5

Mapping Urban Settlements and the Risks of Climate Change in Africa, Asia and South America

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Introduction

United Nations forecasts of urban population growth suggest that over the quarter-century from 2000 to 2025, low- and middle-income countries will see a net increase of some 1.6 billion people in their cities and towns, a quantity that vastly outnumbers the expected rural population increase in these countries and which dwarfs all anticipated growth in high-income countries (United Nations, 2008). In the 25 years after 2025, the United Nations foresees the addition of another 1.7 billion urban-dwellers to the populations of low- and middle-income countries, with the rural populations of these countries forecast to be on the decline. Where, precisely, will this massive urban growth take place? Is it likely to be located in the regions of poor countries that appear to be environmentally secure or in regions likely to feel the brunt of climate-related change in the coming decades?

This chapter documents the current locations of urban-dwellers in Africa, Asia and South America in relation to two of the ecologically delineated zones that are expected to experience the full force of climate change: the low-elevation coastal zones and the arid regions known to ecologists as drylands. Low-lying cities and towns near the coast will most probably face increased risks from storm surges and flooding; those in drylands are expected to experience increased water stress and episodes of extreme heat. Climate-related hazards will present multiple threats to human health, as described in more detail in Chapter 10. The risks are likely to be especially severe in the cities and towns where private and public incomes are low and protective infrastructure is lacking.

To assess the risks that global climate change presents for urban-dwellers in poor countries, it is obviously of vital importance to know enough about the locations of people who will be exposed to these hazards and for the most vulnerable among them to be identified and given priority. Planning for improvements in urban drainage, sanitation and water supply requires both spatial and population data, as do forecasts of where urban fertility and migration will augment the populations of towns and cities in the path of risk. National economic strategists need to be made aware of the implications of locating special economic zones and promoting coastal development in what will become environmentally risky sites. Until recently, however, the data needed to create a global map of the populations exposed to climate-related risks had not been drawn together.

The essential ingredients for such a map have been assembled over the course of a large-scale collaborative effort involving the United Nations Population Division, the Global Rural-Urban Mapping Project (GRUMP), housed at the Socio-economic Data Applications Center at Columbia University's Earth Institute, and researchers based at the City University of New York and the Population Council. For every low- and middle-income country, population data can now be mapped according to the most finely-disaggregated administrative units that the research team could obtain. For cities with a population of 100,000 and above, information on population growth over time has been drawn from the most recent version of the United Nations Population Division's cities database (United Nations, 2008). The reach of the data has been extended to include hundreds of additional observations on small cities and towns (accounting for a significant percentage of all urban residents), which were collected in the 2008–2009 update of GRUMP (SEDAC, 2008; Balk, 2009). Each urban settlement in the combined data set is located in spatial terms by latitude and longitude coordinates, and also by an overlay indicating the spatial extent of the urban agglomeration, which is derived from remotely-sensed satellite imagery (Elvidge et al., 1997; Balk et al., 2005; Small et al., 2005). With their locations having been pinpointed, it becomes possible to determine whether all or part of city and town populations are situated in the low-elevation and drylands ecozones. To assess the likely pace of urban growth in these zones, the United Nations' city time-series are used, supplemented by a large collection of demographic surveys covering the period from the mid-1970s to the present. The latter supply additional information on urban fertility and mortality rates.[2]

In an earlier analysis, McGranahan et al. (2007) showed how data such as these could be combined to estimate the number of rural- and urban-dwellers worldwide who live in coastal areas within 10 metres of sea level—the low-elevation coastal zone (LECZ)—an elevation that is above the currently predicted rise in sea levels but which often lies within the reach of cyclones, storm surges and other indirect impacts of sea level rise. With the benefit of several additional years of data collection, it is now possible to refine the coastal zone analysis and extend it to cover urban residents of the drylands ecosystems, whose total population substantially exceeds that of coastal zones.

The remainder of this chapter is organized as follows: In the first section the health implications of climate-related hazards in low-lying coastal areas and drylands are reviewed. In the second, the GRUMP data are employed to calculate the numbers of urban-dwellers who currently live in areas where these hazards are likely to be pronounced. For selected countries, data from the World Bank's Small-Area Poverty Mapping project are used to identify where the communities of the urban poor are located in relation to the LECZ. Next, to indicate how urban exposure and vulnerability are likely to be reshaped by future population growth, estimates and forecasts of city population growth rates are presented by ecozone for the major regions of the developing world, in this case using the city time-series provided by the United Nations. The chapter concludes with a discussion of how such information could advance the efforts of cities and towns to adapt to climate change.

Urban Risks in Low-elevation Coastal Zones and Drylands

Because seaward hazards are forecast to increase in number and intensity as climate change takes hold, and coastal areas are disproportionately urban, it is especially important to quantify the exposure of urban residents in low-elevation coastal zones, and to understand the likely implications for their health. The other vulnerable ecosystem—drylands—contains (globally) far larger populations than found in the LECZs. Much of the discussion of climate change for drylands has focused on the rural implications—but what will it mean to be an urban resident of the drylands?

The low-elevation coastal zone

According to current forecasts, sea levels will gradually but inexorably rise over the coming decades, placing large coastal urban populations under threat around the globe. Alley et al. (2007) foresee increases of 0.2 to 0.6 metres in sea level by 2100, a development that will be accompanied by more intense typhoons and hurricanes, storm surges and periods of exceptionally high precipitation. Many of Asia's largest cities are located in coastal areas that have long been cyclone-prone. Mumbai saw massive floods in 2005, as did Karachi in 2007 (Kovats and Akhtar, 2008; The World Bank, 2008). Storm surges and flooding also present a threat in coastal African cities (e.g., Port Harcourt, Nigeria, and Mombasa, Kenya[3]) and in Latin America (e.g., Caracas, Venezuela, and Florianópolis, Brazil[4]). As explained in Chapter 10, a coastal flood model used with the climate scenarios developed for the Intergovernmental Panel on Climate Change (IPCC) suggests that the populations of the areas at risk, and the income levels of these populations, are critical factors in determining the health consequences of such extreme-weather events.

Urban flooding risks in developing countries stem from a number of factors: impermeable surfaces that prevent water from being absorbed and cause rapid run-off; the general scarcity of parks and other green spaces to absorb such flows; rudimentary drainage systems that are often clogged by waste and which, in any case, are quickly overloaded with water; and the ill-advised development of marshlands and other natural buffers. When flooding occurs, faecal matter and other hazardous materials contaminate flood waters and spill into open wells, elevating the risks of water-borne, respiratory and skin diseases (Ahern et al., 2005; Kovats and Akhtar, 2008). The urban poor are often more exposed than others to these environmental hazards, because the only housing they can afford tends to be located in environmentally riskier areas, the housing itself affords less protection and their mobility is more constrained. The poor are likely to experience further indirect damage as a result of the loss of their homes, population displacement and the disruption of livelihoods and networks of social support (Hardoy and Pandiella, 2009).[5]

Kovats and Akhtar (2008, p. 169) detail some of the flood-related health risks: increases in cholera, cryptosporidiosis, typhoid fever and diarrhoeal diseases. They describe increases in cases of leptospirosis after the Mumbai floods of 2000, 2001 and 2005, but caution that the excess risks of this disease due to flooding are hard to quantify without better baseline data. They also note the problem of water contaminated by chemicals, heavy metals and other hazardous substances, especially for those who live near industrial areas.

