

Assessing Indian Cities for Vulnerability to Climate Change

Ulka Kelkar, P. Balachandra and Anjula Gurtoo

Department of Management Studies
Indian Institute of Science
Bangalore, India
e-mail: ulka.kelkar@gmail.com

Abstract—This paper critically evaluates the vulnerability of Indian cities to climate change in the context of sustainable development. City-scale indicators are developed for multiple dimensions of security and vulnerability. Factor analysis is employed to construct a vulnerability ranking of 46 major Indian cities. The analysis reveals that high aggregate levels of wealth do not necessarily make a city less vulnerable. Two, cities with diversified economic opportunities could adapt better to the new risks posed by climate change, than cities with unipolar opportunities. Three, highly polluted cities are more vulnerable to the health impacts of climate change, and cities with severe groundwater depletion will find it difficult to cope with increased rainfall variability. Policy and sustainability issues are discussed for these results.

Keywords—climate change; sustainable cities; urban management; system vulnerability

I. INTRODUCTION

Cities in India are significant both from population and from economic points of view. More than 60% of India's GDP originates in the urban sector [1] and 40% of the country's urban population is concentrated in 35 megacities [2]. Although these cities are hubs of rapid economic growth, they face multiple stresses, such as continued in-migration, strain on infrastructure and services, environmental degradation, loss of open spaces, congestion, and growth of slums [1,3].

Climate change is likely to be an additional stress on Indian cities, but its potential effects are not well understood. It can profoundly affect development by depleting scarce resources, exacerbating existing inequities, and impeding our ability to achieve the Millennium Development Goals [4,5]. Moreover, rapid urbanization in developing countries can concentrate people and assets in relatively high-risk locations, pushing an already stressed urban system across a threshold of sustainability [6].

II. AIMS AND APPROACH

This paper aims to understand the nature of cities in India that are likely to be more vulnerable to climate change, and to identify the policy measures that can facilitate sustainable adaptation to climate change impacts. This is a critical need for several reasons. First, policymaking on climate change adaptation is still at a very nascent stage in India. Indian cities have only recently started inventorizing emissions and considering mitigation options, but none has yet formulated a climate change adaptation plan. Second, research on urban

vulnerability to climate change in developing countries like India has been limited to qualitative assessments [7], since data constraints prohibit the application of rigorous forecasting methods (such as employed by [8] and [9]).

We use an indicator-based approach, which provides a comprehensive tool to study the comparative socio-economic vulnerability to climate change at the city level [10]. Although indicators are single variables, they are manifestations of multi-dimensional factors [11], and can summarise complex information from multiple sources into useful signals for decision-making [12]. Hence, this approach compares the Indian cities on multiple dimensions of vulnerability, and helps identify hotspots where adaptation efforts could be targeted.

III. METHODOLOGY

As the first step, an integrated framework is developed at the city scale. We define the city in terms of basic assets or capitals, including human, social, financial, technological, and natural capital. Indicators are identified to measure the level of each capital, and the security of use of each capital. As the second step, the framework is applied using secondary data for 46 major Indian cities. Principal component analysis and factor analysis with alternative weighting schemes are employed to construct a composite vulnerability ranking. This brings out the differential vulnerability across cities, and helps identify the factors that account for differences in the vulnerability.

IV. FRAMEWORK

We define vulnerability as “the lack of capitals”. These capitals are key assets that distinguish a city from the rural or natural landscape. They can be tangible (such as buildings and infrastructure) or intangible (such as finance or technology), owned individually (such as skills or food) or collectively (such as the air or roads). They can be viewed as stocks that have the capacity to produce flows of economically desirable outputs. They can be augmented (for instance, by increasing power generation capacity) or eroded (for instance, by reducing natural cover).

From the user's perspective it is desirable to look at these capitals through the lens of accessibility-equity-quality-diversity. This is essential as the mere existence of these capitals does not imply their actual availability for use. For instance, piped water connections may be *physically inaccessible* to the residents of a slum; transport infrastructure may be *unevenly distributed*; electricity

services may be irregular or of poor *quality*; and there may be little *diversity* of food and other goods. Moreover, rising temperature or delayed rainfall are expected to exacerbate scarcities of water, food, or energy [5], bringing issues of distribution, equity, and purchasing power to centre stage.

