Mapping the Risks of Climate Change in Developing Countries

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Abstract

This paper examines the climate-related risks that will face the urban populations of developing countries in the decades to come. We base our study on a new and comprehensive database that draws upon city size and growth data for several thousand cities in the developing world (United Nations 2008) and which—for the first time—situates these data spatially, making use of the highly detailed geographic information on both urban and rural populations that has been assembled in the Global Rural–Urban Mapping Project (SEDAC 2008; Balk forthcoming). These data are joined to spatially-coded time series on weather-related and other disasters as well as to spatially-specific information on temperature. This combination of data supplies the basis for detailed estimates of the climate-related risks that will confront urban populations in poor countries. To be sure, much of the urban investment needed to ready cities to meet these risks will be determined by national and local-level decision-makers, who will need to know more about the location and nature of risks than global datasets can currently provide. To show what is involved in connecting global models and data such as ours to country-specific and local-level needs, we carry out a case study of India, whose cities are likely to face mounting risks from storm surges, flooding, and episodes of extreme heat.

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1 Overview

Urban dwellers are more likely to be exposed to the risks of storm surges, cyclones, hurricanes, and other severe coastal disturbances than are rural villagers (Alley et al. 2007; McGranahan et al. 2007). This is in part because urbanites are more likely to live on or near the coast: cities and towns account for nearly two of every three residents of coastal areas world-wide (McGrahanan et al. 2005). In Asia, nearly one of every five urban residents lives in low-lying coastal areas, as against one out of every eight persons in the Asian population as a whole.

Enough is now known of the climate-change risks that will face poor countries to sketch the elements of an urban adaptation strategy (Huq et al. 2007; McGranahan et al. 2007; Satterthwaite et al. 2007). According to current estimates, gradual increases in sea level are now all but inevitable over the coming decades, and this will place large coastal urban populations under threat. Alley et al. (2007) forecast rises in sea level of between 0.2 and 0.6 meters by 2100, which will be accompanied by periods of exceptionally high precipitation, more intense typhoons and hurricanes, and episodes of severe thermal stress. (The health effects of heat waves have not been much studied in the developing countries, but the effects in Europe and the United States have been well-documented.) In Asia, many of the region's largest cities are located in the flood-plains of major rivers (the Ganges–Brahmaputra, Mekong, and Yangtze rivers) and in coastal areas that have long been cyclone-prone. Mumbai saw massive floods in 2005, as did Karachi in 2007. Flooding and storm surges also present a threat in coastal African cities (e.g., Port Harcourt, Nigeria, and Mombasa, Kenya) and in Latin America (e.g., Caracas, Venezuela).[1]

Urban flooding risks in poor countries stem from a number of factors: the predominance of impermeable surfaces that cause water run-off; the general scarcity of parks and other green spaces to absorb these 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 urban flooding takes place, fecal and other hazardous materials contaminate flood waters and spill into open wells, elevating the risks of water-borne disease. 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 riskier areas.

[1] See Douglas et al. (2008) on urban flooding in Africa and Awuor et al. (2008) for the case of Mombasa, Kenya.

2 New data: Mapping the populations at risk

To assess the risks that global climate change presents for the city and town dwellers of poor countries, it is vitally important to know who lives where—that is, to know enough about the locations of the people who will be facing climate change 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 does projecting where migration will swell the populations of towns and cities that lie 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 populations and risks had not been drawn together.

Over the past several years, many of the necessary elements have been assembled in a large-scale collaborative effort involving the United Nations Population Division, the Global Urban–Rural Mapping Project housed at the Socioeconomic Data Applications Center (SEDAC) at Columbia University's Earth Institute, and researchers based at Baruch College and the Population Council. For every country of the developing world, population data can now be mapped according to the most finely-disaggregated administrative units that could be obtained, and for cities with 100,000 population and above, information on city population growth over time has been drawn from the most recent version of the United Nations Population Division's remarkable cities database (United Nations 2008). The research team has extended the reach of the UN data to include hundreds of additional observations on small cities and towns (accounting for a significant percentage of all developing-country urban residents), which were collected in the course of the 2008 update of SEDAC's Global Urban-Rural Mapping Project (SEDAC 2008; Balk forthcoming). Each urban settlement is located in spatial terms by its latitude and longitude coordinates, and also by an overlay indicating the spatial extent of the urban agglomeration, which itself is derived from remotely-sensed satellite imagery (Elvidge et al. 1997; Balk et al. 2005; Small et al. 2005).

