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Comparative Analysis of India's Tier-1 Cities Climate Vulnerability Assessment

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Abstract: The present study conducts a comparative analysis of India's eight Tier-1 cities, Mumbai, Delhi, Chennai, Kolkata, Bengaluru, Hyderabad, Ahmedabad, and Pune, for their climate vulnerability assessment. The secondary data was collected from the India Meteorological Department and published climate vulnerability atlas to draw the relative importance index (RII) score for each exposure indicator of climate vulnerability for each city on the ten climate parameters, including earthquake, rainfall, wind, thunderstorm, cyclone, drought, floods, heatwave, cold wave vulnerabilities. The cities based on inland and coastal boundaries were also considered in scoring calculations. The study's findings indicate that Chennai and Mumbai are the most vulnerable cities, primarily due to extreme weather events and sea-level rise, necessitating targeted adaptation strategies. Bengaluru shows lower vulnerability, reflecting its resilient infrastructure and proactive measures. Mid-range vulnerabilities are observed for Delhi, Kolkata, Ahmedabad, and Pune, highlighting diverse challenges from heat waves to flooding. Hyderabad's relatively lower score suggests moderate risk yet underscores the importance of continuous infrastructure improvement. The comparative analysis offers critical insights for urban planners and policymakers to develop tailored climate resilience strategies, emphasising sustainable infrastructure, community preparedness, and proactive urban design to mitigate climate risks and foster sustainable development across these urban conglomerates. The study serves as a foundational step towards enhancing the climate resilience of India's major cities.

Keywords: Urban cities; Climate vulnerability; Vulnerability assessment; Climate resilience; Indicators.

Introduction

The rapid urbanisation of the 21st century, a direct consequence of unprecedented population growth and migration trends, has led to the emergence of urban cities as significant contributors to global greenhouse gas (GHG) emissions. Urban cities, with their dense populations and concentrated economic activities, are not only significant sources of GHG emissions but also highly vulnerable to the impacts of climate change. The implications are far-reaching and multifaceted, from increased heatwaves leading to health risks to rising sea levels threatening coastal cities. This dual role of urban cities, as both contributors to and victims of climate change, presents a complex and urgent challenge. India is currently the third largest CO_2 emitter in the world (as per Global Carbon Atlas reports), and the urban city population is growing rapidly. This rapid increase in emissions and population makes the cities more vulnerable in the coming decades to climate change impacts. Forecasting predicts that cities will be responsible for more than 70% of the country's GDP by 2030 (MoEFCC, 2022), therefore making it essential to understand the climate vulnerabilities of these major cities of India.

This study conducts a comparative analysis, focussing on the complex dynamics between natural hazards and their impacts on megacities, to comprehend

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Abbreviations
CVI- Climate Vulnerability Index
GDP- Gross Domestic Product
GHG- Greenhouse Gas
IMD- Indian Meteorological Department
RII- Relative Importance Index

the distinct challenges these urban conglomerates face due to climate change. Our examination of the diverse vulnerabilities of Mumbai, Delhi, Chennai, Kolkata, Bengaluru, Hyderabad, Ahmedabad, and Pune seeks to reveal the immense potential these cities possess to transform into exemplars of climate resilience and sustainable development amidst global change. Furthermore, this analysis provides crucial insights for formulating specific adaptation strategies. By unveiling the diverse vulnerabilities and untapped potential of these Tier-1 cities, we aspire to gain insights into their transformation into centers for climate-conscious growth. This comparative analysis serves as an initial step in assessing their current susceptibility to climate change and paves the way for future investments to create climate-neutral cities.