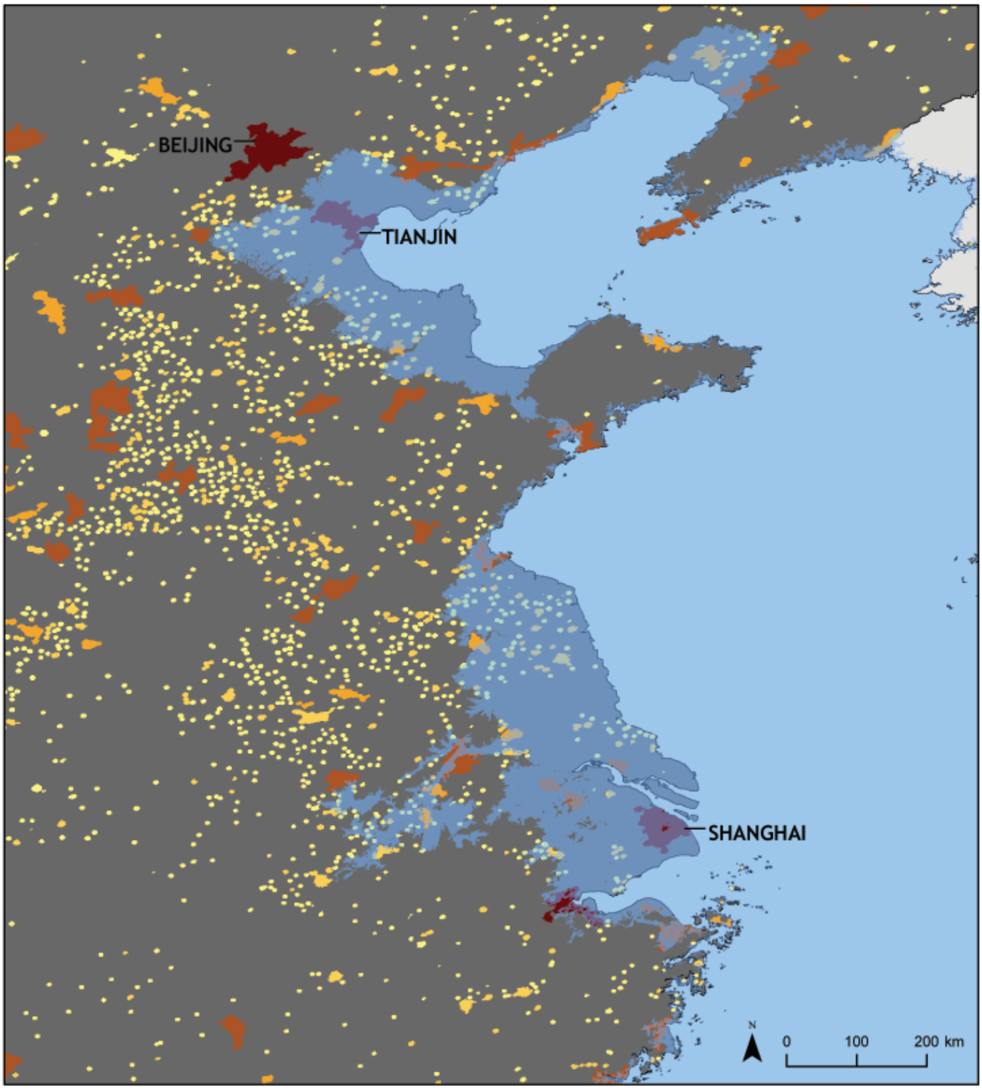
Figures 5.1–5.3 map the location of cities and large towns in relation to the low-elevation zone for several important metropolitan regions. Figure 5.1 presents a broad-scale overview of the the low-elevation zone of China near Beijing, Tianjin and Shanghai. This is a region in which China's extraordinarily successful growth strategy has perhaps overly concentrated population and production, without (it seems) due consideration of the upcoming environmental risks. Figure 5.2 shows how the low-elevation zone bisects Ho Chi Minh City in southern Viet Nam, and Figure 5.3 depicts the cities and towns in the low-lying coastal regions of Bangladesh.

Drylands

The principal characteristics of drylands are succinctly summarized by Safriel et al. (2005, p. 651) as follows: "Drylands are characterized by low, unpredictable, and erratic precipitation. The expected annual rainfall typically occurs in a limited number of intensive, highly erosive storms." Figure 5.4 depicts drylands ecosystems around the world. Safriel et al. (2005, p. 626) estimate that this ecosystem covers 41 per cent of the Earth's surface and provides a home to some 2 billion people. Developing countries account for about 72 per cent of the land area and some 87-93 per cent of the population of the drylands (the range depends on how the former Soviet republics are classified). McGrahanan et al. (2005) estimate that about 45 per cent of the population of this ecozone is urban.

Water shortages are already apparent in drylands ecosystems. There is an estimated 1,300 cubic metres of water available per person per year, well below the 2,000 cubic metre threshold considered sufficient for human well-being and sustainable development (Safriel et al., 2005, pp. 625, 632). Even for regions such as East Africa where climate scientists foresee increases in precipitation (Table 5.1), the rise in temperature is expected to cancel out the effects of greater rainfall, and, as a result, in some regions the frequency of rainy season failure will increase (Commission on Climate Change and Development, 2008). In the dryland areas where rivers are currently fed by glacier melt, the flows from this source will eventually decrease as the glaciers shrink, rendering flows in some rivers seasonal (Kovats and Akhtar, 2008). Cities dependent on these sources of water—such as in the Andes

Figure 5.1: Combined UN and GRUMP Urban Data for Beijing, Tianjin, Shanghai and Their Environs, China

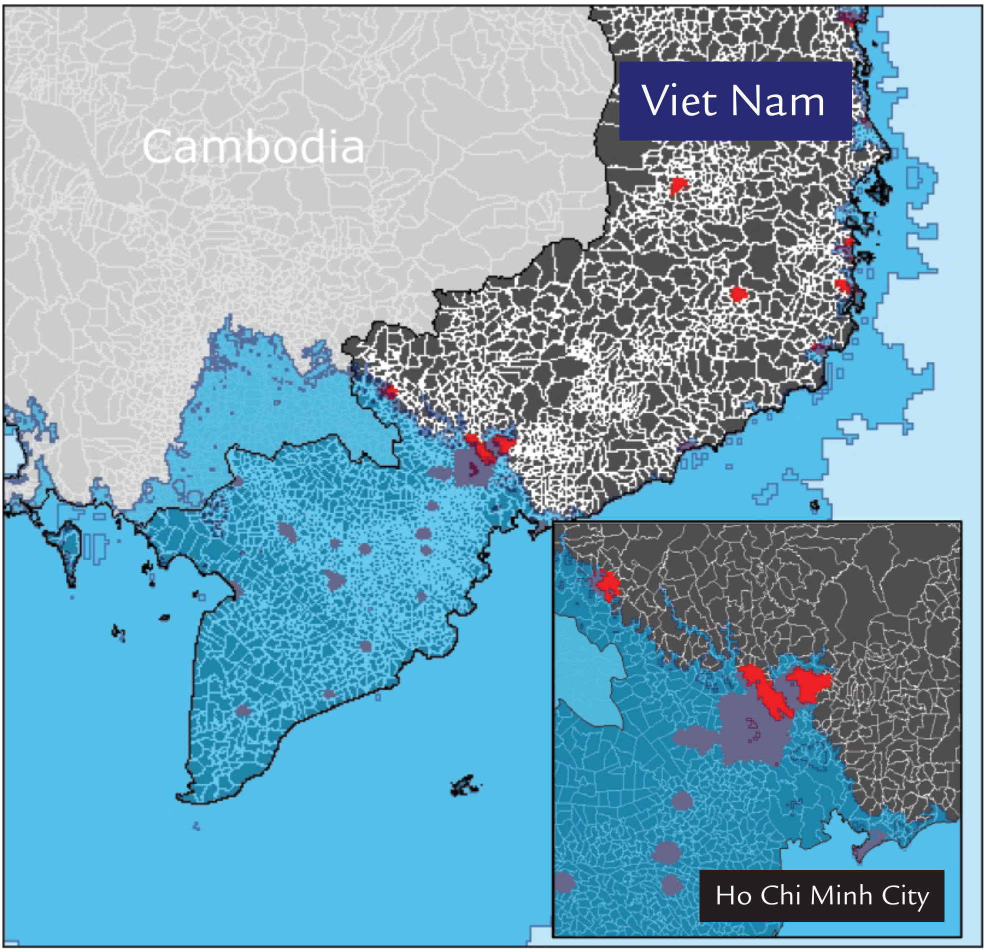


Note: Low-elevation coastal zone depicted in medium blue shading. Urban areas shown as points of light or patches of yellow or brown.
Source: McGranahan et al., 2007.

and in the areas fed by the Ganges and Brahmaputra Rivers—will eventually need to find alternatives.

