

Climate-Responsive Design & Adaptation

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ABSTRACT

Anthropogenic climate change, as seen in the form of increasing global temperatures, increasing climate driven extreme weather events, and increasing rate of biodiversity loss, is one of the greater challenges that face architecture, urban planning, and infrastructure today. In this context climate responsive design and adaptation, are an important paradigm through which to achieve reconciliation between environmental concerns, human development and development wedges. This project outlines a multidisciplinary framework that combines resilient building and infrastructure planning, basics of nature and equity-based solutions, climate adaptive architecture and total risk assessment into a distinct approach for enhancing the adaptive capacity of urban and rural spaces. Resilient planning sits at the strategic core of the recommendation, specifically through was of climate risk maps and scenarios based forecasting into preliminary design stages; to enhance climate sensitive site selection, redundancy of vital systems and adopting materials and technology for durability based on previously modelling and known stressors into climate adaptive architecture. Nature-based solution- not just as an aesthetic measure, but that are part of this "continuum" of urban reforestation and multi-use green infrastructure, coastal ecosystem restoration and permeable surfaces - may help regulate micro-climates, manage hydrological risk, and sequester carbon on the landscape. Climate adaptive architecture operates on a building scale, using passive design methods to enhance naturally occurring factors like solar orientation, natural ventilation, thermal massing, and day lighting and to limit energy intensive mechanical systems. This can be accompanied by adaptive envelopes, renewable energy, and responsive building systems that can adapt to changes in the environment. Risk assessments serve a critical analytical function, utilizing Geographic Information Systems (GIS), climate simulation models, and socio-economic vulnerability mapping to establish exposure pathways and to prioritize adaptive measures. The proposed framework promotes the climate-resilience of disaster, while maintaining synergies with socio-ecological resilience. With this framework, communities are developed to be potentially disaster resilient, with functional integrity and actively regenerative environmental integrity. This research has highlighted that successful climate-responsive design requires the employment of technical solutions, environmental stewardship, and participatory governance. Resilient planning, nature-based solutions, and climate-adaptive design provide synergies that reduce the immediate impacts of climate, while co-benefitting public health and economic well-being, and while pursuit of cultural continuity and equity. The research recommends embracing adaptability, redundancy, and ecology as fundamental to build infrastructure in the pursuit of sustainable, climate-positive futures during times of uncertainty in the Anthropocene.

Keywords: Climate-responsive design, resilient planning, Nature-based infrastructure, Passive design strategies, Climate adaptation, Disaster-resilient communities.

INTRODUCTION

In recent years, climate change presents a significant hazard to human habitats and structural efficacy [1]. The exhaustion of energy supplies and the threat of global warming need sustainable growth in the construction industry, emphasizing renewable energy and energy efficiency. Climate change is recognized by extended fluctuations in meteorological variables. The impact, amount, and time are indeterminate. The adaptation of a system refers to its intrinsic capacity to modify and react to alterations and the consequences resulting from such alterations. It entails acquiring knowledge, adaptability, and enhancing the ability to manage the effects of change. As a system's adaptive capability escalates, its resistance to climatic

stressors correspondingly enhances, while vulnerability diminishes via the attenuation of sensitivity and exposure. This is accomplished by facilitating interactions among the components inside a system. Resilient and climate-responsive design has become an essential strategy in architecture and urban planning to tackle the difficulties of climate change and promote sustainability. Amidst the escalating frequency of severe weather events, rising temperatures, sea-level elevation, and other climate-related effects, there is an increasing acknowledgment of the need to create constructed environments capable of adapting to, enduring, and flourishing under shifting climatic circumstances.

In recent years, the discourse surrounding architecture, urban planning, and design has shifted significantly towards resilience and climate responsiveness. This paradigm shift addresses the pressing need to alleviate and adjust to the impacts of climate change on the constructed environment. The ideas of resilient and climate-responsive design are being used in projects ranging from modest structures to large metropolitan developments, aiming to create environments that are ecologically sustainable and capable of enduring and recovering from diverse climate-related difficulties. In design and planning, resilience denotes a system's ability to withstand shocks and stressors, preserve critical functions, and adapt to evolving situations without undermining its general function, structure, or identity [4]. In architectural and urban design, this entails developing places and buildings capable of enduring harsh weather events, natural catastrophes, resource scarcity, and other environmental stresses, while ensuring safe and acceptable living conditions. Resilient and climate-responsive design is essential in the context of climate change. A comprehensive strategy is necessary, taking into account environmental, social, and economic issues to develop constructed environments that can withstand and prosper under uncertainty. Through the integration of resilient techniques and adaptation to local climatic circumstances, architects and planners may foster the development of sustainable, liveable, and resilient communities for current and future generations.

This research has demonstrated that urban resilience requires more than just architectural innovation—it demands systemic thinking across planning, governance, and community engagement. The study's mixed-method approach revealed how climatic vulnerabilities in cities like Ahmedabad manifest both spatially and socially, disproportionately affecting peripheral and low-income neighbourhoods. By integrating GIS-based risk mapping, climate-adaptive architecture, and participatory insights, the proposed framework advocates for a holistic model of climate-responsive urban design.

The remaining structure of this paper is organized as follows: Section 2 presents a comprehensive review of literature, highlighting key global and regional studies on climate-responsive architecture, resilience planning, passive design strategies, and nature-based solutions, while identifying gaps in integrated urban approaches. Section 3 details the methodology, explaining the mixed-method approach including GIS-based spatial analysis, primary household surveys, expert interviews, and temporal climate data analysis focused on Ahmedabad. Section 4 illustrates the findings, showcasing spatial vulnerabilities to flooding, heat islands, and disease outbreaks, as well as community perceptions of urban shocks and stresses through charts and zone-wise analysis. Section 5 discusses case studies from other Indian cities like Surat, Gorakhpur, and Panaji to draw comparative insights and validate the proposed framework. Finally, Section 6 concludes the study by summarizing the research contributions and proposing a scalable, integrated model for climate-resilient urban planning and design.

REVIEW OF LITERATURE

Nickayin et al., (2025)[6] studied that Climate change has become a significant global issue, substantially impacting the built environment. As a result, climate-responsive design has emerged as a crucial architectural approach that integrates environmental considerations into the design process. The study investigates the concepts, methods, and applications of climate-responsive design, emphasizing sustainability, resilience, and environmental ethics. This study analyzes academic literature and notable architectural case studies to illustrate how design elements such as site orientation, passive cooling, renewable energy integration, and sustainable materials may alleviate environmental impacts and enhance occupant comfort. Case studies including Masdar City, Bosco Verticale, The Edge, and Sustainable Floating Homes illustrate actual applications of climate-responsive strategies. The findings demonstrate that climate-responsive design mitigates environmental challenges while fostering social equity and economic sustainability, making it an essential practice for a resilient

future.