Building on the foundation of our comparative analysis, this study delves into the climate vulnerabilities of India's eight Tier-1 cities. The broad objective of the study is to discern the significant hazards leading to climate vulnerability in the cities considered (RQ1). This will lead to understanding the nature and extent of these hazards, their frequency, and their potential impacts on urban environments. This understanding will provide a comprehensive idea of indicators of the threats these cities face in a changing climate. The second objective is to assess how the vulnerabilities of India's eight Tier-1 cities to climate change differ based on various factors. These factors include but are not limited to, susceptibility to earthquakes, droughts, cyclones, and other natural disasters. By examining these variables, we hope to uncover each city's unique challenges and identify targeted strategies for climate resilience. The outcome of the studies will contribute to the body of knowledge on urban climate vulnerability and resilience, providing valuable insights for researchers, urban city planners, policymakers, and other stakeholders in their efforts to build sustainable and climate-resilient cities.

Urban Climate Vulnerability and Framework

The implications of climate change necessitate a deeper understanding of urban vulnerability, especially in rapidly developing Tier-1 cities characterised by high population density. These metropolitan areas are subject to a broad spectrum of climate risk factors, necessitating a consistent and comprehensive methodology for assessing their exposure to climate change hazards. This literature review was undertaken to comprehend the current state of climate vulnerability and to investigate the application of the Climate Vulnerability Index (CVI) to Tier-1 cities. The CVI, a well-established framework for assessing climate vulnerability, comprises three primary components: exposure to climate-related hazards, sensitivity based on socioeconomic predisposition, and adaptive capacity, which is the ability to cope and adjust (IPCC, 2014; Brown and Westway, 2011; Smit and Wandel, 2006). The strength of the CVI lies in its comprehensive approach, capturing the complex interplay between biophysical and socioeconomic factors (O'Brien et al., 2004). It has been applied extensively at various scales, from global (Lincke et al., 2002) and regional (Arora, 2023) to city-level (Henríquez et al., 2019), demonstrating its adaptability and effectiveness. However, selecting sub-indicators and weighting each component is not standardised, as it can be potentially subjective and context-dependent (Eakin, 2005). This aspect underscores the need for careful consideration in applying the CVI to ensure accurate and relevant climate vulnerability assessments.

Tier-1 cities, characterised by dense populations and complex urban structures, are particularly susceptible to the impacts of climate change. Coastal cities within this category face extreme vulnerability due to rising sea levels and frequent unpredictable storms. In contrast, inland cities grapple with challenges such as heatwaves, water shortages, and an increased likelihood of severe weather events (Charak et al., 2024). In addition to environmental risks, social hardships such as poverty and insecure housing, compounded by inadequate infrastructure, exacerbate the inherent vulnerability of these cities. This disproportionately impacts the most disadvantaged communities, such as squatter settlements (Mittal and Wilbanks, 2010).

Despite the existing body of research on urban vulnerability and the application of the CVI to various cities, there is a noticeable lack of comprehensive comparative studies across numerous Tier-1 cities in different locations and circumstances. This Study addresses this gap by applying a uniform CVI framework to a selected sample of Tier-1 cities across India. This will yield a comparative climate risk profile for each city, utilising context-specific sub-indicators tailored to each city's unique characteristics and leveraging reliable data sources, including national meteorological agencies and international databases.

Research Methodology

The methodology employed in this study aimed to assess the climate vulnerability of eight tier-1 cities of India by integrating data from the Indian Meteorological Department (IMD) Pune and the Bhuvan portal. The methodology involved a systematic approach to collect, analyze, and interpret data related to ten different climate parameters. The following outlines the step-by-step process employed for the study.

This study collected data from the IMD Pune official portal and collated the secondary data from the Climate Hazards and Vulnerability Atlas of India for 10 climate hazard parameters in tier 1 cities of Pune (IMD, 2023). Earthquake, wind hazard (m/s) (gut wind), rainfall, cyclone vulnerability index, thunderstorm vulnerability index, drought vulnerability index, flood vulnerability index, heat waves vulnerability index, cold waves vulnerability index, and coastal boundaries were the sets of climatic data considered for Pune. The data for each parameter, framed in Excel, included the original values from the IMD and Bhuvan portals (Table 2). The collected data also included the Likert scale scores: 1 = nil risk, 2 = low risk, 3 = medium risk, 4 = high risk, and 5 = very high risk for each parameter (Table 1). The Climatic hazard parameter-related vulnerability duration considered from the IMD atlas is cyclone storm (annual 1961-1970), thunderstorm (average number of thunderstorm days in the annual period 1981-2010), drought (drought normalised vulnerability index based on precipitation index), flood events (annual during the period 1969-2019), heatwaves (annual during the period 1969-2019), and cold waves (annual during the period 1969-2019).

