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United Nations Population Fund (UNFPA)
Analytical Review of the Interaction between Urban Growth Trends and Environmental Changes

Paper 1

URBAN DENSITY AND CLIMATE CHANGE[1]

David Dodman[2]

Introduction

This paper presents an analytical review of the interaction between urban density, climate change, and sea-level rise. The paper has a focus on two main themes: the interaction between urban density and the generation of greenhouse gases and how this affects mitigation strategies; and the consequences of climate change on urban settlements of varying population densities and how this affects adaptation strategies. Throughout, there is a recognition that changing population densities in urban centres can both affect, and be affected by, global environmental change.

Firstly, and as is already well known, climate change is caused by the emission of greenhouse gases, primarily from the combustion of fossil fuels. Greenhouse-gas emitting activities are distributed in a spatially uneven manner. At a global scale, the 20 percent of the world's population living in developed countries account for 46.4 percent of global greenhouse gas emissions, while the 80 percent of the world's population living in developing countries account for the remaining 53.6 percent. The United States and Canada alone account for 19.4 percent of global greenhouse gas emissions, while all of South Asia accounts for 13.1 percent, and all of Africa just 7.8 percent (Rogner *et al* 2007). Even greater differences can be seen if individual countries are compared: per capita carbon dioxide equivalent emissions vary from less than one tonne (e.g. Bangladesh 0.38; Burkina Faso 0.60) to more than twenty tonnes per year (e.g. Canada 23.72; the USA 23.92; Australia 26.54) (United Nations Statistics Division, n.d.). Even within countries there are spatial disparities in the production of greenhouse gases: per capita emissions in New York City are only 29.7% of those in the United States as a whole (PlaNYC 2007); those in Rio de Janeiro are only 28.0% of those of Brazil as a whole (Dubeux and La Rovere 2007); and those in Barcelona are only 33.9% of those of Spain as a whole (Baldasano *et al* 1999) (for a more detailed discussion of this topic, see Dodman 2009).

The paper therefore examines the implications of different urban densities for the emission of greenhouse gases (particularly, although not exclusively, in high-income countries), and the implications of this for global climate change. The paper explores the relationship between form, density, economy and society within cities to assess whether particular spatial patterns can have a positive or negative effect on the emission of greenhouse gases and consequently climate change.

[1] The paper has benefitted from the comments of Gordon McGranahan and Daniel Schensul.
[2] Researcher, Human Settlements and Climate Change Groups, International Institute for Environment and Development

Secondly, and as is increasingly accepted, the effects of climate change will also be distributed unevenly. In this case, high urban densities can both contribute to and reduce the vulnerability of human populations. If populations are concentrated in vulnerable locations, without proper infrastructural or institutional frameworks, then density can increase risk. However, if effective means can be found for supporting dense populations in safe locations with suitable infrastructural and institutional frameworks, then this can provide a viable alternative – particularly for the urban poor – to living on marginal and unsafe sites.

The paper therefore examines patterns of urban density and vulnerability (particularly, although not exclusively, in low- and middle-income countries), and the inter-relationships between the two. Specifically, it examines case studies of high population densities that increase exposure to the effects of climate change and vulnerability; and case studies of high population densities that can be seen to reduce risk. If well-managed, the increasing concentration of population in urban centres can mean reduction in vulnerability to the direct and indirect impacts of climate change; if poorly managed, it can mean increasing levels of risk for large sections of the urban population.

These processes do not act in isolation, and cannot be separated from broader demographic, economic and social transformations. The paper therefore views the interaction between climate change and urban density in a holistic manner that can identify appropriate, context-specific, and policy-relevant recommendations. The analysis provided by this paper will help to strengthen capacity at the national and local levels to comprehend and deal effectively with urbanization in the face of the challenges posed by climate change.

Approaches to Urban Density

> "What options are left for shaping the city? In essence, perhaps, we have only two. First is the option of the high-density city. This, we tell ourselves, is the anti-suburban model, based on an ideal of diversity and inclusiveness. Those infected by the European prejudice towards cities taking a certain kind of physical form embrace this model in opposition to what they maintain, for a variety of reasons – sometimes snobbish, sometimes well-meaning – to be the shortcomings of the low-density city.
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> "Low-density urbanism, on the other hand, is a model equated with what is considered the destructive selfishness of the gated community and the environmentally disastrous results of low-density car-orientated suburbs, which allegedly will become unsustainable long before fossil fuels run out and which do nothing to support the traditional energy and vitality of urban life. However, it could equally well be presented as a model of freedom and sturdy individual choice… To those who promote this model, the high-density city is, despite the claims of its champions, a claustrophobic, overdeveloped and dehumanizing ant-hill.
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> "Is there nothing in between these two poles that could be used as a model for shaping the city in a constructive and positive way? Is there as yet enough understanding of the lessons taught by cities outside the traditional compounds of Europe and North America that have shaped the majority of thought about what cities can be? What can they do to manoeuvre themselves to a position where they are actually improving life for the people who flock to them – which, in the end, is the underlying justification for a city?" (Sudjic 2008: 44)

As the extract above indicates, views of urban density have tended to be starkly polarized. Low density cities are seen to enable individual freedom and spacious living, or to be a profligate and wasteful use of space and resources. Dense urban populations seen either to be indicative of claustrophobic squalor, poverty and deprivation; or of diversity and community. On the one hand, Ebenezer Howard's protests against urban overcrowding are still invoked: Howard argued that "It is wellnigh universally agreed by men of all parties… that it is deeply to be deplored that the people should continue to stream into the already overcrowded cities" (Howard 1996: 346). On the other hand, Jane Jacobs' (1996) passionate defense of urban life in *The Death and Life of Great American Cities* is still taken as a mantra, particularly for those in the intellectual movement of 'new urbanism' who are opposed to the growth patterns of suburban sprawl and restrictive residential enclaves. In this latter grouping, low urban densities – frequently associated with the process of suburbanization – are often characterized as urban sprawl.

The definition and effects of urban sprawl are widely debated. Frenkel and Ashkenazi (2008) identify five different systems for measuring sprawl – growth rates, density, spatial geometry, accessibility and aesthetic measures – with settlement patterns identified as sprawl by one measure not necessarily meeting the other characteristics. Urban sprawl is often associated with a variety of social problems including "social isolation and obesity; asthma and global warming; flooding and erosion; the demise of small farms; extinction of wildlife and the unbalancing of nature" (Gottdiener and Budd 2005: 148). In contrast, however, some planners see sprawl as inevitable or harmless, arguing that it maximizes the overall welfare of society as an outcome of free-market decision-making, provides easy access to open space, and results in lower crime rates (Frenkel and Ashkenazi 2008).

In low- and middle-income countries, the related process of peri-urbanization is increasingly taking place. In the peri-urban interface, the boundaries between the 'urban' and the 'rural' are continually being re-negotiated, and rather than being clearly defined are characterised by transition zones. These interfaces are affected by some of the most serious problems of urbanization, including intense pressures on resources, slum formation, lack of adequate services such as water and sanitation, poor planning and degradation of farmland. They are of particular significance in low- and middle-income countries, where planning regulations may be weak or weakly enforced, and result in areas with complex patterns of land tenure and land use (McGregor *et al* 2006; Tacoli 2006). Although they provide a variety of activities and services for urban centres, they are generally beyond or between the legal and administrative boundaries of these cities, with the result that the process of urbanization can be unplanned and informal with frequent struggles over land use.

In terms of a broad assessment of quality of life, it appears that the benefits of higher urban densities are mixed: a study of medium-sized English cities suggested that higher urban densities have some positive and some negative effects on social equity. Specifically, "likely benefits include improved public transport, reduced social segregation and better access to facilities, while the main problems are likely to be reduced living space and a lack of affordable housing" (Burton 2000: 1969). A similar outcome is likely in relation to the challenges of climate change: higher urban densities will yield certain advantages for both mitigation and adaptation, although in extreme cases may have a more general detrimental impact on quality of life; whereas lower urban densities may have the converse effects. In addition, it is unlikely that there is an 'optimum' urban population density, as this will be affected by a variety of social, historical and environmental factors.