Yang et al., (2025)[7] examined the Qinba Mountains in central China (30°30'—34°37'N, 103°44'—113°13'E), noted for its considerable altitudinal diversity. A field research was performed in three various temperature zones to gather objective environmental factors and subjective thermal perception data (n=937), aimed at analyzing the facets of thermal comfort and adaptation. Partial Least Squares (PLS) Structural Equation Modeling (SEM) was conducted using this data to identify the primary elements influencing thermal comfort. The main conclusions are: The mean neutral temperature is 23.85 °C during summer and 14.54 °C in winter. It varies with altitude. A dual-pathway adaptation strategy is presented, including behavioral modifications such natural ventilation and little clothing in summer, with fire pit heating and layered clothes in winter. Moreover, those exposed to outdoor environments for more than five hours each day have diminished temperature sensitivity relative to those living inside. A novel three-stage process termed "Environmental Drive-Perception Acquisition- Evaluation Feedback" has been developed. It demonstrates that individuals see the world variably over various seasons. In summer, comfort is mostly influenced by wind and heat, but in winter, it is predominantly impacted by heat and humidity. These results provide data for climate-adaptive rural house design and thermal comfort evaluation in mountainous areas.

Yalaz and Disli, (2024)[8] developed a prototype of a building façade influenced by traditional methods, materials, and features suitable for a semi-cold temperature zone. The hamlet of Sarıhacılar was selected as a case study due to the notable energy efficiency and eco-friendly practices of its historic structures. This study's primary scientific innovation and objective is to illustrate the impact of novel techniques and alternative building materials (Crushed autoclaved aerated concrete-CAAC/Adobe with gypsum-AwG) on diminishing the U-value of conventional rubble stone (RS) walls through the design of a prototype façade. The primary factors in the design are user comfort, climatic adaptability, respect for local character and culture, energy efficiency, inspiration from historical passive technologies, and cost- effectiveness. Field tests and a literature analysis were performed to assess the effectiveness of the prototype façades, using the IZODER TS825 software. The study's findings indicated that two suggested wall types (CAAC and AwG), differing in porosity and particle size, markedly reduced the U-value more effectively than traditional walls with RS. This is crucial not just for the development of very comfortable buildings but also for mitigating the adverse impacts of climate change.

D'amato et al., (2024)[9] studied that climatic responsive techniques denote a systematic methodology that carefully evaluates climatic and environmental factors throughout the architectural design process, with the objective of attaining maximum thermal comfort while reducing energy usage. Throughout the world, ancient societies and civilizations have mastered the interpretation of their local climate to tailor their structures to the natural surroundings, using accessible materials in their immediate context, therefore creating distinctive vernacular buildings in various regions. This study emphasizes the crucial importance of climate-responsive strategies in the design of vernacular architecture across various latitudinal contexts, pinpointing techniques and methods that can facilitate the creation of more comfortable spaces utilizing local resources, minimizing energy consumption, and reducing the overall carbon footprint of constructions. This methodology fosters sustainable building and serves as an effective instrument for preserving local customs and cultural heritage within a globalized context. This research uncovers a range of passive tactics that are actively examined and used in vernacular architecture across four diverse cultural and environmental contexts: India, Colombia, Sweden, and South Africa. The climate adaptive techniques of vernacular architecture in these places have been examined using a case study and the Mahoney table. The study results confirm that climate-responsive design, via the prudent use of passive measures, serves as an effective technique to mitigate adverse climatic conditions.

Vakhaira et al., (2024)[10] examined as living standards increase and the world population expands, energy consumption in buildings is anticipated to rise significantly. Constructing buildings using climate-sensitive design principles may boost both energy efficiency and occupant comfort. Vernacular architecture, the traditional architectural style of a place, has evolved over the years to adapt to the local environment. An instance of vernacular architecture using climate-responsive design for energy efficiency and visual appeal is the Wada style, found in the Pune area of India. This study investigated the performance and thermal properties of the traditional Wada House envelope. This study examined the thermal efficiency of conventional Wada dwellings using simulation models, validation, and analysis of climate change projections between 2050 and 2080. Studies indicate that passive design techniques are extensively used in Wada architecture to regulate inside temperatures

and reduce energy consumption. Insulation via substantial walls and roofs, strategic orientation to minimize solar heat input, and natural ventilation constitute these approaches.

Yuan et al., (2023) [11] aimed to analyse the correlations between microclimate, outside thermal perception, and resident behaviour in a residential district in Xi'an, China. Four sample open areas inside the residential area were examined using meteorological data, a questionnaire survey, and behavioural records to ascertain the relationship between persons' thermal comfort and their outside activities. The Physiological Equivalent Temperature (PET) was used to objectively assess the outdoor thermal standards in Xi'an, leading to the formulation of climate- responsive solutions for open spaces based on these criteria. The results indicated that: (1) environmental conditions demonstrated considerable fluctuations in air temperature, wind speed, solar radiation, globe temperature, mean radiative temperature, and PET, but not in relative humidity; (2) during summer, residents favoured activities in shaded areas, with attendance exhibiting an inverse linear relationship with PET; and (3) recommended optimal design strategies for open spaces included shelterbelts, shaded amenities, vegetation, water features, and surface materials. These findings will assist urban planners in enhancing their comprehension of the correlation between behaviour and thermal comfort, while offering design recommendations for open spaces in residential zones inside China's cold region.

Gabor et al., (2023) [12] examined that the persistent impact of climate change on urban heat is compelling cities to use the adaptive capacity of their public open spaces. Streets and squares are significant urban open spaces that might facilitate climate change adaptation via the strategic implementation of certain interventions. To ensure the efficient and appropriate execution of climate-related activities for public benefit, the city of Vienna is formulating a guideline that highlights measures connected to urban green and blue infrastructure (UGBI) and specific technical measures (TM) inside urban open spaces. This guidance would be facilitate the selection of suitable measures by municipal staff in the future. In the framework of an applied research project, current and potential measures in Vienna were gathered, analysed, and evaluated for their climatic, ecological, and social sustainability according to the concept of ecosystem services (ES). The objective is to include the extensive subject of sustainability and climate change while integrating a wide range of insights from scientific research and practical applications. The outcome is a methodological framework that other cities may use as a foundation for creating specific guidelines to promote climate-relevant initiatives and to critically assess the application of co-creation in the framework's evolution.

Gaspari et al., (2022) [13] examined cohesive design-research methodology for climate- responsive building envelopes, particularly in the continental climates of China. This study began with a pragmatic illustration from China's Cold Zone to exemplify how architects include climate responsiveness in building façade design and to elucidate the obstacles that static structures encounter in adapting to changeable external climates. A prototype of climate- responsive skin was developed based on the Cold Zone scenario and then transformed into a full-scale testing platform. A series of comparison tests is conducted to determine the perfect solution for each of the four key design features and their ideal combinations for summer and winter, respectively. The thermal performance effects of each design component and the energy-saving strategies of the seasonally best configurations are statistically assessed. A revolutionary dynamic skin design with moveable triangular blades demonstrates the integration of significantly different summer and winter configurations for enhanced environmental flexibility. This study seen to amalgamate research and design of climate- responsive building facades, establishing a standard for their use in analogous circumstances.