In their 2007 paper in *Environment and Urbanization*, McGranahan et al. (2007) showed how such data resources 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, an elevation that is above the expected rise in sea levels according to current forecasts but which lies within the reach of the effects of severe cyclones and storm surges. As the authors explain, this particular definition of *low-elevation coastal zone* was chosen to allow for global estimation of the population at risk; it can be greatly refined for individual countries, as we will show for the case of India.

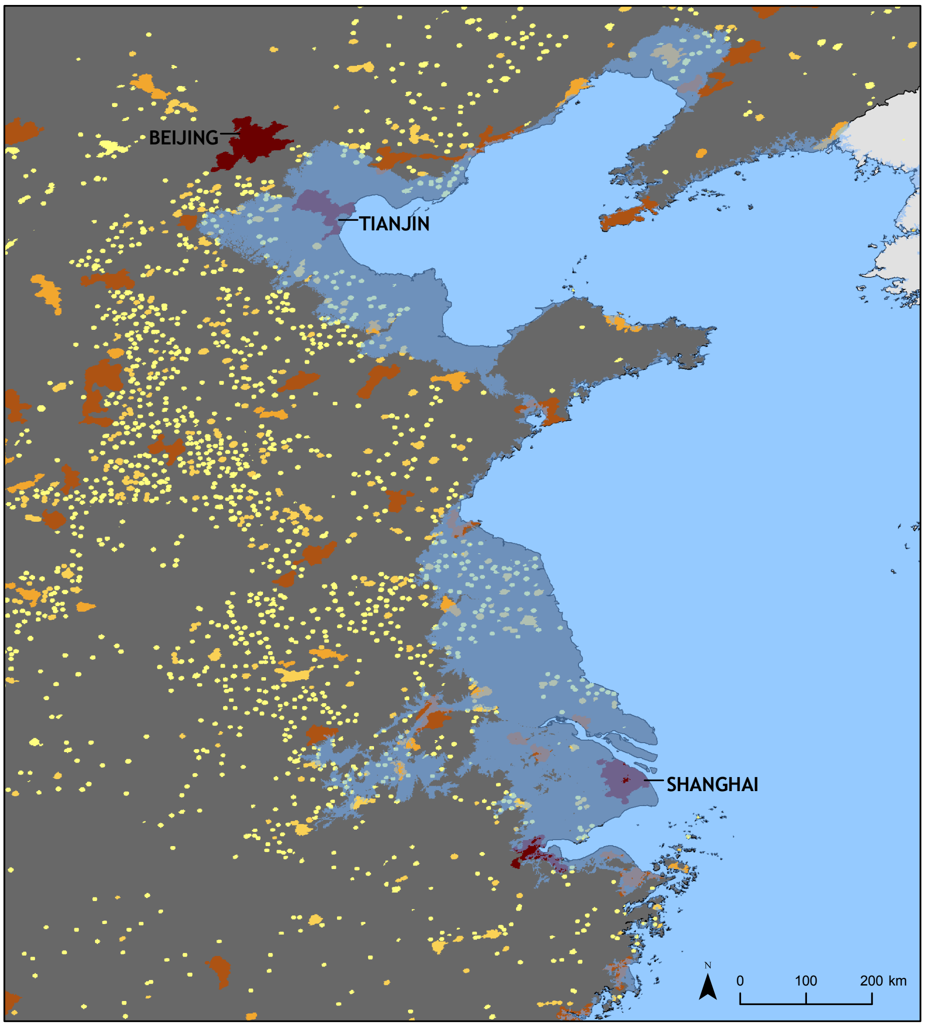

Figure 1: Combined UN and GRUMP urban data for Beijing, Tianjin, Shanghai and their environs, China. Low-elevation coastal zone depicted in medium blue shading. Source: McGranahan et al. (2007).