The relationship between urban population density and the environment in its broader sense is further complicated by the spatial displacement of environmental costs. Although it is often argued that denser urban settlements make more efficient use of land and other resources, at least some of this can be attributed to their 'ecological footprints' outside the spatial boundaries of the city (Wackernagel and Rees 1995; Wackernagel *et al* 2006). This displacement of environmental costs is particularly relevant to climate change if 'consumption-based' rather than 'production-based' measures of greenhouse gas generation are utilised. Many cities in North America and Europe are service-oriented rather than production-oriented, yet traditional mechanisms for identifying the source of greenhouse gas emissions allocates these to the location of production, rather than the location of the consumption of the finished product (Bai 2007). As Walker and King (2008: 2000) describe the situation, "Next time you buy something with 'Made in China' stamped on it, ask yourself who was responsible for the emissions that created it." But even taking this into account, it is hard to deny that "density is potentially useful" (UNFPA 2007: 46). Demographic concentration can assist in achieving the ends of sustainability more broadly, through conserving agricultural land and fragile ecosystems.

Measuring Urban Density

At its simplest, urban density is measured by dividing a given population by a given area. In the case of urban areas, the widely varying definitions of the spatial extent of these areas leads to a great deal of difficulty in generating comparable statistics for different towns and cities. Dividing the population of a metropolitan area by the administrative area contained within its official boundaries is a highly unreliable measure – particularly for comparisons – because the density will vary according to the definition of these boundaries (Angel *et al* 2005). In addition, standard measures of density are calculated over an entire land area, without taking into account the levels of connectivity. In this regard, the gradual transformation of the urban form of Curitiba, Brazil, from a predominantly radial-circular form to a more linear pattern of development has reduced the city's overall density, yet has facilitated the development of a more rapid and effective public transportation system and various other social and environmental benefits.

In general, standard urban models predict a pattern of negative exponential density gradients within cities, where there is a gradual decline in population density from the centre of the city to its outskirts. An analysis of fifty mostly large metropolitan areas by Bertaud and Malpezzi (2003) shows general support for this model, although in some cities there are substantial variations. This is usually where there are highly regulatory environments for land use – for example, cities with particularly rigid regulatory environments such as Seoul, cities such as Cape Town that developed under repressive population controls, and centrally planned cities such as Brasilia and Moscow.

It is perhaps also appropriate to see at least some aspects of urban density as fluctuating in a cyclical pattern. Champion (2001) argues that urbanization, suburbanization, counterurbanization and reurbanization are stages in a cyclic model. Suburbanization became significant as an urban feature during the latter half of the nineteenth century, and has been driven by the negative aspects of city cost, congestion, grime and squalor. Counterurbanization involves an extension of this process, with overspill to new appendages of metropolitan territory, but is also accentuated by residents and employers actively seeking out more remote locations to take advantage of their inherent characteristics. Reurbanization – the increase in population (and density) in central urban areas – has been observed in western Europe and North America, in the 1980s and 1990s. New York City's population declined by 3.6 percent in the 1970s but grew by 3.1 percent in the 1980s; Helsinki, Oslo, Stockholm and London also experienced population growth in that decade – yet in all these cases (except Stockholm) the population of suburban areas grew at an even faster rate. In this regard, reurbanization results in increased population densities in the urban core, but decreased population densities for the metropolitan area as a whole.

In general and at a global level, however, there is strong evidence that urban densities have generally been declining over the past two centuries (UNFPA 2007). Perhaps the most detailed and compelling assessment of this phenomenon is provided by a recent World Bank report (Angel *et al* 2005). This report uses a method of measuring the density of the *built-up* area (as defined through satellite imagery) rather than the *administrative* area of cities, and applies this to a total of 3,943 cities with populations of greater than 100,000. These cities had a total population of 2.3 billion people: 1.7 billion in 'developing' countries and 0.6 billion in 'industrialized' countries. According to the report, the average density of industrialized country cities in 2000 was 2,835 people / km^2, declining from 3,545 people / km^2 in 1990 with an annual change of -2.2 percent. In developing countries, the average urban population density in 2000 was 8,050 people / km^2, declining from 9,560 people / km^2 in 1990 with an annual change of -1.7 percent. Alternatively, these figures can be expressed as the average built-up area per person: 125m^2 in developing country cities, and 355m^2 in industrialized country cities.

This trend of reduced urban densities is likely to continue into the future. It is estimated that the total population of cities in 'developing' countries will double between 2000 and 2030, but their built-up areas will triple (from approximately 200,000km^2 to approximately 600,000 km^2); in 'industrialized' countries the population of cities will increase by approximately 20 percent whilst their built up areas will increase by 2.5 times (from approximately 200,000km^2 to approximately 500,000 km^2). These agglomerated figures for 'industrialized' and 'developing' countries conceal a great deal of regional variation (Figure 1). Southeast Asian cities were almost four times as densely populated as European cities, and almost eight times as densely populated as those in 'Other Developed Countries' (including North America and Australasia). The figures can also be disaggregated by income levels: cities in low income countries are more than four times as densely populated as cities in high income countries.

Figure 1: Average Density of Built-Up Areas (persons per km^2)

	1990	2000
Developing Countries	9,560	8,050
Industrialized Countries	3,545	2,835
East Asia and the Pacific	15,380	9,350
Europe	5,270	4,345
Latin America and the Caribbean	6,955	6,785
Northern Africa	10,010	9,250
Other Developed Countries	2,790	2,300
South and Central Asia	17,980	13,720
Southeast Asia	25,360	16,495
Sub-Saharan Africa	9.470	6,630
Western Asia	6,410	5,820
Low Income	15,340	11,850
Lower-Middle Income	12,245	8,820
Upper-Middle Income	6,370	5,930
High Income	3,565	2,855

[Source: Adapted from Angel *et al* (2005)]

In summary, therefore, the average density of built-up areas in all cities, all regions, and all population sizes is decreasing. However, as has been shown, this is a highly uneven process. In addition, these figures do not capture the variations in density that exist within cities: although the density for any given urban area as a whole may be declining, there are likely still to be pockets of extremely high density, and these are likely to be associated with low-income residential areas. The following sections of this paper assess – in a greater level of detail – the relationship between these patterns of urban density and the different aspects of climate change.

Urban Density and Greenhouse Gas Emissions

Urban form and urban spatial organisation can have a wide variety of implications for a city's greenhouse gas emissions. The high concentrations of people and economic activities in urban areas can lead to 'economies' of scale, proximity and agglomeration that can have a positive impact on energy use and associated emissions; whilst the proximity of homes and businesses can encourage walking, cycling and the use of mass transport in place of private motor vehicles (Satterthwaite 1999). Some researchers suggest that each doubling of average neighbourhood density is associated with a decrease in per-household vehicle use of 20-40 percent, with a corresponding decline in emissions (Gottdiener and Budd 2005 : 153). Newman and Kenworthy (1989) suggested that gasoline use per capita declines with urban density (although they acknowledge that the correlation weakens once GDP per capita is controlled for), while Brown and Southworth (2008: 653) argue that "by the middle of the century the combination of green buildings and smart growth could deliver the deeper reductions that many believe are needed to mitigate climate change".

Yet cities have often been blamed for generating most of the world's greenhouse gas emissions, and contributing disproportionately to global climate change. Referring specifically to climate change, the Executive Director of the United Nations Centre for Human Settlements (UN Habitat) has stated that cities are "responsible for 75 percent of global energy consumption and 80 percent of greenhouse gas emissions"; while the Clinton Foundation suggests that cities contribute "approximately 75 percent of all heat-trapping greenhouse gas emissions to our atmosphere, while only comprising 2 percent of land mass" (for references to these and similar quotations, and a detailed critique of these, see Satterthwaite 2008). Yet at the same time, detailed analyses of urban greenhouse gas emissions for individual cities suggest that – per capita – urban residents tend to generate a substantially smaller volume of carbon emissions than residents elsewhere in the same country.

