

Chapter 2: Urbanization and trends in biodiversity and ecosystem services

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This section of the volume describes conditions and trends in urbanization, biodiversity, and ecosystem services. This is an extremely broad, multifaceted topic, and no one book could ever hope to cover it fully. The chapters within this section, however, cover various facets of this topic, focusing on those that are particularly important for decision-makers or researchers.

This chapter introduces patterns of urbanization, biodiversity, and ecosystem services at the global scale. The chapter starts by introducing the idea that cities both impact and depend upon the biophysical environment. Then, we discuss how urbanization is both the cause of societal or environmental problems and the solution to many problems, depending on the time-scale and scope of the analysis. Next, we provide a global overview of cities' relationship with three key facets of the environment: biodiversity, freshwater, and climate.

2.1. Cities both impact and depend on the environment

There are two primary ways to analyze the interaction between cities and the environment, and both are used by chapters in this section.

One mode of analysis of urban/environment interactions is to focus on the impact of urban areas upon biodiversity or ecosystem services. These impacts can occur over a range of spatial scales (McDonald and others 2009). At a very local scale, the pattern of urban development determines how natural habitat is fragmented, which affects how native biodiversity is impacted and where invasive species get established, as discussed in Chapter 3. Chapter 5 discusses specific factors affecting urban form and their implications for biodiversity and ecosystem services. For a more complete discussion of policymakers' attitudes toward urbanization and policies that can decrease environmental impact, see Chapter 10. In this current chapter, we focus on how global patterns of urban growth intersect with global patterns of biodiversity, which is often seen as the

foundation for ecosystem service provision. We also discuss cities' greenhouse gas emissions and hence their impact on climate.

A second mode of analysis of urban/environment interactions is to study the dependence of urbanites on biodiversity and ecosystem services. Dependencies can occur over a range of scales, just like impacts. To be a true ecosystem service, a desirable ecosystem process has to occur near consumers of that service (McDonald 2009). The degree to which proximity is essential—the transportability of an ecosystem service—varies from service to service. Urban street trees, for instance, provide shade to urbanites over a scale of tens of meters. At a watershed scale, many cities depend on natural habitat to provide an adequate supply of clean water. At a global level, urbanites depend on the climate regulation services supplied by ecosystems. Chapter 4 discusses many kinds of urban dependencies in detail. Chapter 8 looks at how cities depend on a stable climate and how climate change may affect them. Chapter 6 discusses how to restore ecosystem services and biodiversity when ecosystems are degraded. In this chapter, we focus on how cities globally depend upon and impact freshwater ecosystem services.

2.2. Urbanization as a problem and a solution

Global urbanization has been an uneven process; both temporally and geographically (Satterthwaite 2007). The increase in the global urban population began slowly. In 1800, the global urbanization level was approximately 3% with an estimated 1.7% living in cities of 100,000 or more and 2.4% in cities of 20,000 or more. As late as 1900, the world's population share living within cities of these sizes remained less than 10% (Davis 1955). By 1950, however, estimates suggest that approximately, 729 million people worldwide lived in all cities, 29% of the global population (United Nations 2010b). Subsequently global urbanization increased rapidly. By 1960, there were approximately 998 million in the world's cities, by 1985, 1.98 billion, by 2010, 3.49 billion. The period of the most rapid annual increases globally were experienced between 1950 and 1965, when rates exceeded 3.0%. By 2010, the annual growth rate for global urban population had slide to 1.85%. This amounts to adding 67.5 million people to the urban population each year. The UN (2010a) suggests that the numbers of people moving to cities annually continues to increase and will do so until around 2030, when over 72 million people will be added to cities annually. Thereafter the annual additions are expected to decline.

In terms of geographical variability, urbanization has reached high levels in the developed world, which largely manifest in the temperate zone. Generally, cities in these Northern areas are now growing more slowly than those of the South and some are even contracting in terms of population (Chapter 5). At the same time, urbanization is increasing in the developing world, largely located in the tropics and sub-tropics. Here cities are absorbing large numbers of people.

The advance of urbanization, particularly after the 1950s, has coincided with global environmental degradation, increasing consumption of natural resources, habitat loss and ecosystem change (McNeill 2000). It is therefore not surprising that analysts often depict cities as the source of many problems. Lester Brown (Brown 2001, pp.188-190), for example, argues that “People living in cities impose a disproportionately heavy burden on the earth’s ecosystems simply because so many resources must be concentrated in urban areas to satisfy residents, daily needs.” The ecological footprint of a city, the area required to supply its citizens with resources and services from the environment, is much larger than the area of the city itself (Wackernagel and Rees 1996).

This viewpoint of cities as a source of environmental problems, however, often rests on a relatively simple scope of analysis. A simple equation for calculating such an impact is the so-called I=PAT equation (cf., Dietz and Rosa 1997), where Impact (e.g., tons of greenhouse gases emitted) equals the number of People times the Affluence (e.g., energy consumption per capita) times the Technology (e.g., tons of greenhouse gases emitted per unit energy). If total impact from an urban area is the scope of analysis, then in most cases larger cities will cause a larger impact on the environment, for the simple reason that the population is larger. By this logic, a city of zero population size would have zero environmental impact.

However, the process of urbanization also influences both the Affluence and Technology terms in the I=PAT equation, in sometimes complex ways. Incomes tend to be greater in cities than in rural areas, and greater in bigger cities than in smaller cities (Bettencourt and others 2007), which can sometimes increase resource consumption. However, there are often efficiencies that are gained with dense settlement. Studies in the United States, for example have pointed out that residents of cities consume less energy per-capita and therefore generate less greenhouse gas emissions per-capita (Brown and others 2008). Similarly, urban residents in the United States eat less beef and pork (Davis and Lin 2005a; Davis and Lin 2005b) than their rural counterparts.

In the developing world, in contrast, those in cities consume more meat than their rural counterparts (cf., Dhakal 2009), which appears to be primarily due to the increase in income in urban households rather than changes in dietary preferences associated with living in a city (Stage 2009).

It is also, arguably, inappropriate to simply talk about the environmental impact of a city relative to some hypothetical case where the city simply disappeared. A more sophisticated analysis might specify a counterfactual scenario: what would have happened to the environment without the urbanization (McDonald and Marcotullio 2011)? These counterfactual scenarios are very difficult to construct. Without migration to cities, there might be less environmental impact from cities, but perhaps more impacts in the countryside. Economists have long suggested that urbanization has a strong positive correlation with economic activity (Annez and Buckley 2009; Williamson 1965), although rapidly growing urban areas can have offsetting negative effects through crowding, environmental degradation and by overwhelming city administrations' capacities (cf., Bai and others 2012; Bloom and others 2007). Certainly, without urbanization, economic development will potentially be limited, and since rural fertility rates are generally higher, there may be a larger total population than in the urbanization scenario.

As discussed in Chapter 1, urbanization is a multifaceted process, and it is very difficult to specify what would have happened to the environment in a society if urbanization did not occur. Urbanization is promoted by numerous factors, including: increased ease of communications and transport; economies of scale and agglomeration economies (Bai and others 2012); increased personal contact among workers and entrepreneurs; and efficiency gains from the high population density in cities (for a review, see Montgomery and others 2003). As people move to cities they leave the agricultural sector for employment in industry and services, substantially changing the economies of nations as they urbanize. Urbanization is also associated with changes in population structure and decreases in fertility. These dynamics bring substantial benefits for and changes to industries and society (Montgomery and others 2003). Thus, from the perspective of the economic development and human well-being of a nation, urbanization is often an integral part of the solution.

The pragmatic truth is that a counterfactual scenario without urbanization is unlikely to ever occur. All developing economies urbanize and there are no examples of nations with high

economic development that have not experienced urbanization (Figure 1). Moreover, policy attempts to limit urbanization have not only had limited effects on rates of urban growth and they have had disproportionately negative impacts on large portions of societies, typically the poor. As pointed out by the UNFPA (2007), there are a growing number of economies that have implemented policies to lower migration to urban agglomerations, from 51 percent in 1996 to 73 percent in 2005 (cf., Bai 2008). While they have had significant negative impact on the lives of rural-to-urban migrants, these policies have had little long-term effect on urbanization and an arguable negative impact on economic growth (Bai and others 2012; Bloom and others 2007).