The maps that accompany this abstract (Figures 1–3) illustrate the possibilities of the combined data. Figure 1 presents a broad-scale overview of the cities and large towns that lie in the low-elevation zone of China near Beijing, Tianjin, and Shanghai. Large urban areas are shown as dark blobs in the figure, and smaller cities 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 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 regions of Bangladesh. Here some 63 million persons live in the low-elevation coastal zone, with 15 million of them being urban residents.

3 Adding hazards and temperature data

The research team is now linking in additional information on risks from the UN–World Bank disasters database and is adding further geographic detail on spatial differences in temperature, rivers prone to flooding, and other measures that are accessible in global databases.

Some of these new materials are drawn from the project described by Dilley et al. (2005), led by the Columbia University Center for Hazards and Risk Research (CHRR), CIESIN, and the World Bank, with UNDP, UNEP, the International Research Institute for Climate Prediction (IRI), and the Norwegian Geotechnical Institute (NGI). This group systematically compiled data on several hazards for which global data sets did not previously exist, including drought, cyclones, and landslides. In their analysis, drought, flood, and volcano hazards are characterized in terms of event frequency, storms by their frequency and severity, earthquakes by frequency and the probability of exceeding a set threshold of peak ground acceleration, and landslides by an index derived from the probability of occurrence. This group has also produced estimates of both mortality and (for about 50 countries) the economic losses that stem from such events.[2] These data are currently being updated.

Another important bio-physical series that we will integrate provides measures of average annual, seasonal, and monthly temperature data for urban and rural areas. These series are based on the Hansen Global Temperature Index (Hansen and

[2]The data are checked against disaster databases maintained by the Centre for Research on the Epidemiology of Disasters (CRED), based at the School of Public Health of the Catholic University of Louvain in Belgium. CRED maintains EMDAT, a worldwide database that documents the occurrence and effects of some 16,000 natural and technological disasters in the world from 1900 to the present. The database—available from `www.cred.be`—is compiled from multiple sources and its entries are carefully reviewed for accuracy and completeness. See Tschoegl et al. (2006).