In Barcelona, greenhouse gas emissions per capita in 1996 were 3.4 tonnes of CO_2 equivalent, compared to a Spanish average of 10.03 tonnes (in 2004 – figures for the same year are unavailable for comparison) (Baldasano *et al* 1999; United Nations Statistical Division n.d.). This relatively low level of per capita emissions can be attributed to several major factors: the city's economy is primarily service-based rather than manufacturing-based; 90 percent of the city's electricity is generated by nuclear and hydro energy; the city's mild climate and the rarity of household air-conditioning systems; and the compact urban structure in which many residents live in apartments rather than individual houses (Baldasano *et al* 1999).

In London, per capita emissions in 2006 were 6.18 tonnes of CO_2 equivalent, or just over half the British average of 11.19 (in 2004), representing a slight decline since 1990 (Mayor of London 2007). This occurred despite a rise in population of 0.7 million people during the same time period (Mayor of London 2007); or an increase from 9.93 million to 10.03 million between 1989 and 2000 using Angel *et al*'s (2005) methodology of defining the city by its built-up area. Over this same time period, the built up area increased from 1,573km^2 to 1,855km^2, and urban density decreased from 6,314 people per km^2 to 5,405 people per km^2. In this particular situation, therefore, per capita greenhouse gas emissions appeared to decline at the same time as urban density declined. However, the relationship between density and greenhouse gas emissions in this is complicated. Whilst it may appear that the decreased density did not influence greenhouse gas emissions, in fact the decline in emissions can be attributed to the halving of industrial emissions, as industrial activity has relocated to other parts of the UK or overseas.

A recent study of greenhouse gas emissions in Toronto deals with the issue of density more explicitly (VandeWeghe and Kennedy 2007). The study depicts both the overall patterns of greenhouse gas emissions for Toronto, and also examines how these vary spatially throughout the Toronto Census Metropolitan Area (CMA): as the distance from the central core increases, automobile emissions begin to dominate the total emissions. This pattern is supported by Norman *et al* (2006), who found that low-density suburban development is 2.0-2.5 times more energy and greenhouse gas intensive than high-density urban core development on a per capita basis.

New York City also has much lower per capita emissions than the United States as a whole (7.1 tonnes of CO_2 equivalent per person in 2005, compared to a national average of 23.9 tonnes of CO_2 equivalent per person in 2004). Despite the city's high concentration of wealth, the density of the city's buildings and the smaller-than-average dwelling unit size means that less energy is needed to heat, light, cool, and power these buildings; and the extensive public transport system means that car ownership levels in the city are much lower than those nationally (PlaNYC 2005).

Detailed assessments of greenhouse gas emissions have been undertaken in Rio de Janeiro and São Paulo in Brazil (Rio Prefeitura Meio Ambiente 2003; Secretaria Municipal do Verde e do Meio Ambiente de São Paulo 2005). These studies utilize the IPCC framework for the creation of national inventories, and as such are more detailed than many of the other studies discussed in this paper. The studies show similar trends to the European and North American cities described above: at the national scale, Brazil's emissions in 1994 were 8.2 tonnes of CO_2 equivalent per person, while those in Rio de Janeiro and São Paulo were 2.3 (in 1998) and 1.5 (in 2003) respectively. This pattern of emissions is obviously strongly affected by the level of economic development of Brazil as a country: emissions from solid waste represent a much higher proportion than in many other cities, whilst emissions from the transportation sector (both individual and mass transit) are much lower, a situation influenced by the widespread use of ethanol as a fuel for motor vehicles. However, in the case of Brazil as a whole, the main sources of emissions at the national level are related primarily to rural activities such as deforestation and cattle raising.

A variety of factors have been identified as affecting the carbon emissions of cities in Asia. Lebel *et al* (2007) examine the ways in which patterns of mobility, the design and distribution of houses, the organization of food and water systems, and individual lifestyle choices affect emissions in Manila, Jakarta, Ho Chi Minh City, New Delhi, and Chiang Mai (although they do not provide overall figures for these cities). Similarly, Dhakal (2004) examines energy use and carbon dioxide emissions in four Asian cities – Beijing, Seoul, Shanghai and Tokyo – but provides only per capita and not total emissions figures for these cities. What is particularly notable in comparing these cities is that the wealthiest city – Tokyo – has considerably lower emissions than the two Chinese cities assessed, clearly indicating that there is not an inevitable relationship between increasing prosperity and increasing emissions.

A detailed study of 16 environmental variables in 45 Chinese cities concluded that in general there is a positive relationship between urban compactness and agglomerated environmental performance, but that it is likely that urban compaction may be positive only up to a certain level. However, in China (at least) it appears that there may be a negative relationship between urban compactness and domestic energy and resources consumption: there is a statistically significant negative relationship between urban density and energy use efficiency, and between urban density and natural resources consumption (Chen *et al* 2008). However, this may be because the more dense Chinese cities are also those that are more economically successful – and also because a high proportion of Chinese emissions are generated through the production of exports. Indeed, 12 percent of Chinese emissions were due to the production of exports in 1987, a figure that rose to 21 percent in 2002 and 33 percent (equivalent to six percent of total global CO_2 emissions) in 2005 (Weber *et al.* 2008).

The figures above only compare average figures for urban areas with average figures for the countries in which they are located. It is also necessary to assess the greenhouse gas emissions of different types of urban development: both between different cities and within the same city. In this situation, it appears that decreasing urban density may be implicated in increasing greenhouse gas emissions, although the data are confounded by a variety of other variables, including overall income levels. For example, cities in South Asia are not only more densely settled than cities in North America, but also have much lower greenhouse gas emissions: the difference in the latter is due much more to income and consumption patterns than to variations in the former.

Dense urban settlements can therefore be seen to enable lifestyles that reduce per capita greenhouse gas emissions through the concentration of services that reduces the need to travel large distances, the (generally) better provision of public transportation networks, and the constraints on the size of residential dwellings imposed by the scarcity and high cost of land. Yet conscious strategies to increase urban density may or may not have a positive influence on greenhouse gas emissions and other environmental impacts. Many of the world's most densely populated cities in south, central and south-east Asia suffer severely from overcrowding and reducing urban density will meet a great many broader social, environmental and developmental needs. High urban densities can cause localised climatic effects such as increased local temperatures (Coutts *et al* 2007). In addition, a variety of vulnerabilities to climate change are also exacerbated by density: coastal location, exposure to the urban heat-island effect, high levels of outdoor and indoor air pollution, and poor sanitation are associated with areas of high population density in developing-country cities (Campbell-Lendrum and Corvalán 2007). However, these also provide clear opportunities for simultaneously improving health and cutting GHG emissions through policies related to transport systems, urban planning, building regulations and household energy supply.

Conversely, some of the apparent climate change mitigation benefits of high urban densities in industrialized countries may be a consequence of the spatial displacement of greenhouse gas generating activities to other locations within the same country or internationally. Reducing greenhouse gas emissions – or addressing climate change mitigation concerns – can only be meaningfully achieved through a process of reducing both direct and indirect emissions.