Although many discussions of water stress leave the impression that increasing stress in drylands ecosystems already explains why so many of the urban poor find it difficult to secure access to water, the mechanisms by which this is posited to occur need scrutiny. McGranahan (2002) finds surprisingly little empirical evidence indicating that national water scarcity directly translates into a lack of access for the urban poor. Cross-national statistics, for instance, fail to confirm this common view: On the contrary, in a regression analysis of access to water for urban

Figure 5.2: Combined UN and GRUMP Urban Data for Southern Viet Nam

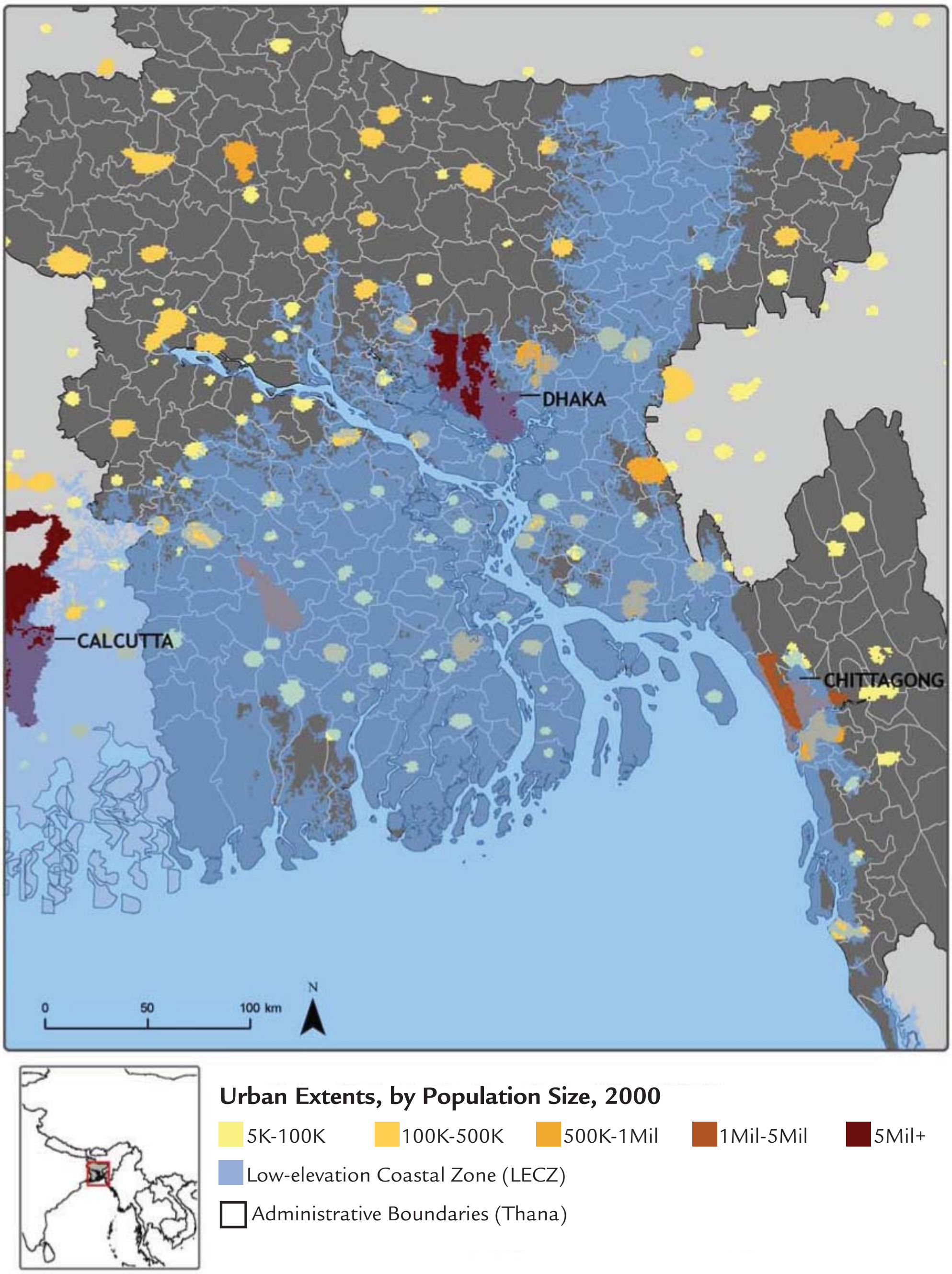


Note: Inset shows the low-elevation coastal zone intersecting Ho Chi Minh city. Low elevation coastal zone depicted in blue. Urban areas shown as points or patches of light shading. Detailed administrative boundaries indicated in light shading.
Data source: CIESIN, 2008.

(and rural) populations as a whole, with national income per capita included as an explanatory factor along with the per capita renewable freshwater resources available nationally, per capita income exhibited a strong positive association with access whereas the quantity of water resources available per capita displayed a weak and unexpectedly negative association. Evidence from more detailed, within-city case studies is also mixed. Summarizing, McGranahan (2002, p. 4) writes, "There is considerable case-specific evidence of cities with plentiful water resources where poor households do not have adequate access to affordable water, and cities with scarce water resources where poor households are comparatively well served."

Similarly, if in the future dryland cities increasingly turn to water conservation and demand management measures, it is far from obvious that this will automatically bring benefits to the urban poor. As McGranahan (2002, p. 4) cautions:

Figure 5.3: Combined UN and GRUMP Urban Data for Bangladesh



Note: *LECZ layer has been made semi-transparent to show the underlaying layers. Thus, the blue color is not uniform.*

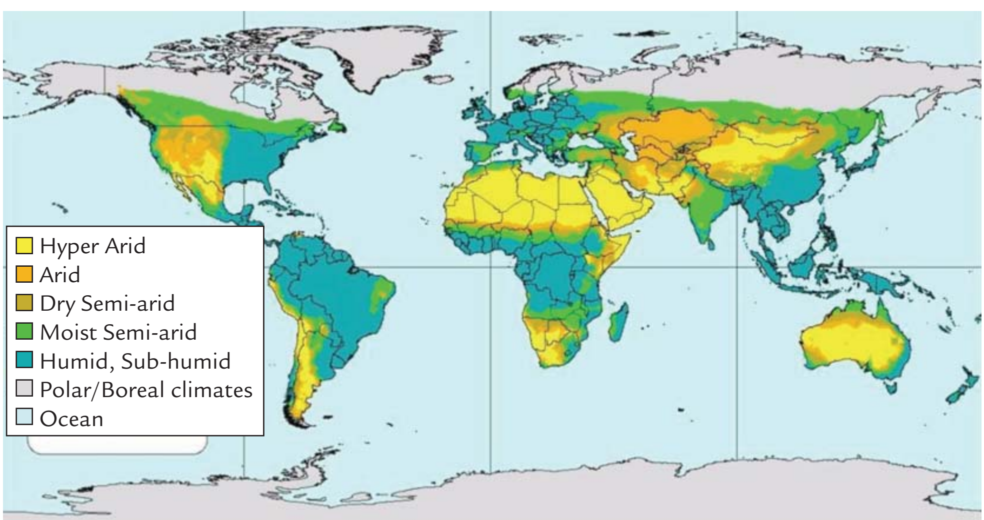
Note: Low-elevation coastal zone shown in medium blue shading. Urban areas shown as points or patches of light shading.
Data source: CIESIN, 2008.

It is often assumed that water saved in one part of an urban water system will be transferred to meet the basic needs of deprived residents in another part of the city (or town). . . . [But] first, even if demand management reduces supply problems within the piped water system, the households with the most serious water problems are typically unconnected, and getting them adequate water is likely to require infrastructural improvements. Second, the reason they are unconnected is likely to be because their needs are not economically or politically influential, and freeing up water within the piped water system is unlikely to change this. Third, if conservation is being promoted in response to water supply problems, then there are likely to be competing demands for the saved water, and quite possibly a need to reduce water withdrawals. In short, it is extremely unrealistic to assume that water saving measures will yield water for the currently deprived, unless this is made an explicit and effective part of a broader water strategy.

Thus, for example, if the governmental response to increasing water scarcity was to invest in a carefully regulated piped water system that reached all urban-dwellers, the most vulnerable residents could actually benefit. Alternatively, if the response involved placing greater restrictions on access to the existing piped water system, the most vulnerable residents would almost certainly suffer the most. However straight-forward the linkages between national water stress and the access of the urban poor may at first appear to be, there are multiple intervening social, political, economic and technical factors that complicate the situation and make it difficult to anticipate the consequences for the poor.

