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Article

Assessment of Urban Vulnerability to Climate Hazards of Selected Indian Cities

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Abstract: There has been an increase in the inefficiencies of urban infrastructure services in Indian cities as a result of rapid and unplanned urbanization (UNDP, 2017). Indian cities have grown multidimensional as a result of massive industrialization and technological spread backed by globalization impacting the early 2000. It has transformed the city fabric and the associated challenges. Therefore, an Urban Climate Vulnerability Assessment (UCVA) is needed to identify, target and recognize climate vulnerable urban cities, sectors, or populations. The UCVA framework consists of seven broad thematic indicators — physical, hazard, social, demographic, financial provisioning, infrastructure and administration vulnerabilities, and their sub indicators to represent the climate vulnerability of Indian cities. This assessment is for seven Indian cities namely Delhi, Mumbai, Chennai, Bengaluru, Srinagar, Shillong, and Ahmedabad which were selected based on their geographical location, population, ecosystem types and hazards/ hazard trends to understand and assess the respective vulnerabilities. The Assessment is done through a comprehensive approach using a robust and predictive qualitative framework. It helps in determining respective risks and in improving community resilience to the climate hazards by integrated planning and improved preparedness. UCVA can support as a decision support mechanism for devising suitable mitigation and adaptation strategies for building urban climate resilience.

Keywords: India; urban; climate vulnerability; disaster resilience; climate hazards; vulnerability assessment framework

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1. Background

Most Indian cities are vulnerable to climate induced natural hazards (IRADe, 2014). There has also been an increase in the inefficiencies of urban infrastructure services in Indian cities as a result of rapid and unplanned urbanization (UNDP, 2017). Indian cities have grown multi-dimensional as a result of rapid urbanization, massive industrialization and technological spread backed by globalization impacting the early 2000. It has transformed the city fabric and the associated challenges. Therefore, an Urban Climate Vulnerability Assessment (UCVA) is needed to identify target and target recognize climate vulnerable urban cities, sector or populations. It is needed to, raise awareness, and to develop a holistic strategy to periodically monitor the state of climate vulnerability in those urban regions and raise awareness. For The UCVA framework consists of, seven broad thematic indicators - physical, hazard, social, demographic, financial provisioning, infrastructure and administration vulnerabilities, and their sub indicators to represent the climate vulnerability of the Indian cities. The assessment is done for seven Indian cities namely Delhi, Mumbai, Chennai, Bengaluru, Srinagar, Shillong and Ahmedabad. These cities are selected on the basis of their geographical location, population, ecosystem types and recent encounter with hazards/ hazard trends and the severity caused/ impact of the same, to understand and assess the respective vulnerabilities and risks incurred by them. It is done through a comprehensive assessment approach which uses a robust and predictive qualitative framework, whilst also acting as a vulnerability monitoring tool The comprehensive framework prepared can be replicated to both developing and developed country cities.

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2. Introduction

India has experienced exponential urban growth in the last few decades. The urban population of India has grown from 285 million in 2001 to 377 million in 2011 (Census (GoI), 2014), which is likely to touch 533 million by 2025 (Census of India, 2006). The pattern of urbanization in India is characterized by continuous concentration of population and activities in large cities. Urbanization exerts environmental stress (air, water and land pollution, deforestation, construction activities) which also increases the risk of frequency of natural disasters like floods, landslides, water scarcity and likewise.

Cities have complex and inter-connected systems where services rely increasingly upon uninterrupted infrastructure networks. Disruption of these services would have repercussions on the functioning of the city and the well-being of its residents. Due to concentration of people and property, a hazard can turn into disasters that affect millions of people and property with aggregate worth billions.

The present circumstance where Indian economy is on the path of rapid growth, cities cannot function on their usual ways. It is for this reason that we require a climate resilient urban planning using an assessment of the climate vulnerabilities and risks. Climate change is an inevitable and pressing environmental concern for developed as well as developing economies and will likely to add additional stress on urban infrastructure and lifeline services. Climate induced stress on urban services will impact residents in many direct (urban floods, hot and cold periods, water shortage, and increased morbidity and mortality from hazard events, stress from sea level rise and increased cyclonic storms) and indirect ways (rise in ozone gas resulting in exacerbation of Asthma, increase in the vector growth responsible for conditions like dengue, malaria, chikungunya, etc. owing to the increased temperatures). The IPCC special report on "Managing the risks of Extreme Events and Disasters to Advance climate Change Adaptation" (UN IPCC, 2012), establishes a strong link between extreme weather events and climate change. It explains the causal relation between both and the correlated events including urban floods, cyclonic storms, heat waves and droughts. The unprecedented extreme weather events are result of the distortion in the natural climate. The phenomenon might affect the spatial extent, frequency, duration and trend of the extreme climate weather events. Morbidity from climate change could rise in cities, especially among populations that are vulnerable.

The UN's Sustainable Development Goal (SDG 11) (UN, 2019) on city resilience is now accepted as a critical urban agenda. For achieving SDG 11, cities are striving towards affordable basic services, livable housing conditions, sustainable transport systems and urban development, efficient waste management, accessible greens, participatory governance and local level strategies with a focus on risk reduction. Inefficient urban systems act as a hindrance to combat climate change, making urban areas less resilient. Hence the growing interest in bringing resilience is backed by addressing the short and long terms challenges of climate change.

31% of the population in India live in urban areas and the pace of urbanization is projected to increase. According to the world cities report of 2018 the population of cities like Delhi, Mumbai and Bengaluru will increase by 27%, 22% and 30% respectively in 2030.The existing demand and supply gap of infrastructure services is further widened by unplanned development and growing population. The inadequacies progress into creating a negative feedback loop.

According to the National Disaster Management Authority (NDMA) 58.6% of the Indian landmass is vulnerable to floods and river erosions, 5700 kilometers of country's coastline is vulnerable to tsunamis and cyclones, and more than half (68 %) of its cultivable area is drought prone. In terms of the magnitude of disasters faced by India, it has been found that within a period of thirty years (1980-2010) the country has experienced a total of 431 disaster events, killing 43,039 lives and affecting 1521 million people. The total economic damage caused by these disasters were approximately US$ 48 billion. On an average the natural disasters affect 49 million people per year in India and bring estimated economic damages of US$ 1.55 billion to the country's economy.

Past decadal incidents like Maharashtra floods of 2005 resulting in the death toll of 1000 plus, 2013 flash floods in Uttrakhand and Himachal Pradesh affecting around 5700 people, Kerala floods of 2018 causing the causalities of 433 and heat waves of 2013 affecting states like - Andhra Pradesh, Telangana,

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Odisha (Orissa), Rajasthan and Assam, depicts the vulnerability of Indian states and the need for disaster risk management in the urban India. Furthermore, recent events of disasters experienced by Indian cities like the cyclone Nisarga, cyclone Nirvar, Locusts attack, Kerala, Assam and Bihar floods, have exposed the vulnerability of Indian cities to multiple hazards. Cities incur heavy economic losses due to these hazards. As per the Central Water Commission data, US$ 0.63 billion is the total economic loss from the weather event flood in the last 65 years, from 1952 to 2018. The loss is inclusive of crops, housing and miscellaneous damages. Climate change is correlated to the intensity and frequency of the extreme weather events. The lives and live hoods of million people is affected by these events. Climate change erodes the developmental policies and affects the economic performance of the country.

The extreme weather events in the country in past decades have impacted numerous regions. They have adversely affected the lives and livelihood of the people. Many climate events in the recent past lead to the loss of lives and properly due to the absence of preparedness.