However, density is just one of a variety of factors that influences the sustainability of urban form. Whilst Neumann (2005) concludes that compactness alone is neither a necessary nor sufficient condition for sustainability, Jabareen (2006) identifies seven design concepts of sustainable urban form – compactness, sustainable transport, density, mixed land uses, diversity, passive solar design, and greening – and uses these to compose a sustainable urban form matrix. Based on these criteria, the "compact city" model is identified as being most sustainable, followed by the "eco-city", "neotraditional development" and "urban containment" – although this classification and ranking is based on reviews of literature rather than empirical research. However, this analysis does serve to highlight the variety of ways in which urban form and process can influence overall sustainability, and shows that density alone is not equivalent to sustainability. A more detailed analysis (Mindali *et al.* 2004) suggests that the relationship between urban density and energy consumption is more complex than is often proposed, and that social, urban structure, and transportation factors all play an important role. The use of multivariate analysis (accounting for 26 variables) in 31 cities shows that there is no direct impact of total urban density on energy consumption, but that there are a variety of other relationships between energy consumption and density attributes. Rather than expressly examining density, therefore, it is perhaps more relevant to discuss urban form in a broader sense: as Glaeser and Kahn (2008: 29) conclude, "holding population and income constant… the spatial distribution of the population is also an important determinant of greenhouse gas production". However, other factors such as temperature also strongly influence emissions: within the United States, cities that experience particularly high July temperatures generate more emissions as a result of energy use for cooling; whereas cities with particularly low January temperatures generate more emissions as a result of energy use for heating (Glaeser and Kahn 2008).

Overall, however, the research reported by these authors suggests that density is one of several factors that affects energy use – and by extension greenhouse gas emissions – from towns and cities. Further, they all point to the importance of analysing urban processes rather than simply assessing urban form at a particular moment in time.

Urban Density and Climate Change Vulnerability

A second major inter-relationship between population density and climate change is in patterns of density and vulnerability. Densely populated urban areas – particularly in low- and middle-income countries – are particularly vulnerable to the effects of climate change. Where there are dense concentrations of households and economic activities, the effects of climate change can affect large numbers of people and have a major impact on urban economies – even if they affect only relatively small land areas. Yet at the same time, if appropriate infrastructure is developed in areas that are less likely to be influenced by climate change, this provides the opportunity to build large-scale resilience in a relatively cost-effective manner.

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report of 2007 unequivocally states that the earth's climate system has been undergoing warming over the last fifty years. Projected future global averaged surface warming (for the decade 2090-99 relative to 1980-99) ranges from 1.1° to 6.4°C, whilst sea level rise (for the same period) is predicted at 18 to 59cm (Intergovernmental Panel on Climate Change 2007). Mean temperatures are likely to increase, mean precipitation will fluctuate, and mean sea-level will rise; extreme rainfall events and tropical cyclones are likely to be more frequent and intense, leading to flooding (both riverine and storm surge). Population changes and ecological changes may result in increased exposure to disaster risk. Changes in means will intensify the stresses faced by poor urban residents on a day-to-day basis, and may reduce or deplete their stocks of assets and resources they require to face occasional extreme events; while increases in the intensity of these extreme events will have significant implications for the households, livelihoods and lives of these groups of people.

Specifically in relation to urban areas, the IPCC report states that "climate change is almost certain to affect human settlements, large and small, in a variety of significant ways" (Willbanks *et al* 2007: 371). Climate change is likely to exacerbate many of the risks faced by low-income urban residents – the IPCC also states that "poor communities can be especially vulnerable, in particular those concentrated in relatively high-risk areas" (Willbanks *et al* 2007: 359). Urban areas in low- and middle-income nations already house a large percentage of the people and economic activities most at risk from climate change, including extreme weather events and sea-level rise – and this proportion is increasing. The types of changes that will affect urban areas can be summarised as changes in means, changes in extremes, and changes in exposure (Figure 2).

Figure 2: Climate Change Impacts on Urban Areas

Change in climate	Possible impact on urban areas
Changes in means	
Temperature	• increased energy demands for heating / cooling • worsening of air quality • exaggerated by urban heat islands
Precipitation	• increased risk of flooding • increased risk of landslides • distress migration from rural areas • interruption of food supply networks
Sea-level rise	• coastal flooding • reduced income from agriculture and tourism • salinisation of water sources
Changes in extremes	
Extreme rainfall / Tropical cyclones	• more intense flooding • higher risk of landslides • disruption to livelihoods and city economies • damage to homes and businesses
Drought	• water shortages • higher food prices • disruption of hydro-electricity • distress migration from rural areas
Heat- or cold-waves	• short-term increase in energy demands for heating / cooling
Abrupt climate change	• possible significant impacts from rapid and extreme sea-level rise • possible significant impacts from rapid and extreme temperature change
Changes in exposure	
Population movements	• movements from stressed rural habitats
Biological changes	• extended vector habitats

[Adapted from Willbanks *et al* (2007)]

The main impacts of climate change on urban areas, at least in the next few decades, are likely to be increased levels of risk from existing hazards. For poorer groups, these will present a variety of impacts: direct impacts such as more frequent and more hazardous floods; less direct impacts such as reduced availability of freshwater supplies for many cities that may reduce supplies available to poorer groups; and indirect impacts such as the effects of climate-change related weather events that increase food prices or damage poorer households' asset bases (for a more detailed discussion of the relationship between urban poverty and climate change vulnerability, see Dodman and Satterthwaite 2008). In addition, poorer groups are disproportionately vulnerable for a variety of reasons, including:

- greater exposure to hazards (e.g. through living in makeshift housing on unsafe sites);
- lack of hazard-reducing infrastructure (e.g. drainage systems);
- less adaptive capacity (e.g. the ability to move to better quality housing or less dangerous sites);
- less state provision for assistance in the result of a disaster (indeed, state action may increase exposure to hazards by limiting access to safe sites for housing);

- less legal and financial protection (e.g. a lack of legal tenure for housing sites, lack of insurance).

The effects of climate change in densely populated urban areas are clearly illustrated in Bangladesh. The population of the capital, Dhaka, has grown more than 20-fold in the last fifty years, and it now has more than 10 million inhabitants. Severe floods – particularly in 1988, 1998 and 2004 – caused by the spill-over from surrounding rivers have had major economic impacts. Large sections of the city are only a few metres above sea level, and the combination of sea-level rise and increased frequency and intensity of storms is likely to greatly increase these risks (Alam and Rabbani 2007). These flooding risks can also be seen in other urban centres in Bangladesh. Khulna is a coastal city with a population of 1.2 million people. Large parts of the city are frequently waterlogged after heavy rainfall. In addition, the city experiences problems with salinisation of surface water, and it is anticipated that climate change and sea level rise will cause this to worsen in the future.

Urban Population Density, Climate Change, and Disasters

The dense concentration of urban populations can increase susceptibility to the disasters that are likely to become more frequent and more intense as a result of climate change. Many aspects of urban areas are vulnerable to disasters and climate change. Economies, livelihoods, physical infrastructure and social structures are all important components of urban systems and are vulnerable to disasters and climate risk in different ways. However, far more is known about the environment of risk (the factors leading to vulnerability) than of the risk impact (the number of deaths and serious injuries and the damage to property and livelihoods when disasters occur). But the (limited) available evidence suggests that the number of serious injuries and deaths from disasters in urban areas has been growing in most low- and middle-income nations (UN-Habitat 2007).

The proportion of disaster-related deaths and injuries that occur in urban areas in low- and middle-income nations is likely to grow, in part because an increasing proportion of the world's population live and work there (and almost all the world's population growth anticipated in the next few decades is likely to occur in urban areas in low- and middle-income nations) (Satterthwaite 2007). Climate change is likely to increase the number of serious injuries and deaths from disasters in urban areas significantly – and many cities in low- and middle-income nations are at high risk from climate change (Satterthwaite *et al* 2007). In addition, there are disaster risks that are inherent in an increasingly urbanized world that do not take place in urban areas – for instance many road, air and sea transport accidents take place outside urban areas but are linked to the increasing flows of people and goods between urban centres or between rural and urban areas. However, there is no automatic link between increasing urban populations and increasing disaster risk; indeed, the experience in high-income nations and some middle-income nations has been that highly urbanized populations and production structures can also develop with much reduced risk from most kinds of disaster.