Water stress in drylands ecosystems has important implications that reach beyond access to drinking water. Especially in sub-Saharan Africa, a number of cities have become dependent on hydropower for much of their electricity (Showers,

Figure 5.4: The World's Drylands



Source: Commission on Climate Change and Development, 2008.

Table 5.1: Forecasts of Climate Change in Drylands Ecosystems

Region	Median projected temperature increase (°C)	Median projected precipitation increase (%)	Projected frequency of extreme warm years (%)	Projected frequency of extreme wet years (%)	Projected frequency of extreme dry years (%)
West Africa	3.3	+2	100	22	
East Africa	3.2	+7	100	30	1
Southern Sahara	3.4	-4	100	4	13
Southern Europe	3.6	-6	100		
Mediterranean	3.5	-12	100	46	
Central Asia	3.7	-3	100	12	
Southern Asia	3.3	+11	100	39	3

Source: Adapted from Commission on Climate Change and Development, 2008. See original for further notes and discussion of agreement among climate models.

2002; Muller, 2007). As Showers (2002, p. 639) described it, hydroelectric power is "a major source of electricity for 26 countries from the Sahel to southern Africa, and a secondary source for a further 13. . . . Hydroelectric dams are, however, vulnerable to drought when river flows are reduced. Cities and towns in countries from a wide range of climates were affected by drought induced power shortages in the 1980s and 1990s." Furthermore, "[i]n several nations urban areas receive electricity from hydropower dams beyond their national boundaries. . . . National drought emergencies, therefore, can have regional urban repercussions. Lomé and Cotonou suffered when interior Ghana's drought reduced power generation at the Akosombo Dam" (Showers 2002, p. 643).

Safriel et al. (2005) discuss other likely impacts of climate change in drylands ecosystems, including reductions in water quality and a higher frequency of dry spells that may drive farmers to make greater use of irrigation: "Since sea level rise induced by global warming will affect coastal drylands through salt-water intrusion into coastal groundwater, the reduced water quality in already overpumped aquifers will further impair primary production of irrigated croplands" (p. 650). The productivity consequences may have the effect of increasing the costs of production in agriculture, which may, in turn, cause prices to rise, reduce employment and earnings and possibly encourage both circular and longer-term migration to urban areas (Muller, 2007; Adamo and de Sherbinin, 2008).

New Data: Mapping Populations at Risk

Focusing on drylands and the low-elevation coastal zone, Table 5.2 shows the distribution of urban population by city-size ranges in Asia, and Table 5.3 expresses these data by showing the percentage of all Asian urban-dwellers in a given city-size range who live in these zones.[6] Tables 5.4 and 5.5 present the figures for Africa and South America. These tables show that drylands are home to about half of Africa's urban residents irrespective of city size and, in the important case of India, even greater percentages—ranging from 54 to 67 per cent. In South America and China, however, much lower percentages of all

Table 5.2: Distribution of the Asian Urban Population and Land Area in the LECZ and Drylands, by Population Size Ranges

City Population	Number of Cities	All Ecozones Population	All Ecozones Area	Drylands Population	Drylands Area	LECZ Population	LECZ Area
All Asia							
Under 100,000	10,582	341,000	446,295	142,000	219,204	27,200	28,753
100,000–500,000	1,470	301,000	279,866	122,000	141,552	37,000	26,061
500,000–1 million	180	124,000	94,797	48,500	46,348	15,700	8,689
1 million+	200	722,000	327,318	229,000	128,032	174,000	59,873
India							
Under 100,000	2,845	77,100	113,396	51,700	76,986	2,839	3,733
100,000–500,000	300	59,300	53,033	38,300	33,703	4,473	2,898
500,000–1 million	33	22,200	13,785	13,100	7,005	896	699
1 million+	37	126,000	41,800	68,500	24,355	29,400	4,321
China							
Under 100,000	5,711	198,000	167,796	58,000	54,829	15,700	11,040
100,000–500,000	690	141,000	81,895	40,300	30,713	15,300	6,803
500,000–1 million	81	56,400	29,438	13,100	9,502	8,406	3,164
1 million+	76	221,000	80,575	60,000	26,700	58,700	19,198
Asia Other Than India and China							
Under 100,000	2,026	65,900	165,102	32,300	87,389	8,661	13,980
100,000–500,000	480	100,700	144,938	43,400	77,137	17,227	16,361
500,000–1 million	66	45,400	51,574	22,300	29,841	6,398	4,827
1 million+	87	375,000	204,943	100,500	76,977	85,900	36,354

Note: Based on size and area in 2000, estimated using GRUMP methods.

urban-dwellers-live in drylands. For all of the regions considered here, significant numbers and percentages of urban residents live in the LECZ, although the figures are lower than for the drylands. Among all urbanites residing in cities of 1 million or more, the percentages in the LECZ range from 9.7 per cent in South America to 26.6 per cent in China.

Urban population density

The density of the urban population, especially in coastal areas, has important implications for the costs of climate-change adaptation, as well as for mitigation strategies to reduce emissions. Denser cities may (depending on many factors, including the quality of urban governance and management) economize on the use of scarce resources, including those of ecozones both within and near the city, and may produce fewer climate-damaging emissions. To a degree, density lowers the per-resident cost of providing water supply, drainage, sanitation and other infrastructure essential to urban adaptation. However, denser cities also present governments with health and management challenges, especially in large cities that lack adequate infrastructure (Dodman, 2008).

For a subset of data in which geographic units can be finely disaggregated (in terms of the number and geographic size of the city's administrative units)

Table 5.3: Percentages of the Asian Urban Population and Land Area in the LECZ and Drylands, by Population Size Ranges

City Population	Drylands Population	Drylands Area	LECZ Population	LECZ Area
All Asia				
Under 100,000	41.6	49.1	8.0	6.4
100,000–500,000	40.6	50.6	12.3	9.3
500,000–1 million	39.2	48.9	12.7	9.2
1 million+	31.7	39.1	24.1	18.3
India				
Under 100,000	67.1	67.9	3.7	3.3
100,000–500,000	64.5	63.6	7.5	5.5
500,000–1 million	59.1	50.8	4.0	5.1
1 million+	54.2	58.3	23.2	10.3
China				
Under 100,000	29.3	32.7	8.0	6.6
100,000–500,000	28.5	37.5	10.8	8.3
500,000–1 million	23.2	32.3	14.9	10.7
1 million+	27.2	33.1	26.6	23.8
Asia Other Than India and China				
Under 100,000	49.0	52.9	13.1	8.5
100,000–500,000	43.1	53.2	17.1	11.3
500,000–1 million	49.1	57.9	14.1	9.4
1 million+	26.8	37.6	22.9	17.7

Note: Based on size and area in 2000, estimated using GRUMP methods.

densities in the LECZ and the non-LECZ portions of the city can be compared. The GRUMP-based estimates indicate that population density is markedly higher in LECZ cities (Table 5.6). In Africa and Asia, LECZ cities, and the portions of such cities actually in the LECZ, exhibit substantially higher population densities. In South America, cities located (wholly or in part) in the LECZ are more densely populated than other cities, but, for cities that are only partly in the low-elevation zone, there is not much within-city difference in density evident between the LECZ and non-LECZ areas. The average density of these cities exceeds that of dryland cities and cities in other zones. Is the greater density of the LECZ due mainly to the presence of large cities in this zone? The bottom panel of Table 5.6 suggests otherwise. For cities both above and below 1 million persons, urban population density is greatest in the LECZ. Indeed, for cities having land outside the low-elevation zone, population densities in the non-LECZ areas are generally lower than densities in the zone.

Poverty: Looking Closer at Vulnerability

There is every reason to think that the urban poor are, and will continue to be, more vulnerable to climate change than other urban residents. The data needed to quantify such poverty-related vulnerabilities, however, are not yet available in

Table 5.4: Distribution and Percentages of the African Urban Population and Land Area in the LECZ and Drylands, by Population Size Ranges

City Population	Number of Cities	All Ecozones Population	All Ecozones Area	Drylands Population	Drylands Area	LECZ Population	LECZ Area
Under 100,000	3,247	61,800	123,359	29,800	67,017	3,820	5,042
100,000–500,000	301	61,400	58,417	27,800	28,854	6,870	4,695
500,000–1 million	32	22,100	13,050	10,700	7,107	3,531	1,788
1 million+	42	130,000	56,985	61,700	28,686	17,300	4,787

Percentage of Population and Land Area

City Population	Drylands Population	Drylands Area	LECZ Population	LECZ Area
Under 100,000	48.3	54.3	6.2	4.1
100,000–500,000	45.3	49.4	11.2	8.0
500,000–1 million	48.4	54.5	16.0	13.7
1 million+	47.5	50.3	13.3	8.4

Note: Based on size and area in 2000, estimated using GRUMP methods.