In the recent decades the increased number of extreme weather events (EWEs), which are., heatwaves, cold waves, tropical cyclones, floods, lightning, heavy rainfalls, and likewise highly impacted various regions of the Indian subcontinent leading to losses of lives and property and adversely affecting the livelihood of the vulnerable community. In a study by Kamaljit Ray (Kamaljit et al, 2021)., the trend analysis of last 50 years (1970-2019), depicts mortalities caused by extreme weather events. It is observed that the floods (46.1%) cause the highest share of deaths followed by cyclones (28.6%) and Heat wave (12.3%)

3. Literature Review

A draft methodology for the Urban Climate Vulnerability Assessment (UCVA) was developed after a detailed review of the existing literature available on various frameworks and indexes. The review was spread across international to national studies and the intersection between the both. In order to tabulate a comprehensive indexing, the research was not limited to sector specific but also many national and international successful frameworks were refereed such as Swachh Surveskshan and Urban Governance Index respectively.

Urban Governance Index (UGI) (UN - Habitat, 2004) provided a quantitative top-down and vice versa approach for developing an index to measure good urban governance based on the five principles namely effectiveness, equity, participation, accountability and security. The Environmental Vulnerability Index (EVI) (South Pacific Applied Geoscience Commission, 2004) provided the basis for understanding the different aspects of vulnerability, environment, society and economy also knows as the three pillars as defined in the index. . It used 50 Smart indicators to measure status of vulnerability which otherwise are difficult to quantify in absence of a simplified model. The City Prosperity Initiative (CPI) (UN Habitat, 2014) identifies the various areas of potential and opportunities for the cities to be more prosperous. It comprises of six 'spokes' also known as six sub-indices , namely, productivity, infrastructure, quality of life, equity and inclusion, environmental sustainability and governance and legislation for the assessment. . The City Disaster Resilience Scorecard (UNISDR, 2017) follows the UNISDR's 'Ten Essential For Making Cities Resilient' in order to assess a city's disaster resilience. The developed scorecard reviews the progress and the associated challenges in the implementation of Sendai Framework for the disaster risk reduction:2015-2030. It is an assessment for local government to monitor and review the steps taken in order to combat the risks. The City Resilience Index (ARUP, 2015) defines the 'immune system of the city'. It represents all the aspects where the weakness in one area may be compensated by the strength in another to assess a city's vulnerability. The Swachh Surveskshan (Ministry of Urban Development, Government of India, 2017) is a policy management tool devised to rank cities on the bases of the Swachhta index. It is a comprehensive and inclusive assessment framework which provides ranking based on cumulative scored obtained on the basis of three major data collection sources namely – municipal documentation, independent observation and citizen feedback. The Hazards, Infrastructure, Governance, and Socio- economic (HIGS) framework developed by Integrated Research and Action for Development (IRADe) calculates the Rapid Vulnerability Assessment (Parikh, Jindal, & Sandal, 2008) of cities. The assessment is based on the

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framework comprising information on four major themes – physical and metrological hazards, governance institutions, infrastructure and urban services and socioeconomic and demographic composition, which contain 23 indicators. Disaster Resilience Framework (Parikh, Jindal, & Sandal, 2008) is a holistic methodology to assess vulnerability by incorporating factors allowing local/regional diversification and flexibility to be customized for use in other regions/cities for calculating disaster resilience. The vulnerability of the cities was categorized as high, medium, low depending upon the impact and exposure of city to the disasters.

4. Materials and Methods

4.1. Developing methodological framework

The HIGS (Hazard Exposure, Infrastructure, Governance, Socio-Economic variables) (Parikh J. e., 2014) framework developed by IRADe served as the basis for developing the methodological framework for the current study. The framework consists of gathering relevant data in each category in order to identify key vulnerabilities and their linkages with natural causes, sustainable practices and the capacities of the concerned authorities.

New thematic indicators and sub-indicators were developed, after extensive literature review, to create a holistic risk assessment of climate change at the city level. The extent of Climate Change Vulnerability of the cities is measured based on the following thematic indicators viz.: Physical Vulnerability, Hazard vulnerability, Demographic Vulnerability, Financial Provisioning, Social Vulnerability, Infrastructure Vulnerability and Administration-Governance

A comprehensive index is developed to capture each of these seven thematic indicators. Further, the future vulnerability and preparedness of a city is a weighted aggregation of sub-indices (sub-Indices follow the above mentioned indicator/sub-indicator). These sub-indices are identified and then are quantified, normalized and aggregated to obtain composite vulnerability indices for different thematic indicators for the sectors.

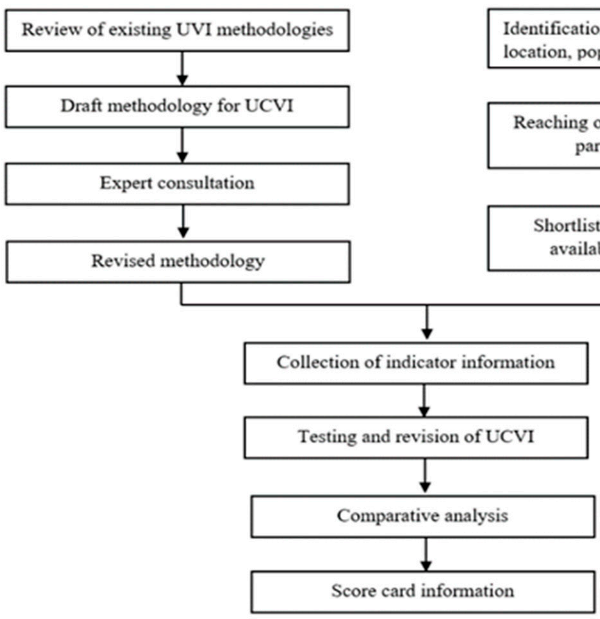

Figure 1. Methodology for preparing Urban Climate Vulnerability Assessment Index.

4.2. Vulnerability Assessment Framework:

The extent of climate change vulnerability for the cities is measured based on respective thematic indicators: **Physical, Hazard, Demographic, and Financial provisioning, Social, Infrastructure and**

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Administration-Governance. Each of these thematic indicators will be supported by sub-indicators, with an objective to derive the vulnerability of each city. All the sub-indicators are ranked in three categories: low, medium or high, assessing its level of vulnerability. There is weightage assigned to each ranking (Low, Medium and high), wherein Low represents an indicator least affected by climate change, and a High is most affected by it. The weightage for each of these rankings is determined in accordance with the national and international benchmarks.

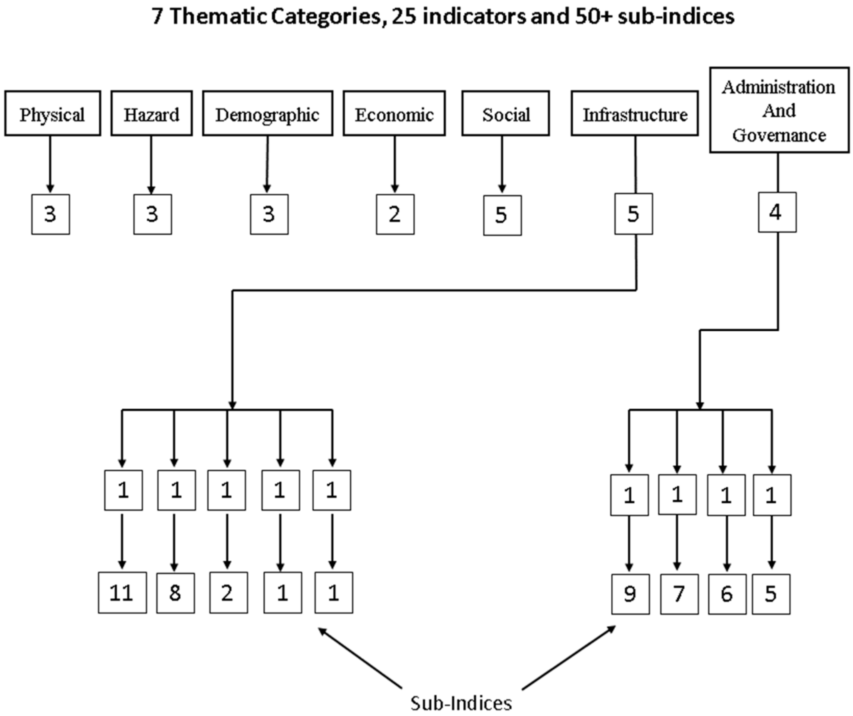

Figure 2. Urban Climate Vulnerability Assessment Framework.