Perhaps not surprisingly, many city case studies also highlight how disaster risk is heavily concentrated within low-income populations or within urban districts with high concentrations of low-income groups. These are almost always among the most densely populated sections of urban centres. Official statistics on the scale of economic losses from disasters can also be misleading in underplaying the impact of losses on low-income groups. For instance, the economic value of houses destroyed by floods or fires in, for instance, illegal settlements or of the possessions they contained may be low in monetary terms yet devastating to the lives and livelihoods of large numbers of low-income groups. In addition, many losses are qualitative and hard to measure – for instance the work and school days lost and the disruptions to informal income-earning activities. Organizations responsible for disaster-response (whether local, national or international) often have little capacity or incentive to work with low-income groups and little capacity to address issues in a pro-poor way – for instance in allowing displaced groups a key influence in recovering their land and rebuilding their homes and livelihoods.

In regard to local governments, dense urban populations in high-income nations take for granted a web of institutions, infrastructure, services and regulations that protect them from disasters – including extreme weather, floods, fires and technological accidents. Many of the measures to protect against these also supply everyday needs, including health care services integrated with emergency services, and sewer and drainage systems that serve daily requirements but that can also cope with storms. Almost everyone lives and works in buildings that meet health and safety regulations and that are served by infrastructure designed to cope with extreme weather. The police, armed services, health services and fire services, if or when needed, provide early warning systems and ensure rapid emergency responses. Consequently, extreme weather events rarely cause a large loss of life or to serious injury. Although occasionally such events cause serious property damage, the economic cost is reduced for most property owners by property and possessions insurance. The monetary cost of all the above is also accepted by almost all the population and the costs of these routinely funded through charges and taxation. While private companies or non-profit institutions may provide some of the key services, the framework for provision and quality control is supplied by local government or local offices of provincial or national government. All the above have contributed much to higher life expectancies and much reduced risk from disasters.

Only a very small proportion of urban centres in low- and middle-income nations have a comparable web of institutions, infrastructure, services and regulations, although there are very large variations between such centres in the extent of provision and the extent of coverage. For instance, the proportion of cities' populations living in legal homes built meeting appropriate building regulations varies from 10-20 percent to close to 100 percent. The proportion of the population living in homes adequately served by sanitation, waste water removal and storm drains varies as much; most urban centres in Africa and Asia have no sewers and for many of those that do, these serve only a very small proportion of the population (Hardoy *et al* 2001). It is common for 30-50 percent of the population to live in illegal settlements to which the local authorities and utilities refuse to extend the infrastructure and services that do so much to reduce disaster risk (or are prevented from doing so by law or regulation). There are no statistics on the proportion of the urban population covered by good quality fire services or rapid response to serious injuries or illnesses (including ambulances and hospitals able to provide rapid treatment) but the inadequacy or complete absence of such services is evident in many dense informal settlements.

However, the fact that disasters often have a disproportionate impact on areas of high population density does not necessarily imply that density itself is to blame for increasing vulnerability. Rather, it is the fact that inadequate institutions and lack of infrastructure are often also concentrated in areas where there are high population densities of low-income urban residents. In and of itself, reducing density is not a solution to reducing vulnerability to climate-change related disasters: after all, many poor, dispersed, rural populations also suffer horrendously from climatic and other disasters. Instead, reducing vulnerability to climate change in high density urban settlements requires the provision of adequate infrastructure and services: and given the appropriate political will and financial resources, this can be achieved relatively economically in dense settlements, as any improvements made can benefit a large number of people.

Low-income groups often have no choice but to locate themselves on already densely populated marginal land, as no other suitable land is available. Because of this, one particularly important response to urban climate change vulnerability is to make adequate and appropriately located land available to low-income urban groups. This approach has been implemented successfully in the city of Manizales in Colombia, which has managed to avoid rapidly growing low-income populations settling on dangerous sites (Velásquez 2005). The population of Manizales was growing rapidly, with high levels of spontaneous settlement in areas at risk from floods and landslides. Local authorities, universities, NGOs and communities worked together to develop programmes aimed not only at reducing risk, but also at improving the living standards of the poor. Households were moved off the most dangerous sites but re-housed nearby, and most of the former housing sites were converted into eco-parks with strong environmental education components. A similar approach was implemented in the city of Ilo in Peru (Díaz Palacios and Miranda 2005): although the city's population increased fivefold between 1960 and 2000 there have been no land invasions or occupation of risk-prone areas by poor groups, because local authorities have implemented programmes (such as the acquisition of an urban-expansion area) to accommodate this growth and to support the poor in their efforts to achieve decent housing. At the same time, improvements were made in water supply, sanitation, electricity provision, waste collection, and the provision of public space. Similar interventions – with a strong focus on providing safe and accessible land for high density housing for the urban poor – are required to reduce climate change vulnerability in densely populated towns and cities around the world.

Urban Population Density, Climate Change and Health

Climate change is also likely to affect human health in urban centres. This is of particular concern in the Least Developed Countries, which already experience a high burden of climate-sensitive diseases. Many of these health risks are accentuated in densely populated urban areas. As well as the direct mortality effects of more frequent and extreme weather events, climate change will also affect human health through changes in vector-borne disease transmission, increased malnutrition due to declining food yields, and increases in diarrhoeal diseases from changes in water quality and water availability. This is a highly inequitable process, as those who are at greatest risk are also those who have contributed the least to greenhouse gas emissions.

The IPCC Fourth Assessment Report concluded that climate change has already contributed to the global burden of disease and premature deaths, has altered the distribution of some infections disease vectors, and has increased heat wave related deaths. It suggests that projected climate change will increase malnutrition and associated disorders; increase the number of people suffering from death, disease and injury from heat waves, floods, storms, fires and droughts; change the range of some infectious disease vectors; increase the burden of diarrhoeal diseases; increase cardio-respiratory morbidity and mortality associated with ground-level ozone; and increase the number of people at risk of dengue. The effects of current and projected climate change will be felt most strongly by the urban poor, the elderly and children, traditional societies, subsistence farmers, and coastal populations (Confalonieri *et al* 2007).

Weather and climate can have a wide range of effects on human health. Deaths from cardio-respiratory disease increase with high and low temperatures; weather affects the concentration and distribution of air pollutants; higher temperatures reduce the development time of pathogens in vectors and increase potential transmission to humans; vector species require specific climatic conditions to be sufficiently abundant to maintain transmission; the survival of bacterial pathogens is related to temperature; heavy rainfall and flooding are associated with outbreaks of water-borne diseases due to contamination of water supplies; and drought conditions may affect water quality due to extreme low flows (Kovats and Akhtar 2008).

Climate change is likely to result in more frequent and intense heat waves. In cities, these are exacerbated by the urban heat-island effect as a result of lower evaporative cooling and increased heat storage in roads and buildings – which can make temperatures 5-11ºC warmer than in surrounding areas. Heat waves can have dramatic impacts on human health: the European heat wave of August 2003 caused excess mortality of over 35,000 people (Campbell-Lendrum and Corvalán 2007). Heat waves can result in significant economic effects from decreased productivity and the additional cost of climate-control within buildings, as well as generating 'knock-on' environmental effects, such as air pollution and increased greenhouse gas emissions if these cooling needs are met with electricity generated from fossil fuels (Satterthwaite *et al* 2007). There is also some evidence that the combined effects of heat stress and air pollution may be greater than the additive effect of the two stresses (Patz and Balbus 2003). The effects of heat stress are distributed unevenly within urban populations, with elderly persons being increasing vulnerable to this issue.

Densely populated urban areas may become increasingly vulnerable to vector-borne diseases due to climate change, as shifting climate patterns extend the range of certain vectors. In general, the higher rates of person-to-person contact in dense urban settlements can help to spread infectious diseases more quickly. Rapid unplanned urbanization can produce breeding sites for mosquitoes, high human population densities provide a large pool of susceptible individuals, and increased temperatures cause an increase in high absolute humidity that can also extend the species range (Campbell-Lendrum and Corvalán 2007). Diseases spread in this way include dengue fever, malaria and filariasis. However, although climate change is likely to result in the expansion of malaria-carrying mosquitoes to some new locations, it is likely to cause the contraction of this range in other places (Confalonieri *et al* 2007).