The data were further analysed using the Relative Importance Index (RII) method. This involved giving scores to the risk grades on the Likert scale. It was assumed that the risk, high risk, moderate risk, low risk, and very low risk stood for 5, 4, 3, 2, 1, and 0, respectively. The RII was then calculated for each parameter using the relation: RII = Weighted Total/N where the 'Weighted Total' is the sum of the product of grade on the Likert scale and weight of parameters for the risk; A = The highest grade on the Likert scale; and, N was the total number of observations (Table 3).

It used this RII to calculate the vulnerability score of each city by multiplying it with the original observation score from the portal and websites for each of the eight-tier 1 cities and ten parameters. The total vulnerability score for each city was calculated by adding their scores across all parameters. When the vulnerability scores (for 8 cities) were obtained, the city with the highest was considered most vulnerable and the one with the lowest was deemed least vulnerable to natural hazards.

Table 1: Likert scale for the vulnerability parameters of the study

Parameters	*CVI*	*Score*
Earthquake	Zone V: Very High Damage Risk Zone (MSK IX or more)	4
	Zone IV:High Damage Risk Zone (MSK VIII)	3
	Zone III:Moderate Damage Risk Zone (MSK VII)	2
	Zone II: Low Damage Risk Zone (MSK VI or less)	1
Extreme Wind Speed (In m/s) Annual	58.1 -69.7	5
	47.1 - 58	4
	36.1 - 47	3
	28.1 - 36	2
	16 -28	1
Extreme Rainfall(Days)	87 -109	5
	63-86	4
	36-62	3
	18 -35	2
	<=17	1
Vulnerability Index		
Cyclone Thunderstorm Drought Flood events Heat waves Cold Waves	Very High (0.76 to 1)	4
	High(0.51 to 0.75)	3
	Moderate(0.26 to 0.50)	2
	Low (0 to 0.25)	1
	Nil(0)	0
Coastal Region	Yes	5
	No	0

Using this RII method, as mentioned earlier, the respective Likert scale scores of high, moderate, low, and nil risks to each city for earthquake vulnerability were allocated, as shown in Table 1 above. Subsequently, the calculated RII was then applied to the observation

Table 2: Data for the individual city parameter vulnerability index

City/ Parameters	*Earthquake*	*Wind Hazard (m/s)*	*Rainfall*	*Cyclone Vulnerability Index*	*Thunderstorm Vulnerability Index*	*Drought Vulnerability Index*	*Flood Vulnerability Index*	*Heat Waves Vulnerability Index*	*Cold Waves Vulnerability Index*	*Coastal Boundaries*
Delhi	High	47.2	12	0.03	0.32	0.6	0.05	0.04	0.27	No
Mumbai	Moderate	45.6	24	0.41	0.21	0.6	0.91	0.03	0	Yes
Bengaluru	Low	41.5	15	0.13	0.53	0.5	0.57	0.01	0	No
Chennai	Moderate	59.7	18	0.68	0.21	0.6	0.35	0.04	0	Yes
Hyderabad	Low	52.9	9	0.2	0.14	0.5	0.38	0.16	0.05	No
Kolkata	Moderate	37.1	16	0.29	0.38	0.8	0.25	0.1	0.05	Yes
Ahmedabad	Moderate	34.4	16	0.35	0.14	0.6	0.4	0.08	0.11	No
Pune	Moderate	42.9	54	0.16	0.15	0.6	0.49	0.02	0.03	No

(Based on Raw Data Compiled from IMD and Bhuvan Offical Sources)