Soudian and Berardi, (2021) [14] constructed a pre-design tool to facilitate the selection of appropriate technologies for the development of multifunctional CRFs. The suggested approach comprises five phases that provide a qualitative evaluation of façade needs grounded on quantitative measures. The process involves establishing the goals of a CRF, identifying performance thresholds according to environmental and architectural settings, formulating a responsive operational framework, choosing the best appropriate technology, and ultimately creating a conceptual design for the CRF. The execution of the construction is validated by the design of a transparent and opaque CRF module, using the configuration of a vented cavity Trombe wall. The discussion section indicated that the many indicators within the framework and their quantitative ranges are adaptable and may be tailored to align with specific architectural, environmental, and technological considerations. The importance of the framework for the initial decision-making phases of façade design is ultimately evaluated, with potential techniques for enhanced integration of climate-responsive façades.

METHODOLOGY

In this research methodology, a mixed-method approach is adopted to assess climate vulnerability and resilience in Ahmedabad. Secondary data such as spatial development plans, meteorological records, census data, and satellite imagery is analysed to understand long-term climate patterns and urban changes. Primary data is collected through stratified random surveys of 300 households across 12 localities and expert interviews with urban planners and officials. GIS-based spatial analysis is used to map urban flooding zones, urban heat islands, and disease-prone areas using DEM, SRTM, and Landsat data. A temporal analysis evaluates historical temperature and rainfall variability, while perception-based surveys capture community experiences of shocks and stresses. The following section, reports, spatial plans, policies and statistical records in the context of Ahmedabad were used for the analysis:

Data Collection

Secondary Data

Secondary data sources include spatial development plans (1965–2021), policy documents, census data (2001 and 2011), meteorological data (IMD), Landsat satellite imagery (1998, 2010), and administrative records from AMC, AUDA, and GSDMA. These datasets were utilized for temporal and spatial analysis of urban shocks, stresses, and vulnerabilities.

Primary surveys and Interviews

Stratified random sampling of 300 samples was attempted at 12 spatial locations of Ahmedabad to understand the shocks and stresses perceived by the community. Semi and unstructured interviews and discussion were conducted among 20 urban planners, government officials and experts in the city.

Methods of Inquiry

Stage I: Temporal Analysis of Climate Variability

Historical data on temperature and rainfall were statistically analysed to assess climatic variability and past shock events in the city.

Stage II: Spatial Vulnerability Assessment

GIS-based spatial analysis was conducted to map vulnerability to urban flooding, urban heat island (UHI) effects, and vector-borne diseases. DEM/SRTM datasets were processed in ArcGIS to generate watershed maps and apply buffer zones around rivers and drains. UHI mapping utilized Landsat imagery and surface temperature indices.

Stage III: Preliminary Resilience Assessment

A city-wide perception survey assessed public experiences and perceptions of climate-related shocks (e.g., floods, heat waves) and stresses (e.g., water scarcity, pollution). Respondents ranked the top five perceived shocks and stresses. The survey instrument included both closed and open-ended questions and was pilot-tested and translated into Gujarati for field deployment.

Qualitative Research in Shock Prone Areas

In order to understand the settlement-level shocks, stresses and coping strategies, two settlements were chosen, Sankalitnagar and Bopal. Both these settlements have been subject to multiple stresses and shocks in recent decades. While Sankalitnagar falls within the AMC boundary, the Bhopal area has been added recently and a spatial plan for this area is being taken up. In both the cases, initially, a detailed spatial analysis was done to understand the changes in settlement structure, infrastructure and services. Subsequently, interviews and discussions were planned to draw data through people's perception, experience and opinions about the climatic

shocks and stresses as well as quantitatively, statistical data of climate and spatial databases. Table 1 describe the sample distribution by areas as shown below.

Table 1. Sample Distribution by Area

Zone	Locality	No. of Respondents
North-West	Chandkheda	38
	Thaltej Gam	12
	Ranip	16
North-East	Meghaninagar	24
	Asarwa	20
	Bapunagar	39
South-West	Bopal	12
	Juhapura	14
	Sankalitnagar	12
	Vasna	25
South-East	Vastral	28
	Amraiwadi	24
	Maninagar	22

Methodology for Spatial Vulnerability Analysis

For the assessment of city-wide spatial vulnerability, the following shocks and stresses were taken up:

Urban Flooding

The DEM/SRTM (Digital Elevation Model/Shuttle Radar Topography Mission) data for urban floods was first acquired from the relevant municipal corporations and governmental entities. The collected data was further refined to correspond with the study area and put into the ARC GIS platform. Subsequent analysis was performed inside the ARC MAP environment, according to established standards. The generated watersheds were further classified into suitable categories:

Table 2 outlines the buffer distances applied around various water bodies—rivers, lakes/other water bodies, and drains—as part of the GIS-based spatial vulnerability analysis to assess urban flooding risks in Ahmedabad. All stream, lakes and rivers were given multiple buffers as under:

Table 2: Buffer in drains, River and Lakes/Other Water Bodies

River Buffer	Lakes/Other Water Bodies Buffer	Drain Buffer
101-200m	0-5m	0-15m

51-100m	6-10m	16-25m
0-50m	11-20m	26-50m

Urban Heat islands

Urban heat islands (UHIs) were recognized by the evaluation of surface or atmospheric temperatures. Surface temperatures have a considerable, although indirect, impact on air temperatures. Parks and green spaces, characterized by decreased surface temperatures, promote cooler air temperatures. Conversely, densely populated urban areas often result in elevated air temperatures. The correlation between surface and air temperatures varies according to atmospheric mixing. Landsat satellite data was used to categorize land cover and detect heat islands. The Landsat 7 satellite, a U.S. asset, captures remotely sensed photos of the Earth's terrestrial surface and adjacent coastal areas, supplying data that allows researchers to ascertain surface temperatures and assess heat islands. The comprehensive procedure used in the creation of the UHI maps for the city is outlined in Figure 9 below:

