Climate change risk: an adaptation and mitigation agenda for Indian cities

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ABSTRACT This paper considers the needed adaptation and mitigation agenda for cities in India – where the urban population is likely to grow by around 500 million over the next 50 years. It considers the likely changes that climate change will bring in temperature, precipitation and extreme rainfall, drought, river and inland flooding, storms/storm surges/coastal flooding, sea-level rise and environmental health risks, and who within urban populations are most at risk. It notes the importance for urban areas of an effective rural adaptation agenda – especially in maintaining the productivity and functioning of rural systems. It highlights the importance of today's infrastructure investments, taking into account climate changes, given the long lifespan of most infrastructure, and the importance of urban management engaging with changing risk profiles. One important part of this is the need to connect official adaptation initiatives to the much-improved natural hazard risk assessment, management and mitigation capacity that responded to major disasters. The paper ends by describing a possible urban climate change adaptation framework, including changes needed at the national, state, city and neighbourhood levels, and linkages to mitigation.

KEYWORDS adaptation / climate change / mitigation / urban disasters

I. INTRODUCTION

India is one of the more vulnerable and risk-prone countries in the world.[1] Over the centuries, its population has learned to cope with a wide range of natural and human-made hazards. Rapid population growth, high densities, poverty and high differentials in access to housing, public services and infrastructure have led to an increase in vulnerability over the last few decades, especially in India's urban centres.

Climate change is expected to increase the frequency and intensity of current hazards and the probability of extreme events, and also to spur the emergence of new hazards (e.g. sea-level rise [2]) and new vulnerabilities with differential spatial and socioeconomic impacts. This is expected to further degrade the resilience of poor, vulnerable communities, which make up between one quarter and one half of the population of most Indian cities.[3] Climate change is set to become an increasingly important strategic economic and political concern as it starts to eat into India's high economic growth rates and affect the lives and livelihoods of millions of people.

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Overall risk in Indian cities typically is associated more with vulnerability than hazard exposure. It is therefore important to understand a number of processes that are rapidly changing India's urban landscape, altering livelihood opportunities and wealth distribution, which in turn affect the vulnerability of many communities and stakeholders and their capacity to adapt to long-term risks.

This analysis focuses on an adaptation-led strategy to reduce climate change risk and increase urban resilience in keeping with India's development priorities and challenges. It shifts the emphasis from the mitigation and techno-centric response that has come to dominate the OECD-led climate crisis discourse, and suggests a more independent route to a more sustainable future.[4]

Climate change in India can be seen in the perspective of a three-part transition: a demographic transition that will see India's population stabilizing at about 1.6 billion in the 2060s; a simultaneous rural to urban (*RUrban*) transition, which will add nearly 500 million people to the country's urban settlements over this period; and a simultaneous environmental transition – brown (water, sanitation and environmental health), grey (air and water pollution) and green (climate change).[5] Multiple sub-regionally nuanced strategies will be needed to respond to the climate crisis, drawing on considerable local experience of coping with uncertainty and with systems far from equilibrium.

II. INDIA'S *RURBAN* TRANSFORMATION (2000–2050)

Unlike most of the rest of the world, South Asia has been marked by low levels of urbanization despite being one of the most urbanized pre-colonial regions of the eighteenth century.[6] Only about 30 per cent of India's population lived in urban areas in 2006,[7] but given its 1.1 billion-plus population, its urban population still exceeds that of Japan, the European Union and most other regions of the world except for the United States and China.[8] Over the next 40 years, India will experience one of the most dramatic settlement transitions in history, as its urban population grows from about 300 million to more than 700 million.[9] By 2025, an estimated 70 Indian cities are expected to have a population exceeding one million. Three mega-urban regions: Mumbai–Pune (50 million), the national capital region of Delhi (more than 30 million) and Kolkata (20 million) will be among the largest urban concentrations in the world.[10] By mid-century, India could have both the largest urban and rural populations of the time. This will have an important bearing on global climate vulnerability and the potential for mitigation and adaptation. Hence, the future direction of Indian urbanization is not only an important domestic concern but also a major international opportunity to demonstrate the viability of a more sustainable development.

Urban India overtook rural India in its share of GDP in the late 1990s, and urban per capita incomes are more than three times those in rural areas.[11] India's agricultural sector currently contributes only 18 per cent of GDP, although it provides livelihoods to almost 60 per cent of the population as well as the biomass and ecosystem services that enable the "metabolism" of most Indian cities to function.

Climate change-induced disruptions and the pre-emption in net primary productivity by human systems[12] could force many Indian cities

1. IFRC (2005), *World Disasters Report*, Geneva; also Parasuraman, S and P V Unnikrishnan (2000), *India Disasters Report*, Oxford University Press, New Delhi.

2. Nicholls, R J and J A Lowe (2006), "Climate stabilization and impacts of sea-level rise", in H J Schellnhuber, W Cramer, N Nakicenovic, T Wigley and G Yohe (editors), *Avoiding Dangerous Climate Change*, Cambridge University Press, pages 195–202.

3. Satterthwaite, David, Saleemul Huq, Mark Pelling, Hannah Reid and Patricia Lankao Romero (2007), "Adapting to climate change in urban areas; the possibilities and constraints in low- and middle-income nations", IIED Climate Change and Cities Series, Working Paper 1, London, 110 pages. e

4. De Vries, H J M, A Revi, G K Bhat, H Hilderink and P Lucas (2007), *India 2050: Scenarios for An Uncertain Future*, Netherlands Environment Assessment Agency (MNP), Bilthoven.

5. McGranahan, G et al. (2007a), "The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones", *Environment & Urbanization* Vol 19, No 1, April, pages 17–37.

6. Revi, A, N Dronin and B de Vries (2002), "Population and environment in Asia since 1600 AD", in B deVries and J Goudsblom (editors), *Mappae Mundi: Humans and their Habitats in a Long-Term Socio-Ecological Perspective*, Amsterdam University Press; also Banga, B (editor) (2005), *The City in Indian History: Urban Demography, Society and Politics*, Manohar, Delhi.

7. Census of India (2006), *Population Projections for India and States 2001–2026*, Office of the Registrar General and Census Commissioner, New Delhi.

8. United Nations (2006), *World Urbanization Prospects: The 2005 Revision*, United Nations, New York.

to adapt in the medium term by altering their extractive relationship with the countryside. *RUrbanism* or "keeping the balance between rural and urban areas" will become increasingly important in India, as rural–urban and inter-urban resource and socioeconomic conflict became sharper in the future.[13]

Migration in India has been constrained by a number of factors, including:

- a crisis in creating new urban formal-sector livelihoods in an era of globalization;
- dismal living and working conditions for the poor in cities;
- high urban poverty levels driven by high costs of living;
- poor improvements in rural education until the late 1990s; and
- a slow process of social transformation.[14]

It is possible, however, that climate change may force the pace of rural–urban migration over the next few decades. The ongoing agrarian crisis in rural India[15] could be catalyzed by climate change into a migratory rout, driven by increases in extreme events, greater monsoon variability,[16] endemic drought, and flooding and resource conflict.[17] (These scenarios have only been broadly articulated, but not systematically investigated with fine-grained GIS-linked models.[18])

Alternatively, severe stresses induced in urban areas due to a mix of water scarcity, the breakdown of environmental services, flooding and consequent water-borne diseases and malaria-type epidemics combined with a rapid rise in health expenditure could maintain the low current level of rural–urban migration. A greater mobility of the backward castes and women could also, in time, alter the migration dynamics across demographically dominant northern and eastern India. This indicates the potential for climate change (along with other driving factors) to induce bifurcation behaviour in migration, and hence urbanization, trends – questions that need to be investigated further.

Maintaining two-way flows of food, biomass, water, energy, livelihoods, products and services across the *RUrban* continuum will be crucial to India's "development transition" and medium-term sustainability. Climate change adaptation in both cities and their embedding countryside is an undiscovered near-term policy concern – intimately connected with livelihoods and drought, biomass and energy security.[19]

India, like China in the 1990s, is starting to massively ramp up infrastructure investment in the energy, water, transportation and telecommunications sectors, to support their growth and expansion. These systems have a typical service life of 50 to 150 years. More importantly, they are difficult to replace (if damaged or destroyed in extreme weather events), challenging to relocate (if necessary for effective adaptation) and may spur significant greenhouse gas contributions (if executed using business-as-usual technologies and management methods).