Urban health risks can also be exacerbated as a result of extreme weather events[3]. In Mozambique, heavy rains followed by two cyclones in 2000 had the direct impacts of causing 700 deaths and making 500,000 people homeless. However, indirect impacts that affected human health included the destruction of rural water points and pit latrines in Gaza Province, and the overflowing of 3,000 septic tanks in the cities of Chókwè and Xai-xai. Extreme events of this kind are likely to become more frequent as a result of climate change, and the secondary health effects caused by these in dense urban settlements cannot be ignored. Studies in Nepal have shown that residents of the Kathmandu Valley are almost twice as likely to contract chronic obstructive pulmonary disease than persons living outside this urban area. The density of people, traffic, and economic activities in the city contribute to air pollution; but climate change may accentuate the problem through intensifying temperature inversions and trapping pollutants in the valley. Other research in Kathmandu shows a distinct association between temperature and recorded cases of typhoid, raising the possibility that increased temperatures as a result of climate change may cause an increased incidence of this disease.

But the effects of climate change on human health in densely populated urban settlements are not insurmountable. Indeed, the current burden of climate-sensitive disease is highest among the urban poor: it is not the rapid development, size and density of cities that are the main determinants off vulnerability, but rather the increased populations in hazard zones, flood plains, coastal hazard risk zones and unstable hillsides vulnerable to landslides. Good environmental and public health services should also be able to cope with any increase in other climate-change-related health risks in the next few decades – whether this is through heatwaves or reduced

[3] The examples from Mozambique and Nepal are taken from a series of as yet unpublished studies conducted by the International Institute for Environment and Development and partner organisations through the CLACC network in 2007.

freshwater availability, or greater risks from communicable diseases. However, this requires firm commitments to provide necessary infrastructure on the part of municipal and national governments, as well as the mobilization of appropriate financial resources to facilitate this.

In Durban, South Africa, the eThekwini Municipality identifies human health as a key component of its 'Headline Climate Change Adaptation Strategy' (Roberts 2008). This strategy recognizes that the municipal government will have to respond to greater risks of heat-related deaths and illnesses, extreme weather (particularly the vulnerability of sewage networks and informal settlements to flooding), potentially reduced air quality, and impacts of changes in precipitation, temperature, humidity and salinity on water quality and vector-borne diseases. It also recognizes the need for public education, to develop community responses, to ensure that electricity supplies can cope with peaks, to promote more shade provision and increased water efficiency, to develop an extreme-climate public early-warning system, and to facilitate research and training for environmental health.

Coastal density and sea-level rise

One of the major effects of climate change is likely to be global sea-level rise. As the global population becomes increasingly coastally concentrated, it is important to assess the implications that will arise from increasingly dense populations in an increasingly vulnerable physical environment. Coastal areas have always been densely populated because of the possibilities they offer for transportation and trade. Yet settlements in these locations have also been exposed to a variety of natural hazards – including from erosion, storms, tsunamis and flooding – and are likely to become increasingly vulnerable as a consequence of climate change. Both urban disasters and environmental hot spots are already located disproportionately in low-lying coastal areas (Pelling 2003), and low-income groups living on flood plains are especially vulnerable. Very small rises in the global average annual temperature will result in increased damage from floods and storms, temperature increases of 2°C and more will mean that millions more people could experience coastal flooding each year, and a temperature rise of 3°C or more could result in the loss of about 30 percent of global coastal wetlands (Intergovernmental Panel on Climate Change 2007). The effects will be felt in both directions: increased population density in coastal areas will also exacerbate the impact of climate change on coasts (Nicholls *et al* 2007).

Coastal areas are considerably more densely populated than the world's land areas as a whole. Based on a definition of near-coastal areas as being within 100 horizontal kilometres and 100 vertical metres of a coastline, Small and Nicholls (2003) determined that the average population density of the near-coastal zone is 112 people per km^2, compared to an average global population density of 44 people per km^2. This same methodology concluded that, in 1990, approximately 23 percent of the world's population, of 1.2 billion people, lived in near-coastal areas. However, the majority of inhabitants of the near-coastal zone live at moderate population densities (100 to 1,000 people per km^2), and only about one-tenth of the inhabitants of the near-coastal zone live at the very high population densities (more than 10,000 per km^2) associated with the dense urban cores of large cities.

An alternative, and more recent, methodology (McGranahan *et al* 2007) identifies the Low Elevation Coastal Zone (LECZ) as land area contiguous with the coastline up to a 10 metre elevation. The LECZ does not imply that all settlements and activities within the zone are at risk from sea-level rise, but it is a useful proxy for identifying the extent of a country or region's population at risk. The LECZ covers 2 percent of the world's land area but contains 10 percent of the world's population and 13 percent of the world's urban population; of the approximately 600 million people living in the LECZ, approximately 360 million are urban dwellers. In

Bangladesh and China, the population in the LECZ grew at almost twice the national population growth rate between 1990 and 2000, indicating an increasing densification of the coastal zone: thus "even as the seaward risks associated with climate change are increasing, the areas most at risk are experiencing particularly high population growth" (McGranahan *et al* 2007: 33). On average, the Least Developed Countries have a higher share of their total population living in the LECZ (14%) and a higher proportion of their urban population living in the LECZ (21%) – and it is these countries that are also most at risk from the effects of climate change. By absolute numbers, China, India and Bangladesh have the highest numbers of people living in the LECZ (143.9 million, 63.2 million and 62.5 million people respectively); as a proportion of their total population, the Bahamas, Suriname and the Netherlands have the highest percentages (88 percent, 76 percent and 74 percent respectively – although these figures exclude countries with a total population of under 100,000 or a land area of less than 1,000 square kilometres).

Just as the LECZ contains a greater share of the world's urban population than of its rural population, it also contains a greater share of large urban settlements than of small urban settlements (McGranahan *et al* 2007): overall, 65 percent of urban settlements with populations of greater than five million are located – at least partially – in the LECZ. Perhaps alarmingly from the perspective of climate change risk, in some countries both the absolute number and the share of the population living in the LECZ is growing rapidly. In both Bangladesh and China, the population in the LECZ grew at almost twice the national population growth rate between 1990 and 2000: even as the coastal risks associated with climate change are increasing, the areas most at risk are experiencing particularly high population growth. However, it is difficult to estimate precisely how many people are at risk from the sea-level rise that climate change will bring. The number of people affected by coastal flooding as a result of climate change will certainly increase: one estimate suggests that 10 million people were affected by this phenomenon in 1990, but that this number may have more than tripled by the 2080s (Nicholls 2004).

In India, the deltas of the Ganga, Krishna, Godavari, Cauvery and Mahandi on the east coast; and Khambhat and Kachchh in Gujarat; Mumbai and parts of the Konkan coast and South Kerala are particularly vulnerable. India's coasts – especially its western seaboard and stretches along the Bay of Bengal – are expected to grow dramatically in population, infrastructure and industrial investment in the next two decades, leading to a non-linear increase in coastal sea level rise vulnerability (Revi 2008). Elsewhere in Asia, large sections of the urban and rural population in densely populated deltas such as the Ganges-Brahmaputra (that includes Dhaka), the Mekong, the Chang jiang (also known as the Yangtze which includes Shanghai) and the Chao Phraya (with Bangkok) are particularly vulnerable to sea-level rise and changes in run-off. Large sections of Mumbai, Dhaka and Shanghai are only 1 to 5 metres above sea level (de Sherbinin *et al* 2007).

Sea-level rise is also expected to cause a variety of impacts in densely populated African cities. Half of the continent's 37 'million cities' are within or have parts within the low-elevation coastal zone. Frequent coastal floods in Mombasa, Kenya, result in the destruction of homes and property, the loss of human lives, and the increased incidence of diseases such as cholera and typhoid. Around 17 percent of Mombasa's land area could be submerged by a sea-level rise of 0.3 metres, with a larger area rendered uninhabitable or unusable for agriculture because of water logging and salt stress (Awuor *et al* 2008). Inundation of land and salination of water supplies not only affect densely populated areas, but may also be a factor encouraging people to relocate – thereby increasing population densities elsewhere. Elsewhere in Africa, the Nile, the Niger (with Port Harcourt) and the Senegal (with Saint Louis) have large urban and rural populations at risk (Diagne 2007).