Vulnerability can also be viewed as the opposite of “security” [13]. Diversity of choices (for instance, in employment, markets, or water supply sources), control and power (through financial strength or political empowerment), and capacity to adapt to stresses, make a system more secure. We, therefore, also define vulnerability as “the lack of security” in use of these capitals. Fig.1 summarizes the framework.

V. STATISTICAL INVESTIGATION

Table I lists the variables identified to measure the levels of the various capitals and securities. Data for 46 large Indian cities were obtained, primarily from the Government of India publications and websites. To ensure comparability across the cities, data for the same year were used for a given variable. The data were standardized to remove scale effects. Some data gaps were filled through linear regression. Variables for natural capital and built capital had to be dropped due to lack of data. Principal component analysis was carried out separately for the set of capital variables and for the set of security variables.

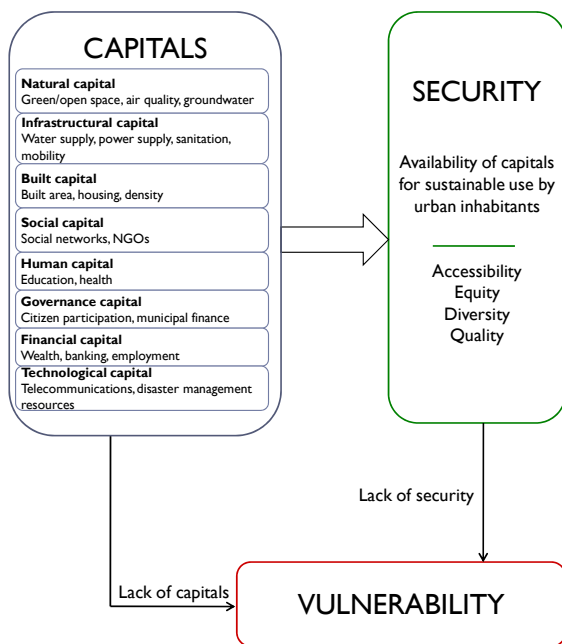


Figure 1. Summary of framework

TABLE I. VARIABLES FOR CAPITALS AND SECURITIES

Variables		
Type of capital / security	Capital variables	Security variables
Natural	Per capita area under green spaces	Per cent violation of standard for Respirable Suspended Particulate Matter (RSPM) Ratio of groundwater usage to availability
Built	Per cent built-up area	Population density Per cent population living in slums
Infrastructural	Per cent households with access to tap water in premises Per cent households with access to electricity Sanitation score	Ratio of annual mean total rainfall to annual mean number of rainy days (normal propensity for urban flooding) Diversity index of percent shares of groundwater and surface water Share of hydropower in installed capacity
Social	Registered NGOs per 10,000 population	Age dependency ratio
Human	Doctors per 10,000 population Per cent population with health insurance Schools per 10,000 population	School enrollment
Governance	Voting per cent in assembly elections Per capita municipal revenue income	Operating ratio (Ratio of municipal revenue expenditure to municipal revenue income) Number of consumer court cases
Financial	District domestic product Number of bank offices	Gross bank credit Diversity index of employment shares of primary, secondary, and tertiary sectors Exports from Special Economic Zones (SEZs)
Technological	Number of ham radios and two-way radios	Per cent population with mobile phones

VI. PRELIMINARY RESULTS

Principal component analysis for the capital variables reveals that wealth or financial strength explains a large portion of the variance in the dataset. The first principal component has a large eigen value relative to the subsequent principal components (Table II). The variables with significant loadings on the first principal component are 'district domestic product', 'number of bank offices', and 'number of radios'. A composite index of the capital variables is constructed as a linear combination of the original variables weighted by the factor loadings on the first principal component. (See [14] for details of the methodology.) The ranking of cities based on this composite

index is presented in Table III (rank 1 indicates the city that is likely to be most vulnerable).

