongst people is a slow process. Under the guidance of the Asian Cities Climate Change Resilience Network (ACCCRN), the Gorakhpur Environmental Action Group has evolved a resilience framework and formulated a strategy that considers the interconnectedness of three risk categories within the city of Gorakhpur (i.e., natural, behavioral and governance) for increasing the city's resilience to climate change. The strategy advocates that resilience development cannot be achieved through just a single intervention point, but requires an integrated approach. The basic concept behind the strategy is the proactive role on part of the government in developing the resilience of the city, while citizens must likewise be organized and ready to take ownership and partnership in the city's development towards resilience.

This concept, (see Figure 6) emphasizes the behavioral aspects along the outer circle, while the inner core addresses the physical, infrastructural, and governance components. It is believed that

Figure 6 | Resilience strategy



Source: Wajih et al., 2010

the strengthening of behavioral aspects (circle of influence) through awareness will positively influence the inner core (circle of concern, i.e., system) to become more responsive, transparent and accountable. This will in turn aid in the development of a citizen–government synergy for the development of the city and its resilience capacities over the long term.

Strategy for moving ahead

As stated, resilience cannot be achieved through a single intervention point. The strategy created for Gorakhpur advocates integrated courses of action to address a combination of institutional, behavioral, social and technical issues. Hence, the areas identified for strengthening resilience vis a vis vulnerable sectors and respective actions can be summarized in Table 1.

Conclusion

Thus, to develop resilience in an urban system and achieve sustainability, it is essential to adopt a multi-pronged, multi-scale strategy targeting diverse groups and stakeholders; this type of approach speaks to the complexity of the urban system and addresses those factors of which it is comprised (i.e., natural, behavioral, governance, institutional and political). An urban developmental plan should be prepared on the basis of real-time facts and information rather than projected data. Additionally, it is also requisite to develop proper coordination amongst associated departments on their development agendas before such a plan becomes implemented. Lastly, it cannot be stressed enough that there must be extensive interplay between the system and the people, as this is pivotal in making both entities accountable and responsive to the impacts of environmental change.

Table 1 I Identified actions for strengthening resilience

Vulnerable Sectors	Areas to Strengthen Resilience	Actions
Housing	Effective master planning and proper enforcement Awareness among citizens Water harvesting	Ward-level micro-resilience plan developed and institutionalized review of master plan
Industries and commerce	Environmental Impact Assessment (EIA) measures Effective monitoring of waste treatment Organized housing for industrial workers	Sensitization of industries and commercial establishments for EIAs, energy efficiency, waste management and organized housing
Basic services	Quality of drinking water monitoring and awareness generation	Establishing multiple channels for data collection and reporting on water quality
	Effective drainage system according to geo-hydrology of the city	Making the proposed drainage system more effective and energy efficient
	Decentralized community-owned solid waste management	Designing a city-wide community-based Solid Waste Management (SWM) system based on a pilot Public–Private-Community Participation (PPCP) model
Transportation	Planned transport system for the city Public transport system to be enhanced Compressed Natural Gas (CNG) vehicles to be introduced	Designing for a green and resilient transport system for the city
Energy / Electricity	Alternate energy sources Conversion to Compact Fluorescent Lightbulbs (CFL) in private and public places	Sensitizing industries and commercial establishments to adopt energy efficient measures
Health	Effective health surveillance system Preventive health measures Sensitization and education	Establishing a city-wide health surveillance system Identifying and promoting preventive health measures and practices for water and vector borne diseases
Ecosystem	Conservation of water bodies	Mapping, demarcation and conservation
	Plantation and public land to be protected	Promoting plantation public land
	Sensitization and awareness	School education programmes

Source: Wajih, et al. (2010)

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Makoko, a slum of houses on stilts in central Lagos, Nigeria

Local Knowledge and Capacity for Global Environmental Change Adaptation in Urban Slums and Informal Settlements of the Developing World

Peter Elias

Vulnerability to global environmental change is closely associated with poverty which means that the world's poorest peoples and places are exposed to the greatest risks of global environmental change impacts. Vulnerability to global environmental change occasioned by the increasing frequency and severity of extreme weather events such as storm surges, droughts, floods, heat waves and hurricanes, as well as the semi-permanent or permanent effects of sea-level rise, land subsidence or desert encroachment will mostly impact urban areas in developing countries (IPCC, 2007; The World Bank, 2010b). Yet, the capacity to adapt to climate change is the lowest in these impoverished areas (see Table 1). Global population and demographic analysis indicate that cities in these countries are growing in size and number without the capacity to support the urban poor who largely live in slums and informal settlements.

Presently, about two billion people, the majority of whom are found in Africa, Asia and Latin America, are living in congested, overcrowded edges of cities surrounded by heaps of uncollected garbage which become playing grounds for children (UN-HABITAT, 2009). They do not have potable water and proper plumbing and are plagued by extreme anxiety, poverty and violence.

In 2000 the world's wealthiest nations created the Millennium Development Goals (MDGs) to improve the lives of 100 million slum dwellers by year 2020 (UN-HABITAT, 2009). If the goals of eradicating extreme poverty and improving the living conditions of the world's poorest people and places are to be realized through the MDGs, then adaptation to global environmental change must be enhanced at the grassroots level, through the recognition of local knowledge, local responsiveness and local capacity.

Whereas there is much in the literature on the relationship between global environmental change and cities, there is a dearth of comparative studies on vulnerability, local knowledge, responsiveness and capacity in urban slums throughout developing countries. As a starting point of comparison, this article examines urban slums and informal settlements in developing countries within the context of urbanization and global environmental change, levels of vulnerability, and the role of local knowledge, local responsiveness and local capacity for adaptation to global environmental change impacts.