Densely populated coastal areas are also at greater risk from extreme weather events such as tropical cyclones (Intergovernmental Panel on Climate Change 2007). There is some evidence that hurricane force winds will become more frequent and more intense, and possibly also that the hurricane belt will move southwards. Highly urbanized coasts most at risk from these events include Vietnam, Gujarat in west India and Orissa in east India, the Caribbean (including major urban settlement such as Santo Domingo, Kingston, and Havana), and central America.

There is little information explicitly linking density within coastal settlements and risk from climate change. However, it is mostly low-income households living in informal or illegal settlements that face the greatest risks from flooding, and who are also most severely affected by extreme weather events (Satterthwaite *et al* 2007). These same people are also those who are most likely to live in densely populated communities and settlements. The risks to human settlements could be reduced if people and enterprises could be encouraged to move away from the coast, or at least from the most risk-prone coastal locations – however, current population movements are in the opposite direction, and turning these around is likely to be slow, costly or both (McGranahan *et al* 2007). Preventing settlement in vulnerable locations can best be achieved by urban and national authorities ensuring that adequate safe land is available for low-income urban residents. And where technological and infrastructural solutions are necessary to protect already existing settlements, high urban densities means that these are more likely to be cost effective.

Conclusion

This paper has examined the relationship between urban density and climate change, and has accounted for this relationship from the perspectives of both mitigation and adaptation to climate change. Future patterns of greenhouse gas emissions and consequent climate change will be driven substantially by the activities taking place in urban areas; similarly, the ways in which climate change impacts the lives and livelihoods of more than half the world's population will also be mediated through actions that are taken – or not taken – in towns and cities. What is clear, however, is that there is no 'ideal size' for urban settlements – indeed, "different sizes and shapes of cities imply different geographical advantages" (Batty 2008: 771). In addition, there is no ideal density for cities and towns – instead, broader issues of urban form and structure are equally or more important.

There is also a complicated series of interactions between urban density, economic status, and greenhouse gas emissions. The residents of the densely populated cities of low- and middle-income countries are generally wealthier than residents of their hinterlands, yet far less wealthy than residents of the (less densely populated) cities in high-income countries. This confounds a straightforward relationship between urban density and greenhouse gas emissions: in low-income countries, residents of denser settlements are likely to have higher per capita emissions as a function of their greater wealth than residents of surrounding areas; in high-income countries, residents of denser settlements are likely to have lower per capita emissions than residents of surrounding areas as a result of smaller housing units and greater use of public transportation systems.

In relation to the impacts of and adaptation to climate change (and other environmental hazards), density has another set of effects. The extremely high population densities of many urban areas in low- and middle-income countries contribute to environmental health problems and may concentrate risk in particularly vulnerable locations, and any potential sustainability gains from greater densification are likely to be limited where densities are already high. Indeed, “under these circumstances the merits of urban densification postulated for developed country cities seem far less convincing in the context of developing countries” (Burgess 2000: 15).

In summary, therefore, density is one of several major components affecting the ways in which urban areas will influence and be affected by a changing climate. Adopting ‘increasing densification’ as a strategy without assessing these other factors – including distribution of employment opportunities and the nature of transportation systems – is not likely to provide lasting sustainability or resilience benefits. Yet in association with a wider awareness of urban form and process, well-planned, effectively-managed, and densely-settled towns and cities can help to limit greenhouse gas emissions and facilitate resilience to the challenges of climate change.

References

Alam M, Rabbani M (2007) 'Vulnerabilities and responses to climate change for Dhaka' *Environment and Urbanization* 19(1): 81-97.

Angel S, Sheppard S, Civco D (2005) *The Dynamics of Global Urban Expansion*. Transport and Urban Development Department, World Bank, Washington DC.

Awuor C, Orindi V, Adwera A (2008) 'Climate Change and Coastal Cities: the case of Mombasa, Kenya' *Environment and Urbanization* 20(2): 231-242.

Bai X (2007) 'Industrial Ecology and the Global Impacts of Cities' *Journal of Industrial Ecology* 11(2): 1-6.

Baldasano J, Soriano C, Boada L (1999) 'Emission inventory for greenhouse gases in the City of Barcelona, 1987-1996' *Atmospheric Environment* 3: 3765-3775.

Batty M (2008) 'The size, scale and shape of cities' *Science* 319: 769-771.

Bertaud A, Malpezzi S (2003) *The Spatial Distribution of Population in 48 World Cities: Implications for Economies in Transition*. Working Paper. Available from http://alain-bertaud.com/AB_Files/Spatia_%20Distribution_of_Pop_%2050_%20Cities.pdf (accessed and printed 31/7/08).

Brown M, Southworth F (2008) 'Mitigating climate change through green buildings and smart growth' *Environment and Planning A* 40: 653-675.

Burgess R (2000) 'The compact city debate: a global perspective' in Jenks M, Burgess R (eds) *Compact Cities: sustainable urban forms for developing countries*. London, Spon Press. Pp 9-24.

Burton E (2000) 'The Compact City: Just or Just Compact? A Preliminary Analysis' *Urban Studies* 37(11): 1969-2001.

Campbell-Lendrum D, Corvalán C (2007) 'Climate Change and Developing Country Cities: implications for environmental health and equity' *Journal of Urban Health* 84(1): 109-117.

Champion T (2001) 'Urbanization, Suburbanization, Counterurbanization and Reurbanization' in Paddison R (ed) *Handbook of Urban Studies*. London, Sage, pp143-161.

Chen H, Jia B, Lau S (2008). 'Sustainable urban form for Chinese compact cities: Challenges of a rapid urbanized economy' *Habitat International* 32: 28-40.

Confalonieri U, Menne B, Akhtar R, Ebi K, Hauengue M, Kovats R, Revich B, Woodward A (2007) 'Human Health' in Parry M, Canziani O, Palutikof J, van der linden P, Hanson C (eds) *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.

Coutts A, Beringer J, Tapper N (2008). ‘Impact of Increasing Urban Density on Local Climate: spatial and temporal variations in the surface energy balance in Melbourne, Australia’ 46: 477-493.

de Sherbinin A, Schiller A, Pulsipher A (2007) ‘The Vulnerability of Global Cities to Climate Hazards’ *Environment and Urbanization* 19(1): 39-64.

Dhakal S (2004) *Urban Energy Use and Greenhouse Gas Emissions in Asian Mega-Cities*. Institute for Global Environmental Strategies, Kitakyushu, Japan.

Diagne K (2007) ‘Governance and natural disasters: addressing flooding in Saint Louis, Senegal’ *Environment and Urbanization* 19(2): 552-562.

Díaz Palacios J, Miranda L (2005) ‘Concertación (Reaching Agreement) and Planning for Sustainable Development in Ilo, Peru’ in Bass S, Reid H, Satterthwaite D, Steele P (eds) *Reducing Poverty and Sustaining the Environment*. London, Earthscan, pp254-278.

Dodman D (2009) ‘Blaming Cities for Climate Change? An Analysis of Urban Greenhouse Gas Emissions Inventories’ *Environment and Urbanization* 21(1): 185-201.

Dodman D, Satterthwaite D (2008) ‘Institutional Capacity, Climate Change Adaptation, and the Urban Poor’ *Institute for Development Studies Bulletin*, October 2008.

Dubeux C, La Rovere E (2007) ‘Local perspectives in the control of greenhouse gas emissions – the case of Rio de Janeiro’ *Cities* 24(5): 353-364.

Frenkel A, Ashkenazi M (2008) ‘Measuring urban sprawl: how can we deal with it?’ *Environment and Planning B: Planning and Design* 35: 56-79.