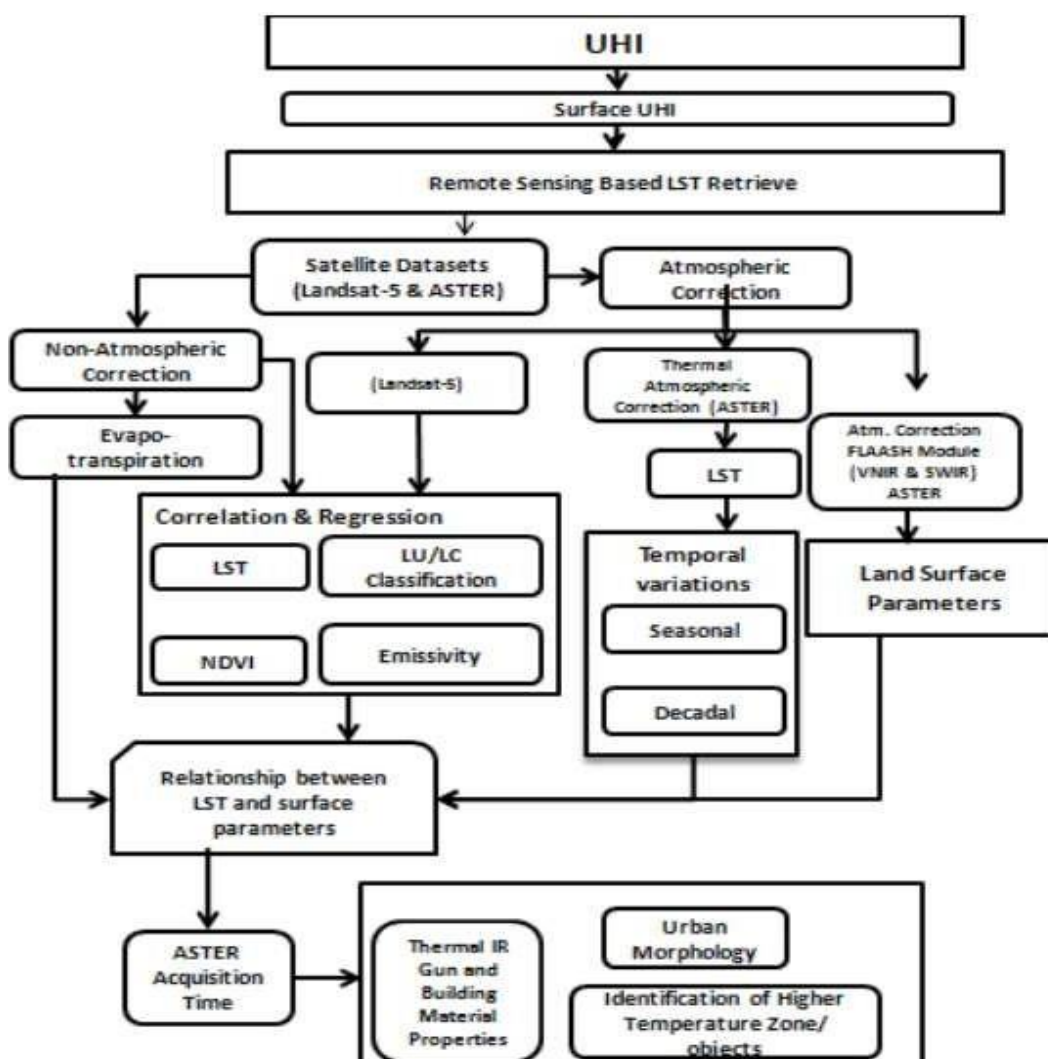


Figure 1: Process Followed in Generating the UHI Maps

Analysis and Findings

Key shocks

Experience of heavy rainfall in recent years, followed by the incidence of major disease outbreaks like plague, dengue, malaria and chikungunya were identified as the key shocks. A large section of the respondents reported that they are adversely affected by the multiple disease outbreaks in the recent past.

Figure 2 presents the shock-wise distribution of affected respondents based on the primary household survey in Ahmedabad. The chart reveals that heavy rainfall (196 respondents) and major disease outbreaks (182 respondents) are the most commonly experienced shocks, highlighting the significant impact of monsoonal flooding and vector-borne illnesses such as dengue and chikungunya on urban communities. Heat wave's affected 108 respondents, followed by terrorist attacks (65) and riots/strikes/civil unrest (56), indicating that socio-political instability also poses a serious concern. Severe storms (32) and infrastructure or building failures (16) were reported less frequently, yet still represent important vulnerabilities in specific local contexts. Overall, the figure underscores the dominance of climate-induced and health-related shocks, reinforcing the need for integrated urban resilience strategies addressing both environmental and infrastructural challenges.

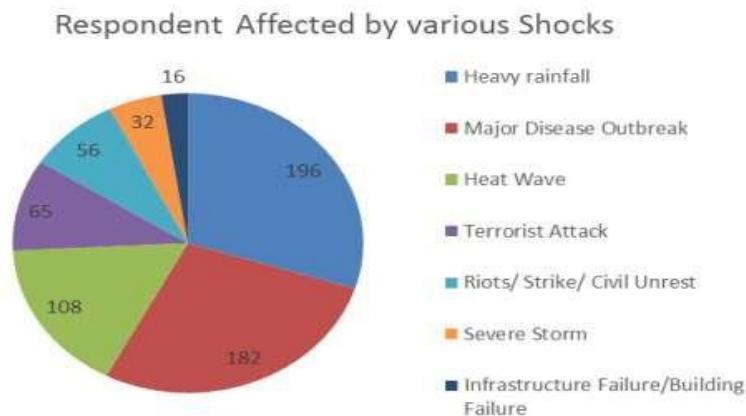


Figure 2. Shock-wise distribution of affected respondents

Figure 3 illustrates the distribution of respondents affected by various shocks across localities in Ahmedabad, highlighting the spatial variability of urban vulnerabilities. Heavy rainfall and major disease outbreaks emerge as the most widespread shocks, affecting over 80–100% of respondents in areas like Asarwa, Bapunagar, Bopal, Thaltej Gam, and Sankaltnagar, indicating the severe exposure of peripheral and low-lying settlements to monsoon-related and health crises. Heat waves are notably reported in most localities, particularly Sankaltnagar and Thaltej Gam, reflecting the growing thermal stress in dense urban zones. Incidents of riots/strikes/civil unrest and terrorist attacks are also prominently reported in several locations, including Maninagar, Bapunagar, and Meghaninagar, suggesting persistent socio-political vulnerability. The presence of infrastructure failures and severe storms, although relatively less frequent, adds to the cumulative stress in these neighborhoods. Overall, the figure demonstrates that urban shocks are unevenly distributed, with marginalized and peripheral settlements bearing the brunt of multiple risks. This underscores the urgent need for localized resilience planning tailored to the specific vulnerabilities of each area.