In short, if demographic forecasts are correct, a large amount of urban growth is coming as poorer countries urbanize. Therefore, it is necessary to examine the types of biophysical environmental impacts expected from urbanization without forgetting that the process of economic development and urbanization can also help the world find solutions to poverty and environmental degradation.

2.3. Global urbanization and biodiversity

Biological diversity is an essential component of many invaluable ecosystem services for human material welfare and livelihoods. For example, many components of our homes are provided, regulated or supported by biodiversity, including our food, the wood in the building, fresh water from taps and fuel in our stoves. Nitrogen fixation is important for biological productivity, and only a few plants such as legumes can perform this service. Preserved forests close to coffee-plant flowers, provide reliable sources of pollinators, which have been estimated to improve yields by 20 percent (Melillo and Sala 2008). Biodiversity contributes to human security, resiliency, health and freedom of choices and actions (Millennium Ecosystem Assessment 2005). Moreover, biodiversity preservation is the goal of the Convention on Biological Diversity and many national-level laws (e.g., the Endangered Species Act in the United States).

Despite these important contributions to society, biodiversity is declining. Researchers have identified a sixth great extinction event promoted by anthropogenic activities (Wilson 2005). Human actions are fundamentally and to a significant extent irreversibly changing diversity of life on the planet (Millennium Ecosystem Assessment, 2005). Rates of extinction continue to increase and the numbers of species threatened continues to grow (Pimm and others 1995)

despite attempts to preserve biodiversity through the international Convention on Biological Diversity and many national-level laws (e.g., the Endangered Species Act).

In this section we examine the global impact of urbanization on biodiversity. We examine this relationship through a review of the direct impact of urban growth as well as through an examination of the indirect impacts of urbanization.

2.3.1. The global distribution of biological diversity

Biodiversity can be examined a number of different ways. In this overview we examine species richness and endemism. While species richness and endemism varies unevenly across the Earth's surface, a number of broad trends have been observed.

Species richness is generally higher in high productivity sites like tropical rain forests and lower in low productivity sites like arctic tundra, for unclear reasons (Willig and others 2003). The pattern of distribution is called the latitudinal geographic gradient because the highest levels of biodiversity are found near the equator and they drop off as one moves towards the poles (Turner and Hawkins 2004). Figure 2 depicts this relationship for birds, but this pattern is true for major taxa (classes, orders and families), for microbes, plants and animals and for both terrestrial and aquatic systems. The latitudinal gradient is supplemented by a number of other gradients including distance to coast, position within a peninsulas, local elevation and topographic relief and depth (bathymetry) in the ocean (Lomolino and others 2010).

Species endemism is the number of species unique to one location and is a major concern to conservationists. Examples of endemic species include the Devil's Hole pupfish (*Cyprinodon diabolis*), Australia's koala (*Phascolarctos cinereus*) and many different species of cichlid fish found in Lakes Victoria, Tanganyika and Malawi. Endemism is distributed very differently from species richness. While species richness is low on isolated islands, endemism is high in proportional terms, as the geographic isolation of biota leads to speciation that fills empty niches. Coastal areas are also places with a high degree of marine and terrestrial endemism because of the high habitat diversity (Dirzo and Raven 2003).

2.3.2. Direct impact of urbanization on biodiversity

Cities are concentrated along coastlines and some islands (Figure 3) as well as major river systems, which also happen to be areas of high species richness and endemism. Ecologists have

explained this pattern by examining the correlation between human population density and productivity (Luck 2007), while urban historians have focused on the importance of freshwater and marine trade routes for city formation.

Urban growth is clearly a significant global driver of land-use conversion and deforestation. Urban areas occupy approximately 3% of the Earth's land surface (McGranahan and others 2006), although the actual number varies significantly depending on the definition of urban and the spatial grain of analysis (Schneider and others 2009; Seto and others 2010).

The spatial correlation between urban growth and endemism means urban growth has already impacted biodiversity significantly. One study found that around 10% of terrestrial vertebrates are in ecoregions that are heavily impacted by urbanization (McDonald and others 2008).

Information on land-use change due to urbanization is not available over long periods of time. However, it is instructive to look at how urban population in different habitat types has changed over time (Figure 4). In 1950, the habitat type with the most urban dwellers was temperate broadleaf forests, followed by tropical moist forests and Mediterranean habitat. However, a more useful proxy measure of biodiversity impact is the urban population density in a habitat type (i.e., urban population divided by the total area in a habitat type). Note that this proxy measure is much lower than the population density at which urban settlements occur, but it gives a rough sense of how many urban people are crowded into this habitat type. By this proxy measure, the Mediterranean, mangrove, and temperate broadleaf forest habitat types all have high urban population density per habitat area and hence likely high biodiversity impact. By 2000, the number of urban dwellers increased significantly in almost all habitat types. However, the rank ordering of both urban population and urban population density per habitat area stayed similar to patterns in 1950.

The majority of the global urban population is currently located in the temperate zone (Figure 5). At the turn of the 21st century, urban populations were largely located temperate zone between 25 and 55 degrees North latitude. The percent of the urban population trails off approaching the equator with another small peak in the South Temperate Zone. One might argue that this pattern has actually limited urbanization's direct impact on biodiversity to date as the tropical zones are the areas of highest concentration of different species.

In the future however, urban growth patterns will change. With urban growth, urban land use will likely double (McDonald 2008), although there is significant uncertainty in predicting how much urban population and urban area will increase (Seto and others 2010). One recent study suggested that between 1970 and 2000 urban areas grew by 58,000 km² and by 2030, cities are expected to grow by more than another 1,527,000 km² or approximately 43,000 American football fields every day for the next 18 years (Seto and others 2011). Figure 5 provides estimates of the latitude of the global population growth. According to the UN over 95% of this population growth will occur in cities. The chart dramatically demonstrates how the future urban population will increasingly reside in tropical areas. Indeed, the UN predicts that the latitudes between the equator and 15 degrees north will after 2050, grow to overwhelm the current urban population in the temperature zone.

This trend is visible in predictions of urban population by major habitat in 2050 (Figure 4). Urban population will increase in essentially all habitat types. There will be particularly noticeable increases in urban population in tropical moist forests, deserts and tropical grasslands. Note that in terms of urban population per habitat area, there will be significant increases in impact in mangroves, flooded grasslands, and temperate broadleaf forests. Also worth noting are impacts to tropical conifer forests, a unique habitat type found only in a relatively small area globally.

Expansion of cities also fragments the remaining blocks of natural habitat. This increases the isolation of natural habitat patches, as the average distance between them increases. Increased isolation tends to reduce population and gene flow among patches, and may break a large regional population into several discrete subpopulations. Seasonal and intergenerational migration is also restricted. Highly mobile taxa like birds are generally less affected by isolation than less mobile taxa like amphibians, although some apparently mobile species disliking moving across urban land cover (Saunders and others 1991).

Fragmentation necessarily increases the amount of habitat that is near a habitat/non-habitat edge (Murcia 1995). This systematically alters conditions near the edge, affecting the species and processes found there (Fagan and others 1999). For example, at forest/non-forest edges temperature is significantly increased at the edge during the growing season due to greater solar insolation. This increases average temperatures for tens of meters into the forest interior, the

equivalent change in climate to a movement of hundreds of kilometers in latitude (Smithwick and others 2003). Roads create a particular type of edge, with particular ecological effects (Forman 2000). Road noise is a commonly studied edge effect, and has been shown to significantly alter when and how bird species sing (Rheindt 2003). Finally, biotic interactions may change near edges. Birds' nests, for instance, are more likely to be parasitized by cowbirds when they are near an edge (Lloyd and others 2005).