Table 3: Relative importance index (RII) of each city parameter

Relative importance index of parameters	
Parameters	*Weighted Total/A*N*
Earthquake	0.48
Wind Hazard (m/s)	0.73
Rainfall	0.42
Cyclone Vulnerability Index	0.44
Thunderstorm Vulnerability Index	0.42
Drought Vulnerability Index	0.65
Flood Vulnerability Index	0.52
Heat Waves Vulnerability Index	0.33
Cold Waves Vulnerability Index	0.29
Coastal Boundaries	0.48

scores of the original parameters for each city, providing a weighted measure of the vulnerability of each city to this peril. In other words, the RII transformed the ordinal Likert scale risk scores to a continuous scale, allowing for a more refined parametric analysis of the contributing factors.

The study includes eight tier-1 cities and relies only on specific vulnerability indicators to determine the vulnerability indices of each city. The selection of eight Tier-1 cities for the study was based on representing major urban centres with significant populations and economic activities, which are crucial for development and particularly vulnerable to climate change impacts because of their concentration of people, resource dependency, and infrastructure. Additional criteria considered were data availability and representative nature in terms of comparability and comprehensiveness of data. While the study may not cover all Indian cities, these selected tier-1 cities have the potential to serve as a representative example of urban vulnerability in different regions of India. The selection of specific parameters (earthquake, wind hazard, rainfall, cyclone, thunderstorm, drought, heatwave, flood risk, cold wave, and coastal boundaries) represents some of the most common climate hazards considered globally and nationally by many agencies and institutions. These parameters are well documented, and reliable data are available from the IMD. When compared, these parameters have potential direct implications for urban infrastructure, economic activities and public health.

Result and Analysis

Using the RII values and individual city parameter index as per the methodology explained above, the final vulnerability scores for India's Tier 1 cities were derived across all ten climate parameters. The results provide insights into the comparative climate vulnerabilities of all the cities in comparison (Table 4).

Chennai ranks the top most vulnerable city with a score of 12.88, dominated by extreme weather events, particularly cyclones and excessive heatwaves. These findings underscore the critical need for context-specific adaptation strategies for coastal cities that integrate infrastructure resilience design and community preparedness to address critical heat and sea-level rise in the face of intense weather patterns. Mumbai emerges as one of the most vulnerable cities (score of 12.02) with elevated risks across cyclone vulnerability, flood events, and heatwaves. The results call for strategic interventions that enhance the region's adaptive capacities and targeted efforts to reduce avoidable vulnerabilities in Mumbai.

Bengaluru, with a score of 7.96, is less vulnerable to the evaluated climatic attributes, and its climate resilience could be attributed to the steps that it has taken and its pre-existing infrastructure, which is quite resilient. Scores ranging from low- to mid-range for most metrics indicate that it has a more balanced threat profile. Bengaluru is an example of how to capitalise on advantages and proactively bolster resilience, underscoring the critical importance of sustainable infrastructure development and urban design. However, more detailed scientific studies will be required to validate the climate-resilient infrastructure of these cities, which is the limitation of this study.

With ratings from 7.73 to 9.42, Delhi, Kolkata, Ahmedabad, and Pune are categorised under the amid-range vulnerability spectrum. The towns face unique challenges, from extreme wind speeds to the potential for earthquakes to susceptibility to different climate events. The mid-range vulnerability shows that comprehensive policies addressing all aspects of climate hazards, including environmental and socioeconomic issues, are essential. As illustrated by the vulnerability score of 7.63, Hyderabad has a lower susceptibility to the evaluated climate risk per the parameters considered for the study. Despite its moderate risk profile, the city can handle stress like drought or intense wind speeds. The findings indicate that existing infrastructure and adaptive capacity are a reason for Hyderabad's comparatively less vulnerable. This underscores the complex interactions among infrastructure, socioeconomic inequality, and geographic position, forming vulnerability to climate change among Tier 1 cities. Vulnerability to severe storms and rising sea