The challenge for India is to re-examine whether its current development trajectory and growth framework may be more appropriate than an exclusive engagement with mitigation and greener systems and production. A climate policy that has a closer fit with India's initial conditions, strengths and capacities may serve both the country and the world's purposes better than a "recycled" programme of action from a rather different context.

9. Hughes, B and E E Hillenbrand (2006), *Exploring and Shaping International Futures*, Paradigm, London.

10. Dyson, T and P Visaria (2004), "Migration and urbanization: retrospect and prospect", in T Dyson, R Cassen and L Visaria (editors), *Twenty-First Century India, Population, Economy, Human Development and the Environment*, Oxford University Press, New Delhi, pages 108–157; also Revi, A (2006a), *Long-range Macro-dynamics of Indian Urbanization in a Globalizing World*, Proceedings of the Conference on India and China in a Global Perspective, April 2006, New School, New York; and see reference 7.

11. CSO (2006), *National Accounts Statistics*, Central Statistical Organization, New Delhi; also Reserve Bank of India (2006), *Handbook of Indian Economic Statistics*, Mumbai.

12. Fischer-Kowalski, M and H Haberl (2007), *Socioecological Transitions and Global Change: Trajectories of Social Metabolism and Land Use*, Edward Elgar, Cheltenham.

13. Revi, A, S Prakash and R Mehrotra (2006b), "Goa 2100: the transition to sustainable design", *Environment & Urbanization* Vol 18, No 1, April, pages 51–65.

14. See reference 10, Revi (2006a).

15. Sainath, S (2002), *Everybody Loves a Good Drought: Stories from India's Poorest Districts*, Penguin, New Delhi.

16. Zickfeld, K et al. (2005), "Is the Indian summer monsoon stable against global change?", *Geophysical Research Letters* Vol 32, L15707, Potsdam Institute for Climate Impact Research, Potsdam, Germany.

17. Gosain, A K et al. (2006), "Climate change impact assessment on hydrology of Indian river basins", *Current Science* Vol 90, No 3, 10 February, pages 346–353; also Mall, R K et al. (2006), "Water resources and climate change:

III. URBAN RENEWAL, DISASTER MANAGEMENT AND CLIMATE CHANGE MITIGATION

India made a late start in engaging with questions of climate change despite early environmentalist and academic positions on these questions.[20] While climate change has started to creep into the post-Rio (1992)[21] global policy agenda, India has been preoccupied with pressing poverty, economic and social development and political challenges.

India has undertaken four officially supported national technical assessments of climate change risks, impacts, adaptation and mitigation options since 1992.[22] These assessments were all largely externally funded and driven, they were coordinated by the Ministry of Environment and Forests, which is far from being a politically powerful ministry, and they were primarily focused on the "science" of climate change, closely allied to the IPCC agenda and trends of analysis.[23] They were therefore weak in engaging with the complex nature and intensity of vulnerability in India, probably the most critical factor in risk mitigation.[24]

The official Indian position on climate change has been strongly tied to fixing responsibility for correcting historical emissions by the OECD countries.[25] Hence, it is focused largely on the greenhouse gas–energy nexus, its impact on energy security and technology transfer,[26] and the post-Kyoto opportunities for financial leverage from expected cross-national flows of capital; or as a fringe issue taken up by environmental NGOs and activists that has little to do with the mainstream economic "development" agenda.[27] The debate on adaptation has been weak despite a moderate Indian scientific presence in the IPCC process and an Indian IPCC Chair since 2002.[28]

A great missed opportunity in the last 15 years was the chance to connect the official climate change adaptation agenda with the rapid development of natural hazard risk assessment, management and mitigation capacity, after devastating disasters in the 1990s and the early 2000s. A series of moderately successful post-disaster reconstruction and mitigation programmes, especially after the Orissa super-cyclone (1999), the Kachchh earthquake (2001) and the Indian Ocean tsunami (2005), dramatically altered perceptions and the institutional and technical capacity to address vulnerability reduction and risk mitigation in India. India is one of the few large countries that have a central authority to address disaster management and similar well-developed institutions at state level.

The devastation wrought by the 2005 tsunami also brought a long-simmering concern to the fore – the integrated management of India's coastal zone, balancing environmental and biodiversity conservation, livelihood and economic development and risk mitigation concerns. A series of integrated coastal zone management plans are now in progress, along with a review of the principles for managing the coastal regulation zone. This will provide an important stepping stone for a more evidence-based set of climate mitigation and adaptation measures for coastal India and its cities – a key driver of medium-range economic growth and development.[29]

The other important post-2004 development is the reappearance of urban development, urban renewal and governance as a significant public policy agenda after a decade-long hiatus. The Jawaharlal Nehru National Urban Renewal Mission (JNNURM) was initiated in 2005 to target 60 of

an Indian perspective", *Current Science* Vol 90, No 12, 25 June, pages 1610–1626; and Ramesh, R and M G Yadava (2005), "Climate and water resources of India", *Current Science* Vol 89, No 5, 10 September, pages 818–824.

18. Rupa Kumar, P et al. (2006), "High-resolution climate change scenarios for India for the 21st century", *Current Science* Vol 90, No 3, 10 February, pages 334–345; also GSDMA/TARU (2005), *Gujarat Vulnerability and Risk Atlas*, Gandhinagar.

19. See reference 10, Revi (2006a).

20. Agarwal, A, S Narain and A Sharma (1993), *Green Politics: Global Environmental Negotiations,* Centre for Science and Environment, New Delhi.

21. IPCC (1995), *Second Assessment – Climate Change*, Geneva.

22. The first was supported by the Asian Development Bank; the second, the Asian Least Cost Greenhouse Abatement Study (ALCGAS) (see ADB (2002), *Asian Least Cost Greenhouse Abatement Study (ALGAS)*, Manila) was supported by the Global Environment Facility (GEF); the third was a climate impact assessment study funded by DEFRA, the government of the UK; and the fourth was the recently concluded National Communication Project supported by the GEF. See Sathaye, J et al. (2006), "Climate change, sustainable development and India: global and national concerns", *Current Science* Vol 90, No 3, 10 February, pages 314–325. There have also been a number of long-range resource, energy and sustainable development studies but these have had limited impact on the government of India agenda. See TERI (1998), *Looking Back to Think Ahead: GREEN India 2047*, Tata Energy Research Institute, New Delhi; also Planning Commission (2002), *India Vision 2020*, New Delhi.

the most important cities with a US$ 10 billion challenge fund to address infrastructure development, urban poverty and urban governance.

A chasm exists between the official urban "city building" development agenda and vulnerability reduction for those most at risk in these urban areas. The Indian state and its elite have been ambivalent in accepting the centrality of the poor in the process of urban development and economic growth. The imperative of delivering adequate services (water, sanitation, solid waste, drainage, power) and equitable access to land and housing to the bulk of city residents is still a matter of contention. This ongoing institutional and cultural failure has been documented for decades, but the current scale of demolitions and relocations is compounding the vulnerability of many urban residents.

Breaking this impasse will be central to the next conceptual leap of political and bureaucratic attention – from the state provisioning of basic services, access to livelihoods and housing, to alternative mechanisms for ensuring their sustainable provisioning, functioning and financing. This can be supported through multiple variants of community–public–private partnerships. The role of risk reduction and climate change adaptation in lowering the mounting social costs of recurrent disasters will need to be situated around action in this space. However, no JNNURM component addresses either urban vulnerability or risk mitigation. This will call for advocacy by the climate change community and would need to be linked to sustainable city and regional development initiatives.[30] Otherwise, urban adaptation and mitigation could be limited to signing operationally meaningless memoranda of understanding between Indian and OECD cities, official junkets and press releases, with little impact on the most vulnerable.