Table 5.5: Distribution and Percentages of the South American Urban Population and Land Area in the LECZ and Drylands, by Population Size Ranges

City Population	Number of Cities	All Ecozones Population	All Ecozones Area	Drylands Population	Drylands Area	LECZ Population	LECZ Area
Under 100,000	2,739	45,000	170,998	12,300	49,244	2,055	7,179
100,000–500,000	198	40,200	68,926	14,300	28,964	2,890	4,974
500,000–1 million	28	19,900	23,257	6,220	6,627	1,946	1,956
1 million+	34	111,000	71,677	25,500	20,234	10,800	5,844

Percentage of Population and Land Area

City Population	Drylands Population	Drylands Area	LECZ Population	LECZ Area
Under 100,000	27.4	28.8	4.6	4.2
100,000–500,000	35.6	42.0	7.2	7.2
500,000–1 million	31.2	28.5	9.8	8.4
1 million+	22.9	28.2	9.7	8.2

Note: Based on size and area in 2000, estimated using GRUMP methods.

a spatially-specific form on a global basis. To highlight the potential that would be inherent in such data, another large-scale, spatially-specific exercise is used: the World Bank's Small-Area Poverty Mapping project (Elbers et al., 2003, 2005; Muñiz, et al. 2008).

To set the stage, Figure 5.5 depicts the GRUMP data available for Medan, Indonesia's third largest city, located on the northern coast of Sumatra. The figure shows the low-elevation coastal zone in cross-hatching; underneath can be seen the administrative units whose population sizes are indicated by shading

Table 5.6: City Population Density in Persons per Square Kilometre, by Ecozone and City Population Size Ranges, All Regions, Medan, Indonesia

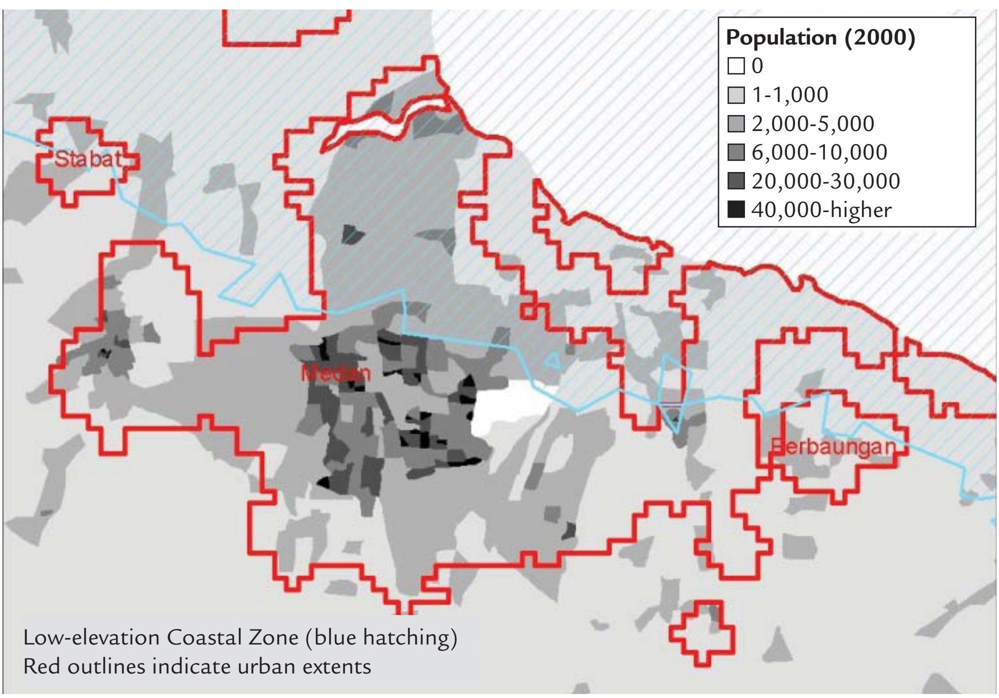
Region	Cities Outside LECZ Density	Cities Fully or Partly in LECZ: LECZ Density	Cities Fully or Partly in LECZ: Other Density
Africa	620	2,406	1,680
Asia	1,473	1,827	1,525
South America	661	1,079	1,003

Region	Cities Outside LECZ Density	Cities Under 1 Million, Cities Fully or Partly in LECZ: LECZ Density	Cities Under 1 Million, Cities Fully or Partly in LECZ: Other Density	Cities Outside LECZ Density	Cities Over 1 Million, Cities Fully or Partly in LECZ: LECZ Density	Cities Over 1 Million, Cities Fully or Partly in LECZ: Other Density
Africa	542	1,274	872	2,705	4,294	2,960
Asia	1,313	1,463	1,136	2,413	3,518	3,125
South America	560	805	678	1,251	1,665	1,676

Note: Figures are for cities that intersect more than one administrative area; cities contained within a single administrative area are omitted.

(darker shades represent larger populations). The outlined areas are the GRUMP urban extents as identified through satellite imagery. This assemblage of data gives a detailed picture of the population exposed to coastal risks, but it does not distinguish residents according to their levels of income, an important factor in

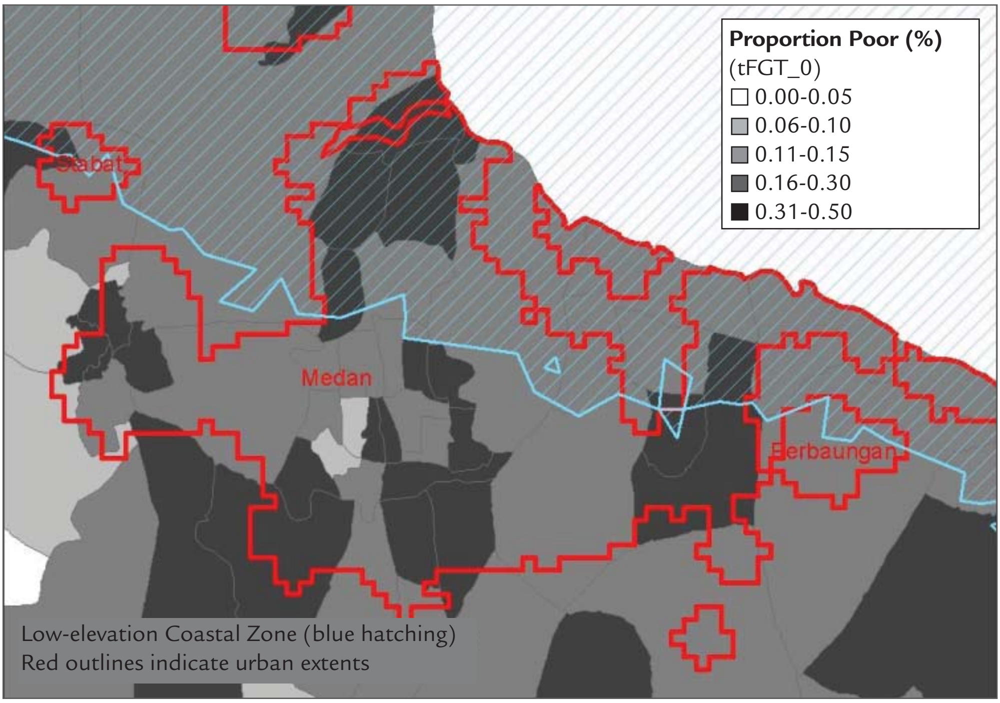
Figure 5.5: Population exposed in the LECZ: Medan, Indonesia (Total population of each administrative area)



Low-elevation Coastal Zone (blue hatching)
Red outlines indicate urban extents

Source: Columbia University's Global Rural–Urban Mapping Project.