Table 4: Vulnerability Index of the cities towards each parameter of the Study

City/Parameters	*Earthquake*	*Wind Hazard (m/s)*	*Rainfall Frequency*	*Cyclone Vulnerability Index*	*Thunderstorm Vulnerability Index*	*Drought Vulnerability Index*	*Flood Vulnerability Index*	*Heat Waves Vulnerability Index*	*Cold Waves Vulnerability Index*	*Coastal Boundaries*	*Final Score*
Delhi	1.44	2.92	0.42	0.44	0.83	1.94	0.52	0.33	0.58	0.00	9.42
Mumbai	0.96	2.19	0.83	0.88	0.42	1.94	2.08	0.33	0.00	2.40	12.02
Bengaluru	0.48	2.19	0.42	0.44	1.25	1.29	1.56	0.33	0.00	0.00	7.96
Chennai	0.96	3.65	0.83	1.31	0.42	1.94	1.04	0.33	0.00	2.40	12.88
Hyderabad	0.48	2.92	0.42	0.44	0.42	1.29	1.04	0.33	0.29	0.00	7.63
Kolkata	0.96	2.19	0.42	0.88	0.83	2.58	0.52	0.33	0.29	2.40	11.40
Ahmedabad	0.96	1.46	0.42	0.88	0.42	1.94	1.04	0.33	0.29	0.00	7.73
Pune	0.96	2.19	1.25	0.44	0.42	1.94	1.04	0.33	0.29	0.00	8.85

levels present challenges for cities along the coast, such as Chennai and Mumbai. Chennai's vulnerability is due to its coastal location, which puts it at an increased risk of storm surges, sea level rise, flooding, water scarcity, and severe weather, while Mumbai's vulnerability is due to heatwaves in addition to being susceptible to storm surges, flooding, and sea-level rise. Although in the mid-vulnerable city category, as per study results, Bengaluru is exposed to heatwaves, urban flooding, water scarcity, and drought. The rise of urban populations and water issues are key parameters affecting the vulnerability indexed under different categories cumulatively. The city's low-to-middle ratings for most readouts create a more balanced profile of climate risk, indicating its climate resilience is influenced by a combination of proactive steps taken by corporations and their current infrastructure. Like other inland cities, Delhi, the capital of India, is vulnerable to extreme heatwaves, droughts, water scarcity, and air pollution. Kolkata's 11.40 score lands it in the middle of the vulnerability scale. The city has moderate vulnerability with increased risk associated with flooding, cyclones, and heatwaves. Socioeconomic factors like poverty and inadequate and unplanned infrastructure also exacerbate climate vulnerabilities of all inland and coastal cities, which is not considered in this study.

Vulnerabilities demand dynamic, location-specific approaches for cities to endure climate change. Those engaged in interventions for climate resilience, such as urban planners, policymakers, and stakeholders, will find this section helpful. Cities scoring higher on vulnerability indices, in other words, like Chennai and Mumbai, will require strategic investments in infrastructure that are climate resilient and planned, early warning systems and community engagement encouraging public awareness, promoting climate adaptive water management systems, and providing support for climate-resilient agriculture and livelihoods, to enhance their adaptive capacity. Pune city's moderate susceptibility is tied to its exposure to heatwaves, floods, and cyclones, as indicated by its 8.85 vulnerability score. Similarly, despite being the lowest of the three cities in Ahmedabad, Ahmedabad's mid-range vulnerability is mainly due to its moderate sensitivity to heatwaves, flood events, and cyclones, as indicated by its 7.73 vulnerability score. Hyderabad has a score of 7.63, indicating lower vulnerability to the tested climatic parameters, which illustrates the low-risk category, but it's counteracting problems from extreme winds to drought.

Conclusion

Studying urban cities' climate vulnerability and index is crucial in the Indian context for understanding and ensuring a climate-resilient sustainable future and related risks. Cities with higher final scores will be of more significant concern due to their overall vulnerability. Examining the weightage of individual parameters will help understand and highlight the most critical areas for those cities. For instance, if a city's scores are high due to a high weightage on flood vulnerability, then the decision-maker's priority should focus on developing climate-resilient infrastructure on improving drainage infrastructure and flood defence mechanisms, considering the future population expansion and geographical criteria, becomes a top priority. This study explores the distinct dangers of eight major Indian cities - Delhi, Mumbai, Bengaluru, Chennai, Hyderabad, Kolkata, Ahmedabad, and Pune - while drawing from a wide variety of reports and assessments, each with its strengths and idiosyncrasies. While "vulnerability" describes an intricate web of variables, this grading system also considers each city's exposure, sensitivity, and hazards, along with a general performance evaluation.