4.3. City Selection:

The cities are shortlisted on the basis of their geographical location, population, ecosystem types (coastal region, hilly region, flat terrain) and recent encounter with hazards/ hazard trends and the severity caused/ impact of the same. Seven cities identified for this project are; Delhi, Mumbai, Bengaluru, Chennai, Srinagar, Shillong and Ahmedabad.

Table 1. City Typologies.

S.No.	City	City Classification	Geographical Type	Climate
1	Delhi	Mega city	Inland	Hot Semi Desert Climate
2	Mumbai	Mega city	Coastal	Monsoon (Southwest Monsoon) Climate affected by Cyclones
3	Chennai	Metro city	Coastal	Monsoon (Northeast Monsoon) Climate

				affected by Cyclones
4	Bengaluru	Metro city	Southern Plateau	Moderate Climate
5	Shillong	Hill Station	Northeast India	Cold and Wet Climate
6	Srinagar	Valley Station	North India	Cold climate affected by Mid-latitude Weather Systems
7	Ahmedabad	Metro city	Western Inland	Hot Dry Climate

1. Geographical Location
Geography is important in determining the hazards a city's vulnerability. For example, the cities located on coasts, near rivers or water bodies can be more vulnerable to floods while those located on hilly areas can be prone to landslides more. Selection of cities from different geographical locations will help in covering all the possible vulnerability indicators and aspects replicable to determine the climate vulnerability of other cities in the future.
2. Population
All the selected seven cities of the study lie under the category of Class 1 towns as defined by Census 2001 Further the cities lie under the classification of: Class I UAs/Towns, Million Plus UAs/Towns, Metro Cities and Mega Cities
3. Ecosystem Type
The cities selected for the study are located in distinct ecosystems such as; Coastal region, Hilly region, inland etc. The existing ecosystem is vital in understanding the arrangement of urban systems and climatic conditions of a city.
4. Hazards
The existing hazard vulnerability of a city may get aggravated from new hazards. Therefore, a city's previous encounter with hazards and trends in hazards forms an important part of solution to understanding the current vulnerability and also to predict the future hazardous conditions.
5. Severity and frequency of hazards
The hazard severity is and can be assessed in terms of the economic losses, fatality, causality etc. Severity or intensity is a major component of a hazard, along with the frequency of that disaster. This is because a disaster may strike every year, yet might not be a severe one. In contrast, a disaster might strike once in 100 years and cause unimaginable losses, as was the case with Kerala floods of 2018.

4.4. Composite Assessment Framework:

Physical Vulnerability: Under this indicator we recorded the number of residents directly or indirectly exposed to respective hazard, as population which resides in the vicinity of hazardous zones or vulnerable spots of the city are the ones exposed to a particular hazard. ***Hazard Vulnerability***: Geographical location and historical hazard frequency are vital in determining the hazard vulnerability of a city, the susceptibility and preparedness to a hazard. ***Demographic vulnerability***: Population composition is an integral aspect to understand the possible vulnerability of a city. The pace at which a city grows, along with the population density is essential to understand the attached risk and preparedness required. ***Financial Provisioning***: To cope with the damages of hazards it requires various funds and thus the management of same is essential. Disaster management funds are availed from national level, state level, City level, multilateral agencies etc. and its becomes necessary to assess the optimal utilization of such funds. ***Social Vulnerability:*** Limited land supply and affordability in

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urban areas, often leads to slum and squatter settlements being located in places which are highly sensitive and neglected. Its enquires to record aspects of slum location and its population composition to assess the urban poor vulnerability. ***Infrastructure Vulnerability:*** A good infrastructure network is responsible for the uninterrupted working of an urban system. The infrastructure vulnerability is inclusive of city's basic infrastructure – Water, Drainage, Solid waste management, power and telecommunication. The ranges are defined considering the service level benchmarks defined by. Ministry of Housing and Urban Affairs ***Administration and Governance:*** The administration and governance vulnerability aspect covers headers like land use, Planning and strategies, operational preparedness and public participation.

Table 2. Scoring guidance for 5 thematic categories (Physical Vulnerability, Hazard Vulnerability, Demographic Vulnerability, Financial Provisions, Social Vulnerability) and their indicators.

Thematic Category	Indicators	Low	Medium	High
hysical Vulnerability	Percentage of Population exposed to hazards	Less than 10%	10-20%	Above 20%
	Percentage of Population affected due to hazards	Less than 10%	10-20%	Above 20%
	Death / casualties reported due to extreme events	Less than 50	50 to 100	Beyond 200
Iazard Vulnerability	City location (Coastal, Hilly and valley, arid, Semi-arid, Humid etc.)	Located on relatively low hazard prone area	Located on relatively high hazard prone area	Located on highly azard prone area
	Average annual occurrences of major climate/ hazard events	0	1 to 2	Above 2
	Change in the hazard/ disaster frequency/ occurrences over the past decades (preferably 20-30 yrs., minimum 10yrs)	No Changes	Relatively changed	Drastically changed
Demographic Vulnerability	Population density growth	0 to 5%	5 to 10%	above 10%
	Decadal Growth rate	0 to 5%	5 to 10%	above 10%
	Projected Population Growth	0 to 5%	5 to 10%	above 10%
inancial Provisions	Funds available for Disaster Risk Reduction (DRR) management & dedicated Disaster management Budget – state & city level plans	Available & Utilized	Available but not utilized	Iot available
	Optimally utilize the available funds	Available & Utilized	Available but not utilized	Iot available
ocial Vulnerability	Percentage of slum population located on and near vulnerable or hazard prone locations	Less than 10%	10-20%	More than 20%
	Percentage of slum pockets upgraded & rehabilitated after disasters	More than 80%	50-80%	ss than 50%

	Projected Slum Population growth	Less than 5%	5 to 10%	above 10%
	Dependent population (below 14 yrs – Above 60 yrs, women)	Less than 5%	5 to 10%	above 10%
	Records and updated data for vulnerable section being affected by disasters	Yes, recorded & Updated information available	Yes, only recorded but not updated	No records available

Table 3. Scoring guidance for Infrastructure vulnerability, indicators and sub-indicators.