Figure 5.6: Vulnerability and the LECZ: Proportion Poor in Each Administrative Area, Medan, Indonesia



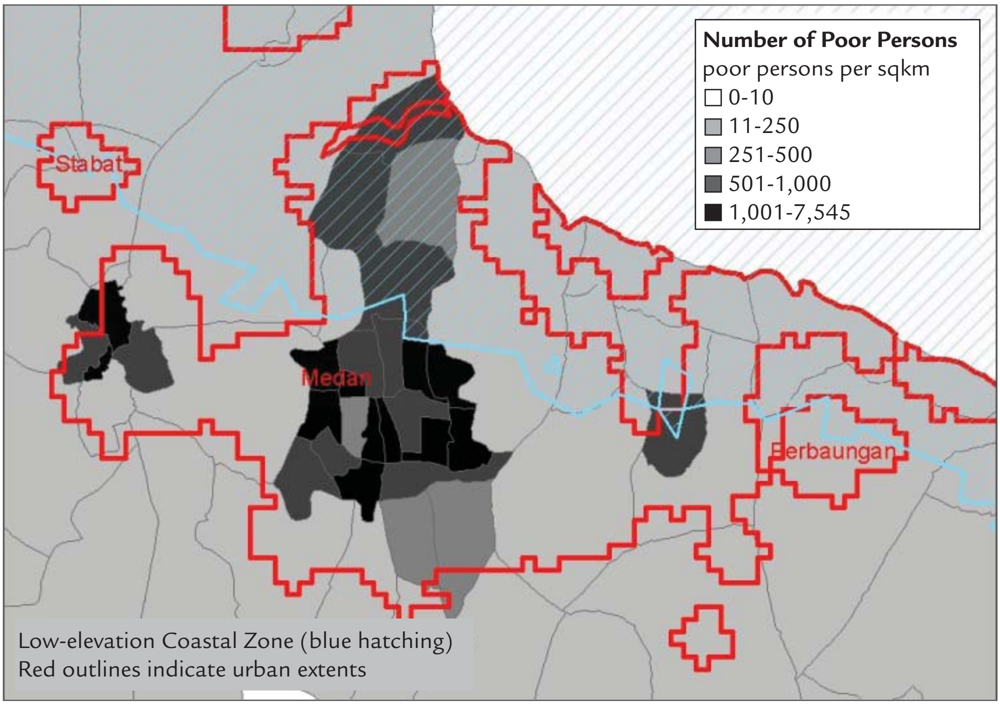
Source: GRUMP and the World Bank's Small-Area Poverty Mapping Project.

determining whether they have sufficient resources (e.g., housing well-enough constructed to withstand at least moderate flooding and storm surges) to fend off climate-related risks.

To shed light on the issue of vulnerability, Figure 5.6 draws the poverty data into the picture. Shown here (in the shading of the administrative areas) is the proportion of Medan's residents who live below the all-Indonesia poverty line.[7] Darker colours indicate higher proportions of the poor. Maps such as this can provide useful guidance to policymakers and planners needing to make decisions about where to allocate scarce urban adaptation resources and intervention efforts. Figure 5.7 presents an alternative view, depicting the total numbers of urban poor exposed to risk, which may be the more salient aspect of vulnerability for disaster preparedness and response agencies, non-governmental organizations and planners.

For countries whose administrative data are finely-enough disaggregated, it is possible to explore whether there is greater poverty in the low-elevation zones than outside them. As with the population density calculations given above, the percentage and number of poor urban-dwellers in the LECZ portion of cities having any land in that zone are estimated, making comparisons with poverty in the portions of the city lying outside the zone, as well as with poverty rates and counts in cities situated outside the LECZ altogether. Table 5.7 presents the results for the seven countries providing spatial data at a resolution high enough to support intra-urban analysis: Cambodia, Ecuador, Honduras, Indonesia, Panama, South Africa and Viet Nam.[8]

Figure 5.7: Vulnerability and the LECZ: Number of Poor in Each Administrative Area, Medan, Indonesia



Source: GRUMP and the World Bank's Small-Area Poverty Mapping Project.

No single message emerges from this analysis; rather, what is striking is the heterogeneity across countries in the association between poverty and the LECZ. In Viet Nam, for example, more than 2 million poor city-dwellers live in the LECZ, and poverty rates are highest in the LECZ portion of these cities. In the Vietnamese cities with any LECZ land, 28 per cent of the LECZ population is poor compared to 20 per cent of the non-LECZ population. However, the poverty rate in the non-LECZ cities is similar to that of the LECZ portion of the LECZ cities, although the non-LECZ cities do not hold nearly as many poor residents in total. The situation is quite different in Honduras and South Africa, where the highest rates of urban poverty (and the greatest numbers of poor) are found outside the coastal zone. In Indonesia, however, the proportion of the poor differs little according to LECZ, with 3.2 million urban poor living in the LECZ and another 4.5 million in the non-LECZ portion of the LECZ cities. To judge from the seven countries in this small sample, the LECZ is not, with any consistency, home to more of the urban poor. Nor do its administrative units tend to have higher poverty percentages. It is clear that estimates of vulnerability couched in terms of percentages of the poor population must be supplemented with estimates of the total number of poor people. These are very different metrics, and, if the examples explored here are any guide, they are likely to lead to different priority rankings for targeting interventions.

Forecasting City Population Growth

This chapter has shown how urban settlements are currently distributed according to ecological zone, but will these patterns be substantially reshaped as cities and towns continue to grow? To generate forecasts of city population growth, the city time-series supplied by the United Nations can be used. Ideally the forecasting exercise would also project changes in the spatial extent of cities; unfortunately, scientifically defensible estimates of spatial change are not yet available for a sufficiently large sample of cities. (As the Landsat archives come fully into the public domain, possibilities for a large-scale analysis of spatial growth will emerge.) Where population growth is concerned, however, the elements are on hand for a detailed analysis. Some illustrative results are presented here.

Estimated regression models of city population growth rates from 1950–2007 have been developed for cities in Africa, Asia and South America. This analysis is based on the United Nations Population Division's longitudinal database of city population, which has been assembled mainly for cities with populations of 100,000 and above. Because the spatial extent of cities can be defined in different ways—in terms of the city proper, the urban agglomeration or even metropolitan regions— and the definition adopted in the data can change from one point in time to the next even for a given city, controls for city definitions must be introduced in this analysis. The important role of fertility as a driver of city population growth must also be recognized, and, in this analysis, use is made of the United Nations estimates of national fertility (the national total fertility rate, or TFR), as well as its estimates of child mortality (Q5, the proportion of children dying before their fifth birthday). The specification also reserves a place for otherwise unmeasured, city- specific features, which are embedded in a time-invariant random or fixed effect in the regression's disturbance term. The influence of the ecozone on city growth can be estimated in the ordinary least squares (OLS) and random-effects models, but because ecozone is a time-invariant feature, its influence on city growth cannot be estimated using fixed-effect modelling techniques.

Tables 5.8–5.11 present the results from one such modelling exercise, first for all cities pooled across regions, and then separately for cities in each of the three regions. Some important results are common to all three regions. In particular, fertility rates display a strong positive effect on city growth rates irrespective of region, with the coefficients for South America being the largest. Even in Africa, however, the fertility coefficients suggest that a 1-child drop in the total fertility rate is associated with a decline of 0.395–0.490 percentage points in city population growth rates. This is a quantitatively important effect. Child mortality rates show the expected negative sign in the pooled results in the regions of Asia and South America, but not in Africa. Across regions, larger cities tend to grow more slowly than do cities with populations under 100,000 (the omitted category in the regression specification). Controls for changes in the statistical concept for which city population is recorded—city proper, agglomeration, etc. (including whether the concept was unknown)—make a statistically significant difference as a group (results not shown), but the details are complicated.

Table 5.7: Estimates of Poverty for Selected Countries, for Cities Located in and Outside the Low-elevation Coastal Zone, Various Years

		Percentage Poor		
		Cities Outside LECZ	Cities Fully or Partly in LECZ	
Country	Year	All Residents	LECZ Residents	Others
Cambodia	1998	31.36%	36.67%	33.50%
Ecuador	2001	55.57%	50.44%	50.06%
Honduras	2001	78.29%	70.21%	70.02%
Indonesia	2000	23.23%	21.96%	22.01%
Panama	2000	46.53%	46.20%	45.01%
South Africa	1996	45.19%	17.16%	18.65%
Viet Nam	1999	27.60%	27.97%	20.32%

Where ecozones are concerned, some differences emerge by region along the lines suggested earlier. In Asia, city growth in the LECZ is significantly faster than in the benchmark zone (other coastal), but no significant effect can be detected in either Africa or South America. City growth in the drylands ecosystem is insignificantly different from the benchmark zone in all three regions. At least for these two important ecozones, therefore, there is nothing in the results to indicate that, outside Asia, cities in climate-sensitive locations tend to grow faster than elsewhere. The LECZ result for Asia is therefore something of a special case, albeit for a region whose total urban population is enormous.