Urbanization and the proliferation of urban slums and informal settlements

Urbanization in developing countries results from the unplanned, uncontrolled and constant migration of rural inhabitants to urban centers and is a consequence of push and pull factors. The neglect of rural areas by governments (i.e., lack of agricultural incentives, poor infrastructure and services, and the absence of government action) contribute to the push factors responsible for the exodus of rural inhabitants. Furthermore, the pull factors of in-migration to the cities is often very strong, offering increased socioeconomic opportunities, a promise of increased well-being, the availability of infrastructure and services, and a larger presence of government action, etc. These push and pull forces that encourage rural to urban migration is complicated by the fact that cities are often without the necessary competences and resources to adequately provide for a growing population, creating a dilemma for present-day urbanization in these countries. This rapid urbanization and government failure in housing provision are the main reasons for the proliferation of urban slums and informal settlements. They are often characterized by a lack of access to housing, land information and registration, and housing finance, inadequate policy frameworks and procedures, inappropriate urban planning methods and urban poverty (UN-HABITAT, 2009).

Transfering drinking water from one pail to the next in Jakarta.
Source: www.irinews.org/photodetail

Table 1 | Urban population and proportion of urban slums in selected developing countries

Country	Urban population (000s)						Proportion of slum dwellers (%)					
	1990	1995	2000	2005	2007	2010	1990	1995	2000	2005	2007	2010
Brazil	111,851	125,685	141,404	157,369	163,462	–	36.7	34.1	31.5	29.0	28.0	–
China	314,845	380,553	454,362	530,659	561,251	–	43.6 40.5	40.5	37.3	32.9	31.0	–
Colombia	23,811	26,979	30,043	33,071	34,237	–	31.2	26.8	22.3	17.9	16.1	–
Egypt	23,972	25,966	28,364	31,062	32,193	34,041	50.2	39.2	28.1	17.1	17.1	17.1
Guatemala	3,663	4,313	5,067	5,997	6,419	–	58.6	53.3	48.1	42.9	40.8	–
India	219,758	253,774	289,438	325,563	341,247	–	54.9	48.2	41.5	34.8	32.1	–
Indonesia	55,922	70,188	88,918	108,828	116,832	–	50.8	42.6	34.4	26.3	23.0	–
Mexico	59,994	67,368	74,524	79,564	81,951	–	23.1	21.5	19.9	14.4	14.4	–
Mongolia	1,264	1,357	1,397	1,464	1,497	–	68.5	66.7	64.9	57.9	57.9	–
Morocco	12,005	13,931	15,375	16,763	17,377	18,374	37.4	35.2	24.2	13.1	13.1	13.1
Nigeria	33,325	42,372	53,048	65,270	70,539	78,845	77.3	73.5	69.6	65.8	64.2	61.9
S. Africa	19,034	22,614	25,827	28,419	29,266	30,405	46.2	39.7	33.2	28.7	28.7	28.7

Source: UN-HABITAT, 2009; UN-HABITAT, 2008; DESA, 2008

The new geography of urban slums and informal settlements in some developing countries reveals the emergence of new urban development corridors at the peri-urban and zones of transition. This is ostensibly due to a lack of government capacity and willingness to address the needs of these new urban areas at the fringes of the cities. Development here is highly fragmented fraught with obvious inequality and marginalization, with dissonance between the large cities at the centre and the medium and small cities at the peripheries. As a result, they are left to grow organically, where development occurs sporadically without the guidance of any legal or planning frameworks. With respect to global environmental change, they are replete with an urban population that is socioeconomically disadvantaged and therefore, at higher risk from extreme weather events and sea-level rise.

Vulnerability of urban slums and informal settlements

The present and future range of vulnerability of urban slums and informal settlements in developing countries varies across geographic regions (see Table 2) and socioeconomic background. The developing world's largest cities are precariously located on the coast and with close proximity to the shoreline. These low-lying areas (defined as areas along the coast that are less than 100 meters above sea-level) comprise two percent of the world's population (McGranahan et al., 2007). Similarly, a study of 136 port cities has shown that the number of people exposed to flooding linked to a 1-in-100 year event will increase from 40 million to 150 million by 2070 and that the loss of land value assets will rise from the present three trillion USD to 30 trillion USD (Nicholls et al., 2008).

The role of local knowledge and capacity for adaptation to global environmental change

Local knowledge is built on the social and cultural underpinnings of local communities which have been established over several generations. (Osunade, 1994; Warren, 1992). This knowledge is developed from the connections people have to their environment and their adjustments to changes that occur over time, thus, providing the foundation for local decision-making and actions in many urban slums and informal settlements. Local knowledge has been widely incorporated into climate change mitigation and aspects of weather forecasting, biodiversity conservation, vulnerability mapping, agriculture, and land-use planning.

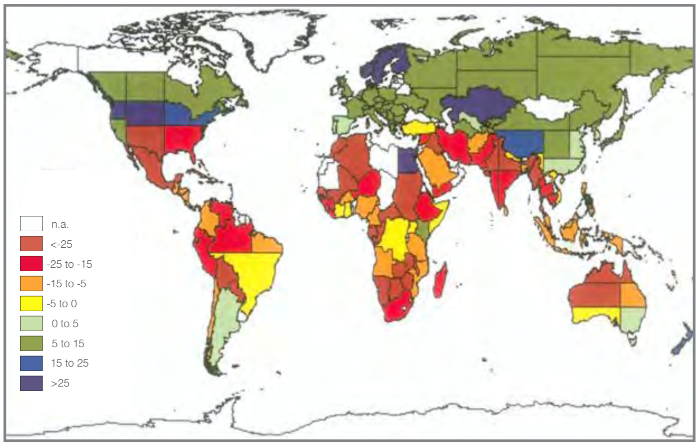
While mitigation strategies require global analysis and global collective actions, adaptation requires local analysis and must be addressed through local actions (The World Bank, 2008; UN-HABITAT, 2008). Global strategies, though anticipatory, require the incorporation of participatory approaches from the local communities and institutions. In this context, local knowledge, local response and capacity for adaptation to global environmental change in the urban slums of developing countries must be emphasized. The positive actions of these local communities and institutions can be used to assist in the provision of municipal infrastructure and services, disaster response planning, regulation of property rights, information dissemination, coordination with decision-makers at multiple levels, and the organization of social actions (Nyong et al., 2007). They also have the potential to attract external support and funding for training and capacity building,

