Forecasting City Population Growth in Developing Countries

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1 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 the high-income countries (United Nations 2008). In the quarter-century after 2025, the UN 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 would appear to be environmentally secure, or in regions likely to feel the brunt of climate-related change in the coming decades?

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This chapter documents the current locations of urban-dwellers in Asia, Africa and Latin 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 zone 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. 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 quantify the risks that global climate change presents for urban-dwellers in poor countries, it is obviously of vital importance to know who lives where. That is, enough must be known about the locations of people who will be exposed to risk 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; so do forecasts of where urban fertility and migration will augment the populations of towns and cities in the path of risk; and 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 Socioeconomic Data Applications Center at Columbia University's Earth Institute, and researchers based at 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 of 100,000 population 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 UN 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 2008–09 update of GRUMP (SEDAC 2008; Balk 2009). Each urban settlement in the combined set of data 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 itself derived from remotely-sensed satellite imagery (Elvidge et al. 1997; Balk et al. 2005; Small et al. 2005). Having pinpointed the locations of cities and towns, we are able to determine whether all or part of their populations are situated in the low-elevation and drylands ecozones. To assess the likely pace of urban growth in these zones, we draw upon the UN city time-series, supplemented by a large collection of demographic surveys covering the period from the mid-1970s to the present, which supply additional information on urban fertility and mortality rates.[1]

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 world-wide who live in coastal areas within 10 meters of sea level—the low-elevation coastal zone, or LECZ—an elevation that is above the expected rise in sea levels according to current predictions but which often lies within the reach of the effects of cyclones, storm surges and other indirect impacts of sea level rise. Having benefitted from several additional years of data collection, we are in a position 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 the paper is organized as follows. In Section 2, we review the health implications of climate-related hazards in low-lying coastal areas and drylands. In Section 3 we employ the GRUMP data to calculate the numbers of urban-dwellers who currently live where these hazards are likely to be pronounced. Next, to indicate how urban exposure and vulnerability are likely to be reshaped by future population growth, we present in Section 4 estimates and forecasts of city population growth rates by ecozone for the major regions of the developing world, in this case using the city time-series provided by the United Nations. The paper concludes with a discussion of how such information could advance the efforts of cities and towns to adapt to climate change.

2 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 health. The other vulnerable ecosystem singled out here for attention—drylands—contains (globally) far larger populations than found in the low-elevation coastal zones. Much of the discussion of climate change for the drylands has focused on the rural implications—but what will it mean to be an urban resident of the drylands?

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[1] We are in the process of adding migration data from these surveys and other sources.

The low-elevation coastal zone

According to current forecasts, sea levels will gradually but inexorably rise over the coming decades, and this will place large coastal urban populations under threat around the globe. Alley et al. (2007) foresee increases of 0.2 to 0.6 meters 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; World Bank 2008). Storm surges and flooding also present a threat in coastal African cities (e.g., Port Harcourt, Nigeria, and Mombasa, Kenya; see Douglas et al. (2008) and Awuor et al. (2008)) and in Latin America (e.g., Caracas, Venezuela, and Florianópolis, Brazil; see Hardoy and Pandiella (2009)).

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, fecal 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 housing they can afford tends to be located in the 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).[2]

Kovats and Akhtar (2008: 169) detail some of the flood-related health risks: increases in cholera; cryptosporidiosis (one of the most common water-borne diseases, the result of a parasite transmitted by environmentally hardy cysts [oocysts] that, once ingested, infect the epithelial tissue of the small intestine); typhoid fever; and diarrheal diseases. They describe increases in cases of leptospirosis (a bacterial infection commonly transmitted to humans when water that has been contaminated by animal urine comes in contact with unhealed breaks in the skin, eyes or with the mucous membranes) 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 contamination

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

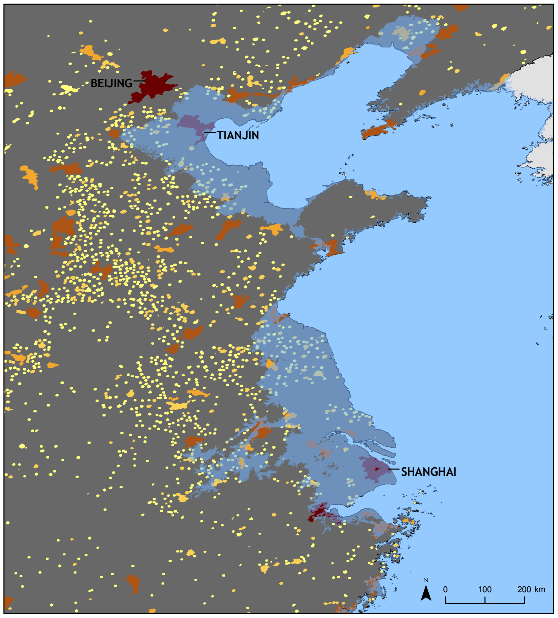


Figure 1: Combined UN and GRUMP urban data for Beijing, Tianjin, Shanghai and their environs, China. Low-elevation coastal zone depicted in medium blue shading. Urban areas shown as points of light or patches of yellow or brown. Source: McGranahan et al. (2007).

with chemicals, heavy metals, and other hazardous substances, especially for those who live near industrial areas.

Figures 1–3 map the location of cities and large towns in relation to the low elevation zone for several important metropolitan regions. Figure 1 presents a broad-scale overview of the the low-elevation zone of China near Beijing, Tianjin, and Shanghai. Large urban areas are shown as dark blobs in the figure and smaller places depicted as points of light. 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 2 shows how the low-elevation zone bisects Ho Chi Minh city in southern Vietnam, and Figure 3 depicts the cities and towns in the low-lying coastal regions of Bangladesh.

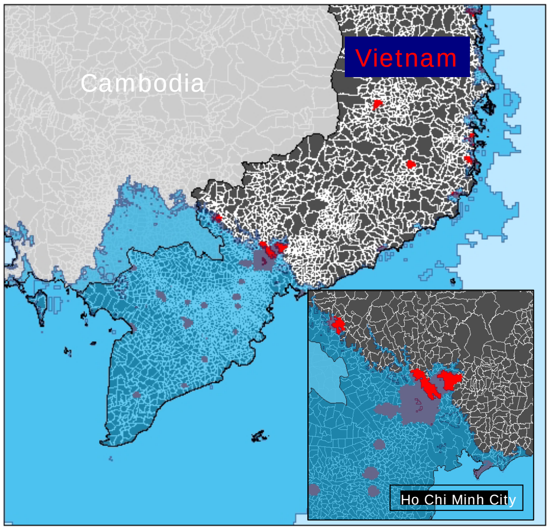


Figure 2: Combined UN and GRUMP urban data for southern Vietnam, with inset showing how the low-elevation coastal zone intersects Ho Chi Minh city. Low elevation coastal zone depicted in blue. Detailed administrative boundaries indicated in light shading. Data source: SEDAC (2008).