Figure 5.8 summarizes the forecasts of city population growth rates in Asia, distinguishing between cities situated in the LECZ and those outside this zone. The median growth forecast is shown, accompanied by the upper and lower quartiles (using the results of the random-effects regression). Although the population growth rates of LECZ cities in Asia are initially somewhat higher than those of non-LECZ cities, both types of cities are projected to experience slower growth in the future—mainly due to projected lower fertility rates, which the regressions demonstrate are powerful, if often-overlooked, influences on city growth rates. Eventually, according to these forecasts, a convergence is to be anticipated between the LECZ and non-LECZ city growth rates in this region of the developing world.

Conclusions

The precision of climate science data and models continues to improve, and more detailed estimates are becoming available on the spatial distribution of climate-related hazards. At the moment, however, far less data-gathering and modelling are underway in the social sciences to document exposure and vulnerability on a spatially-specific basis.[9] This chapter has taken a modest step toward assembling the requisite population and socio-economic data. Using recently mapped information on the populations of cities and towns in Africa, Asia and Latin America,

Number of Poor			Number of 1 km cells observed		
Cities Outside LECZ	Cities Fully or Partly in LECZ		Cities Outside LECZ	Cities Fully or Partly in LECZ	
All Residents	LECZ Residents	Others	All Residents	LECZ Residents	Others
128,347	29,540	107,999	36	13	9
1,277,348	291,947	361,388	73	35	33
642,154	28,859	41,404	71	14	13
4,810,857	3,240,764	4,535,325	403	299	229
41,516	38,420	283,851	30	17	16
2,555,721	59,730	1,037,184	622	29	28
342,030	2,112,987	413,623	79	131	36

Table 5.8: City Population Growth Rate Regressions, Pooled Results for Africa, Asia and South America

	OLS	Random-Effects	Fixed-Effects
National TFR	0.652	0.685	0.775
	(19.80)	(19.83)	(15.61)
National Q5	-0.005	-0.006	-0.011
	(-6.68)	(-7.73)	(-9.47)
Cultivated	0.166	0.218	
	(1.31)	(1.53)	
Dryland	-0.294	-0.290	
	(-4.36)	(-3.71)	
Forest	0.073	0.056	
	(0.99)	(0.66)	
InlandWater	0.400	0.426	
	(5.90)	(5.45)	
Mountain	0.310	0.315	
	(4.60)	(4.06)	
LECZ	0.128	0.090	
	(1.75)	(1.05)	
100,000 – 500,000	-0.901	-0.982	-1.614
	(-11.58)	(-12.11)	(-13.89)
500,000 – 1 million	-1.085	-1.360	-3.115
	(-7.37)	(-8.86)	(-13.76)
Over 1 million	-1.453	-1.723	-4.060
	(-9.13)	(-9.79)	(-13.08)
Constant	1.412	1.437	2.667
	(6.58)	(6.04)	(9.27)
σu	0.978		
	(21.09)		
σe	3.035		
	(128.14)		

Note: Z-statistics in parentheses. Controls for city definition included, but coefficients are not shown.

Table 5.9: City Population Growth Rate Regressions for Africa

	OLS	Random-Effects	Fixed-Effects
National TFR	0.490	0.490	0.395
	(5.80)	(5.83)	(3.40)
National Q5	0.004	0.004	0.003
	(2.27)	(2.28)	(1.00)
Cultivated	0.446	0.446	
	(2.04)	(2.05)	
Dryland	-0.294	-0.294	
	(-1.68)	(-1.69)	
Forest	-0.133	-0.133	
	(-0.76)	(-0.77)	
InlandWater	0.530	0.530	
	(3.34)	(3.35)	
Mountain	0.549	0.549	
	(3.19)	(3.20)	
LECZ	0.059	0.059	
	(0.32)	(0.32)	
100,000 - 500,000	-1.065	-1.065	-1.905
	(-4.94)	(-4.96)	(-5.76)
500,000 - 1 million	-1.698	-1.698	-4.052
	(-3.26)	(-3.28)	(-5.69)
Over 1 million	-2.644	-2.644	-6.254
	(-4.40)	(-4.42)	(-6.45)
Constant	1.421	1.421	3.213
	(2.40)	(2.41)	(3.78)
σu	0.000		
	(.)		
σe	3.964		
	(74.40)		

Note: Z-statistics in parentheses. Controls for city definition included, but coefficients are not shown.

simple maps have been compiled of urban settlements in both the low-elevation coastal zone and the drylands of these world regions. The climate and bio-physical sciences suggest that the hazards expected to materialize in these zones will be substantially different; and, as has been seen in the demographic analysis presented in this chapter, the settlement patterns in these zones are also quite different.

In the low-elevation zone, exposure to flooding and other extreme weather events will depend not only on the settlement patterns that are evident today, but also on how urban populations and their arrangement across risk zones change in the future. In Asia, where a large share of the world's urban population growth is currently taking place, the cities in the low-elevation zone have grown faster to date than have those outside the zone. To explore the longer-term prospects, preliminary city population growth forecasts have been presented which suggest that rates of city growth are likely to decline as fertility rates decline, indicating that cities in the LECZ will eventually come to grow at about the same rates as elsewhere. Of course, the data and methods used to produce such forecasts need to be developed in much more depth. In particular, a way will need to be found to adjust the forecasts to incorporate migration, which is largely induced by spatial differences

Table 5.10: City Population Growth Rate Regression Results for Asia

	OLS	Random-Effects	Fixed-Effects
Over 1 million	-2.644	-2.644	-6.254
National TFR	0.601	0.650	0.929
	(14.09)	(14.44)	(13.68)
National Q5	-0.008	-0.009	-0.019
	(-8.32)	(-9.15)	(-12.76)
Cultivated	-0.303	-0.223	
	(-1.40)	(-0.92)	
Dryland	0.055	0.040	
	(0.59)	(0.38)	
Forest	-0.057	-0.013	
	(-0.63)	(-0.13)	
InlandWater	0.473	0.491	
	(5.38)	(4.96)	
Mountain	0.392	0.345	
	(4.59)	(3.59)	
LECZ	0.303	0.263	
	(3.16)	(2.42)	
100,000 - 500,000	-0.858	-0.927	-1.540
	(-9.04)	(-9.39)	(-10.62)
500,000 - 1 million	-1.137	-1.359	-3.029
	(-6.89)	(-7.87)	(-11.33)
Over 1 million	-1.481	-1.680	-3.780
	(-8.39)	(-8.66)	(-10.28)
Constant	2.097	2.041	2.689
	(6.72)	(5.96)	(7.33)
σu	0.814		
	(12.80)		
σe	2.849		
	(95.40)		

Note: Z-statistics in parentheses. Controls for city definition included, but coefficients are not shown.

in real standards of living. Historically, the lower transport costs of trade provided by the LECZ have proven to be a powerful force attracting migrant labour and capital. In China and elsewhere, it remains to be seen whether climate change will introduce risks that offset the economic logic that has driven coastal development for millennia. Here, as elsewhere, the adaptation policies and investments adopted by national and local governments will have a key role in shaping urban growth.

In drylands, climate change will be manifested in complex ways, but it seems probable that, in many places, the net effect will be to increase water stress. The consequences are difficult to foresee, and, as with coastal settlement, will depend in part on how people and their governments respond to scarcity. The drylands occupy substantially more land overall than the LECZ, and, although population densities are generally lower, a larger share of urban-dwellers live in drylands than in the low-elevation zone. There is also considerable variation in the dryland shares according to region. Preliminary city growth estimates indicate that, in Africa, Asia and Latin America, dryland city populations are growing neither significantly faster nor significantly slower than in other zones. This finding, however, will need to be revisited as data and methods improve.