Table 2 | Vulnerability in developing regions

Region	Vulnerability	Effects
	Costal Cities	
Africa	Storm surges, sea-level rise, increased flooding, and semi-permanent inundation of low-lying areas Cities located on lagoons, estuaries, deltas or large river mouths such as Alexandria, Cotonou, Dar es Salaam, Lagos, Maputo, Mombasa and Cape Town will be at highest risk	Loss of land value assets Inundation of coastal aquifers and agricultural lands, saltwater intrusion Voluntary and involuntary eco-migration, etc.
	Inland Cities	
Asia	Higher extreme weather events and more frequent heat waves resulting in severe heat island effects Vulnerable cities include those experiencing heat stress and related problems as well as those located in the Sahel and those juxtaposed between desert and forest, such as Kano and Ouagadougou Flooding from sudden river surges, creating stress for cities such as Alexandria, Johannesburg, Brazzaville and several desert cities in Burkina Faso and Niger	Potential damage to urban infrastructure Loss of revenues for municipal governments Desiccation of vegetation Shrinking water tables and land subsidence associated urban water shortages Increased morbidity and mortality associated with malaria and water-borne diseases in severe inundated and humid areas Dehydration and other related ailments, even deaths Falling crop yields and a rising number of species extinction
Latin America	Coral biome in the Caribbean: bleaching and mass mortality of corals Mountain ecosystems in the Andes: rapid warming Wetlands in the Gulf of Mexico: subsidence and salinization, increased exposure to extreme weather Amazon basin: forest dieback	Impacts on fisheries, tourism, increased vulnerability of coastal areas Impacts on water and power supply, displacement of current agriculture and changes in planting patterns Impacts on coastal infrastructure, fisheries and agriculture Impacts on global water circulation patterns, agriculture, water and power supply on a continental scale

Source: Nicholls et al., 2008; Vergara, 2009; UN-HABITAT, 2009; Fuchs, 2010; Satterthwaite et al., 2007.

Figure 1 | Declining potential agricultural productivity shown in percentages across world nations



Source: Cline, 2007

information and technology for agricultural productivity which is in decline in many locations (see Figure 1). Furthermore, these efforts ensure more cost-effective responses to global environmental change including participatory vulnerability mapping and land-use planning, functional zoning, and water and waste management. Local communities offer the best loci for experimentation and the replication of innovative governance on this scale and promote place-specific and need-focused adaptation consistent with local dynamics and institutions. Ultimately, successful best practices can be integrated into regional/national adaptation/mitigation frameworks (The World Bank, 2010a).

Despite the critical role of local knowledge and capacity for adaptation to climate change, certain factors limit success and could potentially result in more disastrous consequences for urban slums and informal settlements. Some of these challenges include weak technical capacity, lack of transparency and accountability for disaster reduction and climate resilience, poor relationships among institutions at multiple levels, weak systems for gathering and disseminating information, vague mandates for disaster preparedness and climate adaptation, and poor coordination and conflicting interests between different levels and agencies of governments. Governmental support is essential for creating an enabling environment for the prosperity and progress of these local adaptive capacities and community actions. Higher-level governments must encourage and accelerate the institutionalization and democratization of local governments and local associations including community-based organizations, farmer and fisherman groups, housing cooperatives, and NGOs in developing countries for increasing community resilience to global environmental change.

Conclusion

This article has briefly examined the vulnerability of urban slums and informal settlements in developing countries of Africa, Asia, and Latin America in the context of urbanization and global environmental change. As the world's focus tends towards adaptation to and mitigation of the effects of global environmental change, there is increasing need to promote the link between mitigation at the global level and adaptation at the local level through local knowledge. Respectively, greater emphasis must be placed on the role of local knowledge, local responsiveness and local capacity for adaptation. This could be enhanced by institutionalizing and democratizing local adaptive capacity and resilience in developing countries, particularly in the areas of biodiversity, vulnerability mapping, land management, housing and city planning. Thus, it is necessary to identify through further comparative analysis the incentives that promote local capacity building needed for developing adaptation strategies and resilience in urban slums and informal settlements in developing countries around the globe.

Crowded houses around a public dumping area at a slum outside of Jakarta.

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Mérida, Yucatán, México

Domestic Water Accessibility and Adaptation to Climate Change Impacts in Peripheral Urban Settlements of Mérida Metropolitan Area, Yucatán, México

Mauricio Domínguez-Aguilar and Federico Dickinson Bannack

In Mexico, as in the rest of the world, urbanization processes have created complex human settlement systems known as metropolitan areas. These urban systems are heterogeneous in many respects, e.g., demographically, socio-economically, environmentally, as well as in the ways they are impacted by and respond to climate change. Domestic water access is a basic component of all human settlements, but climate variability and change impact the water availability within them, forcing the development of new adaptive measures (Bates et al., 2008). Settlements located in the periphery of extensive metropolitan areas within developing countries are particularly at risk. Although water availability is affected by climate change, water access is governed by social factors and the adaptive strategies developed by citizens and the processes through which they are implemented represent an understudied topic within climate change adaptation science. The work presented here analyzes this phenomenon by focusing on domestic water access (i.e., water use within the home for consumption and hygiene) in peripheral settlements of Mérida Metropolitan Area (MMA), Yucatán, México.[1]