Apart from geographical locations, the indicators of exposure and sensitivity were used to rank score determination towards the vulnerability of the cities. The critical exposure indicators were cyclone, flood (riverine & coastal), thunderstorm, earthquake, heatwave, and cold wave vulnerability. The sensitivity response was indicated by its geographical location (inland or coastal), and the response was considered based on distance, river distance, and nearest source of flood while performing the analysis. The RII scores provide the relative weightage of each vulnerability parameter defining the city's overall vulnerability. Mumbai and Chennai are the two cities in India that defy all others by combining a unique set of factors, making them the two most vulnerable cities on the subcontinent.

The reason is the city's high population density, Mumbai; its poorly maintained drainage system can't hold up against ever-increasing rainfall. The city experienced the worst flooding in 2005. It resulted in over 900 deaths and caused tremendous harm. Chennai's extreme floods, sea-level rises, and prolonged heatwaves are alike. Chennai city's lasting memories of Cyclone *Amphan* in 2023 are recent proof of its vulnerability to extreme weather and uncertainty. The inadequate drainage infrastructure makes flooding even more likely, and light rainstorms can become potential disasters.

Rising sea levels expose freshwater supplies to saltwater intrusion, and coast erosion exacerbates these problems. These heatwaves persist for long periods and place an additional burden upon the city. They already have scarce resources and make great demands on people's health.

The rise in sea level, in addition to these cities, will impact the likelihood of floods in the vicinity areas due to flooding. In Mumbai, the heat and the average temperature will increase in the near future. The combination produces oppressive circumstances with high humidity and an increase in frequent heatwaves. Kolkata's vulnerability is primarily due to its geography, and regular cyclones make it more critical in terms of vulnerability. The city's vulnerability is best examined by evaluating the extensive damage caused by Cyclone *Amphan*. However, heat waves that are more prolonged and intense are an essential factor contributing to the vulnerability. Like any other, the poor drainage system and unplanned expansions of the urban cities of the coastal town cannot cope with the heavy rains, which results in waterlogging accompanied by all environmental and human health issues. This situation will pose a risk to the people and coastal communities, making them more vulnerable to climate-related complexities.

Forecasts for Delhi suggest an increase in temperatures due to which the city is already experiencing heatwaves. The other impact is rising water scarcity due to increased heatwaves and human health due to air pollution. The weight of frequent heatwaves is causing a spike in medical emergencies, hurting society's most vulnerable members worst. Air pollution, consistently described as one of the worst in the world, hangs over the city and worsens respiratory complaints. Infrastructure and resource constraints imposed by rapid urbanization exacerbate the problems of the metropolis. The urban heat island effect is served by uncontrolled urbanization and an absence of green areas, which puts residents under more heat stress.

However, Bengaluru, Hyderabad, and Ahmedabad all have very average vulnerability index scores, and these cities face many problems due to their exposure to multiple climate vulnerability parameters and uncertainty of climate impacts. The rapid urban growth of Bengaluru has created urban heat islands that not only intensify the effect of heat waves but also raise the likelihood of flash floods during heavy rains. Like other Indian towns, Hyderabad might suffer from floods caused by poorly laid-out drainage systems, and light rains can be extremely dangerous. In addition, Hyderabad is on a semi-arid plain that suffers from water scarcity. Moist air might also be a risk for Pune. Pune saw devastating floods in 2020, highlighting its vulnerability to heavy rainy seasons. Moreover, the city experiences exceptional weather and an increase in average temperature. Perceiving the intricacies of a city's individual social, economic, and environmental background comprehensively, assessing the vulnerability with an integrated scientific modelling approach to enhance climate resilience is essential.