Urbanization increases the number and extent of non-native invasive species by increasing the rate of introduction events and creating areas of disturbed habitat for non-native species to become established in (e.g., McDonald and Urban 2006). There is a suite of “cosmopolitan” species, skilled generalists, that are present in most cities around the world (Kuhn and Klotz 2006; McKinney 2006). Meanwhile, urbanization often leads to the loss of “sensitive” species dependent on larger, more natural blocks of habitat. The net result is sometimes termed “biotic homogenization.” Species richness in cities may actually be higher than that of rural areas, depending on the richness of the suite of cosmopolitan species relative to that in natural habitat, but global species richness declines. The flora and fauna of the world's cities has become more similar and homogeneous over time (Grimm and others 2008; Hobbs and others 2006; Pysek and others 2004). Chapter 3 discusses this complex process in more detail.

Urban expansion will also impact freshwater biodiversity. A study that quantitatively modeled the effect of global urban demographic growth and climate change on water availability (McDonald and others 2011b) that freshwater biodiversity impacts would be largest in places with large urban water demands, relative to water availability, as well as high freshwater endemism. Of particular conservation concern is the Western Ghats of India, which will have 81 million people with insufficient water by 2050 but also houses 293 fish species, 29% of which are endemic to this ecoregion and occur nowhere else in the world.

2.3.3. Indirect effects of urbanization on biodiversity

Cities may occupy a small percent of the global land area, but they contain the majority of the world's population and are concentrated centers of activity. These activities end up shaping land-use over a far larger land area, and influence the decisions of landowners and the policy decisions of governments in ever widening geographic extents. Chapter 9 examines arguably the

most important indirect effect in terms of its areal impact, the impact of city's demand for food on global land-use.

The questions remain, however, how dense settlements interact with other human activities and what would happen if cities were removed from the equation. As mentioned previously more specific policies focused on the process associated with urbanization may provide more valuable conservation tools than a general attack on cities. Three recent research findings that demonstrate our lack of knowledge on the exact role of urbanization and how examining interactions closely may help conservation efforts.

First, a recent article argues that international trade accounts for 30% of all global species threats (Lenzen and others 2012). While the demand for the goods traded probably originated in many of the world cities, this study emphasized better regulation, sustainable supply-chain certification and consumer product labeling as solutions. At the same time, however, there have been all too few studies that have examined the role of urbanization, trade and the environment. Obviously what is traded matters to the outcome of these relationships. How does, for example, the growing trade in electric bicycles to specific cities in the US and Europe impact the environment? Has urbanization influenced production processes to lower environmental impact? Does the concentration of population and subsequent generation of "green" ideology have any impact on individual merchandise choice? In order to understand the role of urbanization in trade's impact on biodiversity, more study is needed to identify not only the distances of materials travel, but also from where are they coming from before arriving at urban centers (Seto and others 2012).

A second study examined global material consumption over the past century. Researchers estimated that during this period, global materials use increased 8-fold to reach almost 60 billion tons (Gt) of materials per year (Krausmann and others 2009). At the same time, the total population increased by 4-fold. What is interesting is that over this century, materials use increased at a slower pace than the global economy, but faster than world population.

Consequently, this research suggests that while material intensity (i.e. the amount of materials required per unit of GDP) declined, the materials use per capita doubled from 4.6 to 10.3 t/cap/yr. The role of technology and increasing wealth in these increases is clear. What is much less clear is the role of the growth of cities. During the century the urban population increased

approximately 18-fold. What was the urban impact on materials consumption? On one hand, cities may have helped to increase the rate of consumption through infrastructure development. Certainly, studies have demonstrated the large flows of material into cities as they grow (Decker and others 2000; Kennedy and others 2007). On the other hand, given that this infrastructure is shared by large numbers of people, urbanization could have slowed overall material consumption growth. That is, if populations were not densely organized, the levels of materials consumed may have been much larger. These questions suggest that cities and the urbanization process may have beneficial aspects that lower overall consumption levels.

Finally, a third research project examined the role of households rather than population in resource consumption and biodiversity loss. In this case analysts examined the decreasing size of households around the world and the impact of this trend on biodiversity (Liu and others 2003). This research suggests that even when population size decreased in some locations, the number of households increased with subsequent increases in impacts. This work places the burden of responsibilities on the decreasing size of households, which increases demands for housing, rather than on urban population. We ask whether urban areas are contributing to or mediating the trend of household decline.

These examples demonstrate that the indirect processes by which urbanization affects biodiversity loss are unclear, but potentially quite significant. Moreover, in many analyses it is difficult to separate the effect of urbanization *per se* from other confounding processes, like economic development and changes in demographics.

2.4. Global urbanization and freshwater ecosystem services

There are many different types of freshwater ecosystem services that cities depend on. Water is directly needed for human use, and supports a variety of other secondary ecosystem services (e.g., recreation, biodiversity, transportation). Globally, water consumption is greatest from the agricultural sector. The energy sector, however, withdraws a large amount of water for use in extracting and processing natural resources (e.g., coal, and cooling thermoelectric power plants). Urban consumption of food and energy contributes to increased water use in agriculture and energy, so in a certain sense a true accounting of cities' water use requires consideration of these

linkages. For instance, the main water use of Chinese cities comes from the water needed to mine coal and burn it in thermoelectric power plants.

Urban residents need water for their daily activities (drinking, cooking, cleaning) as well as disposal of human wastes through sanitation systems. Per-capita water use substantially varies among cities. Within the United States for instance, residents in San Diego use 700 liters/person/day, while residents in Reno, NV use 1166 liters/person/day. Per-capita domestic water use tends to increase as the average income increases (FAO 2011). For example, the average resident of Indonesia (\$3,900 GDP/capita, in purchasing power parity) uses 28.9 m³/person/year, while the average resident of Canada (\$40,200 GDP/capita) uses 276.0 m³/person/year. The overall correlation between per-capita domestic water use and per-capita GDP is fairly high (R=0.59). There are at least two reasons for the increase in water consumption with income. First, poorer cities are more likely to have substantial populations without access to drinking water, decreasing aggregate demand for water. For instance, 27.6% of Sub-Saharan urban residents lack access to clean drinking water, 12.3% of Latin American and Caribbean urban residents, and essentially 0% of urban residents in the United States (UN-HABITAT 2006). Second, richer urban residents have access to technology that requires significant water to run, such as dishwashers and washing machines.

Three things must happen to ensure provision of fresh, clean water to urban inhabitants (McDonald and others 2011a). First, enough water must be available. Availability, the absolute amount of surface or groundwater within a region that can be sustainably appropriated for urban use, is largely a function of climatic setting. Second, the water must be of sufficient quality for use. Water that is polluted, either by upstream users or through pollution *in situ*, must be treated and purified before use in urban households. Third, a system must be in place to deliver that water to urban residents, usually via infrastructure such as piped water supplies, dams and canals, and wells.

Water availability is most likely to be a problem in cities in arid climates. One study (McDonald and others 2011a) found that 21.7% of urban dwellers, some 523 million, live in climates that would at least be classified as semiarid (Figure 6). In the developed world these cities are clustered in the western United States, Australia, and parts of Spain. In the developing world

most of these cities are located in northwestern Mexico, coastal Peru and Chile, North Africa, the Sahara, Namibia, the Middle East, and central Asia (see Figure 6 for a map).

A more detailed paper modeled how population growth and climate change will affect water availability for all cities in developing countries with greater than 100,000 people (McDonald and others 2011b). These cities had 1.2 billion residents in 2000 (60% of the urban population of developing countries). Modeled output suggests that currently 150 million people live in cities with perennial water shortage, defined as having less than 100 liters/person/day of sustainable surface and groundwater flow within their urban extent. By 2050, demographic growth will increase this number to almost a billion people. Climate change will cause water shortage for an additional 100 million urbanites. Cities in certain regions will struggle to find enough water for the needs of their residents, and will need significant investment if they are to secure adequate water supplies and safeguard functioning freshwater ecosystems for future generations.

Water quality is most often a problem globally when there is significant human water use upstream. One useful proxy measure is the population density upstream, which correlates to several measures of water pollution. One study (McDonald and others 2011a) found that 890 million (36.9% of population of cities > 50000), are in cities with an upstream population density greater than 5.5 people/ha, the threshold at which nitrate concentrations may exceed the U.S. drinking water standard of 10 mg l⁻¹. Water quality issues affect all continents (Figure 7), but tend to be concentrated in major river basins like the Ganges (India) and the Yellow River (China).