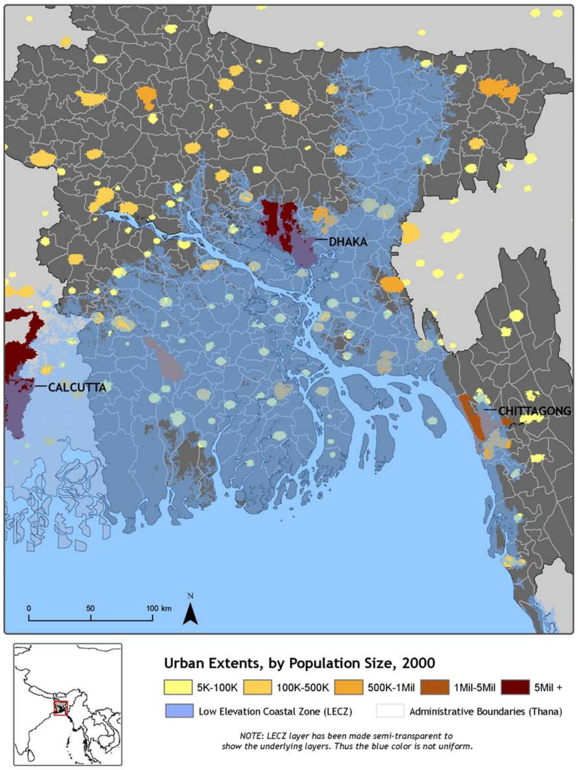


Figure 3: Combined UN and GRUMP urban data for Bangladesh, showing the low-elevation coastal zone (in medium blue shading). Urban areas depicted in light shading. Data source: SEDAC (2008).

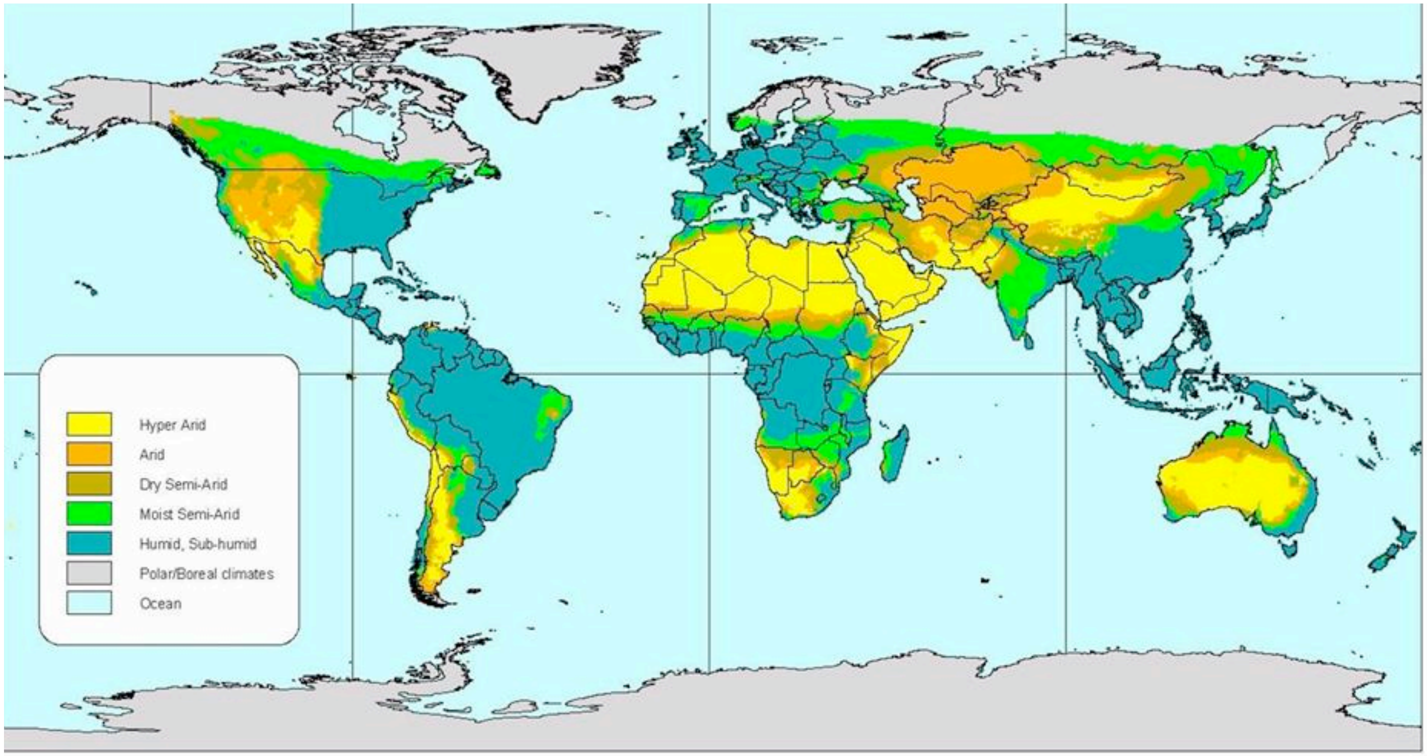
Table 1: Forecasts of climate change in drylands ecosystems. Source: Adapted from Commission on Climate Change and Development (2008). See original for detailed notes and discussion of agreement among climate models.

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 Africa	3.4	-4	100	4	13
Sahara	3.6	-6	100		
Southern Europe and Mediterranean	3.5	-12	100		46
Central Asia	3.7	-3	100		12
Southern Asia	3.3	+11	100	39	3

Drylands

The principal characteristics of drylands are succinctly summarized by Safriel et al. (2005: 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 4 depicts drylands ecosystems around the world. Safriel et al. (2005: 626) estimate that this ecosystem covers 41 percent of the Earth's surface and provides a home to some 2 billion people. Developing countries account for about 72 percent of the land area and some 87-93 percent 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 percent of this ecozone's population is urban.

Water shortages are already apparent in drylands ecosystems—there is an estimated 1300 cubic meters of water available per person per year, well below the 2,000 cubic meter threshold considered sufficient for human well-being and sustainable development (Safriel et al. 2005: 625, 632). Even for the regions such as East Africa where climate scientists foresee increases in precipitation (Table 1), the rise in temperature is expected to cancel out the effects of greater rainfall, and in some regions this will elevate the frequency of rainy season failure (Commission on Climate Change and Development 2008). In the dryland areas whose 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 and in



Source: Global Agro-ecological Zones
(FAO-IIASA, 2000)

Geographic Projection (lat/long)

Figure 4: Source: Commission on Climate Change and Development (2008).

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 urban poor find it difficult to secure access to water, thereby threatening their health, 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: "There is no discernible relationship between national indicators of water stress and national indicators of inadequate access to water in urban areas" (McGranahan 2002: 4). Indeed, in a regression analysis of access to water for urban (and rural) populations as a whole, with national income per capita included as an explanatory factor along with the Falkenmark measure of per capita renewable water resources, per capita income exhibited a strong positive association with access whereas water resources displayed a weak and unexpectedly negative association. Evidence from more detailed, within-city case studies is also mixed. Summarizing, McGranahan (2002: 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."