Table 5.11: City Population Growth Rate Regressions for South America

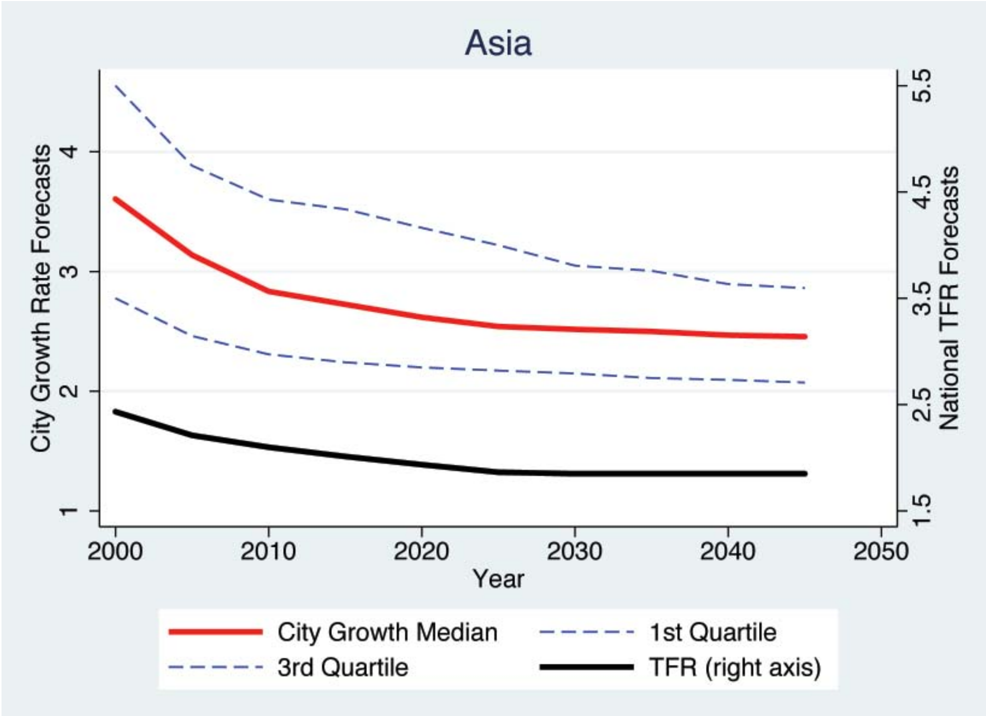
	OLS	Random-Effects	Fixed-Effects
National TFR	0.853	0.964	1.118
	(9.32)	(9.88)	(9.42)
National Q5	-0.002	-0.005	-0.012
	(-0.56)	(-1.67)	(-2.94)
Cultivated	0.189	0.242	
	(0.72)	(0.62)	
Dryland	-0.025	-0.087	
	(-0.20)	(-0.46)	
Forest	0.142	0.148	
	(0.78)	(0.52)	
InlandWater	0.294	0.328	
	(2.59)	(1.86)	
Mountain	-0.232	-0.255	
	(-2.07)	(-1.48)	
LECZ	-0.167	-0.181	
	(-1.32)	(-0.93)	
100,000 - 500,000	-0.800	-0.897	-1.091
	(-6.33)	(-6.95)	(-7.15)
500,000 - 1 million	-0.785	-1.061	-1.588
	(-2.83)	(-3.78)	(-4.69)
Over 1 million	-1.193	-1.348	-1.964
	(-3.91)	(-3.83)	(-4.13)
Constant	0.773	0.723	1.454
	(2.16)	(1.50)	(4.07)
σu	1.224		
	(17.01)		
σe	1.833		
	(53.46)		

Note: Z-statistics in parentheses. Controls for city definition included, but coefficients are not shown.

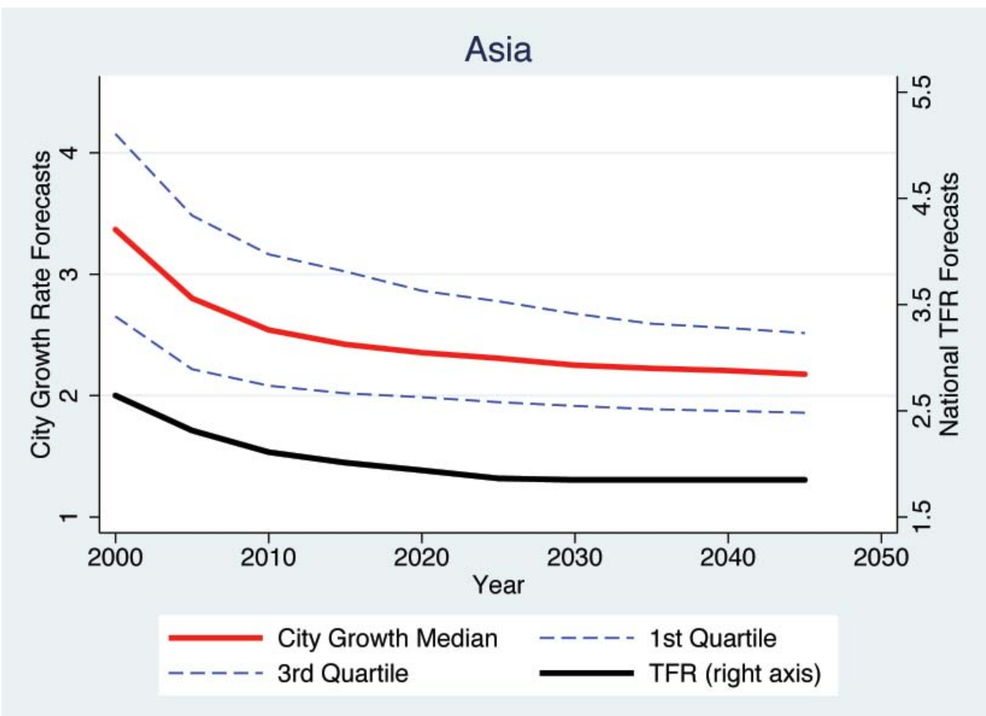
If urban climate adaptation plans are to be effective, they will need to be informed by evidence that is spatially-specific, whether on the populations exposed to risk or on the spatial patterns of these risks. As climate change approaches, more must be learned about the demographic and socio-economic characteristics of the urban and rural populations who will be affected by it, with migration behaviour, age and educational distributions, the quality and durability of housing and measures of poverty all being of high priority. The 2010 round of national censuses will shortly be fielded, and the opportunity must be seized to process these census data and map them in the fine spatial and jurisdictional detail needed for adaptation planning. To be sure, there are technical difficulties in putting census data into a geographic information system; in some countries, no doubt, disagreements over jurisdictional boundaries will need resolution. But once the spatial frame is established, it will provide an organizing framework for all manner of demographic, economic, social and physical data. Maps compel attention: They give national and local authorities and researchers a familiar place to start in documenting vulnerabilities at the finely disaggregated spatial scales needed

Figure 5.8: Forecasts of City Population Growth Rates in Asia

LECZ Growth Forecasts:



Non-LECZ Forecasts:



for effective intervention; and they can be expected to invigorate thinking about climate change at the local, regional and national levels, providing poor countries with a voice in the global conversation on climate change adaptation.

Notes

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2 The authors are in the process of adding migration data from these surveys and other sources. The challenges of integrating satellite with such population data are discussed in Chapter 13.

3 See: Douglas et al., 2008, and Awuor et al., 2008.

4 See: Hardoy and Pandiella, 2009.

5 For further discussion of urban exposure and vulnerabilities, see: Campbell-Lendrum and Woodruff (2006); UNDP (2004); Campbell-Lendrum and Corvalán (2007).

6 The tables are based on GRUMP estimates of the population of urban agglomerations circa 2000; they report the number of such agglomerations that are detected via the night-time lights. Note that the LECZ and drylands are not mutually exclusive; a given city can be located in both zones.

7 An urban poverty line would be preferable, in that urban poverty lines (sometimes) take into account urban-specific costs of living that are not considered in the national poverty lines. See: Montgomery et al., 2003, and Muñiz et al., 2008.

8 Of the poverty mapping efforts conducted in over fifty countries, fewer than half have been made available as spatially-coded datasets (Muñiz et al., 2008).

9 For more on the data issues involved, see Chapter 13.

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