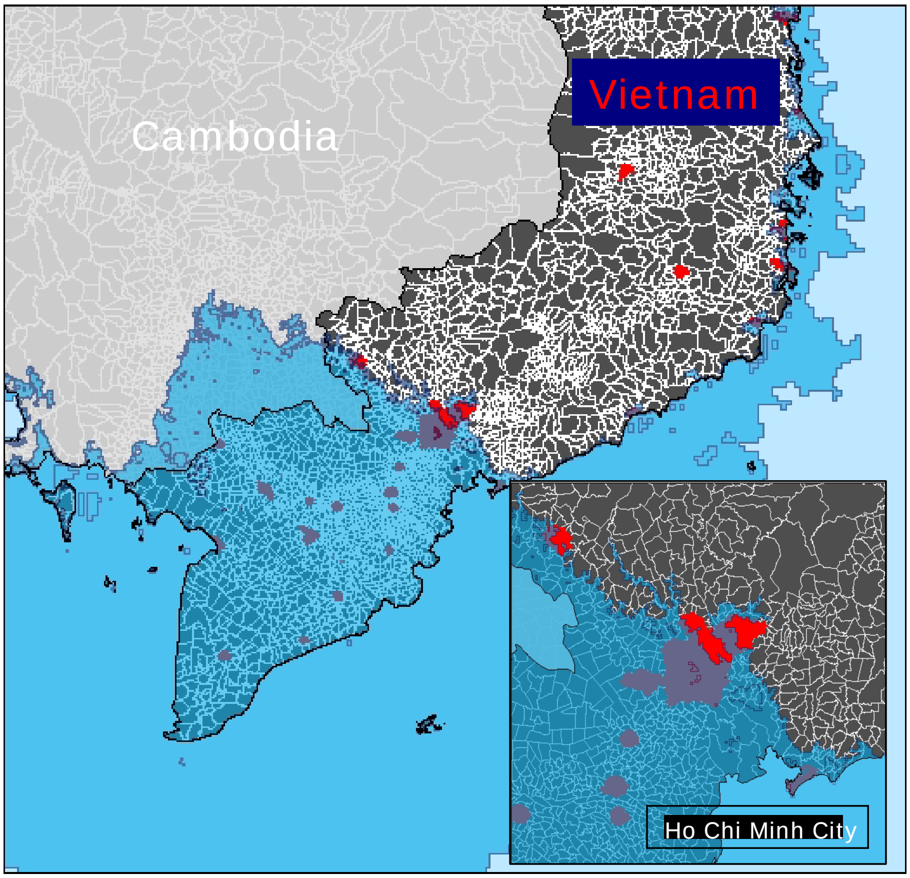

Figure 2: Combined UN and GRUMP urban data for southern Vietnam, with inset showing how the low-elevation coastal zone intersects the city of Ho Chi Minh. Low elevation coastal zone depicted in blue. Detailed administrative boundaries indicated in light shading. Source: SEDAC (2008).

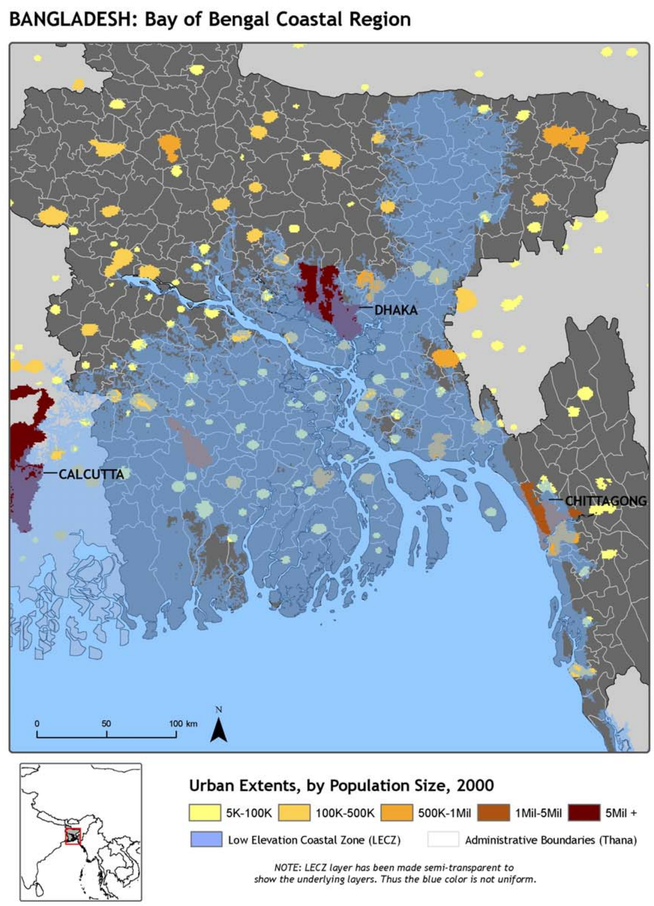

Figure 3: Combined UN and GRUMP urban data for Bangladesh, showing the low-elevation coastal zone (in medium blue shading). Urban areas depicted in light shading. Source: SEDAC (2008).

Lebedeff 1987)—a hundred-year historical record compiled from meteorological stations and transformed into a gridded surface—which can be used to construct spatially coarse estimates of temperature variation between cities.[3] Some of the temperature estimates are based on interpolations between meterological stations rather than precise within-city measurements. Although less spatially-specific than would be ideal, these data will at least allow us to construct zonal temperature estimates for individual cities.

Although similar studies exist for a few individual cities and countries, no previous global study of which we are aware has systematically distinguished urban from rural risk exposures in these important dimensions. For each city in our combined demographic and bio-physical dataset, we know the geographic extent of its settlement area that falls within the low-elevation coastal zone as well as the documented exposure to recent hazards: cyclones, droughts, floods, landslides, earthquakes, and volcanoes, as well as multi-hazard exposure (Dilley et al. 2005).