Thematic Indicator	Indicators	Sub – indicators	Low	Medium	High
Infrastructure Vulnerability	Water supply	Coverage of potable water supply	More than 80% HH Covered	50-80%	less than 50% HH covered
		Per capita water supply	Above 135 lpcd	70-135 lpcd	0-70 lpcd
		Quality of Potable water	Beyond 80% is treated	80-50%	Less than 50% is treated
		Water level in Source of Drinking Water	More than 80%	50-80%	Less than 50%
		Supply network developed in accordance to UDPFI guidelines	Yes	Partially	No
		Frequency of water supply	More than 2 times / day	2 times /day	less than 2 times/ day
		Water Treatment Facilities	Water treatment Plant available along with scientific treatment and metering –more than 80% treated	Water treatment Plant available - 50-80% treated	No Water treatment Plant available- less than 50%
		Age of the Infrastructure	Less than 30 years	30-70 years	Above 70 years
		Frequency of cleaning and maintenance of the infrastructure	Once in a year	Once in 2-3 Years	Once in more than 3 years

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		Segregation of Drinking water lines and sewage line	Both drainage systems are separate, along with covered drains	Work in progress	Not separated & have not planned for the same
		Ground water level in past 5 years	Has increased	Has remained the same	Has changed/ decreased drastically
	Drainage Pattern Sewage	Coverage of drainage connections	More than 80% HH Covered	50%-80% HH Covered	Below 50% HH covered
		Drainage network developed in accordance to UDPFI guidelines	Yes	Partially	No
		Sewerage and storm water drainage system segregation	Both drainage systems are separate, along with covered drains	Work in progress	Not separated & have not planned for the same
		Availability of Waste Water Treatment System	Yes, treatment plants available	Planning to develop CETPs	No CETP
		Central Effluent Treatment Plants (CETPs) treatment capacity	More than 80 % HHs covered	80-50% HHs covered	below 50% HHs covered
		Incidence of water logging in last year (Time) (This does not depict number of instances)	Less than equal to 1	2 - 3	More than 3
		Frequency of cleaning and maintenance of drainage blockade busting infrastructure	Once in a year	Once in 1-2Years	Once in more than 2 years

		Mechanism to handle high discharge levels (heavy rainfall)	Yes, fully equipped and planned	Planning in process	No plans exists
	Solid Waste Management	Municipal Waste Treatment – Collection, segregation & transportation	More than 80 % HHs covered	80-50% HHs covered	below 50% HHs covered
		land filling sites and scientific treatment	land filling sites available and waste scientifically treated	Land filling sites available but waste not scientifically treated	No landfilling site, over burden capacity
	Power	Harnessing renewable sources of energy	Yes, have provision and projects for green energy utilizing	Currently developing projects/ planning stage	Have not made any planning to such harnessing
	Telecom & Communication	Emergency Operating Centres (EOC)	Yes, EOC are developed and working efficiently	Yes, EOC but not working efficiently	No, EOC are available

Table 4. Scoring guidance for Administration and governance, indicators and sub-indicators.

Principle	Indicators	Sub – indicators	Low	Medium	High
Administration and Governance	Land Use Mapping	City Master Plan/ land use maps	Yes, plan & maps available	Process of developing	Not available
		Major changes in the land-use pattern over the decades	less than 50%	50 - 80%	More than 80%
		Green Cover – Playgrounds, parks, gardens, open space, water bodies etc)	12-14% small cities 18-20% - Medium cities 20-25% - Metropolitans	10-12% small cities 14-12% - Medium cities 18-20% - Metropolitans	7-9% small cities 5-7% - Medium cities 12-14% - Metropolitans
		Mapping of the major water bodies (rivers, lakes, ponds etc.)	Yes, mapped & Updated	Yes, only mapped, not updated	Not mapped

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		Mapping of the Hazard prone areas, city level, ward level	Yes, mapped & Updated	Yes, only mapped, not updated	Not mapped
		Mapping of the basic infrastructure	Yes, mapped & Updated	Yes, only mapped, not updated	Not mapped
		Mapping of the Critical Infrastructure	Yes, mapped & Updated	Yes, only mapped, not updated	Not mapped
		Mapping of Ecological Hotspots	Yes, Mapping done	In process	Not mapped
		Mapping of the slum pockets & population cover	Yes, Mapping done	In process	Not mapped
	Planning & Strategies	DRR and climate risk management in City Master Plan, Smart city Plans/ DRR in Urban Planning	Integrated Approach in Planning strategies & Plans	Mixed	DRR not a part of Urban Planning strategies & Plans
		Climate Change & Extreme events Projections in Urban planning	Integrated Approach in Planning strategies & Plans	Mixed	DRR not a part of Urban Planning strategies & Plans
		City Disaster Management Plans	Yes, it exists	Planning in process	Don’t exist
		Natural Resource Management Plan	Yes plan available and is being implemented	Process of developing	Not planned
		Green Space development Plan	Yes plan available and is being implemented	Process of developing	Not planned
		Separate Plans for particular disaster, Climate risk management plans, like Heat wave	Yes plan available and is being implemented	Process of developing	No separate plans available

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		management plans, Dengue or Malaria Action plans, Flood and Earthquake disaster management plans – Hazard Specific Plan			
		Multi- Hazard Planning at city level	Yes plan available and is being implemented	Process of developing	No separate plans available
	Operational Preparedness	Dedicated persons to handle and update disaster related database?	Dedicated persons available and data updated	Dedicated person available but data bot updated	No person available & data not updated
		Dedicated municipal Cadre (trained & specialized personnel),	Dedicated Cadre appointed	Appointment in process	No initiative taken yet
		Dedicated team for disaster management/ disaster response system/ Emergency Administrative Authority	Dedicated persons available and data updated	Dedicated person available but data bot updated	No person available & data not updated
		Early warning and forecasting system	System exists and executes functional efficiently	System exists but don't function efficiently	Don't exist
		Real- Time Hazard Monitoring Systems	System exists and executes functional efficiently	System exists but don't function efficiently	Don't exist
		Awareness Campaigns , training & capacity building sessions mock –	Programmes exist and more than 10 such exercises initiated	Programmes exist but only 1-5 such exercises initiated	No such Programmes initiated

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		drills, evacuation plans for DRR			
	Public Participation	Community participation/ participatory planning- integral part of planning and strategy building in terms of DRR & climate resilience	Documented & implemented	Documented	Not Documented & Implemented
		Inclusion of traditional and local approaches/ indigenous knowledge, methodology to manage/ adapt to climate change and disaster occurrences in planning	Documented & implemented	Documented	Not Documented & Implemented
		Approach Top Down Or Bottom Up Approach	Nil	Documented	Not Documented & Implemented
		Updated previous disaster data base	Not Updated	Partially Without loss figures (economic And human)	Full with loss figures (economic and human)
		Municipal credit rating	Done	Planned	Not planned

4.5. Assessing Vulnerability (Scoring):

Climate vulnerability across the seven selected cities was analyzed using the comprehensive index. The UCVA has in total – seven thematic categories, twenty-five indicators and fifty sub-indices. The sub-indices are confined to Infrastructure and Administration themes. The scoring of the cities' indicators and sub-indicators is done on the basis of providing simple scores ranging between 1 to 3, where 1 indicates least vulnerable and is ranked low, and 3 indicates most vulnerable and ranked as high. The lowest level, Indicator or Sub-Indices, representing its respective thematic category is ranked within 1 to 3, depending upon the degree of vulnerability it holds- high, medium and low. It is then aggregated and normalized to obtain a composite vulnerability score of that degree. Also, the indicators or sub-indices which contain information are only taken in consideration while normalizing and otherwise not.

Two methods are used to aggregate and normalize the score: 1. Lowest degree is Indicator, where the scores are aggregated and normalized twice to obtain the final thematic score. 2. Lowest Degree is Sub-indices, where the scores are aggregated and normalized thrice to obtain the final thematic score, as in the case of Infrastructure and Administration. The normalization is done on the basis of the score factor. The Score Factor differs with each thematic indicator and also with each degree it is calculated at. For this study the method of normalization is taken as equal normalization. No further rankings are allocated to the score factor at the time of normalization, indicator/sub-indices with no information are dropped while calculating

1. Scoring Method 1: Scoring of thematic category and indicator (no sub-indices)

The aggregation and normalization in this case is done **twice**. The scoring of high, medium or low is done at the indicator level as it is the lowest degree in the absence of sub-indices. Once the ranking is done it is then normalized depending upon the score factor.