Climate change impacts and vulnerability

There are two general positions regarding water sector adaptation to climate change. From a management perspective, the perception exists that the water sector is adapted to present climatic conditions and will overcome future challenges (Stakhiv & Schilling, 1998). Conversely, various scholars argue that future climatic conditions will be nothing like previous and present ones (Conde, 2010), and that adaptation usually occurs over the long term. Further, if climate change impacts happen too quickly, it is probable that adaptation responses will not keep pace (Burton et al., 1998). Within the MMA, beyond the attention of some local academic groups, there is not a general concern or discussion

1 This work was developed as part of a post-doctoral internship by Mauricio Domínguez-Aguilar at the Human Ecology Department, of Centro de Investigación y de Estudios Avanzados, Unidad Mérida, and was financed by the Consejo Nacional de Ciencia y Tecnología de México (CONACyT).

about climate change adaptation, including the water sector. Although many daily, commonplace actions occurring within the MMA water sector could be understood as adaptation responses, these are not a conscious set of or organized forms of responses to climate change impacts.

In a recent vulnerability study of settlements within the MMA it was observed that domestic water access is vulnerable to climate change impacts owing to the exposure to changes in the regional precipitation pattern and to the increase of saline intrusion. Although saline intrusion is typically attributed to the increase of the mean sea level, in this case it is correlated more so to human overexploitation of aquifers throughout parts of the region, particularly those settlements located in its coastal zone (Domínguez et al., in review). Climate change (and other) impacts on domestic water access are more severe in MMA peripheral settlements. These impacts operate at different temporal scales: precipitation pattern changes are a product of inter-annual variability, while saline intrusion is simultaneously generated by long-term changes (increase in sea level mean) and by short-term human activities (overexploitation of local aquifers).

Adaptation strategies

Adaptation strategies are defined as those responses or adjustments implemented by societies in socio-ecological systems to keep them in state of adaptation to climate change (Burton et al., 1993). The families residing in the peripheral settlements within the MMA have adjusted their domestic water access through the implementation of three general strategies: extracting water directly from the environment (in this case from the aquifer, the only natural water source in the MMA); connecting their dwelling to public potable water infrastructures; and purchasing bottle water (Domínguez, 2008). Some of these strategies take on variations, for example, some families access potable water from the household interior, while others access it by carrying it from other houses or purchasing it from water tanks. The selection of these and other variations depends on the families' socioeconomic characteristics, as well as the specific use to which the water is needed, i.e., human consumption, hygiene and others. Families often practice more than one of these strategies simultaneously and it is important to mention that the same general strategies are used for these families during hurricane events, although the variations are modified.

Adaptive strategies can be classified by a diverse set of criteria, for example, from the moment in which these are chosen and implemented, their temporary reach, intentionality or the agents implicated in their implementation (Burton et al., 1998; James et al., 2001; Malik et al., 2010). Water extraction directly from the aquifer in the MMA is an independent and anticipatory strategy, meaning that this strategy is implemented directly by the local population without the intervention of the state government or other actors and before the occurrence of climate change impacts. Although water extraction directly from the aquifer has been used throughout the region since pre-Columbian times, the construction of potable water infrastructure is a much more recent development, characterized as a strategy which is anticipatory, public (i.e., implemented by the state government) and planned. Some of the variations of this strategy, however, have been identified as having independent and reactive characteristics, in the sense that the response is a reaction to external stimuli - in this case to the increased water demand from the local population. Bottled water consumption in the MMA began as a reactive response strategy to hurricane impacts twenty years ago, but since this time it has been internalized by the population as a daily practice (for drinking) and has now changed as an anticipatory strategy.

Adaptation processes

As in any other metropolitan area, domestic water adaptation in the MMA is a phenomenon that has changed throughout time and is influenced by technology advances. There are specific social processes that explain the appearance and practice of each strategy. As was mentioned before, water extraction from the environment was the first to be implemented in the MMA; this water was used for all domestic purposes until the appearance of potable water. Since the local aquifer is currently polluted, a consequence of urbanization and other human influences in the region, today, this is not a probable adaptation strategy for the general population. This would increase vulnerability by negatively impacting (Burton et al., 1998) the population's health and economy. The often most negatively impacted population group includes the poorest citizens within the MMA who have no other options for accessing a water source.

Although the three levels of government have implemented some programs to replace water extraction from the environment as a source for domestic uses by introducing potable water infrastructure to the region, there are still a considerable number of people without access to this infrastructure. This phenomenon results from the interaction of two factors: household economic restrictions (poverty) and local legislation. One particularly tenuous piece of legislation mandates that legal tenure must first be proven in order for a house to obtain approval for connecting to the potable water infrastructure. Another factor that has contributed to the restriction of access among the local population is poor allocation of the public budget towards these efforts. In a previous study (Domínguez, 2008), it was revealed that the state and some municipal governments authorized discretionary spending of the water-related public budget in the region over the last decade which allocated funds towards the improvement of water accessibility in areas where the infrastructure already existed, rather than its introduction to areas that are completely without.

Bottled water is a more recently introduced adaption strategy incorporated in the MMA and is used exclusively for human consumption. Implementation of this strategy can be traced back to the end of last century when some intense hurricanes affected the region. Although this practice fulfilled its assignment during these emergency periods, its incorporation among local population is a consequence of effective private sector handling which has transformed this response into a mainstream daily practice. Ironically, and although bottled water is the most expensive strategy of the three identified in the region, its adoption is widespread among the entire population.

Final thoughts

All climate change adaptations bear different kinds of social, economic and environmental costs (Watson et al., 1996) and adaptation of the MMA domestic water sector is no exception. The implementation of the three previously defined general adaptation strategies (i.e., direct water extraction from the aquifer, connecting dwellings to the public potable water infrastructure; and purchasing bottle water) has spread differential costs across the local population. Such costs include transferring higher economic risk to the poor as a result of the widespread consumption of bottled water among the local population. Other costs include

illness and a reduction in economic productivity as a result of direct water extraction from polluted aquifers. Overall, it will be important for climate change adaptation science to reinforce the discussions about the social and environmental costs associated with adaptation; as such, we anticipate our future research within the MMA to move forward in this direction.