Water delivery is most a problem in rapidly growing cities with few financial resources. One study (McDonald and others 2011a) found that 1.3 billion people (53.9% of all urban population) live in cities with more than 10 new residents per GDP per capita, mainly in sub-Saharan Africa, the Indian subcontinent, and Southeast Asia (Figure 8). In contrast, some cities in developed countries have less than 0.5 new people per GDP per capita, and thus have roughly 20 times more financial capacity to deliver water to new urban residents than might a developing world city.

Cities have two broad sets of strategies to cope with insufficient water: those that involve building infrastructure to obtain more water than is currently available, and those that involve

making wiser use of existing supplies, either by improving water-use efficiency or water quality. For the former strategy, the most common solution is tapping into groundwater to meet urban water needs. Groundwater use is sustainable if the rate of aquifer recharge exceeds the rates of withdrawals. However, for many arid cities, groundwater use exceeds the low rates of aquifer recharge. Mexico City has so overused its aquifer that the ground is subsiding 40 cm/year in some areas (Carrera-Hernandez and Gaskin 2007). Many other fast-growing cities face similar problems, but globally the extent of this groundwater mining by cities is unknown.

Regardless of whether cities are investing in infrastructure to increase water supply or trying to use existing supplies more wisely, it is clear that substantial financial resources will be required to address these management challenges in the future. One study estimated that from 2003 to 2025 necessary annual investments would exceed \$180 billion per year (World Panel on Financing Water Infrastructure 2003). While plenty of possible solutions to water quantity and quality problems exist, including some that are relatively less harmful to the environment, they all take money and time to implement. For the more than a billion people in cities facing water delivery challenges, both are in short supply.

2.5. Global urbanization and climate

The closing decades of the 20th century and early years of the present century were warmer than usual. The last 30 years have been the warmest on record and twelve of the 13 years in the period 1995 to 2007 rank among the 13 warmest in the instrumental record. This increasing warmth has brought changes in heatwaves, precipitation, storm intensity and sea levels. Global climate change, as these changes are together called, has occurred largely due to the human interference in the climate system (see for example, Houghton 2009). Urban areas are considered major contributors of greenhouse gases (GHGs) (Dhakal 2010). Estimates vary (Dodman 2009; Satterthwaite 2008), ranging from 40 to 72 percent of global anthropogenic GHG emissions (Satterthwaite, 2008; IEA 2008). Given the recognition of cities as important contributors to these trends, researchers have attempted to isolate the urban role in regional and global climate change (Bader and Bleischwitz 2009; Lebel and others 2007).

An important distinction in understanding GHG emissions from urban areas includes “direct” and “indirect” emissions. More often, local inventories include estimations of GHGs related to

activities of government, businesses and residents emitted from within the urban area, known as “direct” emissions. Measurements may also include emission from activities located outside the local jurisdiction but closely related to economic activities that are conducted within the jurisdiction, known variously as “indirect” emissions (US EPA 2011). For instance, power production and waste disposal may be conducted outside of cities, but relate to the energy and waste disposal needs of urban residents, businesses and governments. Traditional emissions inventories count only emissions that are produced within the study area, regardless of where the related good or service is ultimately consumed, thus placing the full responsibility for emissions reduction within the site of emission production. More recent work attempts to include a consumption component. Some urban emissions research has appropriated the term “scope” used for corporate emissions inventories (WRI 2002). The various scopes define the location of embodied energy-related emissions. Scope 1 emissions are those directly emitted from within an urban area. Scope 2 includes emissions that are related to urban activities, particularly energy consumption, but emitted outside urban areas (in thermal power plants). Scope 3 includes embodied energy within the goods and services consumed in the urban areas (e.g., food, water, cement, etc.).

Several attempts have been made to estimate GHGs and standardize emission protocols across a number of cities (Hillman and Ramaswami 2010; Hoornweg and others 2011; Kennedy and others 2009a; Kennedy and others 2009b; Sovacool and Brown 2010). More frequently, studies have examined individual cities to assess their GHG emissions. For instance, Bangkok, Sydney, and Tokyo have developed mitigation strategies based upon their estimated emissions levels (Bangkok Metropolitan Administration 2007; City of Sydney 2008; Tokyo Metropolitan Government 2007).

The contribution of GHG emissions from cities by sector varies across cities around the world. The variation in estimates for individual cities pertains to both the different methodologies used to calculate emissions as well as factors affecting emission production. Several studies have emphasized various features of cities and their impact on energy consumption and GHG emissions (Lebel and others 2007; Lefevre 2009; Li 2011; Permana and others 2008; Sadownik and Jaccard 2001):

- **Methodology-** There has been some studies that have examined GHG emissions across regions, although these studies use a different estimation method (Bader and Bleischwitz 2009). For example, with the use of gridded GHG emission data, urban boundaries and thermal power plant locations to estimate at the regional scale, urban contributions of GHGs. In these cases, analysts found that amongst sources energy production is the dominant source of GHG emissions, followed by industry, transportation, residential, waste and agriculture.
- **Population-** Population size is the most important contributing factor to overall urban emissions. For example, in the case of Asian cities, the larger cities have higher total energy consumption and therefore higher GHG emissions levels than smaller cities. The highest emitters in Asia are the largest cities (Figure 9).
- **Economic development-**Residents of cities with higher levels of per capita income consume more than those of lower income. The degree to which this is reflected in emission inventories is likely to be dependent on the scope of analysis (production versus consumption focus). Cross national urban comparisons suggest a positive relationship between wealth and GHG emissions (Kennedy and others 2011). At the household scale, energy consumption in India and China is also positively correlated with income (Pachauri 2004; Pachauri and Jiang 2008). The relationship between wealth and greenhouse gas emissions, however, may be more complex than a positive monotonic function. Analysts studying East Asia find that selected cities in lower income countries, Shanghai in China for example, have higher GHG emissions per capita than cities in high income countries, Tokyo in Japan for example (Dhakal and Imura 2004; Sugar and others 2012). Others identify an inverted-U shaped function that defines this relationship, meaning that emissions increase over a range and then decrease after reaching a threshold (Marcotullio and others 2011). The urban environmental transition literature posits there may be non-linearities in the income-environment relationship for community-scale outcomes, such as urban air pollution (McGranahan 2007), which are highly correlated with the urban-scale GHG releases we examine here.
- **Industrial activity-** The economic structure of cities is an important potential influence on GHG emissions. Those cities with high concentrations of industrial activities have higher GHG emission, all else equal. For example, in the case of Asia, the largest urban

GHG emitters per capita are not the largest cities, but rather of those cities with high levels of emissions and smaller populations (Figure 10). In each of these urban areas the population sizes are typically under 250,000 and some have populations under 100,000. Many of these urban areas are important manufacturing and energy production locations.

- **Transportation and urban density-** The pattern of urban GHG emissions per capita highlights the potential effect of density on energy efficiency. As mentioned above, there is a common understanding that the lowest density urban areas use more transportation related energy than the higher density cities (Newman and Kenworthy 1999; Weisz and Steinberger 2010) and studies have verified this relationship (Parshall and others 2010). Australian analysts, for example, have identified the differential dependence on the private automobile among cities of varying densities with the highly suburbanized urban areas having the highest dependence and therefore highest transportation energy consumption (Lenzen and others 2008).
- **Urban growth rate-** Urban growth rate can also influence GHG emissions. The relationship in Asia suggests that slower growing cities are higher GHG emitters than those growing faster. This could be due to the fact that the slower growing urban areas are the largest and hence the biggest emitters. At the same time, the smaller cities are the most rapidly growing or demonstrate the highest relative growth rates but low total emissions (Marcotullio and others 2012).
- **Climate zone-** Finally, biophysical characteristics, such as average temperature can impact the generation of GHG emission from urban areas. Those cities that are located in cooler climates that require heating homes have higher energy needs and therefore produce more GHG emissions (Kennedy and others 2009a).