Indicator Score Factor (Isf) equals to 1 divided by the number of queries in that degree it is used to normalize the ranking. The individual Indicator Score (*ISc*) for the Indicators are calculated by multiplying the indicator weightage *(iw)* with the Indicator Score Factor (*sf*). The scores once normalized are then aggregated and Cumulative Indicator Score (*CISc*) for all three indicators.

Indicator Score Factor (Isf) = 1 / number of queries for each thematic category

Indicator Score (ISc) = iw * Isf

Cumulative Indicator Score (CISc) = {[ISc_1] + [ISc_2] + [ISc_3]}

Thematic category Factor (Tcf) is then calculated, where Tcf equals 1 divided by the number of thematic categories present. Final Score (FSc) for the particular indicator at respective city level is then calculated by multiplying Cumulative Indicator Score (CISc) with the thematic category Factor (Tcf).

Thematic category Factor *(Tcf)* = 1 / total thematic indicator

Final Score (FSc) = CIsc * Tcf

2. Scoring Method 2: Scoring of thematic category and indicator with sub-indices

The aggregation and normalization in this case is done **thrice**. The scoring of high, medium or low is done at the sub-indices level as it is the lowest degree. Once the ranking is done for all the sub-indices for various indicators, it is then normalized depending upon its score factor.

The Sub-Indices Score Factor (*SIsf*) in this case differs amongst different indicators, but is same for the sub-indices under same indicator. Then, the individual Sub-Indices Score *(SISc*) for the Indicators are calculated by multiplying the indicator weightage *(siw)* with the Sub-Indices Score Factor (*SIsf*). The scores once normalized are then aggregated and Cumulative Sub-Indices Score (*CSISc*) for all sub-Indices

Sub-Indices Factor (SIsf)= 1 / number of queries for each sub-indices

Sub-Indices Score *(SISc)* = Indicator weightage x Sub-Indices Factor (*siw * SIsf)*

Cumulative Sub-Indices Score (CSISc) = {[$SISc_1$] + [$SISc_2$], [$SISc_3$], [n]}

The score factor used for the indicator (*Isf*) is 1 divided by the total number of indicators. The Cumulative Indicator Score (*CISc*) for all five indicators is then calculated by multiplying indicator score factor (*Isf*) with Cumulative Sub-Indices Score (*CSISc*) of each sub-indices.

Indicator score factor (Isf) = 1 / number of queries for each thematic indicator

Cumulative Indicator Score *(CISc)* = {[$Isf * CSISc_1$] + [$Isf * CSISc_2$] +…. + [$Isf * CSISc_n$]}

Thematic category Factor (*Tcf)* is then calculated, where *Tcf* equals 1 divided by the number of thematic categories present. Final Score (*FSc*) for the particular indicator at respective city level is then calculated by multiplying *Cumulative Indicator Score* (*CISc)* with the thematic category Factor (*Tcf).*

Thematic category Factor *(Tcf*)= 1 / total thematic categories

Final Score *(FSc) = CIsc * Tcf*

Example 1: Calculation of Cumulative Sub-Indices Score for the Solid Waste Management indicator

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Table 5. Scoring method for the Solid Waste Management indicator.

Indicator	Sub-Indicator	Low	Medium	High	Influence Factor	Sub Indice Factor	Sub Indice Weight	Score	Total
Solid Waste Management	Municipal Waste Treatment, Collection, segregation & transportation	More than 80 % HHs covered	80-50% HHs covered	below 50% HHs covered	High	1/2	3	1.5	2.5
	Land filling sites and Scientific treatment	Available and waste scientifically treated	Available but waste not scientifically treated	No landfilling site, over burden capacity	Medium	1/2	2	1	

Sub-Indices Factor = 1 / number of queries for each thematic sub-indices
$SIsf_1 = ½$
$SIsf_2 = ½$
Sub-Indices Weight
$Siw_1 = 3$
$Siw_2 = 2$
Sub-Indices Score
$Sisc_1 = SIsf_1 * Siw_1 = 1.5$
$Sisc_2 = SIsf_2 * Siw_2 = 1$
Cumulative Sub-Indices Score (*CSISc*)
$= Sisc_1 + Sisc_2$
$= 1.5+1$
$= 2.5$

Example 2: Calculation of thematic category score for *Infrastructure Vulnerability*

Table 6. Scoring method for the entire Thematic Category Infrastructure Vulnerability.

Infrastructure Vulnerability						
Indicator	**Indicator Score Factor**	**Cumulative Indicator Score**	**Score**	**Total**	**Thematic Indicator Factor**	**Total**
Water Supply	1/5	1.91	0.38	1.61	1/7	0.23
Drainage Pattern	1/5	1.63	0.33			
Solid Waste Management	1/5	2.5	0.5			
Power	1/5	1	0.2			
Telecom and Communication	1/5	1	0.2			

Cummulative Indicator Score $CISc_{(IF)}$

$CISc_{(IF)} = \{[Isf * CSISc_1] + [Isf * CSISc_2] + [Isf * CSISc_3] + [Isf * CSISc_4] + [Isf * CSISc_5]\}$

$= \{[(1/5) * 2.5] + [(1/5) * 1] + [(1/5) * 1] + [(1/5) * 1.91] + [(1/5) * 1.63]\}$

$= 1.61$

Thematic category Factor $Tcf_{(IF)} = 1 / 7$

Final Score $FSc_{(IF)} = CIsc_{(IF)} * Tcf_{(IF)}$

$= 1.61 * (1/7)$

$= 0.23$

Comparative Analysis

As earlier discussed in the Methodology chapter, the Urban Climate Vulnerability in Indian cities is assessed based on their **Physical, Demographic, Financial Provisioning, and Social, Infrastructure and Administration-Governance** structure. Sub-indicators and indices are used to support the same. They are ranked in the categories of **High, Medium and Low** to assess/ measure the level of vulnerability of the city at each level.

4.6. Physical Vulnerability

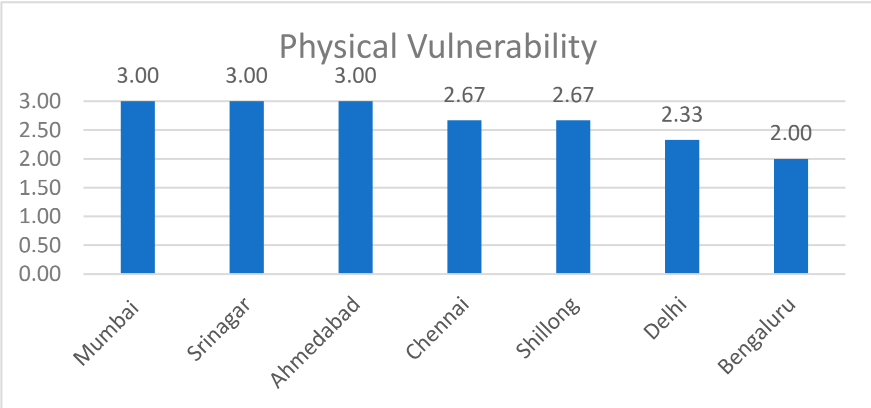

Figure 3. Physical Vulnerability Scores.

Physical vulnerability covers the sub-indicators wherein the population directly or indirectly affected by the hazards has been considered. The impact of any hazard or disaster can be directly measured by the total number of people affected by the same.

The physical vulnerability score of each city obtained by ranking the respective sub-indicator depicts that **Mumbai, Srinagar and Ahmedabad** are the most vulnerable, followed by **Chennai.** This is due to the deaths and casualties reported due to extreme events like the disastrous floods of 2005 in Mumbai, 2014 in Chennai and Srinagar and the 2010 heat wave of Ahmedabad. The population exposed to the city-specific hazards in most cities lies in the range above 20% of the total population. It must also be noted that the percentage of the population affected due to hazards in a majority of the cities is above 20%.