Glaeser E, Kahn M (2008). ‘The Greenness of Cities: carbon dioxide emissions and urban development’ Harvard Kennedy School / Taubman Center for State and Local Government. *Working Paper WP-2008-07*. Available online: [accessed 15/12/08].

Gottdiener M, Budd L (2005) *Key Concepts in Urban Studies*. London, Sage.
Hardoy J, Mitlin D, Satterthwaite D (2001) *Environmental Problems in an Urbanizing World*: *Finding Solutions for Cities in Africa, Asia and Latin America*. London, Earthscan.

Howard E (1996) Extract from *Garden Cities of Tomorrow* (first published 1898). Reprinted in LeGates R, Stout F (eds) *The City Reader*. London, Routledge, pp346-353.

Intergovernmental Panel on Climate Change (2007). *Climate Change 2007. Synthesis Report: Summary for Policymakers*. Cambridge, Cambridge University Press.

Jabareen Y (2006) ‘Sustainable Urban Forms: their typologies, models, and concepts’ *Journal of Planning Education and Research* 26: 38-52.

Jacobs J (1996) Extract from *The Death and Life of Great American Cities* (first published 1961). Reprinted in LeGates R, Stout F (eds) *The City Reader*. London, Routledge, pp103-108.

Kovats S, Akhtar R (2008) ‘Climate, Climate Change and Human Health in Asian cities’ *Environment and Urbanization* 20(1): 165-175.

Lebel L, Garden P, Banaticla M, Lasco R, Contreras A, Mitra A, Sharma C, Nguyen H, Ooi G, Sari A (2007) 'Integrating Carbon Management into the Development Strategies of Urbanizing Regions in Asia: implications of urban function, form, and role' *Journal of Industrial Ecology* 11(2): 61-81.

McGranahan G, Balk D, Anderson B (2007) 'The Rising Tide: assessing the risks of climate change and human settlements in low elevation coastal zones' *Environment and Urbanization* 19(1)17-37.

McGregor D, Simon D, Thompson D (eds) (2006) *The Peri-Urban Interface: approaches to sustainable natural and human resource use*. London, Earthscan

Mayor of London (2007) *Action Today to Protect Tomorrow: The Mayor's Climate Change Action Plan*. Greater London Authority.

Mindali O, Raveh A, Salomon I (2004) 'Urban density and energy consumption: a new look at old statistics' *Transportation Research Part A* 38: 143-162.

Nicholls R, Wong P, Burkett V, Codignotto J, Hay J, McLean R, Ragoonaden S, Woodroffe C (2007) 'Coastal Systems and Low-Lying Areas' in Parry M, Canziani O, Palutikof J, van der linden P, Hanson C (eds) *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.

Neuman M (2005) 'The Compact City Fallacy' *Journal of Planning Education and Research* 25: 11-26.

Newman P, Kenworthy J (1989) 'Gasoline Consumption and Cities: a comparison of US cities with a global survey' *Journal of the American Planning Association* 55: 24-37.

Nicholls R (2004) 'Coastal flooding and wetland loss in the 21st century: changes under the SRES climate and socio-economic scenarios' *Global Environmental Change* 14: 69-86.

Norman J, MacLean H, Kennedy C (2006) 'Comparing High and Low Residential Density: Life-Cycle Analysis of Energy Use and Greenhouse Gas Emissions' *Journal of Urban Planning and Development* 132(1): 10-21.

Patz J, Balbus J (2003) 'Global Climate Change and Air Pollution: interactions and their effects on human health' in Aron J, Patz J (eds) *Ecosystem Change and Public Health*. Baltimore, Johns Hopkins University Press, pp379-402.

Pelling M (2003) *The Vulnerability of Cities: natural disasters and social resilience*. London, Earthscan.

PlaNYC (2007) *Inventory of New York City Greenhouse Gas Emissions*. Mayor's Office of Operations, New York City.

Revi A (2008) 'Climate Change Risk: an adaptation and mitigation agenda for Indian cities' *Environment and Urbanization* 20(1): 207-229.

Rio Prefeitura Meio Ambiente (2003) *Inventário de Emissões de Gases do Efeito Estufa da Cidade do Rio de Janeiro*. Centro de Estudos Integrados sobre Meio Ambiente e Mudanças Climáticas.

Roberts, D. (2008). 'Thinking globally, acting locally: institutionalizing climate change at the local government level in Durban, South Africa' *Environment and Urbanization* **20**(2): in press.

Rogner H, Zhou D, Bradley R, Crabbé O, Edenhofer O, Hare B, Kuijpers L, Yamaguchi M (2007) 'Introduction' In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge, Cambridge University Press.

Satterthwaite D (1999) 'The Key Issues and the Works Included' in Satterthwaite D (ed) *The Earthscan Reader in Sustainable Cities*, pp 3-21. London, Earthscan.

Satterthwaite D (2007). *The Transition to a Predominantly Urban World and its Underpinnings*, Human Settlements Discussion Paper, IIED, London.

Satterthwaite D, Huq S, Reid H, Pelling M, Romero Lankao P (2007). *Adapting to Climate Change in Urban Areas: the possibilities and constraints in low- and middle-income nations*. Human Settlements Discussion Paper, IIED, London.

Satterthwaite D (2008) 'Cities' contribution to global warming: notes on the allocation of greenhouse gas emissions' *Environment and Urbanization* 20(2).

Secretaria Municipal do Verde e do Meio Ambiente de São Paulo (SVMA) (2005) *Inventário de Emissões de Efeito Estufa do Município de São Paulo*. Centro de Estudos Integrados sobre Meio Ambiente e Mudanças Climáticas (Centro Clima) da Coordenação dos Programas de Pós-graduação de Engenharia (COPPE) da Universidade Federal do Rio de Janeiro (UFRJ).

Small C, Nicholls R (2003) 'A Global Analysis of Human Settlement in Coastal Zones' *Journal of Coastal Research* 19(3): 584-599.

Sudjic D (2008) 'Theory, Policy and Practice' in R Burdett and D Sudjic (eds) *The Endless City*. Phaidon pp 32-51.

Tacoli C (ed) (2006) *The Earthscan Reader in Rural-Urban Linkages*. London, Earthscan.

United Nations Human Settlements Programme (UN-Habitat) (2007). *Enhancing Urban Safety and Security: Global Report on Human Settlements 2007*. London, Earthscan.

United Nations Population Fund (UNFPA) (2007) *State of the World Population 2007: Unleashing the Potential of Urban Growth*. New York, United Nations.

United Nations Statistics Division – Environmental Indicators (n.d.) Available online: http://unstats.un.org/unsd/environment/air_greenhouse_emissions.htm (accessed 23/5/08).

VandeWeghe J, Kennedy C (2007) 'A Spatial Analysis of Residential Greenhouse Gas Emissions in the Toronoto Census Metropolitan Area' *Journal of Industrial Ecology* 11(2): 133-144.

Velásquez L (2005). 'The Bioplan: decreasing poverty in Manizales, Colombia, through shared environmental management' in Bass S, Reid H, Satterthwaite D, Steele P (eds) *Reducing Poverty and Sustaining the Environment*. London, Earthscan, pp44-72.

Wackernagel M, Rees W (1995) *Our Ecological Footprint*. Gabriola, New Society Publishers.

Wackernagel M, Kitzes J, Moran D, Goldfinger S, Thomas M (2006) 'The Ecological Footprint of cities and regions: comparing resource availability with resource demand' *Environment and Urbanization* 18(1): 103-112.

Walker G, King D (2008) *The Hot Topic: how to tackle global warming and still keep the lights on*. London, Bloomsbury Publishers.

Weber C, Peters G, Guan D, Hubacek K (2008) 'The contribution of Chinese exports to climate change' *Energy Policy* 36: 3572-3577.

Willbanks T, Romero Lankao P, Bao M, Berkhout F, Cairncross S, Ceron J-P, Kapshe M, Muir-Wood R, Zapata-Marti R (2007). 'Industry, Settlement and Society' in Parry M, Canziani O, Palutikof J, van der linden P, Hanson C (eds) *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.