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Shanghai, China

Global Climate Change and Strategies for Urban Sustainability: A Case Study of the Estuary City – Shanghai, China

Xiangrong Wang, Shixiong Wang, Yuan Wang, Huanran Ling and Zhengqiu Fan

Global change has undoubtedly been a worldwide focus for governments, international organizations and scientists in recent years (Brooks, 2003; Adger, 2006), especially after the 2009 IPCC Copenhagen Conference. According to the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the global average surface temperature increased by 0.74°C (0.56-0.92°C) over the last 100 years (1906-2005) and mainly attributes this warming phenomenon to human activities (IPCC, 2007). As this trend continues, global change will have a tremendous impact on global ecosystems, particularly estuary ecosystems. Thus, many scholars are focusing their research on global climate change within these environments, including climate change vulnerability assessments (Moss et al., 2001; Christensen et al., 2004; Füssel & Klein, 2006) and response strategies that incorporate adaptation and mitigation to climate change (Smith et al., 1996; Rahmstorf, 2007).

Shanghai is the largest economic center of China with a population over 22 million. It is located at the mouth of the country's largest river – the Yangtze Delta – which flows into the Pacific. It is a unique location with both continental and oceanic characteristics. Research has shown that since the late 1980s Shanghai has had the highest level of urbanization in China and experienced two warming phases in the past century (Xu, 2000). Given its ecologically sensitive geographical location, political and economic prominence and profound international influence, our research aims to evaluate the impact of climate change and to understand the zones of vulnerability within the city as well as to suggest comprehensive counter-measures for adapting to and mitigating the impacts of climate change. We intend to develop the case study of Shanghai into a reference study for coastal and estuary cities worldwide.

Estuary cities

A unique natural ecosystem, the estuary has abundant nutrients, high biodiversity and a varied ecological environment. It is often affected by both riverine and marine environments including fresh water and sediment from the former, and ocean tides, waves and the large inrushes of salt water associated with the latter. These inflows of both sea and fresh water make estuarine areas some of the richest natural habitats in the world (Wang & Wang, 2010). However, estuarine and coastal areas are also the most populated environments, housing about 60% of the world's population.

These cities are often political, economic or cultural centers of great importance which have effects at global, regional, national or sub-national scales. As they are located at the intersection of rivers and oceans, these estuarine cities are often important shipping ports, acting as gateways for trade and accessing goods, and industrial areas (including oil, steel, chemical and other traditional industries, advanced manufacturing and high technology industries) due to their convenient location to water and other resources, and ease of transportation. These estuarine areas are usually comprised of densely populated metropolitan cities, which have developed tertiary industries and become financial centers, global stock markets, business centers, research and development bases and tourist destinations.

Meanwhile, the estuarine ecosystem has suffered seriously from anthropogenic interference resulting in: soil erosion and deforestation from over-grazing and unsustainable farming methods; the destruction of wetlands from overfishing, draining and filling; water eutrophication from sewage and animal wastes; the contamination of water from heavy metals, PCBs, radionuclide, hydrocarbons and other pollutants that are discharged into the sewer system; and the disruption of the natural fertilization process of flood plains and of aquatic habitats from flood control embankments and dams.

Furthermore, estuarine cities are some of the world's major sources of carbon emissions and have major effects on global climate change as well as social development and policy formulation. At the same time, these cities are quite vulnerable, as they are exposed to problems associated with sea-level rise, environmental pollution and soil erosion. This, along with the fact that they bear the majority of the world's population makes them extremely sensitive to climate change. In response, many countries and regions located within these estuarine areas have launched evaluation studies and strategies for coping with climate change (e.g., EU countries, USA, UK, Japan, China and other developing countries), some of which have been evaluated in our research.

The following key questions were addressed in our study: (1) What is the inter-annual and inter-decadal variation pattern of temperature, precipitation and other meteorological conditions over the past 50 years in Shanghai? Does this reveal a significant trend of climate change? (2) What is the relationship of regional and local climate change and urbanization in Shanghai? (3) What strategies exist in an estuary city such as Shanghai for adapting to and mitigating climate change?

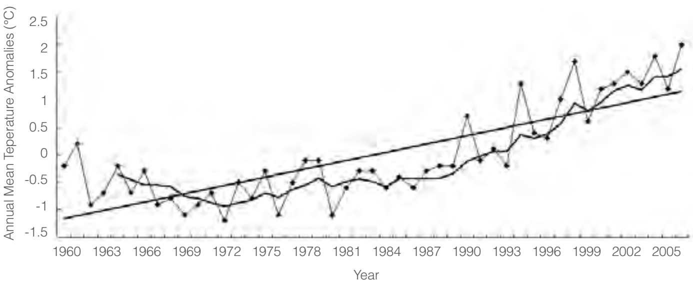
The impacts of rapid urbanization on local climate changes

In our study, we engaged in field investigation, statistical data analysis on climate change monitoring, mathematic modeling using 3S remote sensing, global positioning and geographic information systems on land-use and land-cover change (LULCC) in order to identify key factors in vulnerability evaluation and zoning.

Based on mean climate statistical data including average annual temperature and precipitation, and extreme weather events from 1960 to 2006, as well as future trends of Shanghai obtained from meteorological observation of the Xujiahui Weather Station (urban station) and Fengxian weather station (suburban station), we analyzed the characteristics of climate change over the last 50 years.