2.6. Summary and conclusions

The broad global picture presented in this chapter suffices to show that global patterns of urbanization have had significant implications for biodiversity. In particular, urbanization is a driver of habitat conversion is already important and is expected to increase in importance in the future. Thus, urbanization is relevant to the Convention on Biological Diversity (CBD)'s Aichi Target 5 (*By 2020, the rate of loss of all natural habitats, including forests, is at least halved and*

where feasible brought close to zero, and degradation and fragmentation is significantly reduced).

Habitat conversion driven by urbanization will be particularly important in tropical areas in the future and in coastal and island systems, as well as biomes that are disproportionately urbanized (e.g., Mediterranean habitat). CBD's Aichi Target 11 (*By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes*) is unlikely to be met without addressing urbanization impacts in these places.

Similarly, the global analysis presented in this chapter shows that global urban growth will have significant implications for freshwater ecosystem services. Global urbanization will indirectly increase cities dependence on freshwater ecosystem services that control water quantity, quality, and timing. This has relevance to Millennium Development Goal's 7.B (*Reduce biodiversity loss, achieving, by 2010, a significant reduction in the rate of loss*) and 7.C (*Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation*). The remaining chapters will examine in more detail how cities depend on ecosystem services.

Urbanization has also impacted climate. Cities, particularly large ones, are major contributors of GHG emissions, and their rate of emissions has direct relevance to the goals of the Kyoto Protocol and other accords of the UN Framework Convention on Climate Change (UNFCCC).

Finally, we suggest that urbanization should not be looked at solely as a problem or as a solution. It is dangerous for policymakers to consider urbanization solely as a problem, since it is an unavoidable part of economic development. A more useful way to think about global urbanization is as posing a series of social environmental challenges that must be overcome to achieve sustainability.

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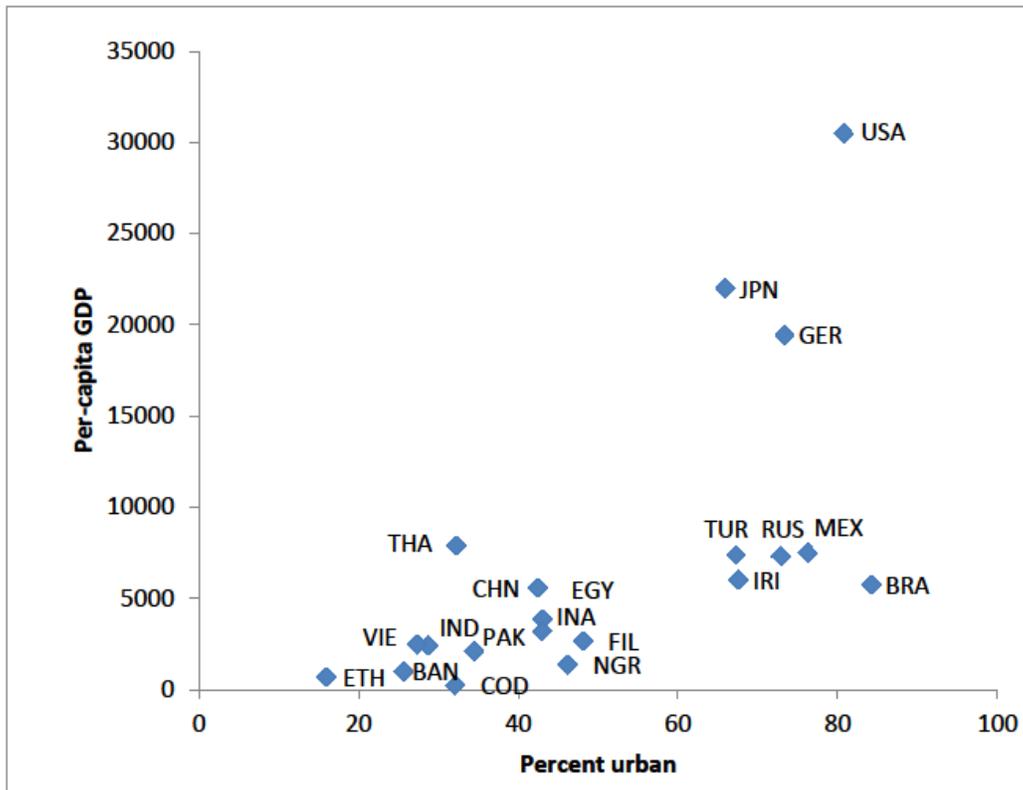


Figure 1. Correlation between percent urban and per-capita GDP for the 20 countries with the greatest population in 2005. Per-capita GDP is taken from Maddison(2001), and is shown in 1990 International Geary-Khamis dollars, a method of correction for different purchasing powers over time and space. Percent urban is taken from the World Urbanization Prospects database (UNPD 2009). Countries are abbreviated as: BAN (Bangladesh), BRA (Brazil), CHN (China), COD (Congo Kinshasa), EGY (Egypt), ETH (Ethiopia), FIL (Philippines), GER (Germany), INA (Indonesia), IND (India), IRI (Iran), JPN (Japan), MEX (Mexico), NGR (Nigeria), PAK (Pakistan), RUS (Russian Federation), THA (Thailand), TUR (Turkey), USA (United States), VIE (Vietnam).

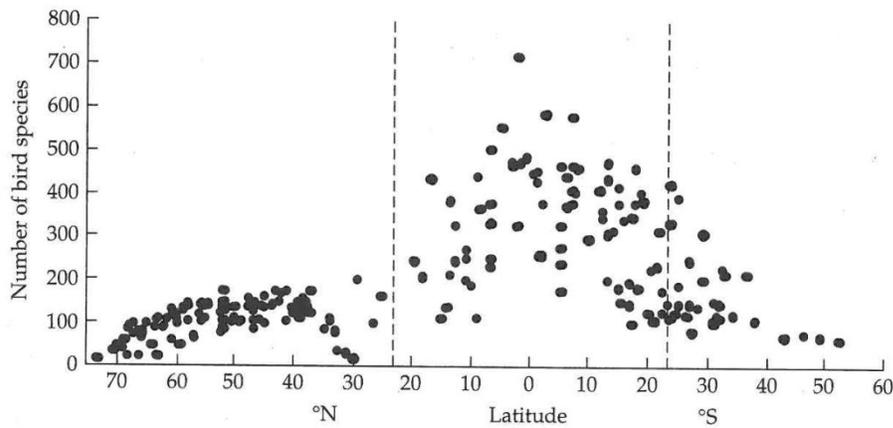


Figure 2. Relationships between avian species diversity and latitude. Each dot is the species richness of terrestrial birds in one of 206 grid cells, each 46,400 km² in size, randomly selected from a larger data set for the birds of North America, northern Central America, South America, Europe, Africa, the republics of the former USSR, and Australia. The tropics are delimited by the dashed vertical lines (Turner and Hawkins 2004).