An important post-1990 factor is the emergence of city-level political processes – community and people's movements – that have started contesting from "below" for "space" for the poor within many cities. This has been accompanied by NGO and judicial activism on a range of environmental questions, which unfortunately have had little impact on more proletarian concerns such as environmental health, which could dramatically reduce the risk exposure of poor households. These currently fractured forces, if adequately mobilized, could provide a base for future citywide, community-based risk mitigation efforts that are crucial to the success of climate change risk adaptation. A parallel but often conflicting development is the increasing concern of the elite with the quality of urban life, security and the sustainability of various urban services. But here again, enlightened self-interest has not come to terms with the challenges and opportunities that the transformation of India's cities present. Concerns for "carbon neutral" lifestyles and enterprises and for higher quality of life must converge with harsh realities on the ground. This remains a largely unexplored area.

IV. INDIA'S CLIMATE CHANGE RISK EXPOSURE

Most Indian communities and institutions have a history of coping with uncertainty and extreme events with great equanimity. However, the current pressure on resources, high population densities and ongoing rapid economic, technological and slower social changes imply that a mix of institutional, market- and community-led mitigation and adaptation

23. TERI (2004), *India Specific Impacts of Climate Change*, Tata Energy Research Institute, New Delhi.

24. Revi, A (2005), "Lessons from the deluge: priorities for multi-hazard risk mitigation in Mumbai", *Economic and Political Weekly* Vol XL, No 36, September 3–9, pages 3911–3916.

25. Parikh, J K and K Parikh (2002), *Climate Change: India's Perceptions, Positions, Policies and Possibilities*, OECD, Paris.

26. Socolow, R and S Pacala (2004), "Stabilization wedges: solving the climate problem for the next 50 years with current technologies", *Science* Vol 305, No 5686, 13 August, pages 968–972.

27. Planning Commission (2006), *Report of the Expert Committee on an Integrated Energy Policy*, New Delhi; also see reference 22, Sathaye et al. (2006); Sharma, S, S Bhattacharya and A Garg (2006), "Greenhouse gas emissions from India: a perspective", *Current Science* Vol 90, No 3, 10 February, pages 326–333; Shukla, P R (2006), "India's GHG emission scenarios: aligning development and stabilization paths", *Current Science* Vol 90, No 3, 10 February, pages 384–395; Shukla, P R et al. (2003a), *Development and Climate – An Assessment for India*, Indian Institute of Management, Ahmedabad; and Gupta, Vijaya (2005), "Climate change and domestic mitigation efforts, *Economic and Political Weekly* Vol 40, No 10, 5 March, pages 981–987.

28. Shukla, P R et al. (2003b), *Climate Change in India: Vulnerability Assessment and Adaptation*, Hyderabad University Press.

29. Government of India (2006), *Report of M S Swaminathan Committee to Review the Coastal Regulation Zone Notification 1991*, New Delhi, accessed 4 July 2007 at <http://mssrf.org/rm/reports/crz_report_prof/crz.htm>.

30. See reference 13.

interventions will be necessary if future losses are to be within tolerable bounds. The poor and vulnerable, who suffer the most in extreme events, should be the first priority.

The following sections explore India's climate change-related risk exposure, unbundling first- and second-order risks and defining a coherent set of adaptation and mitigation measures that could converge with ongoing natural hazard risk reduction and urban renewal interventions.

a. Temperature and precipitation changes

While there is little scientific "doubt" about the emergence of climate change as an important risk in the Indian subcontinent over this century, there is still considerable uncertainty concerning precise mechanisms and impacts, especially related to precipitation and sea-level rise, as presented in Table 1.

In spite of the uncertainty, there is broad consensus on the envelope of first-order climate change impacts in South Asia over the twenty-first century:

- A general increase in both mean minimum and maximum temperatures by 2–4° C, depending on the realized atmospheric greenhouse gas concentrations,[31] with an impact on evapo-transpiration levels and therefore agriculture, horticulture and forestry and human activities, especially in arid, semi-arid and mountain zones.
- This could lead to a mean surface temperature rise of 3.5–5° C by the end of the century, which would imply changes in the location and viability of some settlements (especially in the arid and semi-arid zones) and in the pattern of building across the subcontinent, with an increasing role for passive solar and energy efficient design.[32]
- This regional temperature rise, along with changes in the global climate system and the Indian Ocean monsoon system, may lead to a mean increase of 7–20 per cent in annual precipitation. A 10–15 per cent increase in monsoon precipitation in many regions, a simultaneous precipitation decline of 5–25 per cent in drought-prone central India and a sharp decline in winter rainfall in northern India are also projected.[33] This implies changes in the output of winter wheat and mustard crops in northwestern India, which could have a significant impact on national food security, regional crop mixes and resultant demand for irrigation. This is a most serious risk to rural India and the hope of an agricultural resurgence.

31. See reference 27, Sharma et al. (2006).

32. See reference 27, Planning Commission (2006).

33. See reference 17, Ramesh and Yadava (2005).

TABLE 1
Climate change projections for India based on an ensemble of four GCM outputs

	Temperature change (°C)			Precipitation change (%)			
Year	Annual	Winter	Monsoon	Annual	Winter	Monsoon	Sea-level rise (cm)
2020s	1.36±0.19	1.61±0.16	1.13±0.43	2.9±3.7	2.7±17.7	2.9±3.7	4–8
2050s	2.69±0.41	3.25±0.36	2.19±0.88	6.7±8.9	–2.9±26.3	6.7±8.9	15–38
2080s	3.84±0.76	4.52±0.49	3.19±1.42	11.0±12.3	5.3±34.4	11.0±12.3	46–59

SOURCE: Aggarwal, D and M Lal (2001), *Vulnerability of Indian Coastline to Sea-level Rise*, Centre for Atmospheric Sciences, Indian Institute of Technology, New Delhi.

- The substantial spatial differences in precipitation changes imply adaptation of sub-regional agriculture, changes in water supply arrangements and a strong policy emphasis on water conservation and efficiency in most cities, as more rain could fall in more intense spells and drought intensity could increase. This increase, combined with a shorter wet season, will imply a change in the hydrology of many river systems and therefore a modification in the storage capacity and management regime of many dams and reservoirs, thus impacting urban water systems.
- A decrease in the number of rainy days (5–15 days on average) is expected over much of India, along with an increase in heavy rainfall days and in the frequency of heavy rainfall events in the monsoon season.[34] These changes are expected to increase the vulnerability of Indian agriculture and natural resource-linked livelihoods, and also that of the urban poor who typically reside in areas more prone to pluvial flooding and who are most vulnerable to water scarcity as they largely depend on informal water markets.
- The substantial increase in extreme precipitation (similar to Mumbai in 2005 and the 2005 and 2006 Gujarat flood events) expected over a large area of the west coast and central India[35] will require a significant revision of urban planning practices across city and neighbourhood scales to integrate flood and climate change mitigation and adaptation measures into day-to-day urban development and service delivery activities.[36]

34. See reference 18, Rupa Kumar et al. (2006).

35. See reference 18, Rupa Kumar et al. (2006); also IITM (1989), *Probable Maximum Precipitation Atlas*, Indian Institute of Tropical Meteorology, Pune.

36. See reference 24.

b. Drought

The most serious climate change risk to the Indian economy and its people is the increased intensity, frequency and geographical coverage of drought. Drought typically makes up one half to two-thirds of the natural hazard risk exposure.[37] Its primary impact is in rural areas, where agriculture, animal husbandry and, to a lesser extent, forestry[38] and fishing are significantly affected, leading to cycles of seasonal and distress migration and increasing rural debt, and a spate of farmer suicides across much of semi-arid India over the last few years.[39]

Drought has two typical first-order impacts on Indian cities: drinking water shortages and increases in food and biomass fuel prices. It also has a number of important second-order impacts: depressed demand for urban-produced secondary goods and services because of depressed agricultural demand; and increasing seasonal and distress migration from rural areas.[40] Continuing severe climate change-induced drought that makes subsistence agriculture uneconomical in large parts of semi-arid central, western and southern India could catalyze a sharp increase in migration. This, apparently, is not factored into current economic development or national security strategy.

Climate change is expected to increase the severity of drought, especially in western India where five river basins are expected to face acute to severe water shortages, impacting a large number of cities in Gujarat. Land uses, cropping patterns and poor water resource management in the twentieth century have resulted in a 50 per cent reduction in the surface water discharge of the Ganga over the last 25 years and in a sharp drop in groundwater tables across the entire Indo–Gangetic plain.[41] The Ganga,

37. See reference 18, GSDMA/ TARU (2005).

38. Ravindranath, N H et al. (2006), "Impact of climate change on forests in India", *Current Science* Vol 90, No 3, 10 February, pages 354–361.