In our study we identify the creation of an urban heat island (UHI) effect in Shanghai during its process of rapid urbanization, resulting in significant impacts on local climate change. Economic development and population growth as a part of the process of urbanization combined with the resulting expansion of urban construction, land and energy consumption, have led to temperature differences between urban and rural areas. These differences have forced the flow field to change, which will further affect local winds, clouds, precipitation and other climate change factors. Factors such as urban population density, GDP, energy consumption, built areas, total investment in urban infrastructure, and housing all have significant impacts on local climate change (Wang & Wang, 2010).

Figure 1 | Annual mean temperature increases in Shanghai during 1960-2006



The meteorological monitoring data from 1960-2006 in Xujiahui station and Fengxian station of Shanghai indicate that there is a significant temperature increase since the mid 1980s, especially in winter and spring, but have also shown an increasing trend in summer and autumn (Figure 1).

There is a significant temperature difference between the urban and suburban areas ($P<0.01$) (Table 1), with the mean temperature increasing by 0.51°C and 0.22°C every ten years respectively. The last decades are characterized by a period of rapid urbanization in Shanghai, which has caused significant land-use, land-cover change within the city (Figure 2).

Zoning for climate change eco-vulnerability

Our evaluation model is built from the degree of risk and degree of sensitivity to climate change considering key issues of ecological responses in the area of Shanghai. We carry out a comprehensive vulnerability degree evaluation and identify the critical areas with higher degrees of fragility. Risk assessment is crucial for analyzing rapid urbanization in estuary regions, as urbanization, population expansion and economic development can cause and further regional climate change, also putting stress and pressure on regional ecological and environmental resources. As such, under the stress of climate change, the decrease of agricultural land in Shanghai leads to a loss in soil area with carbon storage function. A gradual reduction of water area interrupts the natural ability of the water cycle and reduces its capacity to filter out pollutants within the estuary. Furthermore, the general construction of built area and impervious surfaces (including industrial, transportation and housing infrastructure, etc.) increases the effect of the urban heat island and puts pressure on the urban environment with respect to water and air pollution, as well as increasing resource consumption (Wang & Wang, 2010).

The correlation between the urbanization intensity and climate change was analyzed through the construction of a regression model. Population, GDP, energy consumption and annual electricity consumption, vehicle use, and urban infrastructure investment, etc. were selected as urbanization intensity variables; the annual precipitation, annual temperature, and difference in suburban temperature were selected as climate

Figure 2 | Comparison of temperature increases by LULCC in Shanghai (1980: left, 2000: right)

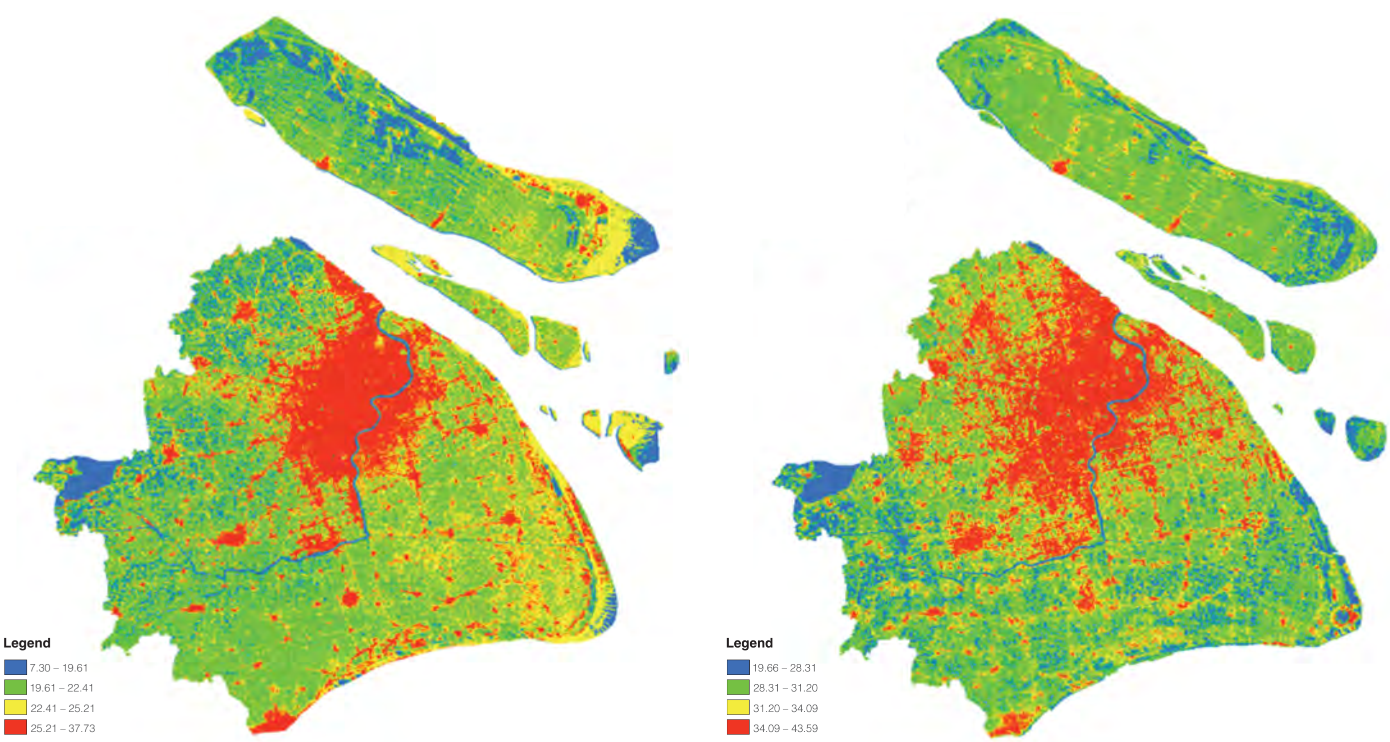


Table 1 I Mean temperature differences between urban and suburban areas

Monitoring Site	1960s	1970s	1980s	1990s	2000 - 2006
Xujiahui Station (City Center) (°C)	15.74	15.68	15.84	16.88	17.77
Fengxian Station (Suburb) (°C)	15.61	15.5	15.47	16	16.5
Difference Between City and Suburb (%)	0.83	1.16	2.39	5.50	7.70

change variables. A gray correlation model (GCM) and methods of principal component analysis (PCA) were employed to analyze the characteristics of these variables in order to show the correlation of urbanization and climate warming in Shanghai.