4.7. Hazard Vulnerability

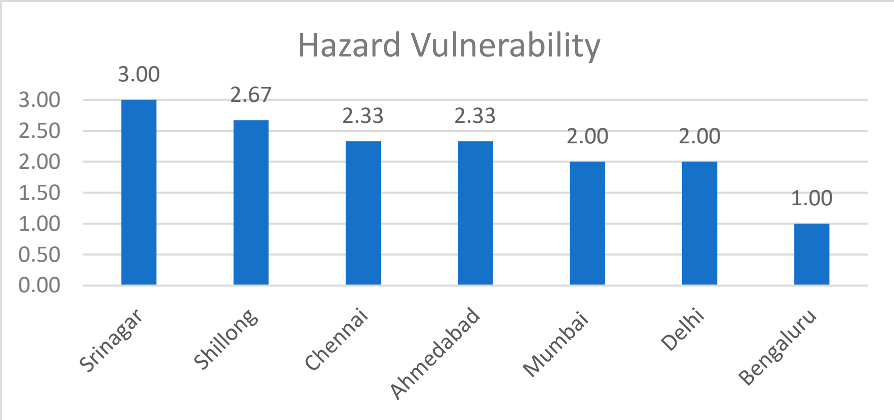

Figure 4. Hazard Vulnerability Scores.

Hazard vulnerability is attributed to the cities' geographical and geomorphology, hazard characteristics, and annual/decadal trends.

The hazard vulnerability score of each city obtained by ranking the respective sub-indicator depicts that **Srinagar** is the most vulnerable, followed by **Shillong and Chennai.**

The selected cities are located in highly hazard-prone areas except for Bengaluru. The average annual occurrences of the major climate hazards in the cities range from medium to high intensity. The cities like Mumbai, Chennai, Delhi, Bengaluru and Ahmedabad experience one to two events annually; Shillong and Srinagar sometimes experience more than two events annually. The trends for these hazards observed over the past decades reveal that such incidences have remained consistent in most cases. Only in Srinagar there was an increase in climate-induced hazards.

4.8. Demographic Vulnerability

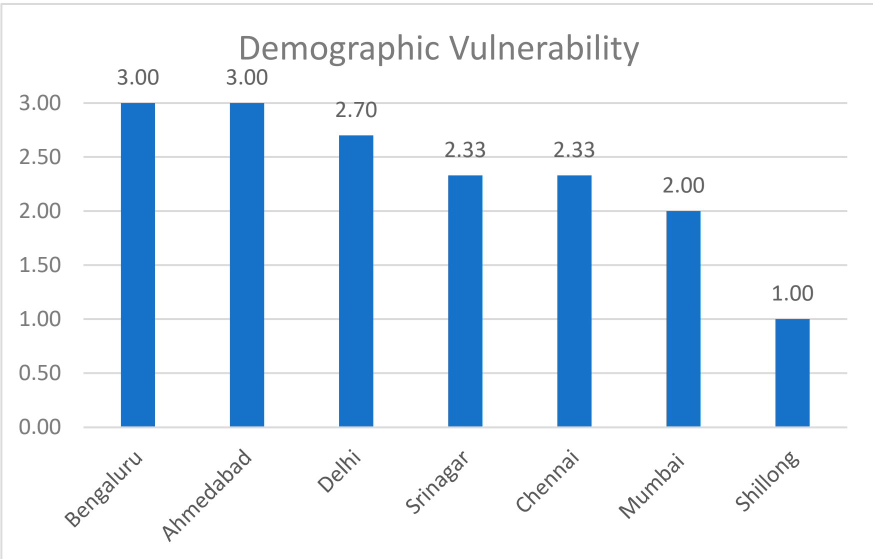

Figure 5. Demographic Vulnerability Scores.

Population growth and distribution, especially increased population density and urbanization, increases vulnerability to disasters.[1]

[1] Charles Perrow, The Next Catastrophe (Princeton, NJ: Princeton University Press, 2007).

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The demographic vulnerability score of each city obtained by ranking the respective sub-indicator depicts that **Bengaluru** is the most vulnerable, followed by **Ahmedabad and Delhi**.

Decadal population density growth (2001-2011), ranging from 5% to 10%, has been reported in most cities. While looking at the decadal growth rate, the cities that have recorded higher growth rate (above 10%) are Bengaluru, Ahmedabad, Srinagar and Delhi. The reasons accounting for this include an increase in the migrant/floating population, Bengaluru an IT hub of the nation, Delhi the national capital, and Srinagar the fastest growing city in the valley. Moreover, the index depicts that the projected population growth in the majority of the cities is lying in the high range that is above 10%. The increase in the population indicates that the number of people exposed to climate-related hazards will increase as the city grows in the future.

4.9. Financial Provisioning

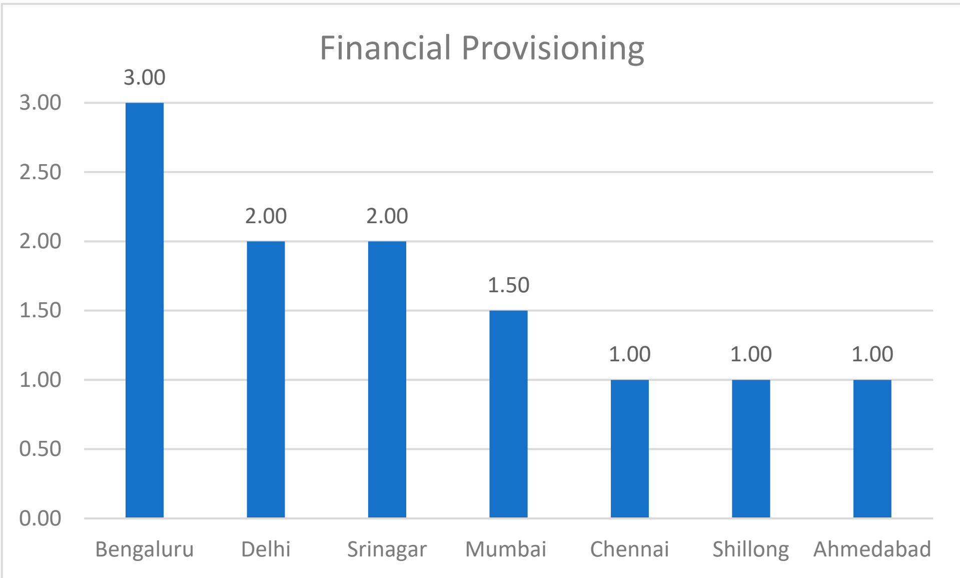

Figure 6. Financial Provisioning Scores.

The vulnerability of a city is often defined as the lack of capital, and the capital is viewed as the stocks that can produce a flow of economically desired outputs. It is not only the availability of the funds that is important but its availability for use/utilization, its accessibility-equity-quality-diversity that needs to be taken into account.

The economic vulnerability score of each city obtained by ranking the respective sub-indicator depicts that **Bengaluru** is the most vulnerable, followed by **Delhi.**

We find that Bengaluru does not have a proper budget allocated for the DRR management at city level plans. Cities like Delhi and Srinagar have DRR budgets, but they are not utilized, resulting in the high vulnerability of such cities.

Information regarding the optimal utilization of the available funds represents a huge shortcoming in this sector as the available funds are not utilized. Chennai is the only city that uses DRR funds.