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

> 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 reaching 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 most. However straightforward 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 as such. Especially in sub-Saharan Africa, a number of cities have become dependent on hydro-power for much of their electricity (Showers 2002; Muller 2007). As Showers (2002: 639) describes 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, "In 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: 643).

Safriel et al. (2005: 650) 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, with implications especially for coastal drylands: "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." The productivity consequences may have the effect of increasing the costs of production in agriculture, which may in turn cause agricultural 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).

3 New Data: Mapping the Populations at Risk

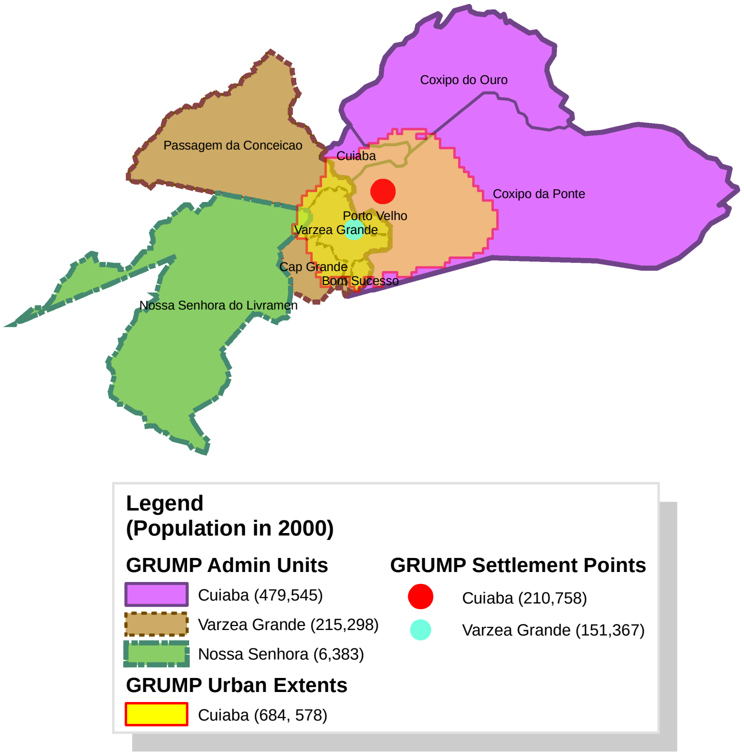
If the manifestations of climate change are likely to affect human health in the ways just described, why is it that to date, demographers have not played a larger role in the global conversation on climate change adaptation? The reason, we suspect, is that international demographic research has become *aspatial* in its orientation—since the early 1980s, the field has been engaged with behavioral questions for which nationally-representative sample surveys are the preferred tool. These surveys can probe deeper into behavior than can population census, and they possess many other advantages. The great disadvantage of such surveys, however, is that they cannot reliably depict individual cities, to say nothing of neighborhoods within cities where the effects of climate change will materialize. The impacts of climate change are spatially-specific; spatially coded data are needed to quantify the numbers of urban residents at risk and to understand where the most vulnerable groups live. Where spatial specificity is concerned, there can be little substitute for census data.

Over the past dozen years, the GRUMP project has made a large investment in collecting population counts by finely disaggregated sub-national administrative units and using these, in combination with satellite imagery, to derive estimates of the spatial extents of urban agglomerations and the populations of these agglomerations. Balk (2009) describes the details of the GRUMP algorithm. As we mentioned earlier, these spatially-specific materials have now been merged with the UN Population Division's city time-series, so that for the first time, we have access to urban data that have a temporal as well as a spatial dimension.

The links between the UN and GRUMP data are illustrated in Figure 5 for Cuiada, the capital of Mato Grosso state in Brazil. The urbanized area of Cuiaba as detected by satellite sensors (stable night-time lights) is overlaid with surrounding three administrative units (Cuiaba, Varzea Grand, and Nossa Senhora along with their sub-units) and two settlements across the administrative units (expressed as points with different colors and sizes depending on their population size in 2000). In the year 2000, some 685,000 persons resided in the Cuiaba urbanized area (filled with yellow and surrounded in red). Within this urbanized area, the settlement of Cuiaba (the red point) accounted for about 211,000 people; the total population of the three administrative units is 701,226.

In the United Nations records, a population count is available for the urban agglomeration of Cuiaba in 2000; at the time there resided some 687,835 persons in the agglomeration according to the reports that national statistical authorities gave to the UN. This figure happens to agrees well with the GRUMP estimate of 685,000 people. Unfortunately, as is often the case, the national authorities did not describe the boundaries of the Cuiba agglomeration in sufficient detail to determine whether the boundaries as they conceive of them (which presumably provide the basis for the population counts reported to the UN) coincide with the boundaries depicted in the GRUMP dataset. The UN Population Division has not previously requested such spatial detail, although it is beginning to take steps to do so.

In this section we use the GRUMP urban estimates to achieve a quantitative accounting of the urban populations currently living in the low-elevation coastal



* Cuiada UN poplation in Uran Agglomeration in 2000 is 687,835
* Varzea Grande is not listed in UN cities database

Figure 5: Administrative units and urban settlements around Cuiada urbanized area in Brazil with population for each entity. Combined UN-GRUMP cities data.

zone and the drylands, where we expect climate change will exert an increasingly important influence.[3] Table 2 shows the distribution of urban population by city-size ranges in Asia, and Table 3 re-expresses these data by showing the percentage of all Asian urban dwellers in a given city-size range who live in these zones. Tables 4 and 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 even greater percentages-ranging from 54 to 67 percent—in the important case of India. In South America and China, however, much lower percentages of all 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 the drylands figures. Among all urbanites residing in cities of 1 million or more, the percentages in the LECZ range from 9.7 percent in South America to 26.6 percent in China.

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[3] 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.

Table 2: Distribution of the Asian urban population and land area in the LECZ and drylands, by population size ranges. Population in thousands (000s) and land area in square kilometers. (Size and area in 2000, estimated using GRUMP methods.)

	Number of	All Ecozones		Drylands		LECZ	
City Population	Cities	Population	Area	Population	Area	Population	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

Table 3: Percentages of the Asian urban population and land area in the LECZ and drylands, by population size ranges. Population in thousands (000s) and land area in square kilometers. (Size and area in 2000, estimated using GRUMP methods.)

	Drylands		LECZ	
City Population	Population	Area	Population	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

Table 4: Distribution and percentages of the African urban population and land area in the LECZ and drylands, by population size ranges. Population in thousands (000s) and land area in square kilometers.(Size and area in 2000, estimated using GRUMP methods.)

	Number of	All Ecozones		Drylands		LECZ	
City Population	Cities	Population	Area	Population	Area	Population	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

	Drylands		LECZ	
City Population	Population	Area	Population	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

Table 5: Distribution and percentages of the South American urban population and land area in the LECZ and drylands, by population size ranges. Population in thousands (000s) and land area in square kilometers. (Size and area in 2000, estimated using GRUMP methods.)