By using Landsat and TM remote sensing image maps of land-use in Shanghai for April 1997, July 2004 and March 2008, and related information of ecological factors (such as the urban physiognomy types, NDVI index, coastal beach, main stream, surface water environment, hydrology, geology, and biodiversity protection), we evaluate vulnerabilities for Shanghai by constructing the "Shanghai Climate Change Eco-Vulnerability Index" (SHEVI):

$$SHEVI = \sum_{i=1}^{3} A_k \cdot W_k$$

where Ak is an array of sub-indices; and Wk are the weights of the array of sub-indices; the sub-indices include: a risk index (RI), a sensitivity index (SI), and a response index (AI). We normalized the evaluation indices with temperature, sea-level rise, extreme climate disasters, economic development, population growth, urban infrastructure and expansion, fossil fuel use and environmental pollution through the application of stacked weighting factors and calculated the climate change eco-vulnerability index (SHEVI) in Shanghai during 1997-2008. The SHEVI value ranges between 0 (lowest eco-vulnerability) and 1 (highest eco-vulnerability).

The results of our research show that an area of 447.66 km^2 in Shanghai is the highest vulnerability area, which includes the east beach of Chongming, Dongping National Forest Park, Sheshan National Forest Park, the wetland influenced by the south branch of the Yangtze river and Dianshan Lake area of Dianmao, upstream water reserves of Huangpu river, Huangpu river and the coastal buffer zone. Another high vulnerability area covers 1849.07 km^2 and includes Northern Chongming Island, the main stream (south) of Chongming Island, Hesan and Changxing Islands, Nanhui estuary, coastal shoal wetlands in Hangzhou Bay, and the downtown main stream of Shanghai (Figures 3-5). These results provide an important basis for defining strategies on how to mitigate, respond and adapt to climate change at low-lying estuarine areas.

Figure 3 I Risk assessment

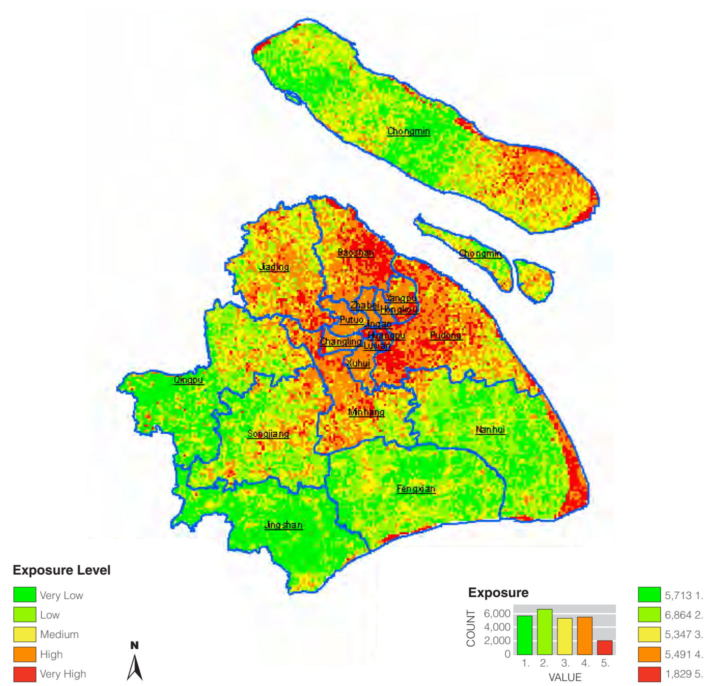


Figure 4 I Sensitivity assessment

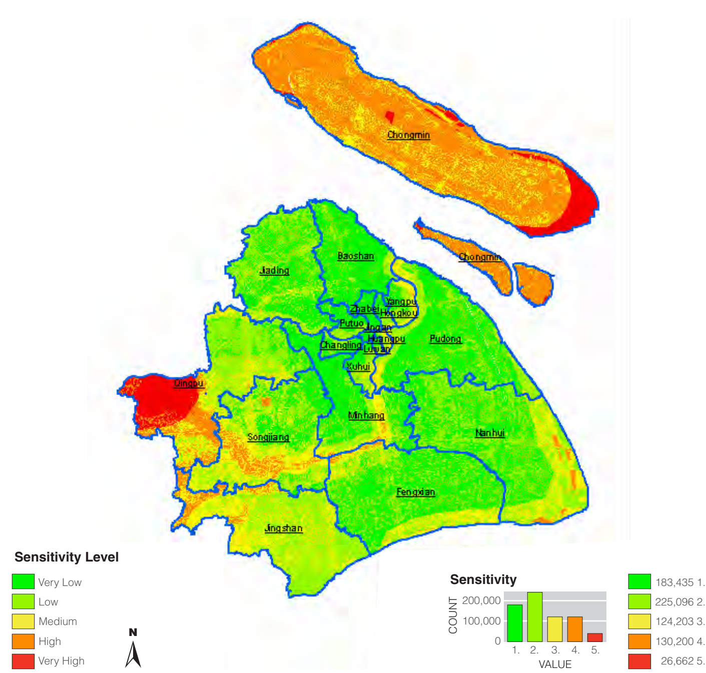
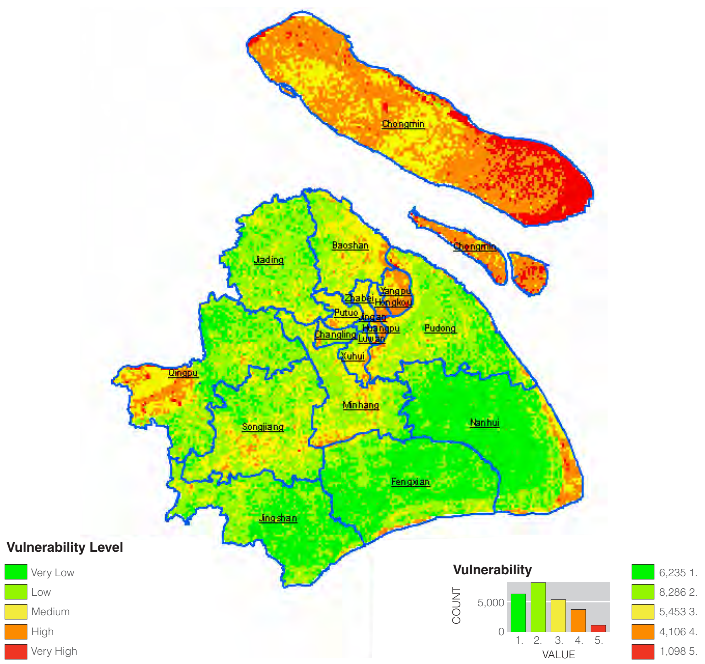