39. See reference 15.

40. See reference 18, GSDMA/ TARU (2005).

41. Kumar, Rakesh et al. (2005), "Water resources of India", *Current Science* Vol 89, No 5, 10 September, pages 794–811.

Narmada, Krishna and Kaveri rivers are expected to experience seasonal or regular water stress, impacting western, northern and eastern India.[42] If the political and economic consequences of the Kaveri dispute and the Narmada struggle[43] are an indication, within the next decade Indian federalism could be severely challenged by these changes.

Climate change is expected to increase drought in semi-arid peninsular and western India, forcing more of the landless and small and marginal farmers to migrate to cities. They often form the most vulnerable groups in cities – having limited skills, education, capital and access to the social networks that underpin much of economic and social mobility in urban India. They often live in illegal, unserviced settlements exposed to a wide range of environmental risks from flooding to fire, and continual cycles of demolition and eviction by civil authorities. They are, therefore, dual victims of existing natural hazards and emerging climate change – displaced from their original places of residence and occupations, and challenged by urban risks in their new urban places of residence.

The most serious regional impact of climate change would be changes in the river hydrology in the Indo–Gangetic plain and the Brahmaputra valley due to glacial melt and regression of the Himalayan glaciers.[44] Ongoing trans-boundary conflicts between India and Pakistan, and Nepal, India and Bangladesh may be compounded by a possible China–India conflict over the use of the Yarlung Tsang-po/Brahmaputra waters as river flows decline and inter-basin transfers are increasingly suggested as solutions to challenges of urban and regional water stress.[45]

Four of the ten largest mega-urban regions of the twenty-first century, namely, Delhi, Dhaka, Kolkata and Karachi, lie on the banks of these great rivers along with more than 30 other million-plus cities. Significant changes in river hydrology and the availability of irrigation and drinking water could have a dramatic impact on the growth and development of the many small and medium-sized towns and million-cities that are expected to mushroom across these fertile plains in the next three decades, adding an unprecedented resource dimension to the social and economic transformation of northern and eastern India.

The bulk of the water extraction from these river systems is for irrigation to provide food for close to one billion people. Hence, an emerging conflict is brewing between cities and the rural areas from where the urban water supply is drawn and to where city water pollution is discharged. Since the 1980s, multiple environmental struggles have been fought over the extraction of surface water from remote watersheds where many relatively poor people have been displaced by exploding urban demand.[46] This will surely accelerate and become an increasing constraint on the current resource-inefficient pattern of urban development – if Delhi's long saga with Haryana and Uttar Pradesh on drinking water transmission is an indication of the future.[47]

The national capital region of Delhi faces a severe water shortfall of 200 million gallons a day (MGD), or more than 32 per cent of its production.[48] Drinking water is being transported from more than 300 kilometres away to meet the demands, and unaccounted-for water losses are more than 44 per cent.[49] Rising temperatures and energy demand for cooling, increasing precipitation variability, fewer rainy days, the unsustainable mining of groundwater and a river system that has been polluted to death could all make the Delhi mega-urban region, with a projected population of more than 30 million, highly unsustainable in spite of rapid growth in

42. See reference 17, Gosain et al. (2006).

43. Murty, K S (2002) "River water sharing: India's problems", *International Association of Hydrological Sciences Publication* No 274, pages 323–328; also Dreze, J, M Samson and S Sarkar (editors) (2003), *The Dam and the Nation: Displacement and Resettlement in the Narmada Valley,* Oxford University Press, New Delhi.

44. Tangri, A K (2003), "Impact of climate change on Himalayan glaciers", Proceedings of V&A Workshop on Water Resources, Coastal Zones and Human Health, NATCOM, 27–28 June, Indian Institute of Technology (ITT), New Delhi.

45. See reference 17, Mall et al. (2006); also Chellaney, B (2007), "Averting water wars in Asia", *International Herald Tribune*, 26 June.

46. See reference 1, Parasuraman and Unnikrishnan (2000).

47. Zérah, M H (2000), *Water. Unreliable Supply in Delhi*, Manohar Publishers, New Delhi.

48. Daga, S (2005), "Private supply of water in Delhi", Centre for Civil Society, accessed 4 July 2007 at <http://www.teri.res.in/teriin/news/terivsn/issue35/water.htm>; also Delhi Jal Board, accessed 4 July 2007 at < http://www.delhijalboard.nic.in/>.

its income and wealth. These questions are far from the minds of both planners and politicians as they prepare to "green" the city for the 2010 Commonwealth Games.

Delhi is simultaneously experiencing the "brown", "grey" and "green" environmental transitions[50] over a period of less than 50 years, but water availability rather than economic and social development challenges may be its undoing, as with two other great capital cities of this region: Mohammed-bin-Tuglak's (1325–1351) Tuglakabad, near Delhi and Akbar's (1556–1605) Fatehpur Sikri, near Agra.

c. River and inland flooding and extreme rainfall events

The next most important climate change risk is increased riverine and inland flooding, especially in northern and eastern India and adjoining Nepal and Bangladesh. Tens of millions of people are currently affected by flood for three to six months of the year in eastern India.[51] Increased precipitation and higher peak monsoon river flows due to glacial regression could exacerbate the situation for additional tens of millions. This is largely due to the high population densities across this region, combined with very high vulnerability due to a mix of poorly designed and executed flood management systems, complex land and water tenure regimes and high levels of poverty, which over the last few decades have severely degraded the coping capacity of millions of residents of eastern India.[52]

Climate change is expected to increase the severity of flooding in many Indian river basins, especially those of the Godavari and Mahanadi along the eastern coast.[53] Floods are also expected to increase in north-western India, adjoining Pakistan, and in most coastal plains, in spite of existing upstream dams and "multi-purpose" projects. Extreme precipitation is expected to increase substantially over a large area of the west coast and central India.[54] Gujarat, one of India's most prosperous states, has experienced severe flooding for three consecutive years since 2004, causing large economic losses in its cities.[55]

The devastating Mumbai floods of 2005 were caused by an extreme weather event. Most city services were shut down for the first time in recorded history for almost five days, with no contact via rail, road or air with the rest of the country. Over 1,000 people lost their lives in the region, and economic life in the city came to a halt[56] due to a combination of institutional failures, poor preparedness and extremely high vulnerability of the poor.[57]

d. Cyclonic storms, storm surge and coastal flooding

The third most important risk is that of cyclonic storms, storm surge and accompanying coastal inundation. A sea surface temperature rise of 2–4° C, as anticipated in the Indian Ocean over the century, is expected to induce a 10–20 per cent increase in cyclone intensity.[58] Since the frequency of cyclones in the Bay of Bengal is about five times that of the Arabian Sea,[59] India's east coast is clearly at more risk in spite of the fact that the north Indian Ocean basin is one of the least intense cyclone/hurricane basins in the world.

The high concentration of population on India and Bangladesh's eastern coasts has led to extremely high vulnerability in this region, leading

49. Government of NCT of Delhi (2002), *Economic Survey (2001–2002)*, New Delhi.

50. McGranahan, G and P J Mercutollio (2007b), *Scaling Urban Environmental Challenges: From Local to Global and Back*, Earthscan, London.

51. Mishra, D K (1999), "Flood protection that never was: case of Mahananda Basin of North Bihar", *Economic and Political Weekly* Vol XXXIV, No 29, July, pages 2013–2018.

52. See reference 4.

53. See reference 17, Gosain et al. (2006).

54. See reference 18, Rupa Kumar et al. (2006).

55. See reference 18, GSDMA/TARU (2005).

56. Government of Maharashtra (2005), *Maharashtra Floods 2005*, Department of Relief and Rehabilitation, accessed 4 July 2007 at http://mdmu.maharashtra.gov.in/pdf/Flood/statusreport.pdf>.

57. See reference 24.

58. Aggarwal, D and M Lal (2001), *Vulnerability of Indian Coastline to Sea-level Rise*, Centre for Atmospheric Sciences, Indian Institute of Technology, New Delhi.