	Number of	All Ecozones		Drylands		LECZ	
City Population	Cities	Population	Area	Population	Area	Population	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

	Drylands		LECZ	
City Population	Population	Area	Population	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

Table 6: City population density in persons per square kilometer, by ecozone and city population size ranges, all regions. Figures are for cities that intersect more than one administrative area; cities contained within a single administrative area are omitted.

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

	Cities Under 1 Million			Cities Over 1 Million		
	Cities Outside LECZ	Cities Fully or Partly in LECZ		Cities Outside LECZ	Cities Fully or Partly in LECZ	
Region		LECZ Density	Other Density		LECZ Density	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

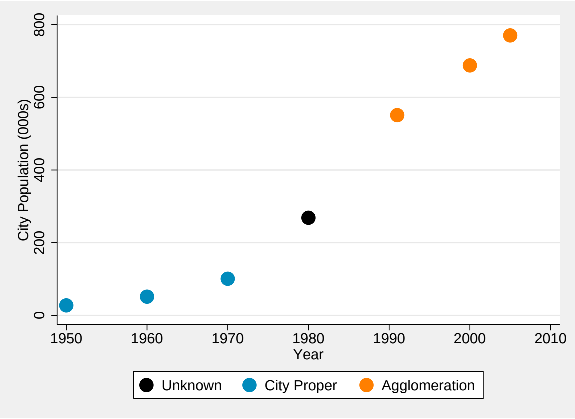

Figure 6: City population time-series for Cuiaba, Brazil

4 Forecasting City Population Growth

We have seen 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, we now turn to the city time-series supplied by the United Nations. 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, we have the elements on hand for a detailed analysis. Some illustrative results are presented here.

We must preface this analysis with a brief discussion of one feature of the United Nations city database: the definition of "urban settlement" differs from that employed in the GRUMP estimates that were discussed in the preceding section. As described in United Nations (2002), each country reports its city population data to the UN using its own national definitions of urban and city. The UN Population Division then endeavors to record the city population count in terms of one of three "statistical concepts" that summarize how city boundaries are defined: the city proper, the urban agglomeration, and the metropolitan region. The agglomeration concept is preferred and where possible, data are adjusted to conform to this concept—but of course adjustment is not always possible.

Indeed, the statistical concept reported for any given city can vary over time. The difficulties stemming from such mixed time-series are illustrated in Figure 6 for Cuiada, Brazil. This city's time-series begins with three entries expressed in terms of city proper; they are followed by one entry of unknown type, succeeded by a final three records couched in terms of the urban agglomeration. In such mixed cases, it is not obvious how to define a rate of population growth for spells of time that begin with one boundary concept but end with another. Despite the strenuous efforts made by UN staff to maintain consistency in reporting, there is an irreducible minimum of such boundary-related variation in the UN city data. Because the spatial extent of cities can be defined in different ways—in terms of the city proper, the urban agglomeration, and even metropolitan regions—and the definition adopted in the UN's data can change from one point in time to the next even for a given city, we must introduce controls for city definitions in the regression analysis.

Specification

The basic city growth model to be estimated is set out as equation (1),

$$g_{i,t} = \alpha + \beta \mathrm{TFR}_t + \delta q_t + \mathbf{D}'_{i,t}\gamma + v_{i,t}. \tag{1}$$

In this equation the i subscript denotes the i-th city and t is a point in time; $g_{i,t}$ is the estimated city population growth rate at that time, expressed in percentage points; and the fertility and mortality components of growth are represented by the urban total fertility rate TFR_t and q_t, the urban child mortality rate.[4] Additionally, $\mathbf{D}_{i,t}$ includes a set of dummy variables indicating the start-of-period and end-of-period units in which the city's population is recorded. In the Cuiaba example shown in Figure 6, these dummy variables would take into account the fact that in the early 1970s, one era of growth began with the population recorded in terms of the city proper but ended with a count expressed in unknown units. To show how our approach generalizes to include observed city-specific explanatory variables, we also present regressions in which city i's population size—classified as under 100,000 persons (the benchmark category), 100–500,000 persons, 500,000 to 1 million, and over 1 million—exerts an influence on its growth rate.

The vector $\mathbf{D}_{i,t}$ includes dummy variables for ecozone, with attention to the LECZ, drylands, and also the inland water ecozone. (These are time-invariant variables.) Table 7 shows the number of UN-recorded cities in each of the ecozones

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[4] Not all countries report fertility and mortality rates for urban areas, and although we have derived estimates of these rates from countries with a World Fertility Survey or a Demographic and Health Survey, a number of countries have participated in neither of these programs. To estimate urban fertility and mortality rates for these cases, therefore, we have used descriptive regressions in which the available urban rates are regressed upon the UN's national-level estimates of the rates—published for all countries, with forecasts to 2050—together with time trends and interactions of time with the UN's national estimates. These imputed urban fertility and child mortality figures (results not shown) generally appear quite reasonable, but obviously more research to refine the estimates is in order.

Table 7: Number of cities in inland water, LECZ, and dryland ecozones. Dryland consists of dry subhumid, semiarid, and arid; the last category includes hyper-arid.

Region	Inland Water	LECZ	Dry Subhumid	Semi-arid	Arid	N
Africa	325	165	143	95	68	720
Latin America	257	163	88	56	27	466
Asia	808	406	265	279	120	1,233
Total	1,390	734	496	430	215	2,421

we consider. (The inland water zone is included here along with the low-elevation coastal zone and drylands.) Table 8 displays the combinations of LECZ and drylands ecozones that are found in our data.

Table 8: Number and percentage of cities by LECZ and aridity.

	All Regions		Africa		Latin America		Asia	
	N	Percent	N	Percent	N	Percent	N	Percent
LECZ								
Humid	463	19.12	81	11.25	83	17.74	299	24.25
Dry sub-humid	162	6.69	45	6.25	55	11.75	62	5.03
Semi-arid	49	2.02	16	2.22	14	2.99	19	1.54
Arid	60	2.48	23	3.19	11	2.35	26	2.11
Non-LECZ								
Humid	817	33.75	333	46.25	214	45.73	270	21.90
Dry sub-humid	334	13.80	98	13.61	33	7.05	203	16.46
Semi-arid	381	15.74	79	10.97	42	8.97	260	21.09
Arid	155	6.40	45	6.25	16	3.42	94	7.62
Total	2,421	100	720	100	468	100	1,233	100

In what follows, we explore two specifications of $v_{i,t}$, the regression disturbance term. The first is a *random effects* specification in which the disturbance term is represented as a composite $v_{i,t} = u_i + \varepsilon_{i,t}$, containing one component, u_i, that is specific to city i and whose value can be estimated as $\hat{u}_i$. In this approach, u_i is assumed to be uncorrelated with the other right-hand side explanatory variables (e.g., TFR_t and q_t). Our second specification is a *fixed effect* specification in which the disturbance term also takes the composite form $v_{i,t} = u_i + \varepsilon_{i,t}$, but in which u_i is allowed to be correlated with other right-hand side variables.