Figure 5 | Eco-vulnerability zoning



Strategies for adapting to and mitigating climate change

The vulnerability zoning results of climate change in Shanghai showed that important areas of the Chongming Dongtan wetland, coastal shoal areas upstream of the Huangpu river, southern and northern portions of Yangtze estuary, and Hangzhou Bay are the areas with high vulnerability and should be paid much more attention when it comes to finding solutions to climate change impacts. The principal measures should include the following:

- Strengthen the adaptability of the countermeasures to cope with sea-level rise; stop coastal erosion through engineering and biological measures; reinforce the engineering of levees; and strengthen protective measures for coastal areas;
- Adopt coping measures that promote the ecological balance of rivers and reservoirs;
- Strengthen the capabilities of marine environment monitoring and warning systems; add a coastal and islands observation component to the construction of modern observation systems; improve the remote sensing and telemetry ability of the marine environment, and the surveillance monitoring capacities for sea-level rise;
- Establish a coastal tide disaster early warning and emergency system and improve the capabilities of a marine disaster warning system;
- Strictly control the reclamation of wetlands and improve the consciousness around water risk management;
- Promote urban sustainability by developing and implementing a low-carbon development strategy that will support a low-carbon economy, improve and adjust industrial structure and changes in lifestyle, and promote low-carbon technology, market-oriented measures, green products and the development of effective economic and industrial policy measures.

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Urbanization and Global Environmental Change
AN IHDP CORE PROJECT

The Urbanization and Global Environmental Change (UGEC) project is a science project that targets the generation of new knowledge on the bi-directional interactions and feedback loops between urban areas and global environmental change at local, regional and global levels. It follows a multi-disciplinary approach and utilizes an innovative framework for the comprehensive understanding of the driving and resulting economic, political, cultural, social and physical processes. An important feature of this core project is the explicit commitment to translate abstract knowledge about GEC into local decision-making contexts. The project is expected to provide a platform for close interaction between practitioners, political decision-makers and researchers and targets a stronger coordination and collaboration between academics, political decision-makers and practitioners working on urban and environmental issues. The UGEC project is currently engaged in ongoing efforts to expand its regional and thematic networks.

Our website provides links to the UGEC Science Plan, information on how researchers can join our network as project associates, and how research projects and agencies can get their projects endorsed by UGEC (www.ugec.org). You can assist us in achieving our goals by forwarding this newsletter to any potentially interested party. Visit www.ugec.org for more information.

IHDP
International Human Dimensions Programme on Global Environmental Change

The International Human Dimensions Programme on Global Environmental Change (IHDP) is an international, interdisciplinary science programme, dedicated to promoting, catalysing and coordinating research, capacity-development and networking on the human dimensions of global environmental change. It takes a social science perspective on global change and works on the interface between science and practice. IHDP is a joint programme of the International Council for Science (ICSU), the International Social Science Council (ISSC) and the United Nations University (UNU).

IHDP was founded by the International Council for Science (ICSU) and the International Social Science Council (ISSC) of UNESCO in 1996, and has been a key programme of the United Nations University (UNU) since January 2007. Financed by a broad range of agencies from different countries, IHDP's research programme is guided by an international Scientific Committee made up of reputable scientists from various disciplinary and regional backgrounds.

IHDP fosters high-quality research. The dynamics of climate change, land-use and land-cover change, interactions between institutions and the global environment, human security, sustainable production and consumption systems as well as food and water issues, urbanization and the global carbon cycle are investigated in the context of global environmental change. Visit www.ihdp.unu.edu for more information.

ASU Global Institute of Sustainability
ARIZONA STATE UNIVERSITY

The Global Institute of Sustainability is the hub of Arizona State University's (ASU) sustainability initiatives. The Institute advances research, education, business practices, and the University's operations for an urbanizing world. Its School of Sustainability, the first of its kind in the US, offers transdisciplinary degree programs that explore and advance practical solutions to environmental, economic, and social challenges.

With over 30 years of environmental research conducted by ASU's Center for Environmental Studies, in 2004, it evolved into the Global Institute of Sustainability established by Julie A. Wrigley. In 2007, the School of Sustainability was formed, offering undergraduate and graduate degrees in sustainability.

The Institute has a comprehensive sustainability research portfolio with a special focus on urban environments. More than half of the world's population lives in cities: global sustainability cannot be achieved without making cities sustainable.

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