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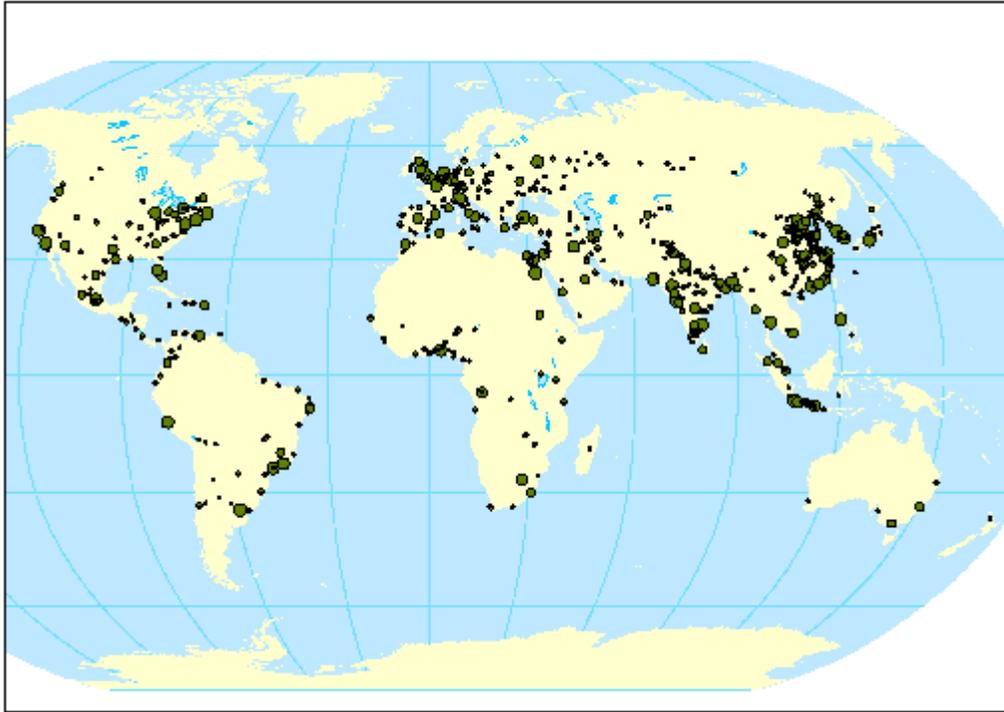


Figure 3. Distribution of urban areas according to the Global Rural/Urban Population (GRUMP) of the World database (CIESIN and others 2004).

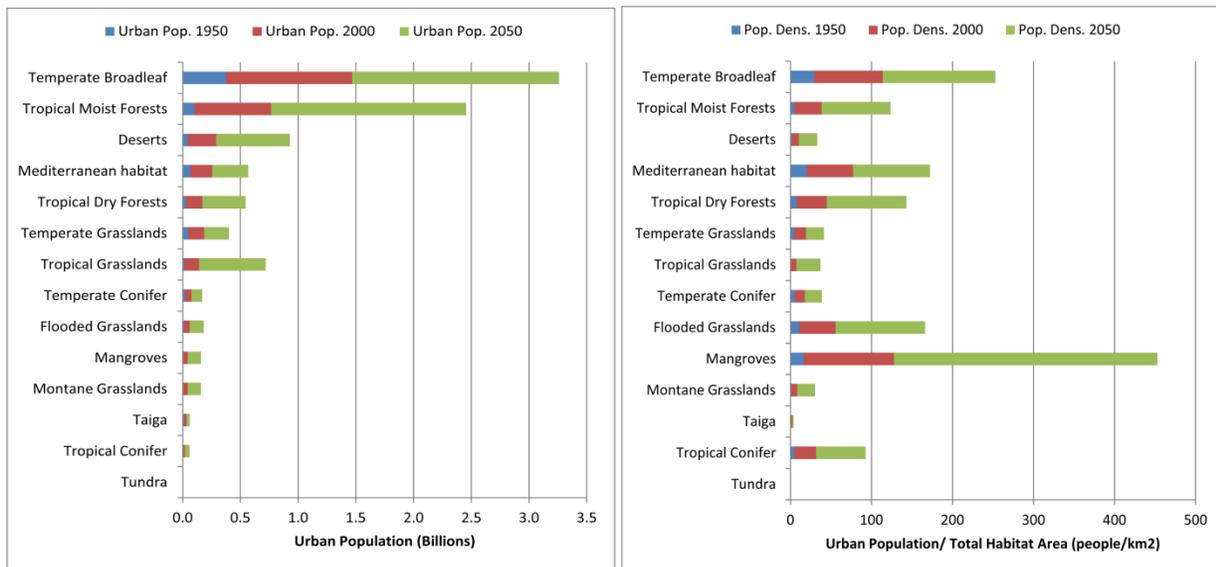


Figure 4. Urban population by major habitat type (left panel) and urban population per total habitat area by major habitat type (right panel). Major habitat types and boundaries are taken from the World Wildlife Fund ecoregional dataset. Urban population information for 2000 taken from the Global Urban/Rural Mapping Program. Urban population information for 1950 and 2050 were interpolated from the GRUMP data based on rates of urban population growth taken from the United Nations Population Division (UNPD 2011).

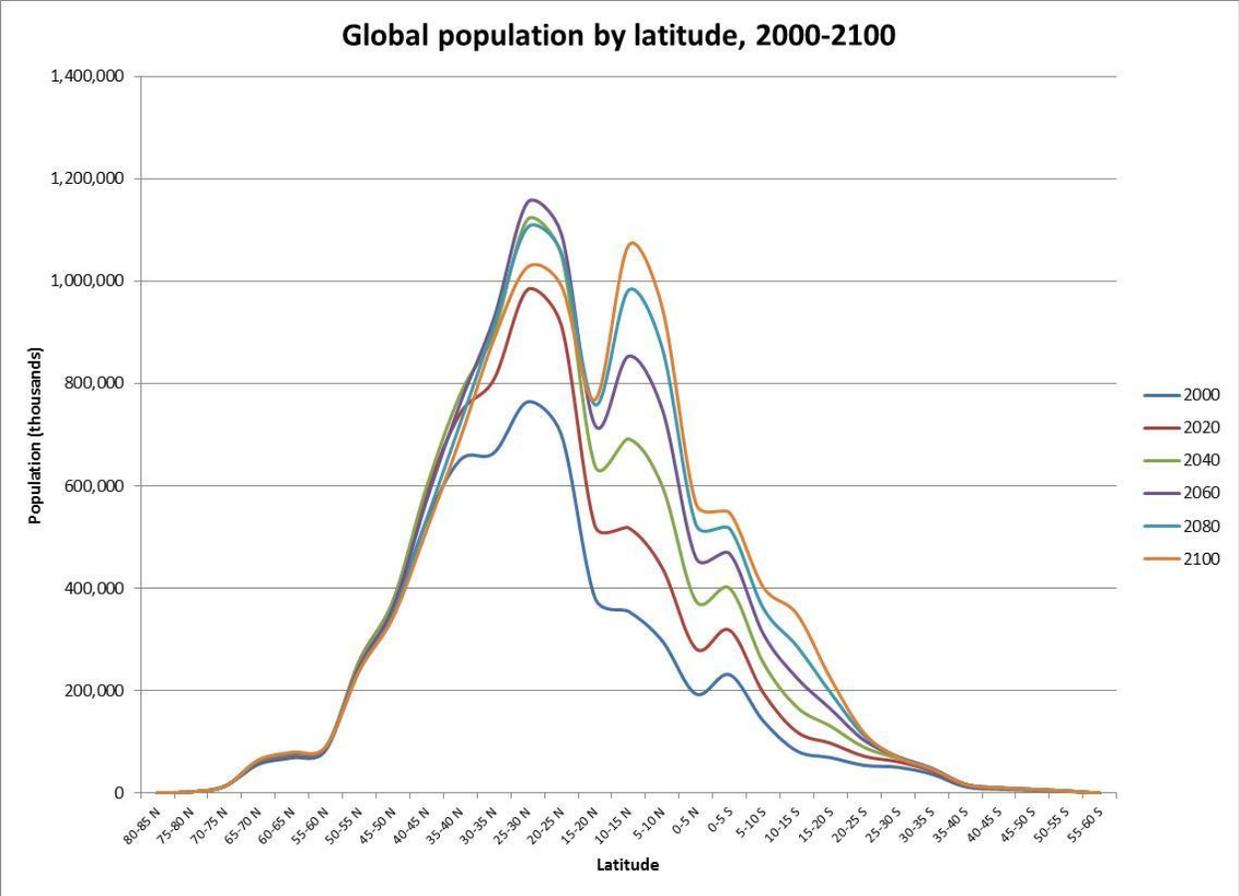


Figure 5. Estimates of growth of global population by latitude, 2000-2100 (United Nations Department of Economic and Social Affairs, Population Division, 2010).