The influence of ecozone on city growth can be estimated in the ordinary least squares (OLS) and random-effects models, but because ecozone is a time-invariant characteristic, its influence on city growth cannot be estimated using fixed-effect modeling techniques. The fixed-effect specification, which does the equivalent of introducing thousands of city-specific dummy variables in the specification, is mainly employed here as a check on the random-effects specification. As in the random-effects approach, the value of u_i can be estimated (using techniques similar although not necessarily identical to those applied in the random-effects method). This specification will prove useful when city-specific endogenous explanatory variables are introduced in the model.[5]

Results

The results are shown in Table 9 for all UN cities, and region-specific results are provided in the appendix. The results for ecozone indicate that cities in the inland water zone grow relatively faster than other cities, the difference amounting to about 0.26 to 0.40 percentage points in the pooled results. The effect is also significant and of roughly the same size across regions, as shown in the appendix. The effects of the low-elevation coastal zone and drylands are more difficult to interpret owing to the need to consider interaction terms. In the models with all cities pooled in the analysis, cities in the LECZ but not in the drylands tend to grow more slowly, with Asia presenting a partial exception. However—see the Wald tests of Table 10—LECZ cities that are also in the drylands tend to grow faster, a finding that is especially clear for coastal Asian cities that are situated in semi-arid or even drier environments.

Urban fertility rates display very strong positive effects on city growth rates in the pooled results of Table 9, which indicate that a decline of 1 child in the urban TFR is associated with a drop of .87 to 1.03 percentage points in the city growth rate, a quantitatively important impact. The effects of urban fertility are also highly significant in the fixed-effect models, where fertility rates have an even larger influence than is evident in the random-effect models (see the appendix). Urban fertility also emerges as quantitatively important in the region-specific results (also in the appendix), where the models for Africa exhibit random-effect coefficients of about 0.70 for the urban total fertility rate, Latin America's coefficient is 0.97, and the coefficient for Asian cities is 1.01, the largest among the regions. Child mortality rates show the expected negative sign in the pooled results (Table 9) and

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[5] A companion paper by Donghwan Kim and Mark Montgomery, "An Econometric Approach to Forecasting City Population Growth in Developing Countries," presents Bayesian and spatial econometric versions of these regression models, as applied to an earlier version of the merged GRUMP-UN database. When time permits, these models will be re-estimated using the updated data.

in Asia (the appendix) but are insignificant in Latin America and take a positive sign in the African results. In the pooled results and also across regions, larger cities tend to grow more slowly than do cities under 100,000 population (which is the omitted category in the regression specification), and the effect is important in quantitative terms as well as being highly significant statistically. 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 9: Regressions with estimated urban vital rates, all UN cities.
(*Z*-statistics in parentheses.)

	Model 1		Model 2	
	OLS	Random-Effects	OLS	Random-Effects
Start-of-period Urban TFR	0.959	1.033	0.816	0.873
	(22.92)	(23.52)	(18.92)	(19.28)
Start-of-period Urban Q5	-0.006	-0.007	-0.005	-0.007
	(-5.81)	(-6.73)	(-5.59)	(-6.99)
Inland Water	0.266	0.257	0.381	0.403
	(4.08)	(3.38)	(5.80)	(5.20)
LECZ	-0.235	-0.285	-0.209	-0.264
	(-2.60)	(-2.67)	(-2.33)	(-2.47)
Dry subhumid	-0.656	-0.649	-0.654	-0.651
	(-6.38)	(-5.45)	(-6.40)	(-5.44)
Semiarid	-0.499	-0.487	-0.452	-0.449
	(-5.41)	(-4.51)	(-4.94)	(-4.13)
Arid and above	-0.424	-0.432	-0.382	-0.403
	(-3.27)	(-2.88)	(-2.97)	(-2.68)
LECZ * Dry subhumid	0.726	0.737	0.685	0.683
	(4.33)	(3.73)	(4.12)	(3.43)
LECZ * Semiarid and drier	0.654	0.626	0.630	0.613
	(3.59)	(2.92)	(3.48)	(2.84)
100,000–500,000			-0.805	-0.905
			(-10.73)	(-11.51)
500,000–1 million			-1.000	-1.311
			(-7.18)	(-8.95)
Over 1 million			-1.270	-1.594
			(-8.35)	(-9.33)
Unknown-Unknown	0.684	0.777	0.500	0.530
	(6.13)	(6.21)	(4.46)	(4.19)
Unknown-Proper	1.180	1.119	0.899	0.777
	(7.77)	(7.07)	(5.88)	(4.86)
Unknown-Agglomeration	0.230	0.346	0.277	0.362
	(0.80)	(1.22)	(0.97)	(1.29)
Unknown-Metro. Area	-0.416	-0.384	-0.292	-0.293
	(-1.12)	(-1.04)	(-0.79)	(-0.80)

Continued on next page . . .

... table 9 continued

	Model 1		Model 2	
	OLS	Random-Effects	OLS	Random-Effects
Proper-Unknown	1.590	1.508	1.202	1.027
	(6.88)	(6.48)	(5.19)	(4.39)
Proper-Proper	0.362	0.347	-0.007	-0.089
	(3.64)	(3.08)	(-0.07)	(-0.76)
Proper-Agglomeration	1.602	1.556	1.520	1.413
	(5.27)	(5.20)	(5.03)	(4.76)
Agglomeration-Unknown	-1.016	-0.932	-0.857	-0.784
	(-1.97)	(-1.84)	(-1.67)	(-1.56)
Agglomeration-Proper	-0.348	-0.293	-0.494	-0.465
	(-0.70)	(-0.60)	(-1.00)	(-0.96)
Agglomeration-Metro. Area	1.235	0.988	1.463	1.212
	(1.53)	(1.25)	(1.83)	(1.54)
Metro. Area-Metro. Area	0.056	-0.003	0.314	0.294
	(0.18)	(-0.01)	(0.99)	(0.85)
Others-Others	3.462	3.445	2.714	2.608
	(5.00)	(4.79)	(3.93)	(3.62)
Constant	0.825	0.707	1.870	1.967
	(5.81)	(4.52)	(11.32)	(10.77)
σ_u		0.993		1.032
		(21.96)		(23.11)
σ_ε		3.037		3.001
		(131.42)		(130.90)

City growth forecasts

The forecasts of city growth based on these regressions are summarized in Figure 7 for all regions, and separately in Figure 8 for each of the three main regions. These figures show the (implied) projection of urban fertility rates (values are displayed on the right axis of each figure) as well as the median forecast of city growth rates and the 25th and 75th percentiles. The projected decline in urban fertility is the dominating factor—it brings about reductions in the median growth rate forecast from nearly 4 percent in 2000 to a level just above 2 percent as of 2045. A similar pattern is seen in the forecasts based on region-specific models (Figure 8) and in

Table 10: Wald tests of the effect of LECZ by aridity, regressions with estimated urban vital rates. (The notation ** means that the null hypothesis of no net effect is rejected at 10 percent significant level but not at the 5 percent level.)