59. India Meteorological Department (1979), *Tracks of Storms and Depressions in the Bay of Bengal and the Arabian Sea 1877 to 1970*, New Delhi; also India Meteorological Department (1996), *Tracks of Storms and Depressions in the Bay of Bengal and the Arabian Sea 1971 to 1990*, New Delhi; and TARU (2005), *Disaster Management Plan Blueprint for the Hazira Area Development Committee*, Gandhinagar.

to devastating loss of life and property. The 1999 Orissa super-cyclone killed more than 10,000 people and devastated buildings, lifeline infrastructure and economic assets across 10 coastal and six inland districts; this was due to a mixture of devastating storm surge, cyclonic winds and coastal flooding.[60] A 1991 cyclone killed more than 139,000 people in Bangladesh and caused a significant compression of its GDP.[61]

Cyclones and storm surge could have a devastating impact on such large urban centres as Mumbai and Chennai and the million-cities of Vishakapatnam, Surat, Bharuch, Bhavnagar and Jamnagar, as well as causing critical bottlenecks in important ports such as Kandla.[62] Storm surge, when accompanied by coastal flooding and cyclonic winds, is the second most devastating, rapid onset hazard in Gujarat, accounting for 12 per cent of the risk to the state and a potential loss of more than 11,000 lives for a probabilistic 100-year event.[63] Losses could rise considerably with increased migration to the coast, drawn by huge investments in coastal infrastructure, settlements and enterprise, but these are located largely unmindful of future risk distribution.

60. TARU/BMTPC (1998), *Rapid Damage Assessment of Cyclone-affected Areas of Kachchh and Saurashtra in Gujarat*, New Delhi.

61. Benson, C and E Clay (2002), *Bangladesh: Disasters and Public Finance*, World Bank, Washington DC.

62. See reference 18, GSDMA/TARU (2005); also see reference 59, TARU (2005).

63. See reference 18, GSDMA/TARU (2005).

e. Mean and extreme sea-level rise

Data over the last century indicate a mean sea-level rise (SLR) of less than one millimetre per year along the Indian coast. More recent observations suggest an SLR of 2.5 millimetres per year since the 1950s. An SLR of between 30 and 80 centimetres has been projected over the century along India's coast, based on multiple climate change scenarios.[64]

Two more recent studies have placed between 6 and 40 million of the coastal population at risk in South Asia. A World Bank-funded study[65] uses multiple scenarios ranging from one to five metres of sea-level rise, based on evidence of increased rates of deglaciation in Greenland and Antarctica and the resultant increased probability of extreme climate scenarios. Up to one per cent of India's urban areas could be inundated by a three metre SLR, and just under two per cent with a five metre rise. A three-metre SLR is expected to affect more than one per cent of the population and a five metre rise, 2.5 per cent of the population. The spatial databases used in this study may leave room for inaccuracies – but it provides a basis for a broad comparative analysis. The overall regional compression of GDP as a result of losses directly due to SLR is estimated at 0.6 per cent from a one metre SLR, 1.6 per cent from a three metre SLR and 2.9 per cent from a five metre SLR for South Asia. The relative impact on India would typically be lower than in Bangladesh, where up to 10 per cent of the area and population are at high risk, but serious adaptation and mitigation measures will be required, especially for coastal cities and ports, which are expected to produce a high share of GDP and underpin India's growing manufacturing exports. There is a clear case for a macroeconomic analysis of risk for India, as has been undertaken for Bangladesh[66] and the UK.[67]

A second study, led by IIED,[68] examined vulnerability within the Low Elevation Coastal Zone (LECZ) i.e. settlements and facilities at risk of a 10 metre SLR – probably the outer boundary of catastrophic climate change.[69] Using a more robust methodology than the World Bank study, it estimated that Asian countries contain three-quarters of the global LECZ population and two-thirds of the global LECZ urban population, with a higher concentration in cities over five million in size. India is estimated

64. See reference 58.

65. Dasgupta, S et al. (2007), "The impact of sea-level rise on developing countries: a comparative analysis", World Bank Policy Research Working Paper No 4136, February.

66. See reference 61.

67. Stern, N (2007), *The Economics of Climate Change: The Stern Review*, Cambridge University Press.

68. See reference 5.

69. Diamond, J (2005), *Collapse: How Societies Choose to Fail or Succeed*, Penguin, London.

to have the second largest LECZ population, with about three per cent of national area at risk.[70]

In short, irrespective of the form and method of assessment, SLR is a serious risk for a number of cities along India's coast. It is clearly in the national interest to invest in more and better science, in order to assess possible risks at various levels of climate change. The costs of inaction on this count alone could outstrip that investment by many orders of magnitude.[71]

The stretches along the western Indian coast that are most vulnerable to SLR are Khambhat and Kachchh in Gujarat, Mumbai and parts of the Konkan coast, and South Kerala. The deltas of the Ganga, Krishna, Godavari, Cauvery and Mahanadi on the east coast are expected to be lost, along with significant settlement areas and irrigated land and a number of urban settlements that are situated there.[72] The loss of these important economic and cultural regions could have a considerable impact on the states of West Bengal, Orissa, Andhra Pradesh and Tamil Nadu.

No estimates of the impact of climate change on saltwater intrusion in the coastal zone and on coastal agriculture and fisheries, and therefore on agricultural, pastoral and fishing communities, are available, but these are expected to be significant.

SLR, combined with an increased frequency and intensity of tropical cyclones, is expected to lead to an increase in extreme sea levels due to storm surge.[73] The fact that India's coast, and especially its western seaboard and stretches along the Bay of Bengal, are expected to grow dramatically in terms of population, infrastructure and industrial investment in the next two decades implies a non-linear increase in coastal SLR vulnerability. The primary driving factors are: differential population densities along the coast and in coastal deltas; a greater openness of the Indian economy to trade; a sharp upturn in energy imports, almost exclusively traded by sea; and strong public investment incentives to coastal development.

f. Environmental health risks

Climate change is expected to accentuate environment-related health risks, including those from water-washed diseases (e.g., diarrhoea, cholera and typhoid), due to water scarcity and malaria. Malaria is expected to expand from its currently endemic range in eastern and northeastern India to western and southern India, thereby placing a large incremental population at risk.[74] Given that Indian cities have become major reservoirs of vector-borne diseases such as malaria and dengue fever, it can be expected that morbidity risks would increase. Additional research needs to be undertaken on the potential impact of water scarcity and flooding on environmental health conditions in cities and their consequent impact on morbidity, mortality and productivity.

V. COMPOSITE MULTI-HAZARD RISK ADAPTATION

Addressing a complex of six major risk groups – temperature and precipitation variability, drought, flooding and extreme rainfall, cyclone and storm surge, sea-level rise, and linked environmental health risk – is a serious public policy and adaptation management challenge for India.

70. See reference 5.

71. See reference 67.

72. See reference 58.

73. Unnikrishnan, A S et al. (2006), "Sea-level changes along the Indian coast: observations and projections", National Institute of Oceanography, Goa and the Indian Institute of Tropical Meteorology, Pune, *Current Science* Vol 90, No 3, 10 February, pages 362–368.

74. Bhattacharya, S et al. (2006), "Climate change and malaria in India", *Current Science* Vol 90, No 3, 10 February, pages 369–375.

An important new method that can help address these concerns is composite risk assessment and adaptation planning. This enables a geographically explicit estimation of probabilistic hazard risk, vulnerability and the imputed composite multi-hazard economic risks. Risk prioritization by hazard, element at risk and location can thereafter be undertaken, assisting in creating evidence-based investment, regional and urban development policies and building a bridge between public agencies, communities and the private sector.[75]

Some capacity has been built nationally and in about one quarter of Indian states to address single rapid onset (e.g. earthquake) and long onset (e.g. drought) risk, but managing a complex portfolio of hazard risks and vulnerabilities is beyond both the current mix of public institutions and the nascent private re-insurance and insurance industry.

India has no robust national estimates of composite economic risk due to natural hazards, unlike Bangladesh.[76] A national vulnerability Atlas,[77] being updated to assess district-level building vulnerability to cyclone, storm surge, earthquake and flood risk exposure does not use probabilistic methods of risk assessment, and the fragility functions used are based on a very limited analysis of loss. Further, no economic loss estimates have been derived. The only robust state-level estimates of composite risk indicate an annual gross state domestic product compression of about two per cent for Gujarat, of which drought makes up 57 per cent, cyclone and storm surge 12 per cent and inland flooding five per cent over a 100-year time horizon.[78] This assessment breaks new ground by unbundling risk for urban and rural areas. This is one of the most detailed sub-regional risk assessments in the world, reaching sub-district level for eight crops, animal husbandry, fisheries, industry, services and critical infrastructure. Yet even though it was completed in 2005, it does not take into account increased hazard risk due to climate change, because of the low awareness of climate risk exposure in India.