TABLE II. PRINCIPAL COMPONENTS FOR CAPITAL VARIABLES DATASET

Principal component			
	<i>Eigen value</i>	<i>Explained variance (%)</i>	<i>Cumulative variance (%)</i>
1	3.94	32.81	32.81
2	1.86	15.47	48.28
3	1.48	12.33	60.61
4	1.25	10.43	71.03
5	1.03	8.58	79.61

TABLE III. RANKING OF CITIES BASED ON COMPOSITE INDEX OF CAPITAL VARIABLES

Rank	City	Rank	City
1	Asansol	24	Kanpur
2	Dhanbad	25	Patna
3	Ranchi	26	Coimbatore
4	Guwahati	27	Amritsar
5	Raipur	28	Visakhapatnam
6	Bhubaneshwar	29	Lucknow
7	Mathura	30	Jaipur
8	Dehradun	31	Rajkot
9	Jamshedpur	32	Kochi
10	Faridabad	33	Nagpur
11	Shimla	34	Ludhiana
12	Allahabad	35	Vadodara
13	Srinagar	36	Nasik
14	Bhopal	37	Kolkata
15	Madurai	38	Chandigarh
16	Agra	39	Surat
17	Jabalpur	40	Ahmedabad
18	Varanasi	41	Hyderabad
19	Panaji	42	Chennai
20	Thiruvananthapuram	43	Pune
21	Meerut	44	Bangalore
22	Vijayawada	45	Mumbai
23	Indore	46	Delhi

TABLE IV. PRINCIPAL COMPONENTS FOR SECURITY VARIABLES DATASET

Principal component			
	<i>Eigen value</i>	<i>Explained variance (%)</i>	<i>Cumulative variance (%)</i>
1	3.01	20.09	20.09
2	2.41	16.06	36.15
3	1.79	11.94	48.09
4	1.63	10.89	58.98
5	1.17	7.82	66.79
6	1.13	7.56	74.35

TABLE V. SIGNIFICANT FACTOR LOADINGS FOR FOUR-FACTOR MODEL OF SECURITY VARIABLES

Factor		
	<i>Variable</i>	<i>Factor loading</i>
1	Ratio of groundwater usage to availability	0.688
	Gross bank credit	0.921
2	Per cent violation of standard for RSPM	0.654
	Age dependency ratio	0.920
3	Operating ratio	0.711
	Diversity index of employment shares of primary, secondary, and tertiary sectors	-0.611
4	Share of hydropower in installed capacity	0.692

The results are somewhat more complex for the security variables (Table IV). Since a single principal component does not dominate, there is no natural composite index unlike the case of capital variables. Instead we carry out an exploratory factor analysis to understand the internal structure of the dataset and identify factors that differentiate cities from each other. We find the important factors to be the resource-intensive nature of economic growth, economic vibrancy, and governance.

Six principal components have eigen values greater than one. However, we consider only the first four principal components since each of them explain at least 10% of the variance, and cumulatively explain close to 60% of the variance, which is sufficient for our purpose of dimensionality reduction. The results of the factor analysis with four factors are presented in Table V.

The first factor, which comprises the 'ratio of groundwater usage to availability' and 'gross bank credit', can be interpreted as representing 'resource-intensive economic growth'. Cities which rank high on both the variables include the metros and the megacities. These cities show high level of industrial development and high per capita income, which account for high groundwater extraction by industrial and domestic users (i.e., through private borewells).

The second factor comprises 'per cent violation of the standard for respirable suspended particulate matter (RSPM)'

and ‘age dependency ratio’. Cities in the Indian states of Uttar Pradesh, Bihar, Rajasthan, and Madhya Pradesh rank high on both these variables. These cities are seen to have ‘old economies’ with an aging industrial structure that offers limited job opportunities. The earning-age population has moved away in search of new economic opportunities and poor governance has historically constrained a move towards greater economic vibrancy in these cities.

The third factor comprises ‘operating ratio’ (ratio of municipal revenue expenditure to municipal revenue income) and the ‘diversity index of employment’. Operating ratio is an indicator of municipal efficiency (an operating ratio of more than one being undesirable). The diversity index is constructed as 1 minus the sum of squares of primary, secondary, and tertiary sector shares in employment. Taken together, these variables point to a ‘governance’ factor. Cities with good governance, which are also able to offer greater diversity of economic opportunities, include the non-metro cities, such as Visakhapatnam, Thiruvananthapuram, Nasik, Nagpur, and Rajkot.