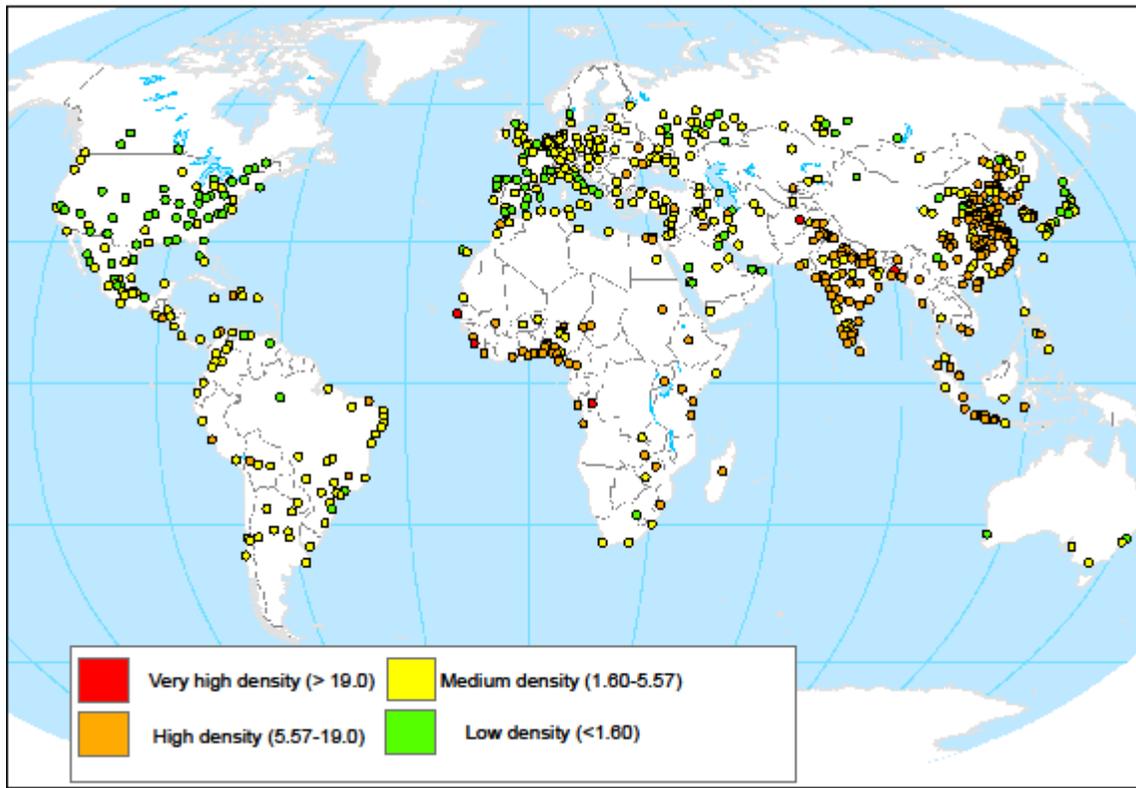


Figure 6. Water availability for the world's cities. Water availability is measured by the aridity index, which is precipitation/potential evapotranspiration. Adapted from McDonald et al. (2011b).

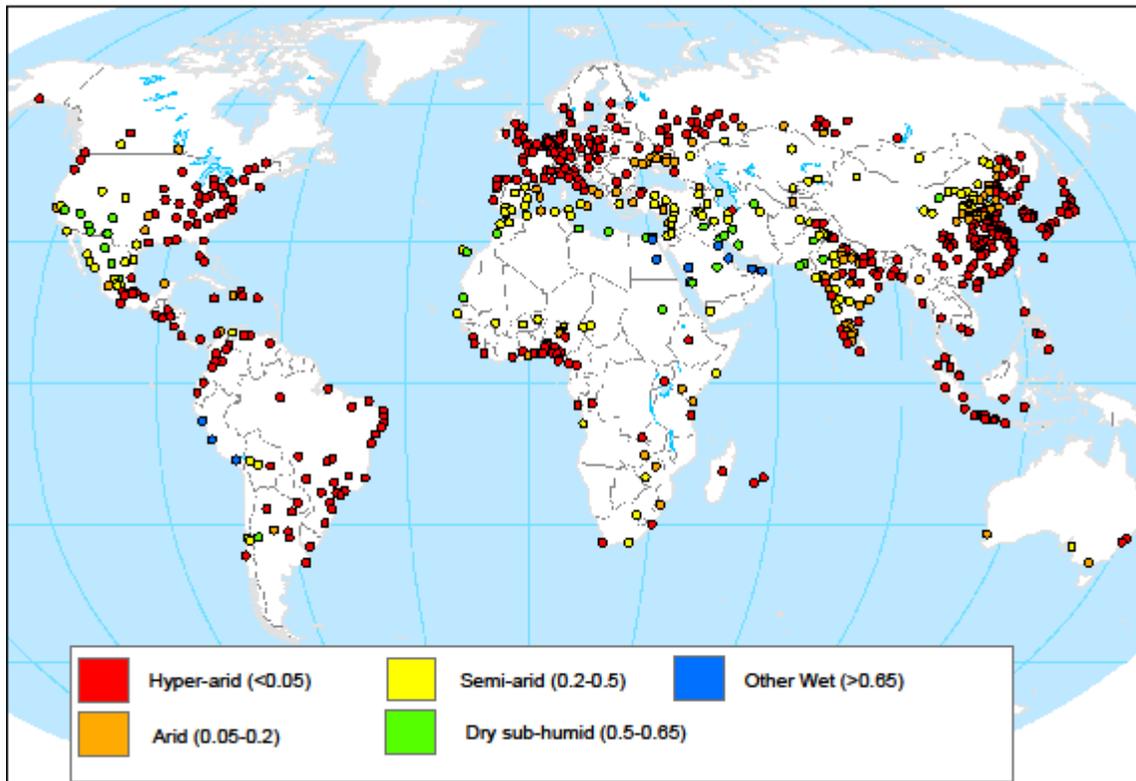


Figure 7. Water quality for the world's cities. Water quality is measured as the density of people in upstream contributing areas (people/km²). Adapted from McDonald et al. (2011b).

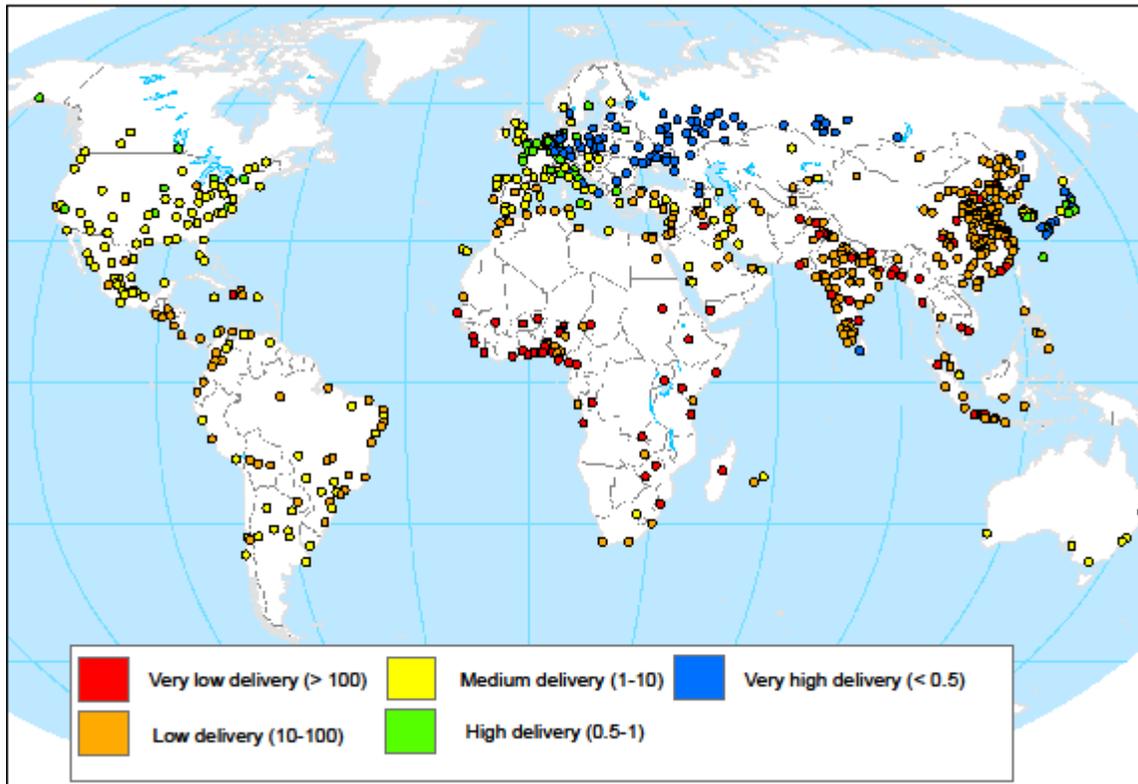


Figure 8. Water delivery for the world's cities. The ability of a city to delivery water to its citizens is measured as the number of people expected divided by per-capita GDP. Adapted from McDonald et al. (2011b).