4 The India case study

In India and elsewhere in South Asia, the risks facing populations in low elevation coastal zones have received considerable attention (Dasgupta et al. 2007). About three-quarters of India's 7500 kilometers-long coastline is beset by cyclones, with the eastern coast and Gujarat being especially cyclone-prone. (See Figure 4 for this state's low-elevation coastal zone.) According to Gupta (2005), who has reviewed a host of Indian studies, an increase in sea level of 1 meter would inundate 1,700 square kilometers of prime agricultural land in Orissa and West Bengal alone. The projected monetary value of losses range from Rs 2,287 billion for Mumbai in Maharashtra State to Rs 3.6 billion for Balasore in Orissa. Some 40 million hectares of the country's land and 68 percent of net sown area are thought to be vulnerable to floods. Over half of India's total area lies in seismic zones at risk of earthquakes, and the Sub-Himalayan/Western Ghat region is afflicted by landslides. It appears that considerations of sea-level rise and natural hazards including earthquakes have not been fully taken into account in determining the location of industries, as is amply evident in the case of the city of Jamnagar in Gujarat. With a population of over half a million, this city lies in the high-risk Seismic Zone IV; and yet it is also home to India's oil refineries, which include the world's largest.[4]

[3] See `http://data.giss.nasa.gov/gistemp` for further discussion.

[4] Sanderson and Sharma (2008) discuss the aftermath of the massive earthquake in Gujarat in January 2001.