The final factor comprises the ‘share of hydropower in installed capacity’. Cities which are in geographical proximity to hydropower sources and which have historically had underdeveloped thermal power capacity are the ones that rank high on this variable. These include cities in the states of Uttarakhand, Himachal Pradesh, Jammu & Kashmir, Assam, Orissa, and Kerala.

The ranking of the cities based on the different factors is presented in Table VI (rank 1 indicates the city that is likely to be most vulnerable).

TABLE VI. RANKING OF CITIES BASED ON FACTORS EXTRACTED FROM SECURITY VARIABLES DATASET

City	Rank			
	<i>Resource-intensive economic growth</i>	<i>‘Old’ economy</i>	<i>Poor governance</i>	<i>Share of hydro power</i>
Mumbai	1	44	45	26
Kolkata	2	35	17	36
Delhi	3	36	7	38
Chennai	4	40	16	43
Bangalore	5	39	36	15
Surat	6	38	39	37
Hyderabad	7	21	40	16
Amritsar	8	13	18	4
Jaipur	9	11	42	21
Ludhiana	10	25	29	2
Meerut	11	4	9	23
Ahmedabad	12	34	31	34
Patna	13	2	6	33
Mathura	14	1	24	11

City	Rank			
	<i>Resource-intensive economic growth</i>	<i>‘Old’ economy</i>	<i>Poor governance</i>	<i>Share of hydro power</i>
Indore	15	20	21	19
Nagour	16	22	37	30
Vadodara	17	24	23	40
Madurai	18	29	32	42
Rajkot	19	27	38	41
Allahabad	20	3	30	9
Kanpur	21	10	20	22
Agra	22	6	25	17
Faridabad	23	8	28	7
Panaji	24	45	8	46
Pune	25	33	35	27
Lucknow	26	9	13	6
Coimbatore	27	41	43	39
Vijayawada	28	26	34	31
Jamshedpur	29	17	46	24
Kochi	30	46	26	28
Raipur	31	5	15	32
Jabalpur	32	14	19	18
Varanasi	33	7	10	14
Asansol	34	28	22	45
Bhopal	35	15	14	8
Visakhapatnam	36	37	27	25
Ranchi	37	12	33	29
Thiruvananthapuram	38	43	41	10
Dehradun	39	19	4	1
Nasik	40	23	44	35
Chandigarh	41	32	3	12
Dhanbad	42	16	11	44
Guwahati	43	18	5	5
Bhubaneswar	44	30	2	20
Srinagar	45	31	12	3
Shimla	46	42	1	13

VII. DISCUSSION

The analysis of capital indicators clearly shows financial strength playing an important role in determining the capacity of a city to respond to the stress of climate change. However, factor analysis of the security variables reveals

subtle differences between cities which cannot be explained by relative financial strength alone. One, the resource-intensive nature of attaining financial strength also makes a difference. Two, cities with high groundwater extraction and greater reliance on hydropower will have low tolerance to increased rainfall variability [5] due to climate change. Three, cities with poor air quality have higher respiration-related disease incidence [15] and will be more vulnerable to the health impacts of climate change. This is particularly so as these cities are also seen to have a greater population of the elderly and children. However, cities with efficient governance and diversity of income opportunities are more likely to adapt to the additional stress of climate change.

These results have important implications for policymaking. They can lead to win-win outcomes for climate change adaptation and sustainable urban development. For example, the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) of the Government of India aims to “create economically productive, efficient, equitable, and responsive cities”. It provides funds for urban infrastructure development, particularly public transport, sanitation, and drainage. The implementation of this programme can be applied with the results of this and similar studies to ensure development and provision of infrastructure services that do not exacerbate the problem of air quality as a result of higher levels of road transport. Similarly, the results can also dovetail with the implementation of the National Urban Transport Policy, which seeks to “move people – not vehicles”; and the National Mission for Sustainable Habitat, which attempts to incorporate climate change considerations into urban infrastructure policy. Moreover, efficient utilisation of municipal revenue should also be emphasised to ensure optimal utilization of the existing funds.