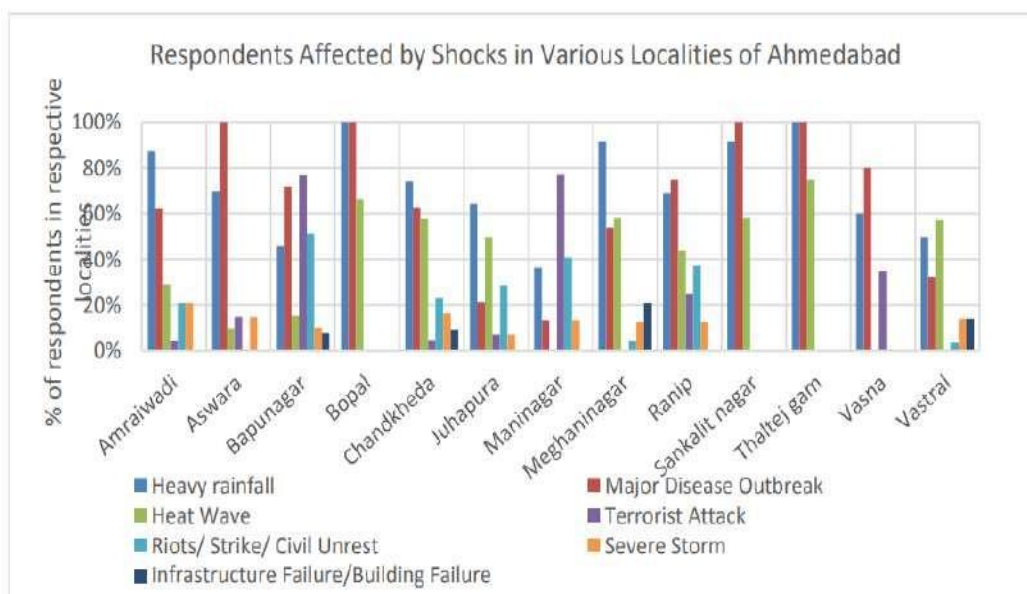


Figure 3. Respondent Affected by Shocks in Various Localities of Ahmedabad

Key City stress

Similar to the earlier survey, various stresses perceived or experienced were also tabulated. Issues like prolonged water logging, lack of green open space, traffic congestions were found to be the major anthropogenic stresses affecting the survey respondents. Figure 4 illustrates the distribution of respondents affected by various long-term urban stresses in Ahmedabad, based on primary survey data. The most commonly reported stressor is prolonged water logging, affecting 145 respondents, followed by traffic congestion (126) and water scarcity (95)—highlighting the severe pressure on urban infrastructure and basic services. Issues like lack of parks and gardens (78) and air pollution (73) also show significant concern, reflecting a degraded urban environment. Meanwhile, crime and violence (41), unemployment (33), and power or energy shortages (22) indicate socio-economic vulnerabilities, particularly in low-income areas. Less commonly reported, but still relevant, are stresses such as lack of public transport (18), housing shortage (14), and food shortage (12). This figure clearly suggests that chronic infrastructural inadequacies and environmental degradation are more pressing for residents than socio-economic stresses, though all contribute to the cumulative burden. These findings emphasize the need for integrated planning interventions that prioritize storm water drainage, transport, water access, and green space provision to build urban resilience.

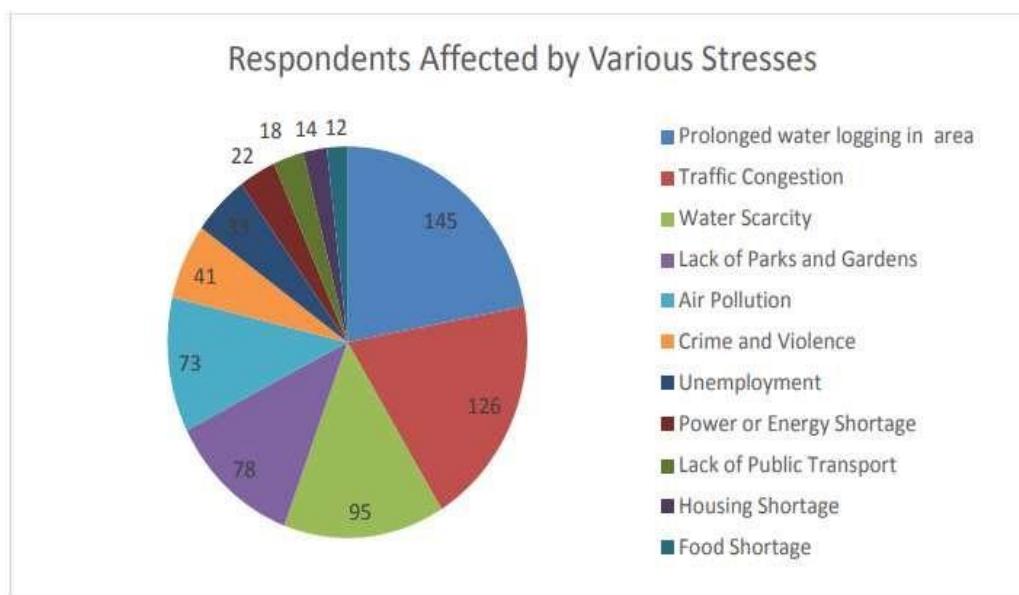


Figure 4. Respondents Affected by Various Stresses

Figure 5 shows the locality-wise distribution of respondents affected by various long-term urban stresses in Ahmedabad, providing a spatial understanding of chronic vulnerabilities across the city. The most striking observation is that Thaltej Gam has the highest percentage of respondents (100%) affected by lack of parks and gardens, indicating severe environmental neglect. Similarly, Bopal reports a high percentage (~70%) of respondents facing the same stress, confirming a pattern of poor access to green spaces in peripheral areas.

Traffic congestion is a prominent stress in Maninagar and Juhapura, where over 50% of respondents are affected. Water scarcity is consistently reported across multiple locations, especially Meghaninagar, Bapunagar, and Vasna, highlighting the strain on basic urban services. Air pollution is a widespread concern in Chandkheda, Ranip, and Sankaltnagar, while crime and violence feature notably in Juhapura and Maninagar, pointing to socio-political stressors in these neighbourhoods.

Other stresses like power/energy shortages, lack of public transport, unemployment, and housing shortage appear scattered across localities but with lesser severity, suggesting localized impact. Overall, this figure highlights the geographical inequality in exposure to urban stresses, reinforcing the need for context-specific planning interventions targeting infrastructure gaps, environmental deficits, and social vulnerabilities.