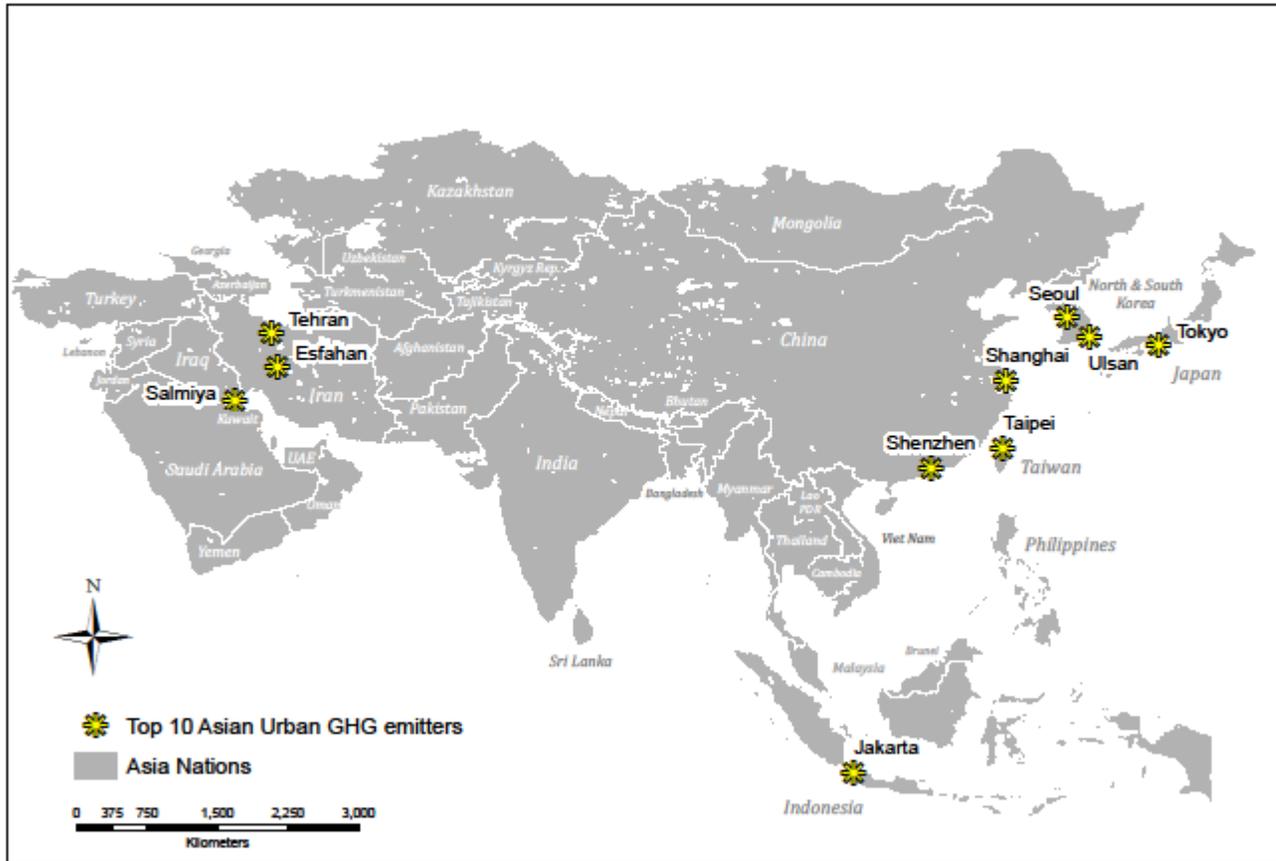


Figure 9. The top 10 largest Asian urban GHG emitters, 2000 (Marcotullio and others 2012).

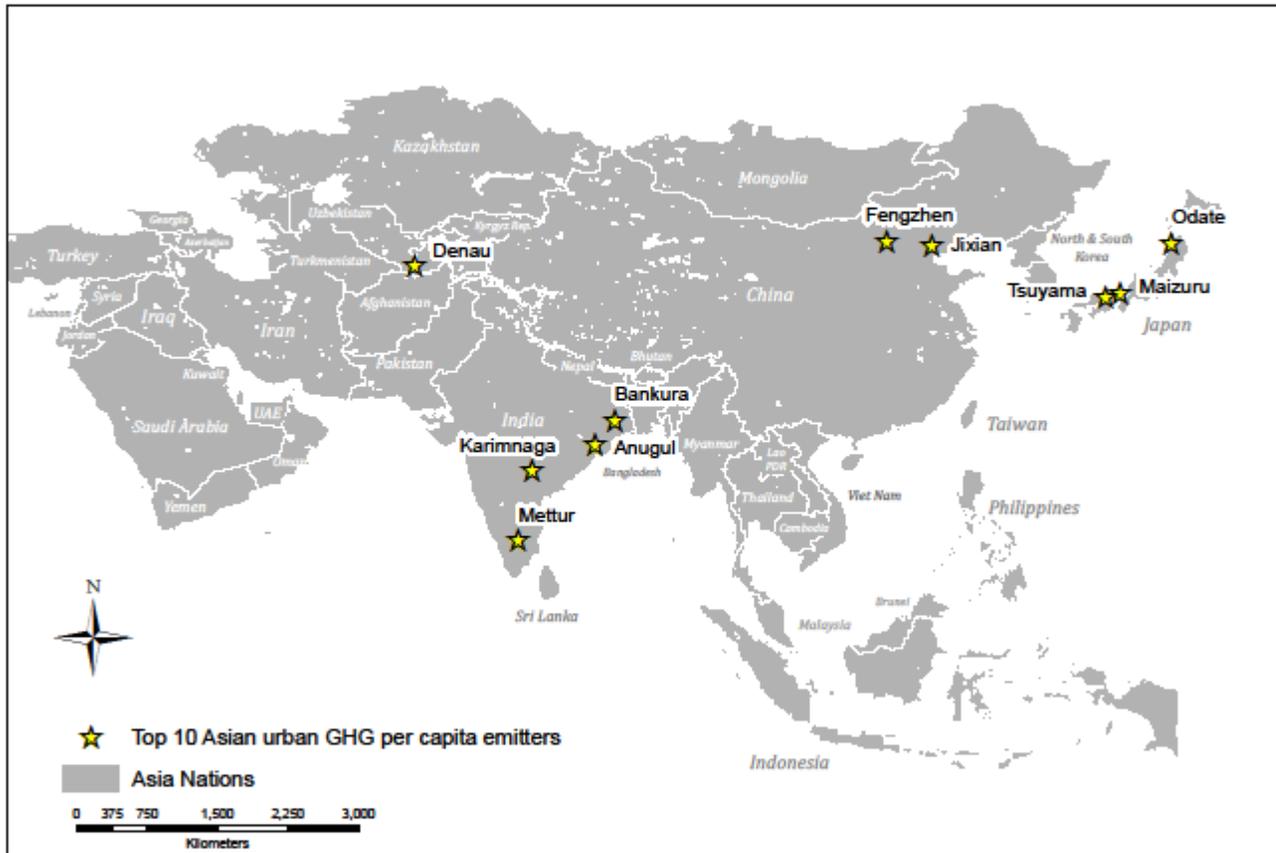


Figure 10. The top 10 largest Asian urban GHG per capita emitters, 2000 (Marcotullio and others 2012).