	Model 1		Model 2	
	OLS	Random-Effects	OLS	Random-Effects
Humid	-0.23	-0.28	-0.21	-0.26
(Wald statistic)	(6.75)	(7.14)	(5.41)	(6.08)
Dry sub-humid	0.49	0.45	0.48	0.42
	(11.73)	(7.15)	(11.19)	(6.05)
Semi-arid and drier	0.42	0.34	0.42	0.35
	(6.83)	(3.29)**	(6.98)	(3.38)**

the forecasts according to LECZ and drylands ecozones (Figure 9), with urban fertility again being the main force projected to drive down city growth rates in the future. It is, however, worth asking whether even by 2045, African urban TFRs are likely to reach the level of 1.5 children that has been projected, which may well be over-optimistic.

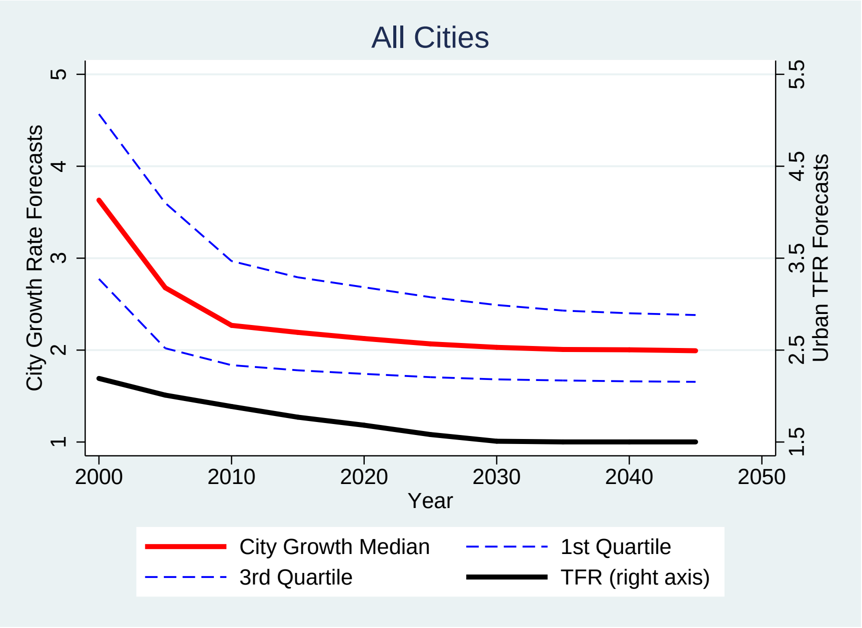
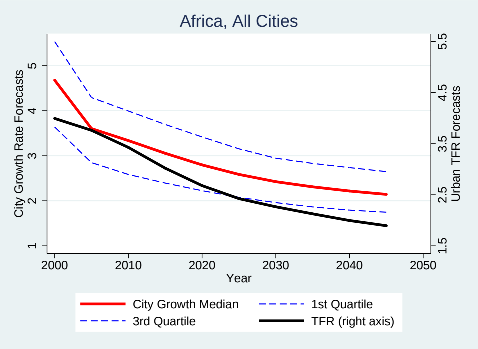
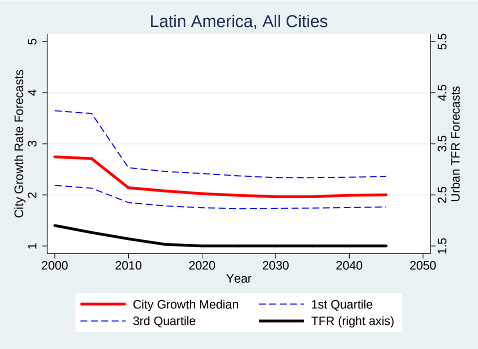


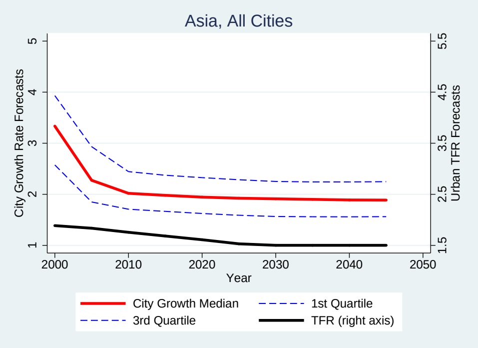
Figure 7: Forecasts of city growth rates conditional on UN projections of fertility and mortality



(a) African Cities

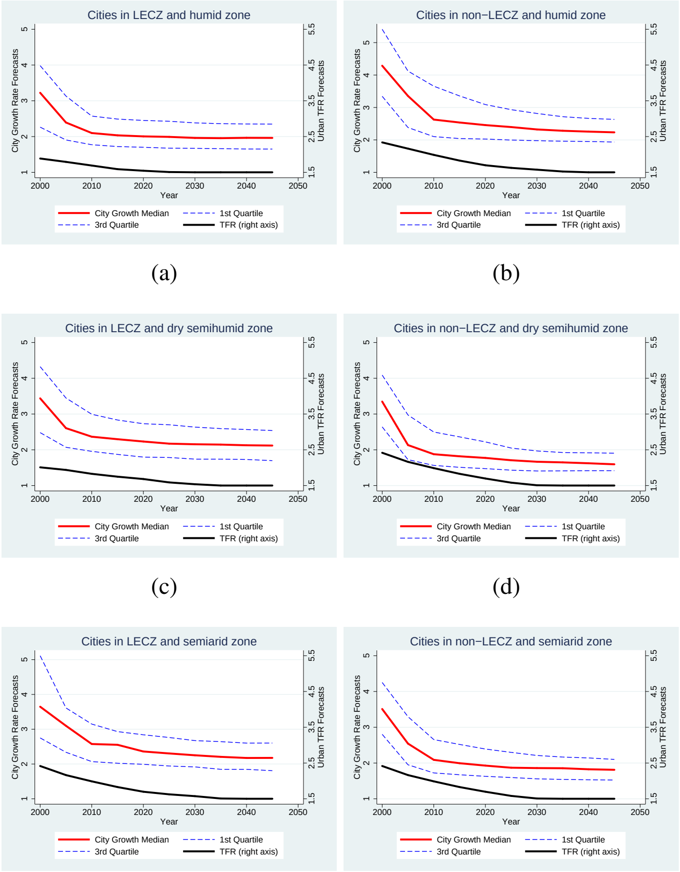


(b) Latin American Cities



(c) Asian Cities

Figure 8: Forecasts of city growth rates by region, conditional on UN projections of fertility and mortality



(a) (b)

(c) (d)

(e) (f)

Figure 9: Forecasts of city growth rates by LECZ and aridity.

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 modeling is underway in the social sciences to document exposure and vulnerability on a spatially-specific basis. This paper has taken a modest step toward assembling the requisite population and socioeconomic data. Using recently mapped information on the populations of cities and towns in Africa, Asia, and Latin America, we have compiled simple maps 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 we have seen in our demographic analysis, 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, we have presented preliminary city population growth forecasts which suggest that rates of city growth are likely to decline as fertility rates decline, and which indicate 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 city growth estimates and forecasts to incorporate migration, which is largely induced by spatial differences in real standards of living. Historically, the lower transport costs provided by the LECZ have proven to be a powerful force attracting migrant labor 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 the arid regions known as 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. Our preliminary city growth results indicate that in Asia, Africa and Latin America, dryland city populations are growing significantly slower than is the case in other zones, although it seems that dryland cities which are also in the LECZ tend to grow somewhat faster. These findings will need to be revisited as data and methods improve.