75. See reference 18, GSDMA/TARU (2005).

76. See reference 61.

77. BMTPC (1997), *Vulnerability Atlas of India*, Building Materials and Technology Promotion Council, New Delhi.

78. See reference 18, GSDMA/TARU (2005).

VI. URBAN POPULATIONS AND ELEMENTS AT RISK

The most vulnerable populations and elements in a typical Indian city are:

- slum, squatter and migrant populations resident in traditional and informal settlements, which are often located in the most vulnerable locations;
- industrial and informal service sector workers, whose occupations place them at significant risk to natural hazards;
- buildings, especially traditional and informal housing that is especially vulnerable to wind, water and geological hazards;
- industrial units, their in-house infrastructure, plant, machinery and raw materials;
- lifeline public and private infrastructure, which includes roads, bridges, railways, ports, airports and other transportation systems; water, sewage and gas pipelines; drainage, flood and coastal defence systems; power and telecommunication infrastructure; and critical social infrastructure such as hospitals, schools, fire and police stations and first responder's infrastructure; and
- ecosystems and the natural environment, especially wetlands, riverine, estuarine and coastal ecosystems, and surface and groundwater systems.

Risk adaptation and mitigation measures need to address particular populations and elements at risk within a *RUrban* landscape to be effective in responding to a heterogeneous field of constraints and opportunities. Hence, decentralized adaptive management strategies that engage with a political, policy and implementation continuum from the neighbourhood, city and region to the national level have proved to be more effective than centralized top-down interventions.[79] A coherent framework, within which public policy, private sector and civil society urban development and planning actions are taken, can reduce vulnerability and risk in a steady iterative manner over a period of decades.[80] This, in turn, requires a new set of incentives and structures that link short-run priorities with long-run strategic actions – a major shift in the current urban management paradigm.

79. Moffat, S (2003), *CitiesPLUS*, Project for Greater Vancouver, Sustainable Urban Systems Design Competition, Tokyo.

80. See reference 24.

VII. URBAN VULNERABILITY TO CLIMATE CHANGE

Ironically, but not surprisingly, the urban residents most vulnerable to climate change are the poor slum and squatter settlement dwellers and those who suffer from the multiple insecurities that poor governance, the lack of serious investment in the commons and a strong nexus between the political class, real estate developers and public agencies bring to cities. Through a long process of loss accumulation, they are multiply challenged by even small events that impact their livelihoods, income, property, assets and sometimes their lives. Because of systematic exclusion from the formal economy of the city – basic services and entitlements and the impossibly high entry barrier into legal land and housing markets – most poor people live in hazardous sites and are exposed to multiple environmental health risks via poor sanitation and water supply, little or no drainage and solid waste services, air and water pollution and the recurrent threat of being evicted. Yet they survive, add considerable economic value to the city and "subsidize" the better-off via their poor living and working conditions.

Until basic entitlements, services and quality of life are ensured for the bulk of India's urban residents and the vulnerability of the rest reduced to acceptable levels, little or no public and community-based structural mitigation action is likely. Urban mitigation activities typically will be led by enterprises and large public utilities that seek carbon offset-linked financial and economic incentives.

In the near term, the focus in Indian cities, neighbourhoods and communities will need to be on adaptation to climate change. The primary challenges here will lie in better and more accountable city governance, democratic decentralization improving the functioning of public institutions, and the re-creation of the "commons" through multiple political and institutional struggles. Technical, purely economic or even institutional "fixes" typically will fail to deliver results unless local democratic, political and sociocultural processes are engaged with around the themes of equity, social transformation, local "voice" and "agency". Given the "distance" between these concerns and those of the global climate change debate, a rather different set of strategies should probably emerge in India than those currently envisaged.

VIII. A POSSIBLE URBAN CLIMATE CHANGE ADAPTATION FRAMEWORK

Developing a climate change adaptation framework for urban India will require opening a dialogue on urban development and growth, vulnerability, risk unbundling, the redirection of ongoing investments and programmes and the building of new alliances between a wide range of actors, not often in engagement. Together, this can help transform existing cities, to make them more inclusive and productive, thereby reducing structural vulnerability.

A pragmatic way forward is to build upon the existing momentum of hazard risk management and mitigation efforts. This is most effectively done by mainstreaming them into urban redevelopment initiatives such as the JNNRURM, and mobilization from below via NGOs, CBOs and political processes in particular cities. Given that a number of these stakeholders have little or no knowledge of climate change issues, the development of a framework linking dialogue, engagement and action would be a useful step.

This framework would need to provide a link between national, state and city-level policy, political institutional arrangements, and interventions at city and neighbourhood levels. It would also serve as a platform for dialogue between government functionaries, political leaders, CBOs and NGOs who are active in trying to channel citizen and community energy towards productive ends, and private entrepreneurs who could provide the motive power for adaptation implementation.

A sketch for a possible framework at multiple levels, involving various stakeholders and institutions, is presented below.

National level. India has not developed a National Adaptation Programme of Action (NAPA) to address urban climate change risk reduction partly because of institutional fractures within the government of India and its status as an emerging middle-income state. The primary responsibility currently lies with the Ministry of Environment and Forests, which has weak traction with more key sectoral ministries. To integrate a cross-cutting climate change agenda into the overall planning and investment process of the government of India would imply a possible relocation of this function to the Cabinet Secretariat or the Planning Commission, with strong support from the Ministry of Finance. This would require an amendment to the Allocation of Business Rules (1961)[81] and the establishment of a climate change secretariat to address cross-cutting issues. This would enable the coordination of adaptation policies and programmes across key line ministries and functions and the mobilization of state governments and cities for adaptation planning and implementation.

The Ministry of Finance could play a central role in defining fiscal and financial measures to "incentivise" both mitigation and adaptation, based on a "NAPA-like" rollout schedule. This could include the creation of a domestic market for carbon credits linked via appropriate institutions to the global carbon market, enabling the financing of state-led, pro-poor adaptation.

The National Disaster Management Authority (NDMA), within the Ministry of Home Affairs, is the apex disaster management agency, although the bulk of this responsibility and action lies with state governments.[82]

81. Government of India (1961), *The Government of India (Allocation of Business) Rules*, New Delhi, accessed 4 July 2007 at <http://cabsec.nic.in/abr/abr_odr.htm>.

82. Planning Commission (2007), *Report of the Working Group on Disaster Management for the XI Plan*, New Delhi.

The climate change agenda could build a bridge between current NDMA priorities and medium- and long-term climate adaptation.

The Ministry of Environment and Forests, along with the Department of Ocean Development, engages with coastal zone regulation in coordination with state-level ministries. This is another locus of convergence that a Cabinet Secretariat-based climate change cell could address.

The departments of urban development and poverty alleviation, which jointly manage the JNNURM, should be the fulcrum of urban climate change risk mitigation at the national level and the primary agency for urban climate policy and programme design once appropriate state and city capacities are built. An integration of concerns into long-range city development plans, infrastructure development and poverty reduction interventions at city level is crucial. Disaster management is one of the many elements of the JNNURM that is poorly resourced at city level. It needs to be scaled up and broadened to encompass a wider climate adaptation agenda.

The creation of a National Technical Mission on Urban Climate Change Adaptation to deliver time-bound outcomes may be a useful way to focus energies and put the climate crisis onto the public policy agenda. Specific priority tasks for the government of India could include the development of a National Risk and Vulnerability Atlas that includes climate change-related risks and estimates of potential losses to economic activity and capital stocks. This will enable the identification of priority cities and sectors for intervention and thereby open appropriate windows of opportunities within the JNNURM. A new series of national building and lifeline infrastructure risk mitigation standards will be necessary, taking into account climate-related risks. This can be taken forward by the NDMA, the Ministry of Urban Development and the Bureau of Indian Standards, based on the pattern of the national earthquake mitigation standards.[83]

A series of insurance instruments for short- and medium-term risk coverage to urban infrastructure enterprises, and incentives for public–community–private partnerships need to be put into place, similar to initiatives in the agricultural sector.