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4.10. Social Vulnerability

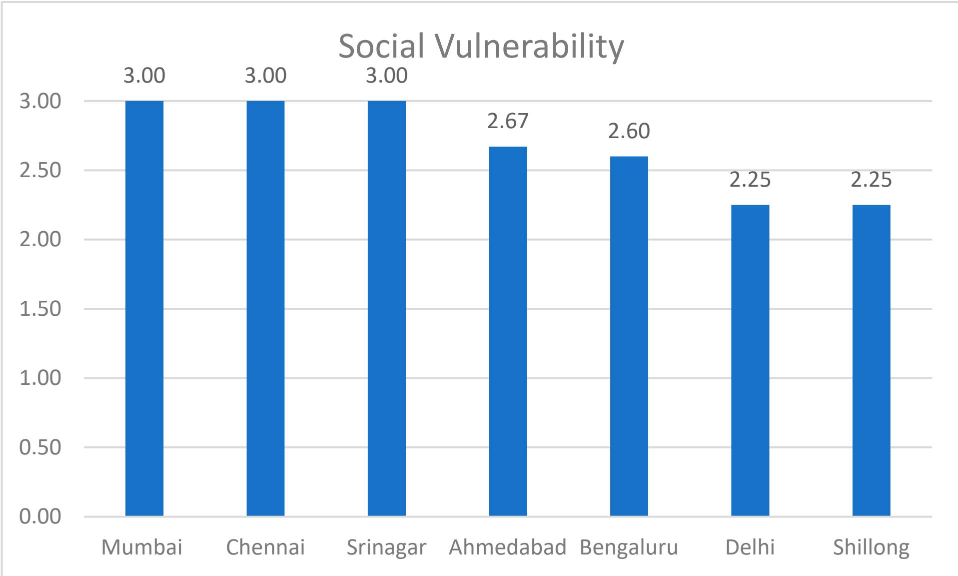

Figure 7. Social Vulnerability Scores.

The social vulnerability of the city is assessed through the slum and existing vulnerable population of the cities. This section manifests the vulnerable, dependent population and deprivation that transcends income poverty.

The social vulnerability score of each city obtained by ranking the respective sub-indicator depicts that **Mumbai, Chennai and Srinagar** are the most vulnerable, followed by **Ahmedabad.**

Most cities record high (more than 20%) slum population occupying hazard-prone areas like low lying flood plains or hilly terrains. In cities like Srinagar and Mumbai, a huge slum population resides on the river banks, making them highly vulnerable to urban floods.

The index depicts that the percentage of slum pockets upgraded and rehabilitated post-disaster was less than 50% in cities like Chennai and Shillong. In the case of Ahmedabad, the population resettled due to the lack of economic opportunities in the relocated sectors. Whereas the data concerning the issue of rehabilitation for Mumbai, Delhi and Srinagar is unavailable.

The vulnerability will rise with the rise in population. Data on the projected slum population portrays that Mumbai, Chennai and Ahmedabad are expected to experience a 10% increase in the existing slum population. This will further worsen the vulnerability of the underprivileged.

Along with this, the dependent/vulnerable sections are highly vulnerable in all the seven cities, and proper records of these sections are not being documented for reference at the time of hazard.

The updated data for the number of children, old (above 60), and women in all the cities are either not available or updated as per the latest records. This is a major limitation in the Indian administrative systems.

4.11. Infrastructure Vulnerability

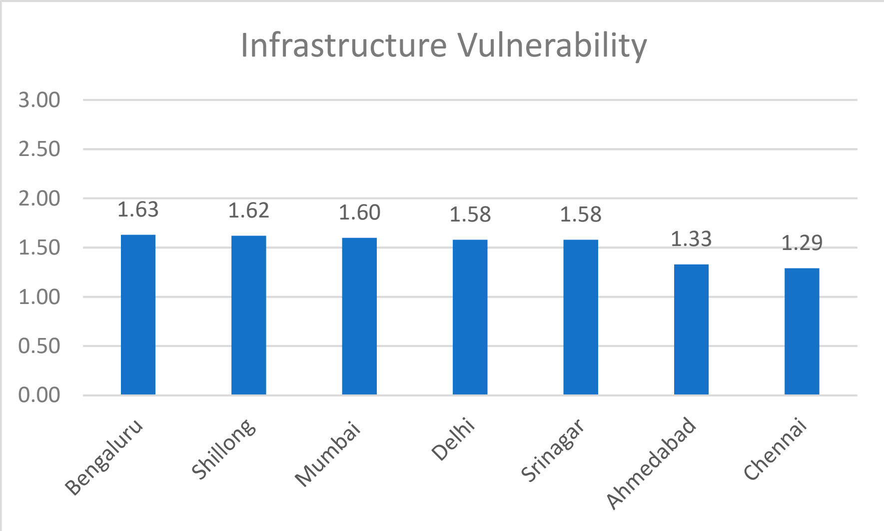

Figure 8. Infrastructure Vulnerability Scores.

The infrastructure and services that have been studied in detail against the MoHUA benchmarks, SLBs, are water supply, sewerage, solid waste management and storm water drainage facilities within the selected cities.

The infrastructure vulnerability score of each city, obtained by ranking the respective sub-indicator, depicts that **Bengaluru** is the most vulnerable, followed by Shillong and Mumbai.

1. Water Supply

Looking into the per capita water supply and availability of the potable drinking water and its quality, we find that the selected cities are at a lower to medium level of risk, as almost 50% of the households have access to nearly 75-135 lpcd of water for daily use and consumption. Also, the cities have tried to develop the supply network as per the SLBs set forth by the Central Govt. However, the water treatment facilities and the age of the water supply systems reveal that the cities are at a medium level of vulnerability as the structures are nearly 70 years old. Cities like Shillong do not have options for the regular cleaning and maintenance of the systems, as it is not cost-effective and may require the water system to be shut down for days, which is not feasible as there is no alternative source of water supply.

Delhi, Mumbai, and Chennai experience constant water shortage as the demand and supply gap in these cities is vast. They are at medium to high risk as the frequency of the water supply is sometimes less than two times a day, knowing that no Indian city has the provision of a 24*7 water supply.

There is a dire need for the cities to segregate the drinking water lines and replenish the groundwater level. These areas are mostly affected during disaster occurrences. Cities Mumbai, Chennai, Delhi and Bengaluru are at higher risk of vulnerabilities due to inadequate water supply facilities.

2. Drainage facilities

The cities of Delhi and Mumbai generate some 17% of all the sewage in the country (Planning Commission, 2012-2017).

The cities have medium risk when it comes to the coverage of the drainage networks (50-80%). They are at low risk with the availability of water treatment plants. However, cities like Shillong and Srinagar have no facilities for segregation of the stormwater and sewage segregation and covered drains making the cities highly vulnerable. Urban flooding has been the major consequences of

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improper drainage facilities and their proper maintenance. Hence, most cities are at the risk of waterlogging, with more than 2-3 such incidences being recorded last year.

Mumbai, Delhi, Bengaluru and Ahmedabad are at higher risk of vulnerability due to inadequate drainage and sewage facilities.

3. Municipal Waste

Solid waste management is defined as discarded solid fractions generated from domestic units, trade centers, commercial establishments, industries and agriculture, institutes, public services and mining activities (NIUA, 2015).

Except for Chennai, other cities have a high to medium risk towards hazards as below 50% of the cities' waste is being treated. All the cities have a provision for landfill sites, but they lack a scientific treatment facility for safely disposing of solid waste without harming the environment.

All seven cities are highly vulnerable due to inadequate solid waste management facilities.