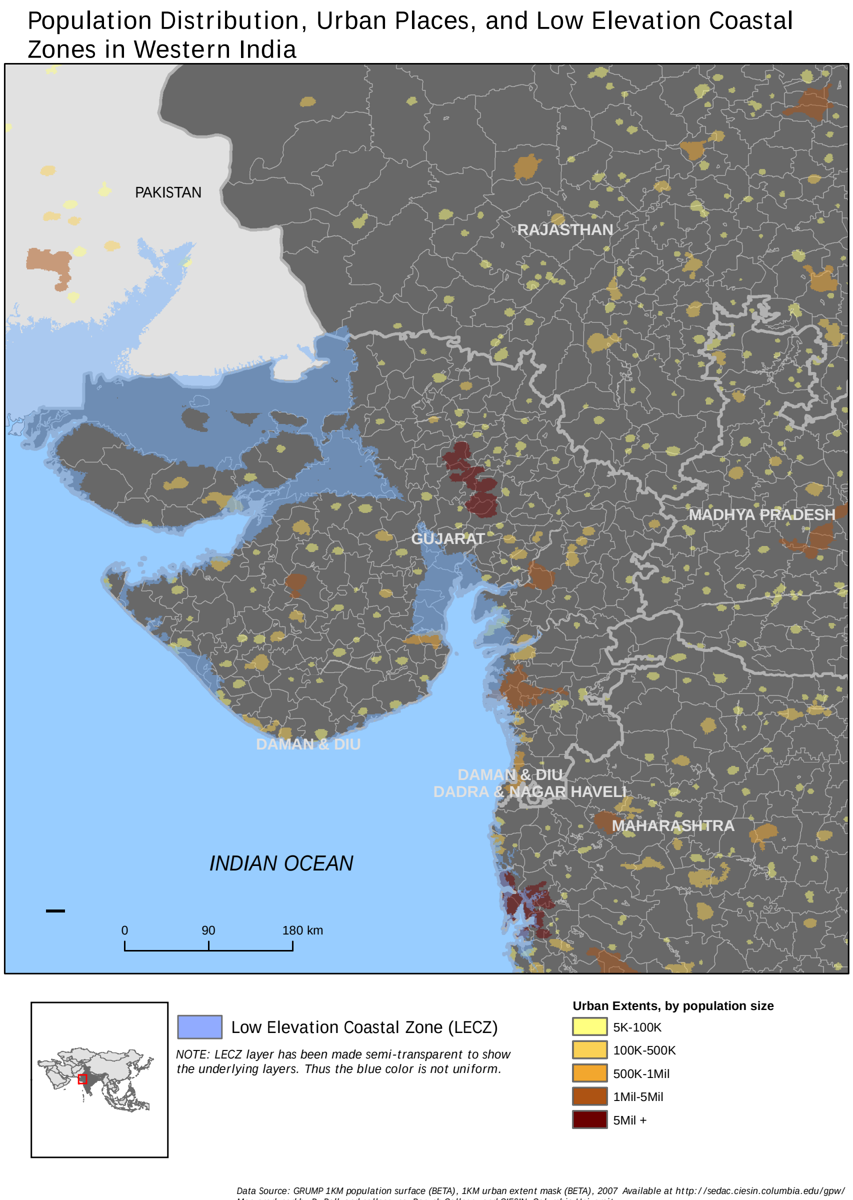

Figure 4: Combined UN and GRUMP urban data for Gujarat and neighboring states, India, showing the low-elevation coastal zone (in medium blue shading). Urban areas depicted in light shading. Source: SEDAC (2008).

Table 1: Estimated losses from natural disasters, India

Year	People Affected Millions	Houses, Buildings Damaged	Property Damage Rupees Million
1985	59.56	2,449,878	400.6
1986	55	2,049,277	307.4
1987	48.34	2,919,380	205.7
1988	10.15	242,533	406.3
1989	3.01	782,340	204.1
1990	3.17	1,019,930	107.1
1991	34.27	1,190,109	109
1992	19.09	570,969	200.5
1993	26.24	1,529,916	508
1994	23.53	1,051,223	108.3
1995	54.35	2,088,355	407.3
1996	54.99	2,376,693	504.3
1997	44.38	1,103,549	n.a
1998	52.17	1,563,405	7.2
1999	50.17	3,104,064	10,209.7
2000	59.334	2,736,355	8000
2001	78.819	846,878	120,000

Data

There are many data sources from which a risk profile of India's districts and cities can be assembled. For example, detailed information on storms and tropical depressions is available through the publications of the India Meteorological Department (India Meteorological Department 1979, 1996). Further detail is available in reports published by National Disaster Management Division, Ministry of Home Affairs, Government of India and National Disaster Management Authority, Government of India. In addition to the city and town population data in the combined UN–GRUMP dataset described above, detailed population characteristics data are available from the Indian Censuses of 1991 and 2001. These data will help identify migration flows and pinpoint the fastest-growing cities and towns.

We can also identify the economic assets at risk by using the information on plant locations, installed capacities, and production levels of Indian companies.[5]

[5] We are grateful to IRIS Business Services (India) Private Limited for giving us access to the IRIS India Corporate database. The database covers the universe of listed companies. Note that in 1991,

An overview of the information available on population and assets at risk by geographical location is given in Table 2.

The Indian policy response

> *The country with its federal system of Government has specific roles for the Central and State Governments. However, the subject of disaster management does not specifically find mention in any of the three lists in the 7th Schedule of the Indian Constitution, where subjects under the Central and State Governments [and] also subjects that come under both are specified. On the legal front, there is no enactment either of the Central or of any State Government to deal with the management of disasters of various types in a comprehensive manner.*
>
> - Government of India 2004

A belated but welcome paradigm shift is underway in Indian policy that is placing increasing emphasis on disaster prevention and mitigation. India's Tenth Five Year Plan addressed the issue of disaster mitigation in general, but fell well short in terms of specifics and resource allocation.[6] Even at the time of this Plan, government efforts continued to concentrate on the narrower tasks of ensuring that relief and rehabilitation efforts followed in the wake of natural disasters. It was only in 2005 that disaster management was finally given the explicit attention that it deserves by the Government of India.