To enhance the resilience of these cities, it is necessary to implement specific actions towards adaptation strategies. The following presents a need to develop city-specific adaptation plans, invest in climate-resilient infrastructure, promote community-based adaptation strategies, and strengthen policy and governance frameworks, including fostering research and innovation. Developing city-specific adaptation plans should additionally consider strategies addressing unique vulnerabilities and considering factors such as demographics, infrastructure, geographical boundaries, and economic activities. Similarly, investing in climate-resilient infrastructure, including sustainable drainage systems and smart and green infrastructure resilient to floods and earthquakes, will be an additional boost to adapt to climate events. Empowering communities and developing community-based adaptation plans would enhance resilience by integrating education, awareness, training and community-centric programs. Such initiatives would integrate climate planning, cooperation, and policy implementation, which are essential for effective adaptation and strengthening governance. Continuous assessment and innovative solutions can inform policy decisions and improve city adaptation strategies.

Based on the city-specific vulnerability assessment, it is suggested that cities with coastal boundaries, like Chennai, Kolkata and Mumbai, should focus on coastal protection through natural mechanisms like mangrove plantations, nature-based solutions, and coastal restoration initiatives to protect against sea-level rise and storm surges. Improving drainage and construction of retention ponds can help reduce these coastal cities' flood risks. Developing evacuation plans, early warning systems, and disaster response training for coastal communities would enhance community resilience towards climate events. Irrespective of coastal or non-coastal regions, the focus on developing green infrastructure and water management would be a crucial strategy for addressing water scarcity, mitigating heat waves and improving the quality of the environment for all cities.

Focussing on vulnerability issues addressed in the study, cities like Bengaluru and Hyderabad should promote sustainable urban development practices, including green building standards, water harvesting, waste management and investments in climate-smart agriculture. To reduce their vulnerability exposure, cities like Delhi and Ahmedabad require a focus on heat mitigation, air quality improvements and water conservation, including sustainable urban development and transit-oriented development.

Furthermore, intra-parameter scores, even within highly weighted categories, can reveal specific weaknesses. For example, a city scoring high in heat stress, even with a high weightage, might benefit most from increasing green spaces if that sub-parameter scores high within the heat stress category. Conversely, a city vulnerable to earthquakes might prioritise retrofitting existing infrastructure and stricter building codes. This data-driven approach allows policymakers to make informed decisions. India can strategically allocate resources and develop targeted adaptation strategies by focusing on the most vulnerable cities and addressing their most critical vulnerabilities. This will lead to building more resilient urban centres prepared to face the challenges of climate change. The study recognises the limitation of its current approach to selected parameters and acknowledges the need for further research to address multi-dimensional aspects of vulnerability assessments, including conducting a more in-depth analysis of socioeconomic and infrastructural factors, potentially using mixed-methods research approaches that combine quantitative and qualitative data. The study also emphasises the selected parameter for vulnerability assessment scores; although it provides a concrete foundation for the study, it is important to acknowledge additional factors due to the complexity of climate risks and their multifaceted nature. Therefore, several other factors like air parameters, water scarcity, and social vulnerability may also play significant roles. Future studies may expand by considering these vulnerability indicators to address interpretations under these extended dimensions. Despite these limitations, this study provides a valuable foundation for understanding climate vulnerability in India's Tier-1 cities. The findings can inform policy decisions and guide future research efforts to address the complex challenges climate change poses.

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Author Contributions

Rahil Shah contributed to the paper in Designing, Planning Data collection, Data Analysis, Preparing the First Draft for review, and Finalization of the Manuscript.

The author, Ravi Sharma, contributed to the Planning and Designing of the paper, Data methodology, Review of the Draft, and Submission of the Manuscript.

Conflict of Interest

The authors report there are no competing interests to declare.

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Ethical Approval

Ethics approval is not required and therefore not sought as the study contains no studies involving animals or patients performed by any authors. The study relies on secondary sources of data without any human participants involved.

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