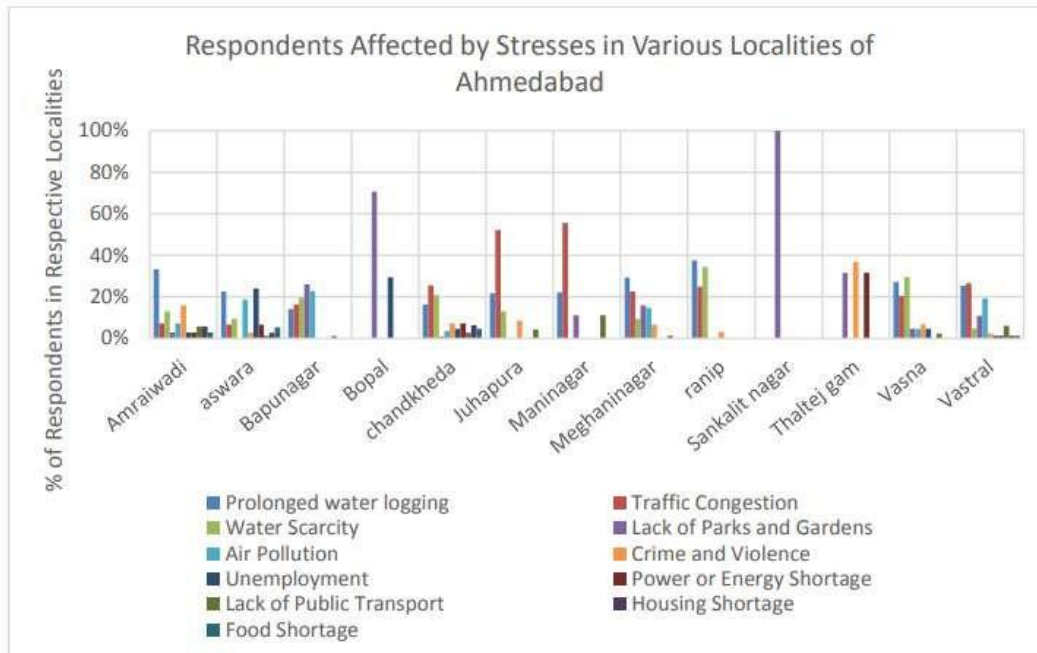


Figure 5. Respondents Affected by Stresses in Various Localities of Ahmedabad

Priority of Stress and Spatiality

In case of city shocks, air pollution and water scarcity were identified as the priority shocks, followed by lack of access to parks and gardens and crime. The issue of unemployment, housing shortage and traffic congestion were also identified some of the priority stresses. Figure 6 illustrates the priority-wise ranking of urban stresses as perceived by respondents in Ahmedabad, revealing that air pollution is considered the most critical issue, with the highest number of people ranking it as their first and second priority. This is followed by lack of parks and gardens, which peaks as the most common third priority, indicating growing concern over shrinking green spaces. Other significant stresses include water scarcity, housing shortage, and traffic congestion, all of which consistently appear across top priorities, reflecting fundamental gaps in urban infrastructure and service delivery. Meanwhile, issues like crime and violence, unemployment, and prolonged water logging are distributed more evenly across fourth and fifth priorities, suggesting that while they may not be the most urgent, they are persistent and widespread. Overall, the figure underscores the multidimensional nature of urban stresses, where both environmental degradation and infrastructure inadequacies dominate public concern, demanding integrated and responsive urban planning.

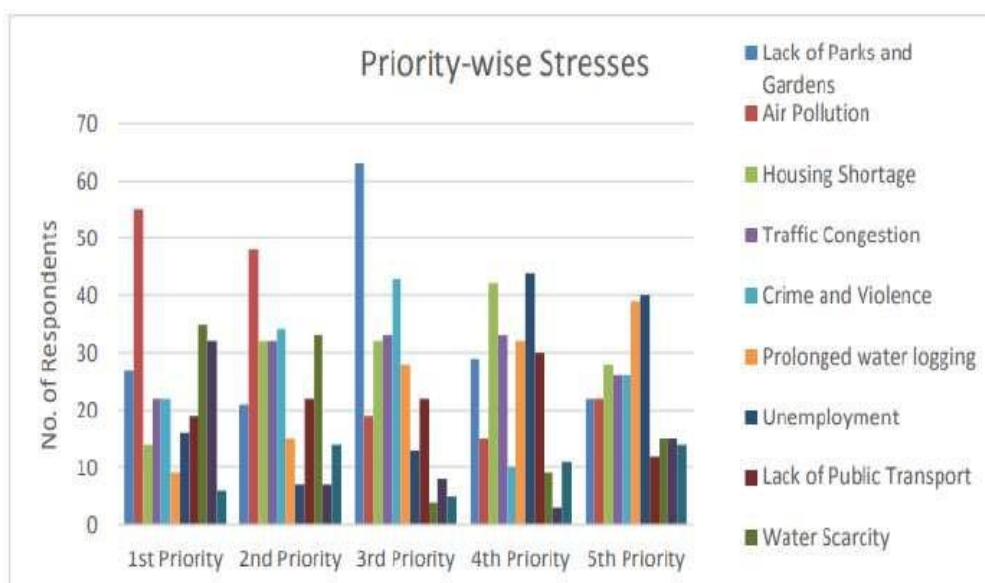


Figure 6. Priority-wise stresses

Assessment of city zone-wise shock and stress

The shocks and stresses and their priorities were further classified as per the city administrative zones order to understand their spatial diversities. Riots, heavy rainfall, heat wave and major disease outbreaks were found to be the priority across the city zones. Similarly, water logging, air pollution and housing shortage were found to be dominating stressors for all zones. These are followed by stresses such as traffic congestion, lack of public transport etc. The zone-wise priority of city shocks and stresses are discussed in the Figures 6-7, below.

Figure 7 shows the zone-wise prioritization of urban shocks across four major zones of Ahmedabad: North-East, North-West, South-East, and South-West. The South-West zone reported the highest concern for riots/strike/civil unrest and heavy rainfall, indicating heightened vulnerability to both social and environmental disturbances. In the South-East, respondents prioritized a combination of heavy rainfall, heat waves, and major disease outbreaks, revealing the compounded impact of climatic and health-related shocks. North-West respondents gave slightly more importance to floods, followed by major disease outbreaks and heat waves, suggesting a mixed risk profile. Meanwhile, in the North-East, riots/civil unrest, major disease outbreaks, and heat waves topped the concerns, reflecting a strong emphasis on anthropogenic and climate-related shocks. Across all zones, heavy rainfall, disease outbreaks, and riots consistently appear as high-priority shocks, highlighting the city's recurring exposure to these hazards. This spatial distribution underscores the need for zone-specific resilience strategies that address both natural and socio-political vulnerabilities.