With the passage of the Disaster Management Act, 2005, the National Disaster Management Authority was established with the Prime Minister of India as the *ex officio* chairperson. The states of Arunachal Pradesh, Goa, Gujarat, Himachal Pradesh, Kerala, Mizoram, Puducherry, Punjab, and Uttar Pradesh subsequently constituted state-level disaster management authorities. The National Action Plan on Climate Change has suggested a 'multi pronged, long-term and integrated strategy,' consisting of eight core missions. These are: National Solar Mission, National Mission for Enhanced Energy Efficiency, National Mission on Sustainable Habitat, National Water Mission, National Mission for Sustaining the Himalayan Ecosystem, National Mission for a Green India, National Mission for Sustainable Agriculture and National Mission on Strategic Knowledge for Climate Change. Many programmes have been initiated and a disaster risk management programme, jointly

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there was a significant relaxation of policies that had previously governed the location of industries. Before then, manufacturing units were not allowed to be located within cities of 1 million population and above, a restriction that shaped the geographical patterns of industrialization and may have also affected the level of urbanization overall.

[6] See Government of India (2008: 208).

Table 2: Evaluating Population and Economic Activity at Risk, India

Geographical	Key Indicators
State	Employment, Poverty, Value of Output in Organised and Unorganised Manufacturing
15 Agro-climatic Zones	Employment, Poverty, Value of Output in Organised and Unorganised Manufacturing
15 Agro-climatic Zones	Access and Utilization of Common Property Resources in Rural India
77 NSS Regions	Employment, Poverty, Value of Output in Organised and Unorganised Manufacturing
Districts of India	Employment, Poverty, Value of Output in Organised and Unorganised Manufacturing
Cities	Location of Manufacturing Plants
Cities	Estimates of Employment, Poverty, Value of Output in Organised and Unorganised Manufacturing
In Relation to Cities	Location of Rivers
In Relation to Cities	Location of Dams
In Relation to Cities	Location of Polluting Industries (Relate this to the data on Air Pollution)
In Relation to Cities	Location of Power Plants
In Relation to Cities	Location of Manufacturing Plants
In Relation to Cities	Development of Indsutrial Clusters - UNIDO has a very active cluster development programme
In Relation to Cities	Development of Industrial Towns
Time Series: Incidence of (by City)	Floods
Time Series: Incidence of (by City)	Earthquakes
Time Series: Incidence of (by City)	Plagues and other Diseases

funded by Government of India and the United Nations Development Programme, is now in place (Government of India 2002a,b).[7] It has at last been recognized that new infrastructure and economic projects should not be commissioned in areas classified as high risk—the Eleventh Five Year Plan laid out this new view in 'Principles for Project Appraisal from the Disaster Management Perspective'.

Even so, as Revi (2008) discusses in a detailed analysis of urban adaptation needs in India, governments from the local to national levels will need to take further steps in anticipation of extreme-weather events. The Indian Ocean tsunami of 2005 heightened attention to coastal zone management in India and the region, but to judge from Revi's account, the responsibilities for urban adaptation and disaster management have been strewn across the bureaucratic landscape and are not yet organized in any coherent manner. Revi puts special emphasis on what is termed the "lifeline" infrastructure needed to cope with extreme events: the roads, bridges and other transport systems; water, sewer, and gas pipelines; infrastructure for coastal defenses and drainage; the power and telecommunications infrastructure that are of vital importance during disasters; arrangements made with local non-governmental and relief agencies for alerting populations to imminent threats and responding to disaster; and the hospitals, fire and police stations, schools, military forces and other first-responders involved during the onset and aftermath of such disasters (Satterthwaite et al. 2007; McGranahan 2007). Many of the priority areas needing attention are already areas of concern on other counts—for instance, improvements in water and sanitation systems for the urban poor—but the prospects of climate change adds a new element of urgency to them.

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[7]Important initiatives include: the National Earthquake Risk Mitigation Project; Accelerated Urban Earthquake Vulnerability Reduction Programme; Mainstreaming Mitigation in Rural Development Schemes; National Cyclone Mitigation Project; Landslide Hazard Mitigation; Disaster Risk Management Programme in 169 Districts; and Disaster Awareness in School Curriculum.

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