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 pattern of these risks. As climate change approaches, we must strive to learn more about the demographic and socioeconomic characteristics of the urban and rural populations who will be affected by it, with migration behavior, 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 to be faced in putting census data into a geographic information system; in some countries, no doubt, squabbles 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 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.

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A Supplementary regression results

Table 11: Ordinary least-squares and random-effect estimates by region, using estimated urban fertility and mortality rates. Models without controls for city size.

	Africa		Latin America		Asia	
	OLS	RE	OLS	RE	OLS	RE
Urban TFR	0.697	0.702	0.840	0.970	0.986	1.101
	(5.98)	(6.05)	(8.92)	(9.81)	(16.78)	(17.47)
Urban Q5	0.007	0.007	0.005	0.001	-0.011	-0.013
	(3.06)	(3.03)	(1.44)	(0.30)	(-8.81)	(-9.58)
Inland Water	0.345	0.342	0.396	0.411	0.242	0.243
	(2.08)	(2.06)	(4.07)	(2.88)	(2.71)	(2.38)
LECZ	-0.453	-0.465	-0.494	-0.507	0.135	0.098
	(-1.82)	(-1.86)	(-3.59)	(-2.53)	(1.08)	(0.69)
Dry subhumid	-0.697	-0.699	-0.129	-0.130	-0.251	-0.242
	(-2.60)	(-2.61)	(-0.69)	(-0.47)	(-1.82)	(-1.55)
Semiarid	-0.599	-0.598	-0.317	-0.318	0.080	0.060
	(-2.30)	(-2.30)	(-1.95)	(-1.33)	(0.62)	(0.41)
Arid and above	-0.545	-0.544	-0.109	-0.087	0.171	0.098
	(-1.68)	(-1.68)	(-0.48)	(-0.26)	(0.94)	(0.48)
LECZ*Dry subhumid	0.878	0.890	0.575	0.584	0.355	0.363
	(1.94)	(1.96)	(2.23)	(1.55)	(1.56)	(1.37)
LECZ* (> Semiarid)	0.048	0.058	0.735	0.735	0.767	0.694
	(0.11)	(0.13)	(2.70)	(1.83)	(2.91)	(2.31)
Unknown-Unknown	-0.067	-0.064	0.212	0.196	0.832	0.931
	(-0.15)	(-0.14)	(1.37)	(0.99)	(5.85)	(5.96)
Unknown-Proper	1.047	1.048	0.628	0.710	1.075	1.003
	(2.31)	(2.32)	(2.74)	(2.92)	(5.49)	(4.95)
Unknown-Agglomeration	0.095	0.102	-0.332	0.019	0.382	0.430
	(0.10)	(0.11)	(-0.96)	(0.06)	(0.97)	(1.09)
Unknown-Metro. Area	-1.676	-1.670	-0.607	-0.812	-0.270	0.066
	(-0.58)	(-0.58)	(-1.97)	(-2.61)	(-0.23)	(0.06)
Proper-Unknown	1.202	1.205	1.499	1.452	0.628	0.510
	(2.01)	(2.03)	(6.08)	(5.65)	(1.21)	(0.99)
Proper-Proper	0.231	0.228	0.385	0.431	-0.005	-0.011
	(0.69)	(0.69)	(2.50)	(2.22)	(-0.04)	(-0.08)
Proper-Agglomeration	2.002	2.004	1.364	1.079	0.942	0.950
	(3.13)	(3.15)	(1.99)	(1.69)	(2.25)	(2.30)
Agglomeration-Unknown	-1.723	-1.719	-0.109	0.596	-0.919	-0.935
	(-1.86)	(-1.87)	(-0.14)	(0.82)	(-0.91)	(-0.94)

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... table 11 continued

	Africa		Latin America		Asia	
	OLS	RE	OLS	RE	OLS	RE
Agglomeration-Proper	-2.557	-2.560	0.222	1.136	0.353	0.395
	(-2.10)	(-2.11)	(0.16)	(0.90)	(0.61)	(0.69)
Agglomeration-Metro. Area	-0.193	-0.191	0.594	-0.002	3.009	2.692
	(-0.07)	(-0.07)	(0.75)	(-0.00)	(2.22)	(2.01)
Metro. Area-Metro. Area	-0.334	-0.328	0.037	-0.308	-0.163	-0.094
	(-0.37)	(-0.36)	(0.12)	(-0.86)	(-0.25)	(-0.14)
Others-Others	0.000		-4.136	-1.434	3.534	3.516
	(.)		(-1.77)	(-0.66)	(5.23)	(5.02)
Constant	0.705	0.697	0.727	0.548	0.918	0.749
	(1.35)	(1.34)	(3.72)	(2.40)	(4.69)	(3.53)
σ_u		0.205		1.168		0.840
		(.)		(18.34)		(12.82)
σ_ε		4.043		2.025		2.893
		(72.22)		(64.19)		(93.97)

Table 12: Fixed-effects city growth regression models, by region. Models without controls for city size.

	All	Africa	Latin America	Asia
Start-of-period Urban TFR	1.231	0.703	1.092	1.673
	(20.24)	(4.37)	(9.28)	(19.00)
Start-of-period Urban Q5	-0.010	0.013	-0.003	-0.024
	(-6.25)	(3.61)	(-0.63)	(-12.02)
Unknown-Unknown	1.227	0.463	0.105	1.535
	(4.73)	(0.61)	(0.29)	(4.37)
Unknown-Proper	1.079	1.235	0.637	0.954
	(4.02)	(1.73)	(1.73)	(2.57)
Unknown-Agglomeration	0.940	0.432	0.232	1.112
	(2.83)	(0.44)	(0.57)	(2.39)
Unknown-Metro. Area	0.077	-0.066	-1.055	1.561
	(0.17)	(-0.02)	(-2.47)	(1.21)
Proper-Unknown	1.343	1.191	1.277	0.311
	(4.18)	(1.39)	(3.36)	(0.50)
Proper-Proper	0.283	0.126	0.333	-0.068
	(1.16)	(0.21)	(0.96)	(-0.20)
Proper-Agglomeration	1.567	2.333	0.907	1.194
	(4.66)	(3.24)	(1.34)	(2.60)
Agglomeration-Unknown	-0.584	-1.378	1.147	-0.633
	(-1.06)	(-1.33)	(1.49)	(-0.59)
Agglomeration-Proper	-0.145	-3.001	1.859	0.427
	(-0.27)	(-2.20)	(1.41)	(0.66)
Agglomeration-Metro. Area	0.336	-0.051	-0.724	1.921
	(0.38)	(-0.02)	(-0.93)	(1.28)
Metro. Area-Metro. Area	-0.172	1.668	-0.995	0.364
	(-0.32)	(0.68)	(-2.09)	(0.40)
Others-Others	1.259	0.000	0.173	1.334
	(1.03)	(.)	(0.08)	(1.08)
Constant	0.119	-0.338	0.611	0.002
	(0.53)	(-0.45)	(2.07)	(0.01)