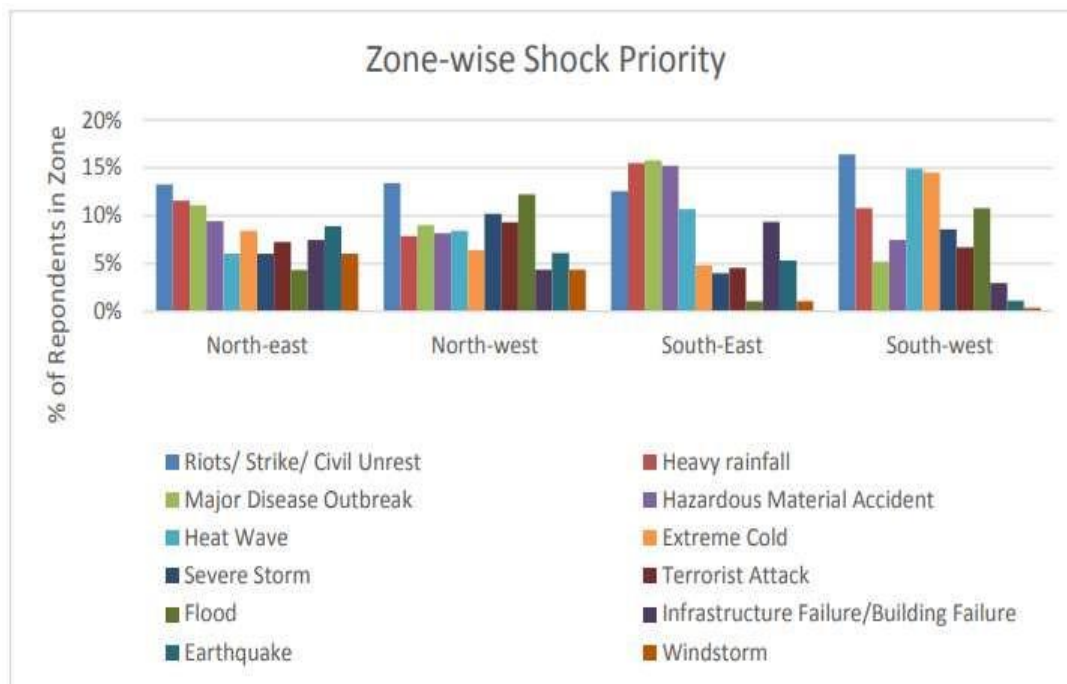


Figure 7. Zone-wise shocks priority

Figure 8 depicts the zone-wise prioritization of urban stresses in Ahmedabad, highlighting the distinct challenges faced in each region. In the North-East zone, the top concerns are prolonged water logging, housing shortage, and water scarcity, pointing to persistent infrastructure and basic service gaps. The North-West shows a relatively balanced distribution, with notable concern for air pollution, traffic congestion, and lack of public transport, reflecting increasing urban pressures in expanding residential zones. In the South-East, the most pressing stress is air pollution, followed closely by housing shortage, water scarcity, and lack of green spaces, signalling both environmental degradation and growing demand for liveable space. The South- West zone exhibits a complex stress profile, led by air pollution, lack of parks and gardens, and crime and violence, with multiple other stresses like unemployment and water scarcity also scoring high. Overall, this figure shows that while some stresses such as air pollution, housing shortage, and water-related issues are common across zones, their severity and combinations vary, reinforcing the need for targeted, localized planning interventions to build resilience at the sub-city level.

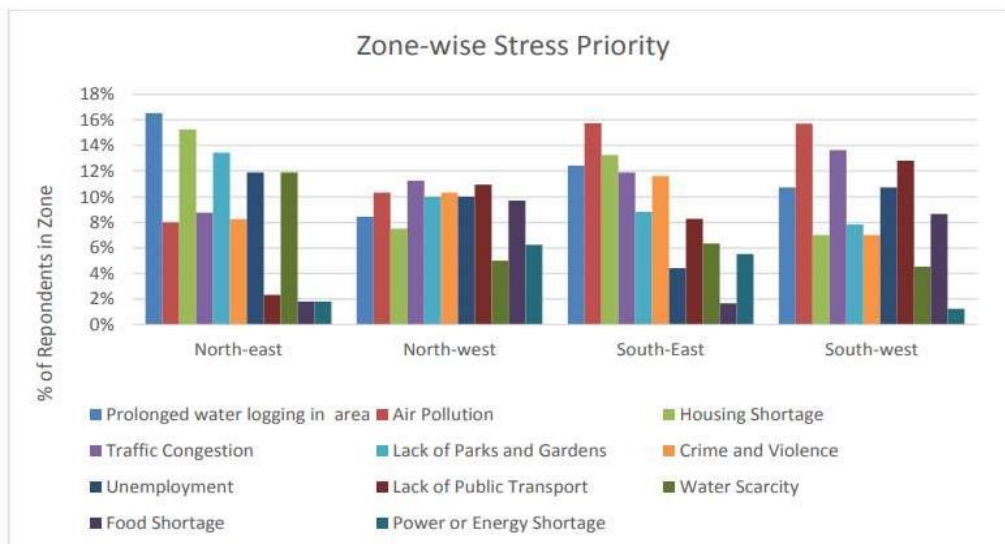


Figure 9. Zone-wise stress priority

Case studies

ACCCRN Urban Resilience Planning Framework (UCRPF)

The ACCCRN (Asian Cities Climate Change Resilience Network) Urban Climate Resilience Planning Framework (UCRPF) was implemented in seven Indian cities—Gorakhpur, Surat, Indore, Guwahati, Shimla, Bhubaneswar, and Mysore—to address urban climate vulnerabilities through a multidisciplinary and participatory approach. The techniques used included GIS-based vulnerability mapping, climate projection modeling, shared learning dialogues (SLDs) with communities, and sectoral impact assessments using frameworks like the Sustainable Livelihoods Framework (SLF). Cities conducted micro-resilience planning (as in Gorakhpur), energy and health infrastructure audits (Surat, Indore), and hazard hotspot identification (Guwahati), integrating climate data with urban systems analysis. These efforts resulted in city-specific City Resilience Strategies (CRS) that informed planning decisions. However, major drawbacks included the limited institutional capacity to sustain efforts post- pilot phase, lack of integration into formal urban governance, and fragmented data systems that hindered consistent application of resilience strategies across departments. Despite these challenges, the ACCCRN model showcased a scalable, inclusive planning framework blending scientific modelling, community participation, and policy linkage.

1. Vulnerability Index Equation

In cities like Guwahati and Indore, vulnerability was quantified using:

$$(E \times S)$$

$$\text{Vulnerability Index (VI)} =$$

$$\frac{E \times S}{AC}$$

Where E = exposure which explain the intensity of climate events like floods, temperature rise, S is the sensitivity that define the population density and slum areas and water dependence, AC is the adaptive capacity.

Urban health & climate resilience: a case of Surat City, India

The coastal city of Surat, which is located in the Indian state of Gujarat, is plagued by a number of severe weather and health issues. It is possible for socio demographic factors to have an effect on the overall vulnerability of a city. As a result of the move from "spontaneous efforts" to "institutionalized resilience," the leadership in urban health resilience in Surat has shifted. The effort that was carried out in Surat by the Urban Health and Climate Resilience Centre (UHCRC) placed an emphasis on evidence-based advocacy to Local Self-Government and

exhibited innovative ways to capacity development among a variety of municipal stakeholders. The UHCRC project was a multidisciplinary program that included research, training, advocacy, and networking. It was the first of its type in India and was carried out by the health department of the Surat Municipal Corporation (SMC). The project was carried out from 2013 to 2016. This effort received its first support from the Rockefeller Foundation's Asian City Climate Change Resilience Network (ACCCRN), which was the original source of funding for the initiative. One of the twenty cities in the world that is being affected the most by climate change is Surat. It is around 16 kilometers distant from the Arabian Sea and is located along the banks of the Tapi River, which drains into the sea. Figure 10 depict the surat's place in hazards typology as shown below.