Apex institutions that bring together public and private sector enterprises, civil society and academic (especially science and technology, management and social science research) institutions will need to be activated at national level to build research and action-oriented networks in and between their sectors of competence. Education, training and capacity building at schools and universities for public functionaries, managers and the media will need to be launched.

State level. Each state needs to establish a state disaster management authority along the lines of the Gujarat State Disaster Management Authority, especially in urban areas. This can build on existing flood, cyclone and surge, and drought risk reduction efforts. Considerable capacity building will be required to prepare these agencies to take on these additional responsibilities and develop actionable state-level adaptation programmes of action.

The boards of the departments of state finance and planning will need to integrate climate change adaptation into their medium-term planning and expenditure frameworks and enable synergy between cross-sectoral adaptation and mitigation investments.

83. NDMA (2007), *Earthquake Disaster Guidelines*, New Delhi, accessed 4 July 2007 at <http://ndma.gov.in/wps/wcm/resources/file/ebfb870f7a208c7/Guidelines%20for%20Management%20of%20Earthquakes.pdf>.

Changes are necessary in the appropriate state housing and urban development, town planning and infrastructure legislation, to integrate disaster and climate change mitigation concerns into urban planning and development. Training and capacity building of state public functionaries and bureaucrats in climate change risk assessment and adaptation is an important human resource investment.

A process of catalyzing entrepreneurial activity around climate adaptation and mitigation is best led in some states by the government, while in others a private sector lead will be most appropriate. Once beyond a critical threshold it could well be spun off.

City level. Current legal, regulatory and governance structures and the institutional culture of most cities are inadequate to address the challenge of climate change adaptation and mitigation.

An urban governance, planning and service delivery framework as well as institutional arrangements will be necessary to link urban renewal and development with short- and medium-term hazard risk reduction and, further, to climate adaptation. An important first step is the development of public entitlements and service delivery to the poor and vulnerable to ensure that existing asymmetries and structural vulnerabilities are addressed. This will involve strong interventions in real estate and housing markets and public service delivery, and a supportive policy and institutional environment at state level.

This is best operationalized via a re-examination of city development plans that attempt to link a long-term vision for urban development with an action plan for infrastructure upgrading, poverty reduction and better governance. An appropriate urban platform to enable multi-stakeholder engagement with strategic risk sharing and adaptation will help create appropriate fiscal and financial incentives for adaptation linked to neighbourhood-led processes, especially in informal settlements. An outcome could be a politically mandated city adaptation programme of action linked to private sector and community-led adaptation that focuses on the primary urban greenhouse gas flux sectors, i.e. transportation, and building and energy systems.

Within this larger framework, a city disaster management plan (DMP) and zonal DMPs need to integrate climate change and other hazard mitigation concerns into the primary land use and zoning instruments, into city structure and development plans, and into zonal development plans and appropriate building regulation and infrastructure development guidelines.

A critical support activity would be a multilingual GIS-based city DMP and zonal DMPs on the Internet, possibly linked to a public database that records property and real estate information, building permissions and public investments in infrastructure. This would provide a framework within which neighbourhood urban renewal and planning are coordinated with risk mitigation.

A public–private–resident partnership to finance, build and retrofit housing and infrastructure to disaster-resistant standards at neighbourhood level, and a public–private partnership to develop strategic flood, cyclone, storm surge and sea erosion defenses at city level will need to be explored for each city.

Neighbourhood level. Each city will need a network of climate change-related community-based disaster management and risk mitigation initiatives, especially for slum, squatter and informal settlements in

vulnerable locations. This would provide a basis for a citywide dialogue on appropriate adaptation and mitigation involving all population groups and stakeholders. This will be critical to developing implementable city adaptation programmes of action.

The private sector. Given the availability of a public domain risk adaptation framework, the private sector should be encouraged to develop appropriate risk assessment, adaptation and mitigation plans for clusters of enterprises in vulnerable areas. This would enable a rebalancing of demand and supply-side initiatives, that is, greenhouse gas emission abatement, decentralization and dematerialization of supply and service chains. Development of private enterprise-led building and infrastructure upgrading, retrofitting and technical support initiatives to enable and scale adaptation will also be important.

Civil society organizations. These need to take the lead in advocacy and mobilization and adaptation centered on the provision and extension of basic services and entitlements. They can also lead on neighbourhood pilot projects to test new methods of community-based adaptation, specifically for slum and informal settlements and vulnerable populations. NGOs can provide independent feedback and checks and balances on the functioning of public and private sector institutions working on natural hazard and climate change risk mitigation.

Key instruments that could help mitigate climate change-related risks include:

- **New construction and development**. This should be executed to incremental standards for land use, planning, construction and operations and maintenance (O&M) that enable fully-built development to meet climate change vulnerability norms, and enable poor residents living in self- or artisan-built construction to upgrade at an appropriate pace and cost. This will require changes in legal, regulatory, planning and design guidelines, along with a recognition of the rights of residence and economic participation of all residents of the city. Considerable enterprise and institutional development inputs will be required to make this a reality. If structured imaginatively, this could well be funded in part by carbon credits.
- **Retrofitting and strengthening buildings**. A large proportion of a typical Indian city building stock does not meet contemporary standards of building safety. Technical measures to strengthen and retrofit these buildings are cost effective (typically 5–15 per cent of capital investment), but have never been implemented across an Indian city except in Bhuj, after the 2001 Kachchh earthquake. For this to be possible would take considerable institutional and financial innovation and well-considered incentives.
- **Lifeline infrastructure development and strengthening**. Building the energy, water, wastewater, transportation, telecom and IT infrastructure for a city typically takes decades. Given current growth trends, it will happen in many Indian million-cities over the next two to three decades and will need to last for a century or more. Appropriate climate change-related adaptation and mitigation measures will need to be integrated into the design of these systems.

  Since they involve lumpy investments and require massive annual expenditure on operations and maintenance, adequate attention to risk-adjusted least-lifecycle costs need to be made. Some of these

services are best provided by public providers, others, given possible quantum leaps in technology and distributed network development, may be better managed privately. There is a need to explore appropriate forms of regulation and management to mitigate climate risk. This is also a prime case for carbon offset financing.

Sequencing of these interventions should ideally be prioritized by their strategic impact and vulnerability reduction potential, especially in slum and informal settlements. The priorities of the poor and the affluent can vary considerably. A pro-poor process of climate change-related priority setting needs to provide adequate "voice" to more vulnerable groups.

- **Hazard modification**. A number of pre-colonial and colonial drainage, urban surge and flood protection systems have been in operation in various parts of India. The rapid pace of urban development has often made them dysfunctional or irrelevant. Repairing and strengthening strategic flood, storm surge and coastal defences are important city-level interventions. Detailed economic, social and environmental cost-benefit analysis will be needed to assess whether these investments are appropriate vis-à-vis relocation and other adaptation options.

  Water use efficiency and conservation measures are the best strategic defense against drought on the demand side, in conjunction with appropriate water management practices. Enabling the conceptualization and implementation of such vulnerability reduction and hazard modification interventions will need to be explored through pilot projects in different cities with varying ecological regimes.
- **Relocation and rehabilitation**. Relocation should emerge as a policy option only after all other options have failed. Typical measures include the relocation of particular settlements, parts of a city or an entire city system depending on the expected level of risk. Changes in the economic structure of cities will be necessary, to move out of sensitive economic activities, as well as changes in systems of governance to enable a more rapid response to emerging risk, both within the public and the private sectors. Planning, market and financial instruments will be needed to address adequately local relocation and associated rehabilitation needs, with recognition of the rights of residents to compensation. Relocating part of a city is clearly a huge political decision that needs to be equitable, transparent and participative in its execution – few such precedents are available in India. The moderately progressive national rehabilitation policy does not address climate change-related concerns.