4.12. Administration and Governance:

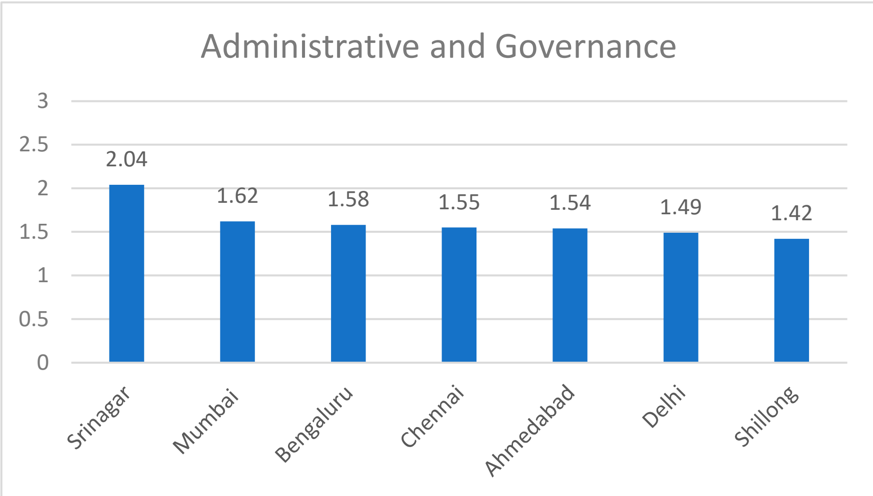

Figure 9. Administration and Governance Score.

The Administration and Governance score of each city ranked by the respective sub-indicator depicts **Srinagar** as the most vulnerable, followed by **Mumbai and Bengaluru.**

1. Land Use Mapping:

Most cities are at low risk to the needs of commons as the changes in the land use patterns observed were less than 50% in most of the cities.

The availability of green cover in cities, like playgrounds, parks and likewise was found to be adequate, ranging from 12%-14% in the small cities, 18%-20% in medium cities and 20%-25% in metropolitan cities. However, Mumbai and Srinagar are the two highly vulnerable cities as they do not meet the criteria set as per the benchmark of urban greening guidelines of 2014.

Mapping of critical resources like water bodies and ecological hotspots are mapped in most of the cities. Chennai and Shillong experience high risks as no records for the same were obtained publically.

Mapping basic and critical infrastructure with slum locations plays a significant role in combating and recovering the hazard vulnerabilities. Except for Shillong and Srinagar, it is observed that most of the cities have acknowledged the need and mapped the essential components like infrastructure services and slums. Mapping of hazard-prone areas is vital to mitigate and prepare for hazards. The index represents that Shillong, Srinagar, and Bengaluru have limited approach to combating hazards as they have no records regarding the hazard-prone areas.

2. Planning and Strategies:

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Planning and strategies are core to prepare, plan and practise for the hazards affecting any city. The cities which are highly vulnerable to climatic hazards are Srinagar and Bengaluru. This is so because they do not have a city-level disaster management plan to manage hazards. They also lack the formation of a hazard-specific plan or multi-level hazard planning map.

It is also observed that the cities like Shillong and Bengaluru have no disaster risk management plans, green space development plan or natural resource management plan which is essential for preparedness purposes. A separate plan for climate change and extreme events projection is missing for most of the cities. Only Bengaluru has an integrated approach in planning strategies and plans for the same.

3. Operational Preparedness:

The operational preparedness team is a backbone for carrying out disaster risk reduction measures. Expect for Chennai and Srinagar, other cities either have or are in the process of developing a dedicated team to handle and update disaster related databases, a dedicated municipal cadre and a dedicated team for disaster management response.

Preventive measures like early warning systems and awareness campaigns, training sessions and mock drills are an integral part of their preparedness measures, except for Shillong. The real-time monitoring systems are lacking for all the Indian cities, including the seven selected cities.

4. Public Participation:

The scoring reflects the lack of public participation in Indian cities. It is often observed in all the cities that public participation initiatives like community participation in building DRR, the inclusion of traditional and local approaches to adapt to climate change and a bottom-up approach is either not documented and implemented or is just documented with no implementation.

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Table 7. Comparative City Analysis.

S.No	City Classification	Cities	Physical	Hazard	Demographic	Financial	Social	Infrastructure	Administrative and Governance	Population 2011 (Millions) (Census 2011)	Categorization on the basis of population (Census 2011)
1	Inland	Delhi	M	M	H	M	M	M	L	16.31	Mega City
2		Ahmedabad	H	M	H	L	H	L	M	5.50	Metro City
3	Coastal	Mumbai	H	M	M	L	H	M	L	18.41	Mega City
4		Chennai	H	M	M	L	H	M	M	8.50	Metro City
5	Hill Cities	Srinagar	H	H	M	M	H	M	M	1.27	Million Plus
6		Shillong	H	H	L	L	M	M	L	0.14	Class 1
7	Southern Plateau	Bengaluru	M	L	H	H	H	M	M	8.70	Metro City

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5. Conclusions

The final vulnerability score obtained by comparing all the seven thematic indicators of the selected seven cities represents Srinagar as the most vulnerable city, followed by Bengaluru and Ahmedabad.

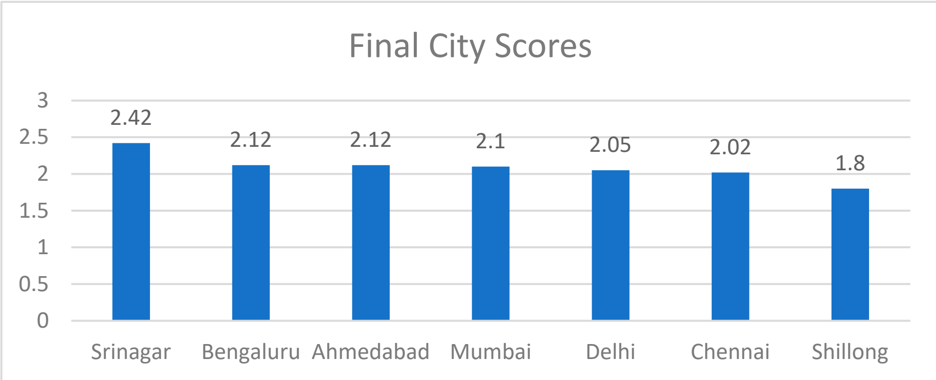

Figure 10. City Vulnerability Scores.

It is observed that each selected city is exposed to climate-induced hazards. The majority of exposure in the cities falls in the range above 20% of the total population, affecting 10% to 20% of the total population on average. In extreme cases caused by extreme events, the death and casualties reported on an average lie in the range of 50-200. Within the range of national density growth rate and population growth rate, it is seen that the Indian cities are growing rapidly. Moreover, the frequency of hazard occurrences has relatively changed in most of the selected cities over the past decades. Therefore, there is a need for preparedness strategies to combat the current risks involved with each growing city.

The funds available for disaster risk management and dedicated disaster management budget allocation are missing for most cities. For the cities which have access to the DRR funds, it is observed that they are unable to utilize the same. Therefore, the risk reduction measures are not utilized as per their intended purpose

The slum projection depicts an increase of 10% and above on average. In most Indian cities, the slum population is located in or in the vicinity of vulnerable or hazard-prone areas. This results in an increased risk of a vulnerable section of society. The direct impact is seen on the economically weaker sections, and the pressure imposed on the natural resources demand due to the same. Basic infrastructure in all the selected Indian cities is not matching the standards of SLBs. The reasons include lack of budgets, and the mechanism and technology to handle the demand. There is a considerable need to incorporate various elements of the urban system to derive holistic and sustainable solutions.

Therefore, through the UCVI, each Indian city can thematically derive their respective strengths, weaknesses, opportunities and threats to the system. This method analyses cross-cutting themes and derives the cumulative score of each theme from the vulnerability score. This will help in guiding the policies and principles for better risk management.

Supplementary Materials: The following supporting information can be downloaded at: https://www.dropbox.com/s/dk6w2weo95gr8jq/Urban%20climate%20Vulnerability%20Assessment%20Report%20IRADe.pdf?dl=0.

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