Table 13: Regressions with national vital rates, all UN cities

	Model 1		Model 2	
	OLS	Random-Effects	OLS	Random-Effects
National TFR	0.697	0.751	0.593	0.634
	(22.92)	(23.52)	(18.92)	(19.28)
National Q5	-0.004	-0.005	-0.004	-0.005
	(-5.81)	(-6.73)	(-5.59)	(-6.99)
Inland Water	0.266	0.257	0.381	0.403
	(4.08)	(3.38)	(5.80)	(5.20)
LECZ	-0.235	-0.285	-0.209	-0.264
	(-2.60)	(-2.67)	(-2.33)	(-2.47)
Dry subhumid	-0.656	-0.649	-0.654	-0.651
	(-6.38)	(-5.45)	(-6.40)	(-5.44)
Semiarid	-0.499	-0.487	-0.452	-0.449
	(-5.41)	(-4.51)	(-4.94)	(-4.13)
Arid and above	-0.424	-0.432	-0.382	-0.403
	(-3.27)	(-2.88)	(-2.97)	(-2.68)
LECZ * Dry subhumid	0.726	0.737	0.685	0.683
	(4.33)	(3.73)	(4.12)	(3.43)
LECZ * Semiarid and above	0.654	0.626	0.630	0.613
	(3.59)	(2.92)	(3.48)	(2.84)
100,000–500,000			-0.805	-0.905
			(-10.73)	(-11.51)
500,000–1 million			-1.000	-1.311
			(-7.18)	(-8.95)
Over 1 million			-1.270	-1.594
			(-8.35)	(-9.33)
Unknown-Unknown	0.684	0.777	0.500	0.530
	(6.13)	(6.21)	(4.46)	(4.19)
Unknown-Proper	1.180	1.119	0.899	0.777
	(7.77)	(7.07)	(5.88)	(4.86)
Unknown-Agglomeration	0.230	0.346	0.277	0.362
	(0.80)	(1.22)	(0.97)	(1.29)
Unknown-Metro. Area	-0.416	-0.384	-0.292	-0.293
	(-1.12)	(-1.04)	(-0.79)	(-0.80)
Proper-Unknown	1.590	1.508	1.202	1.027
	(6.88)	(6.48)	(5.19)	(4.39)
Proper-Proper	0.362	0.347	-0.007	-0.089
	(3.64)	(3.08)	(-0.07)	(-0.76)
Proper-Agglomeration	1.602	1.556	1.520	1.413
	(5.27)	(5.20)	(5.03)	(4.76)
Agglomeration-Unknown	-1.016	-0.932	-0.857	-0.784

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... table 13 continued

	Model 1		Model 2	
	OLS	Random-Effects	OLS	Random-Effects
	(-1.97)	(-1.84)	(-1.67)	(-1.56)
Agglomeration-Proper	-0.348	-0.293	-0.494	-0.465
	(-0.70)	(-0.60)	(-1.00)	(-0.96)
Agglomeration-Metro. Area	1.235	0.988	1.463	1.212
	(1.53)	(1.25)	(1.83)	(1.54)
Metro. Area-Metro. Area	0.056	-0.003	0.314	0.294
	(0.18)	(-0.01)	(0.99)	(0.85)
Others-Others	3.462	3.445	2.714	2.608
	(5.00)	(4.79)	(3.93)	(3.62)
Constant	0.934	0.817	1.958	2.050
	(6.68)	(5.30)	(12.06)	(11.40)
σ_u		0.993		1.032
		(21.96)		(23.11)
σ_ε		3.037		3.001
		(131.42)		(130.90)

Table 14: Regressions with observed urban vital rates, cities with such information available

	Model 1		Model 2	
	OLS	Random-Effects	OLS	Random-Effects
Urban TFR	0.525	0.564	0.428	0.465
	(5.91)	(6.16)	(4.87)	(5.13)
Urban Q5	0.003	0.004	0.002	0.002
	(1.36)	(1.52)	(0.86)	(0.96)
Inland Water	0.201	0.172	0.303	0.283
	(1.86)	(1.50)	(2.82)	(2.49)
LECZ	-0.465	-0.404	-0.419	-0.380
	(-3.14)	(-2.53)	(-2.87)	(-2.43)
Dry subhumid	-0.355	-0.315	-0.310	-0.285
	(-2.19)	(-1.87)	(-1.94)	(-1.72)
Semiarid	-0.406	-0.341	-0.248	-0.202
	(-2.60)	(-2.08)	(-1.61)	(-1.26)
Arid and above	-0.418	-0.487	-0.278	-0.338
	(-1.64)	(-1.83)	(-1.11)	(-1.30)
LECZ * Dry subhumid	0.716	0.635	0.644	0.586
	(2.42)	(2.04)	(2.22)	(1.92)
LECZ * Semiarid and above	0.434	0.393	0.335	0.309
	(1.28)	(1.07)	(1.00)	(0.87)
100,000–500,00			-1.124	-1.061
			(-9.04)	(-8.38)
500,000–1 million			-1.059	-1.076
			(-4.83)	(-4.89)
Over 1 million			-1.298	-1.261
			(-5.50)	(-5.19)
Unknown-Unknown	1.012	1.306	0.846	1.092
	(4.91)	(6.10)	(4.03)	(5.03)
Unknown-Proper	0.439	0.655	0.063	0.243
	(1.87)	(2.81)	(0.27)	(1.03)
Unknown-Agglomeration	-0.056	0.408	-0.138	0.278
	(-0.12)	(0.94)	(-0.30)	(0.64)
Unknown-Metro. Area	-0.101	0.183	0.082	0.305
	(-0.12)	(0.23)	(0.10)	(0.39)
Proper-Unknown	0.154	0.236	-0.052	-0.001
	(0.14)	(0.22)	(-0.05)	(-0.00)
Proper-Proper	0.189	0.187	-0.369	-0.350
	(1.09)	(1.05)	(-1.94)	(-1.80)
Proper-Agglomeration	0.392	0.374	0.455	0.395
	(0.64)	(0.63)	(0.75)	(0.67)

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... table 14 continued

	Model 1		Model 2	
	OLS	Random-Effects	OLS	Random-Effects
Agglomeration-Unknown	0.285	1.112	0.644	1.278
	(0.12)	(0.51)	(0.27)	(0.59)
Agglomeration-Proper	0.019	0.229	-0.719	-0.493
	(0.02)	(0.23)	(-0.73)	(-0.51)
Agglomeration-Metro. Area	0.338	0.341	0.403	0.426
	(0.36)	(0.39)	(0.44)	(0.49)
Metro. Area-Metro. Area	0.207	0.320	0.302	0.405
	(0.47)	(0.69)	(0.68)	(0.88)
Constant	1.212	0.991	2.547	2.319
	(4.97)	(3.90)	(8.87)	(7.76)
σ_u		1.424		1.347
		(17.02)		(15.51)
σ_ε		1.945		1.946
		(34.28)		(34.17)