  A first step in spatial adaptation would be to shift settlements out of highly vulnerable areas, especially the inter-tidal zones, riverine, estuarine and low-lying areas. If this is inadequate, then the relocation of a particular section of a city and, finally, the relocation of an entire urban system to a new location can be considered. Relocation at this scale is unprecedented, other than for reservoir submergence in independent India. This would be a major economic and a political challenge, apart from being difficult to implement in an equitable manner.
- **Joining up with ongoing hazard risk reduction programmes**. The most important ongoing climate change-related risk mitigation programme is the National Cyclone Risk Mitigation programme, which is being implemented across India's coastal states. The governments

of Orissa, Andhra Pradesh and Gujarat have made progress in its implementation in rural settlements.[84] A similar initiative needs to be developed for urban areas that combines natural hazard risk mitigation and climate change adaptation.

The 2005 Tsunami Rehabilitation programme, active in the southern coastal states of Tamil Nadu, Andhra Pradesh and Kerala, is specifically focused on coastal zone management and the mitigation of cyclone, storm surge and sea erosion hazard risk. A climate change-related agenda needs to be expeditiously introduced into this programme before it comes to a close.

A number of independent flood risk mitigation interventions have been launched by state governments and for specific cities in Maharashtra, Gujarat, Orissa, Uttar Pradesh and Bihar. A common method of addressing inland flood risk mitigation is still to be evolved. This is a crucial concern that could influence the lives of tens of millions of people. The integration of climate change adaptation measures into flood mitigation interventions will probably first take root in Gujarat, which has suffered three seasons of extreme rainfall since 2004. This can then be adapted and scaled to other parts of the country.

- **Strengthening regional and rural–urban linkages**. Conventional disaster management and mitigation planning have focused typically either on urban areas or villages. The increasing integration of the Indian economy has led to the strengthening of the forward–backward linkages between urban and rural settlements. The risks to which cities and their embedding countryside are exposed need to be addressed together, by integrating climate change-related adaptation into regional and *Urban* sectoral and investment planning.

  This is particularly important in India, where agriculture is highly sensitive to monsoon variability as 65 per cent of the cropped area is rain fed. Changes in temperature and precipitation could have a significant impact on more than 350 million people who are dependent on rain-fed agriculture.

  Changes in the flows of food and biomass are especially important because the metabolism of Indian cities is still dominated by flows of unprocessed food and traditional biofuels. Similarly, drinking water and renewable biofuels, hydropower and possibly wind energy flows could be affected by climate changes, causing moderate to severe disruption in urban systems. Hence, instead of an exclusive focus on cities, regional climate change risk adaptation strategies and action plans are needed, especially for mega-urban regions and metropolitan cities.

IX. INSTITUTIONAL CAPACITY FOR URBAN CLIMATE RISK ADAPTATION

A fundamental challenge to Indian climate risk adaptation is the declining quality of urban governance and the weak institutional capacity to manage urbanization, ensure equitable and quality public service delivery, and access to housing markets via appropriate planning and regulation. Without these institutional changes, the structural vulnerability of large populations cannot be addressed, providing a weak foundation on which to build climate adaptation.

84. Government of Andhra Pradesh (2000), *Andhra Pradesh Cyclone Contingency Plan of Action*, Hyderabad.

Since the mid-1990s, India has developed significant natural disaster management and risk mitigation capacity at national and state levels. The National Vulnerability Atlas of India[85] was the first such attempt at identifying and mapping vulnerability at district level across the country, but risk unbundling for specific urban centres was weak. Subsequent efforts have attempted to take the process of hazard risk modeling, vulnerability assessment and composite risk assessment to finer resolution, i.e. block, *taluka* and settlement levels.[86]

The National Disaster Management Authority has been established, but the most extensive risk mitigation experience lies with state-level agencies in Andhra Pradesh, Gujarat, Orissa and Tamil Nadu, which have been active in disaster mitigation planning, investment and, to a lesser extent, community-based disaster mitigation.

A number of interventions are currently being implemented in various cities to mitigate natural hazard risk, especially from flood, sea erosion and storm surge. These are, however, responding to a contemporary perception of risk based on historical experience and records. They have little or no capacity to engage with emergent risks induced by climate change. The ability to conceptualize and integrate these measures into existing plans and programmes will need to be developed at state and city level and, if they are of any great magnitude, supported by the government of India.

The government of Maharashtra developed India's first urban disaster management plan for Mumbai in the late-1990s, identifying flooding as a significant risk and pinpointing bottleneck locations in each ward, as well as vulnerable slums and settlements.[87] But there was little follow up and these bottlenecks became the primary cause of the 2005 Mumbai deluge,[88] pointing to the need for a drastic revamp of Mumbai's institutional capacity.[89]

Addressing in a practical way the differential vulnerabilities of population groups within cities is a serious challenge. Improvements in access to affordable housing and land markets and in lifeline infrastructure, along with more appropriate zoning regulations, are important interventions with strong co-benefits for the poor today and climate change risk tomorrow, if they are planned and executed in a pro-poor manner.

A great risk in market-driven adaptation policy is the possibility of a slew of anti-poor interventions leading to a vicious cycle of displacement resettlement and increasing vulnerability in many cities. A number of successful programmes have demonstrated that the cost of in situ risk mitigation is often a fraction that of relocation, typically less than 10 per cent of the capital cost of new development. This needs to be integrated into the urban planning process and legal framework.

X. BUILDING A MITIGATION AGENDA FOR INDIAN CITIES

India became a signatory to the Kyoto Protocol in 2002, which gave it some latitude in initiating mitigation activities because of its developing country status. The impact of the measures taken, for instance in pollution control, conservation and promotion of renewable energy, [90] is expected to be relatively small, primarily because India's energy intensity is growing rapidly from a very small base. Almost half of India's households lack access to electricity, and energy demand can be expected to grow at a faster rate than India's annual growth in GDP.[91] Given that India's

85. See reference 77.

86. See reference 18, GSDMA/TARU (2005).

87. Government of Maharashtra (l999), *Mumbai Disaster Management Plan*, accessible at <http://mdmu.maharashtra.gov.in/pages/Mumbai/>; also Vatsa, K and J Joseph (2003), "Disaster management plan for the state of Maharashtra, India: evolutionary process", *Natural Hazards Review* Vol 4, No 4, November, pages 206–212.

88. See reference 24; also Conservation Action Trust (2006), *Mumbai Marooned: An Enquiry into Mumbai Floods 2005*, Mumbai.

89. Government of Maharashtra (2006), *Chitale Committee Report on the Mumbai Floods of 2005*, Mumbai.

90. See reference 27, Shukla, et al. (2003a).

91. TERI (2006), *National Energy Map for India: Technology Vision 2030*, The Energy and Resources Institute, New Delhi.

energy security can only be assured in the medium term by using coal-based thermal power generation, a domestic debate on greenhouse gas mitigation at the expense of expanding energy services will be challenging in the short term.

A series of macro policy incentives will be required to reduce the carbon intensity of India's energy system and its economy. Debates around city sustainability and greening have opened up in the last decade, and limited progress has been made on strong interventions that would enable the development of more compact cities, mixed land use, a radical improvement in public mobility systems, greater resource efficiency and recycling in buildings and services, and a break with India's twentieth century engagement with colonial and western-oriented planning standards.

Much of the high energy and resource-intensive real estate and building boom is driven by corporations and the urban upper-middle classes who wish to participate in a replication of the "American dream" in India. This is clearly unsustainable both in the short and medium terms and voluntary and public restraints on wasteful consumption and effective resource management using market-based, technological and legal instruments are in order. The private and public sectors will lead much of this mitigation agenda as they make good business sense.

XI. CONCLUSIONS

Although the level of exposure to hazard in India is high, vulnerability typically contributes more to overall risk in India's cities. Reducing this vulnerability will mean a shift in public policy, mobilization and enterprise from mitigation towards adaptation. This needs to be grounded in the institutional, sociocultural and political realities of India and needs to focus on the poor and most vulnerable through a mix of policy, regulatory, fiscal and financial, institutional and mobilization instruments.

This is probably best implemented by mainstreaming climate change risk assessment and adaptation and mitigation measures into ongoing national hazard mitigation programmes, and building a tangible set of links with urban renewal interventions that are being taken up in many of India's largest cities.

To accomplish this, a multi-level climate adaptation framework is necessary, which works at national, state, city and neighbourhood levels and brings together the state, private and civil society sectors. Robust adaptation programmes in a set of pilot cities will allow for the exploration of the important linkages between adaptation and mitigation.

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