Our results also point to the critical role of promoting diversity of income opportunities. Programmes which foster self-employment and entrepreneurship, through skill-building and credit facilitation, can play a crucial role here. This will also help redress the problems of youth migration and age imbalance. Hence, government schemes like the Swarna Jayanti Shahri Rozgar Yojana are important and their effective implementation is vital.

VIII. DIRECTIONS FOR FURTHER RESEARCH

This study contributes to policymaking by fostering greater appreciation of the multi-dimensional aspects of sustainability and vulnerability. Indicators of diversity and equity are used in a unified framework that questions the conventional economic understanding that possessing greater financial resources implies lesser vulnerability. By using indicators that go beyond physical dimensions like sea level rise, the study helps focus attention on inland cities, and highlights the economic and demographic linkages of cities with the rest of the country. Given that no city in India has yet formulated climate change adaptation strategies, this analysis can help add to the current state of knowledge.

The extension of this work will involve multiple regression of proxy dependent variables for vulnerability on the capital and security variables to build a model of urban vulnerability. The sample size of cities can be increased to include smaller cities. Future work could also attempt to move from a snapshot picture of vulnerability to a dynamic version with time series data. Further application of this methodology can contribute to integrated policy-making for sustainable, efficient, and inclusive urban growth.

REFERENCES

- [1] Government of India, “Urban infrastructure, housing, basic services, and poverty alleviation,” in *Eleventh Five Year Plan 2007–12, Volume III: Agriculture, Rural Development, Industry, Services and Physical Infrastructure*. New Delhi: Planning Commission, Government of India, and Oxford University Press, 2008.
- [2] Registrar General of India, *Census of India 2001*. New Delhi: Government of India, 2001.
- [3] Millennium Ecosystem Assessment, *Indian Urban Resource Millennium Assessment by Naturalists*, 30 pp, 2005.
- [4] Millennium Ecosystem Assessment, *Ecosystems and Human Well-being: Synthesis*. Washington, DC: Island Press, 137 pp, 2005.
- [5] IPCC, *Climate Change 2007: Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press, 2007.
- [6] T. J. Wilbanks, et al., “Industry, settlement and society,” in *Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, Eds. Cambridge: Cambridge University Press, 2007, pp. 357–390.
- [7] A. Hunt and P. Watkiss, *Literature review on climate change impacts on urban city centres: initial findings*. Paris: Organisation for Economic Cooperation and Development, 2007.
- [8] N. Jollands, M. Ruth, C. Bernier, and N. Golubiewski, “The climate’s long-term impact on New Zealand infrastructure (CLINZI) project – a case study of Hamilton City, New Zealand,” *Journal of Environmental Management*, vol. 83, pp. 460–477, June 2007.
- [9] P. H. Kirshen, M. R. Ruth, and W. Anderson, “Interdependencies of urban climate change impacts and adaptation strategies: a case study of Metropolitan Boston, USA,” *Climatic Change*, vol. 86, pp. 105–122, January 2008.
- [10] S. L. Cutter, B. J. Boruff, and W. L. Shirley, “Social vulnerability to environmental hazards,” *Social Science Quarterly*, vol. 84, pp. 242–261, June 2003.
- [11] S. L. Cutter, “Vulnerability to environmental hazards,” *Progress in Human Geography*, vol. 20, pp. 529–539, December 1996.
- [12] D. Niemeijer D and R. S. de Groot, “A conceptual framework for selecting environmental indicator sets,” *Ecological Indicators*, vol. 8, pp. 14–25, January 2008.
- [13] UNEP, *Africa Environment Outlook: Past, Present, and Future Perspectives*. Nairobi: United Nations Environment Programme, 2002.
- [14] A. Rajivan, N. Sarangi, and M. Wickramaratne, *Principal component analysis for indexing*, Human Development Reports Unit Brief. Colombo: United Nations Development Programme Regional Centre, 2007.
- [15] A. Seaton, D. Godden, W. MacNee, and K. Donaldson, “Particulate air pollution and acute health effects,” *The Lancet*, vol. 345, pp. 176–178, January 1995.