Natural Hazard Typology & Surat city

	Hazard	Direct risk for Surat	Geographical impact	Onset	Impact duration	Level of Geographical impact
Climatic	Sea level rise and coastal erosion	Yes	0	*	+	0 = Global
	Heat wave	Yes	0	*	+	0 = Regional
	Draught	No	0	*	+	0 = Local
	Floods	Yes	0	*	+	
	Cyclone	Yes	0	*	+	
	Land slide	No	0	*	+	
Tectonic	Tsunami	Yes	0	*	+	
	Earthquake	Yes	0	*	+	
	Volcanic eruption	No	0	*	+	

Onset
 * = rapid
 * = Sudden

Impact Duration
 + = Punctual
 + = Limited

Figure 10. Surat's place in hazard typology

The Urban Health and Climate Resilience Center of Excellence (UHCRC) is a registered non- profit trust that was established when the UHCRC project was formalized as an institution in the year 2016. The UHCRC trust was established in 2017. The trust is formed by the commissioner of SMC, and its board members come from a variety of organizations, including both governmental and private ones. Both the UHCRC and the UHCRC have primarily focused their efforts on the city of Surat, while some of its operations have been extended to include the whole of metropolitan Gujarat. Additionally, there were technical challenges in real-time data acquisition, particularly the absence of interoperable health–climate databases, along with inadequate GIS infrastructure for spatial risk analysis. The program was heavily dependent on external donor funding (Rockefeller Foundation), raising sustainability concerns once funding ceased. Furthermore, low political prioritization and lack of legal integration into the city's master plans prevented the institutionalization of resilience strategies into formal urban governance. These limitations point to the need for technically integrated urban data systems, multi-departmental coordination platforms, and embedded resilience mandates within municipal planning laws to make such models replicable and sustainable.

Climate-change adaptation: A case of Gorakhpur, Eastern Uttar Pradesh in India [18]

The environment is undergoing alterations on global, regional, and local levels owing to various human activities, including greenhouse gas emissions, changes in land use patterns, deforestation, natural resource extraction, and waste disposal. The hamlet of Jungal Augahi, situated in the Campiarganj Block of Gorakhpur, has been selected for the thorough inquiry. This neighborhood is situated along the banks of the Rohini River and often experiences floods. It is situated 35 kilometers from the district headquarters. The personal interview method was used, and 30 houses were selected at random. Campiarganj Block is situated in the northernmost region of Gorakhpur district. It is situated in the eastern part of Uttar Pradesh, India. It is located between Latitude 26° 13' N and 27° 29' N, and Longitude 83° 05' E and 83° 56' E. Gorakhpur is one of the most flood-prone districts in eastern Uttar Pradesh, India. It is located in the Terai area, distinguished for its cup-shaped topography. Regarding population growth, it is now the second largest district behind Varanasi in Eastern Uttar Pradesh. In recent years, there has been a rapid transition and unexpected variations in the climate. Gorakhpur, an agriculturally focused district, with around 80% of its population living in rural regions, with agricultural

viability significantly dependent on summer monsoon rains. In 2006, at a workshop organized by GEAG (Gorakhpur Environmental Action Group), he learned about the water-dependent variety of rice called 'Turanta.' It has the ability to withstand water and demonstrates quick development, which astonished Darmendra. He decided to create 'Turanta' on his own premises in the next season. Initially, he cultivated that kind, but only on half an acre owing to a scarcity of seeds. At the end of July, a flood along the river inundated the adjacent fields, which remained flooded until the water withdrew after 15 days. Darmendra verified that there was no detrimental effect on the 'Turanta' crops. In contrast, new branches had emerged from the sides of the plants. The rice paddy thrived and was later harvested. From a small half-acre, he produced seven quintals of produce. Inspired by this, farmers from adjacent villages are now enthusiastic about cultivating this rice variety.

Planning Climate Resilient Coastal Cities: Learnings from Panaji and Visakhapatnam, India [20]

Goa is the smallest state in India, with a total land area of 3,702 square kilometers and a coastline that stretches for 105 kilometers. It is situated on the western coast of India, close to the Arabian Sea. Panaji, sometimes referred to as Panjim, is the capital of Goa and is a big draw for visitors from all over the world. It is located on around 812 hectares and serves as the capital of Goa. It has essential infrastructure that makes it possible for big tourist activities to take place in the region. The city is situated on an island that is threatened by environmental hazards. It has been determined that Panaji is a coastal city that is susceptible to flooding as a result of the anticipated increase in sea level. The most recent census indicates that there are 114,405 people living in the city of Panaji. The city has a sizeable population of transients, which brings in around one thousand visitors from other countries and five thousand tourists from inside the country every single day. Not only is the city very susceptible due to the fast development in urbanization and the rising demands of visitors on its infrastructure, but it is also extremely vulnerable due to the potential hazards posed by climate change. Using GIS- based spatial analysis and Digital Elevation Models (DEM), the study modelled multiple sea- level rise scenarios, confirming significant future flood risks. It also identified that urban development plans in both cities lacked climate integration, and institutional mechanisms were fragmented, with no single agency responsible for resilience coordination. A critical stage of the study was collecting the locational data of each infrastructure asset, since it required a GIS- based spatial analysis. Coastal zones are classified as 'strategically sensitive'; hence, geographical information on these areas is not publicly available. Channelized permits from relevant governmental authorities for data exchange were unattainable owing to the study's constrained timetable. Horizontal displacements in the database resulting from the use of numerous datasets and their conversion from raster to vector format.

CONCLUSION AND FUTURE WORK

This research presents a comprehensive and context-sensitive framework for climate- responsive urban design, grounded in the case study of Ahmedabad and supported by comparative insights from other Indian cities. By integrating spatial vulnerability analysis, community perception surveys, and climate-adaptive design principles, the study offers a multidimensional understanding of urban resilience in the face of escalating climate risks. The findings underscore the uneven distribution of climate-induced shocks and stresses—such as flooding, heatwaves, and disease outbreaks—across different city zones and socio-economic groups, with peripheral and underserved communities bearing the greatest burden. Comparative analysis with cities like Surat, Gorakhpur, and Panaji further reinforces the need for localized and scalable strategies that balance infrastructure development with ecological sensitivity and participatory planning. While Surat's institutionalized health-climate initiatives and Gorakhpur's community-based agricultural adaptations demonstrate the potential of integrated approaches, Ahmedabad's model highlights the critical role of data-driven planning and spatial assessments. However, the research also identifies a key gap in the institutionalization and mainstreaming of climate resilience within formal urban governance. The proposed framework emphasizes flexibility, redundancy, and inclusivity as foundational principles for climate-positive urban futures. As Indian cities continue to face complex climate challenges, this research offers a strategic blueprint for developing urban environments that are not only resilient and adaptive but also equitable and sustainable.

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