BEATING THE HEAT

Improving Resilience to Heat Stress in the Low-Income Settlements of Vatva

Written By: Sneha Ramachandran
Guided by: Melissa Smith & Abid Hira

Faculty of Planning
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Ahmedabad, India

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Sneha Ramachandran

UG180580

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Melissa Smith & Abid Hira

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Sneha Ramachandran

Abstract

India is highly vulnerable to extreme heat, and with climate change, heat waves are predicted to become more frequent, severe, and prolonged. In Ahmedabad, the growth of GIDC has expedited employment prospects, resulting in the emergence of low-rise, informal settlements in Vatva, the south-eastern part of the city. The vulnerability of the urban poor residing in these precarious informal settlements with limited access to resources is compounded by climate variability and anthropogenic activities. The impacts of such events are often sustained disproportionately across communities and even within a single community and individuals. The study evaluates and compares the vulnerability of six low-income settlements in Vatva to heat stress based on the IPCC framework and recommends community-based heat adaptation strategies. The multi-dimensional approach to vulnerability assessment resonates with the uncertainty and context-dependent character of climate change. The study uses a qualitative empirical methodology that gathers data from primary sources such as surveys and community participation and secondary data sources such as census, reports, and action plans. The settlements' low adaptive capacity and increased exposure and sensitivity make them particularly susceptible to heat-related risks. The impacts of increased heat are evident in the sectors of health, livelihood, well-being, and basic services and infrastructure. The study identifies community-based heat resilient upgradation, retrofitted and socio-cultural strategies from around the world and contextualizes them for the settlements of Vatva. The identified cost-effective solutions at the individual, household, and neighbourhood levels include cool roof and paving options, passive cooling strategies, and community-level interventions. The paper also addresses limitations in the methodology resulting from insufficient data availability and challenges in implementing adaptive strategies due to dependence on external funding and a requirement of sustained community participation. This study thoroughly examines context-specific challenges and feasible and replicable solutions. By utilizing bottom-up approaches, the recommended solutions offer the potential for resource-efficient and tailored outcomes.

Keywords Climate change, Heat Stress, Vulnerability, Resilience, Ahmedabad, Vatva, Informal settlements

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1.

INTRODUCTION

1.1 Climate change in urbanizing cities

The UNFCCC defines climate change as a change in long-term weather patterns attributed directly or indirectly to human activity that alters the composition of the global atmosphere causing multiple adverse impacts (Pörtner, et al., 2022). India ranks 5th in the Global Climate Risk Index[1], which analyses the extent of the impact of weather-related events.

Rapid urbanization and immigration pose a significant threat, particularly to metropolitan cities. Urban areas have become essential drivers of economic development, with over half of the world's population residing in cities and metropolitan regions (Aghamohammadi, Fong, Daliana , Ramakreshnan, & Mohammadi , 2022).

In the least developed nations, a significant proportion of the urban population growth is concentrated in informal settlements. These settlements are characterized by poor living conditions, restricted access to basic needs, and increased susceptibility to environmental stressors. Due to poor infrastructure and urban planning, the urban environment of India, in particular, is susceptible to significant disaster risks (Mani & Waji, 2014). Urbanization, accompanied by natural environmental factors such as climate variability, increases the risk of climate-related hazards.

[1] *The Global Climate Risk Index evaluates the degree to which nations and localities have experienced the consequences of weather-related incidents, such as storms, floods, and heat waves that result in losses.*

[2] *In a study led by the Union Ministry of Forest & Environment, that evaluates the vulnerability of seven Indian cities due to their geography, hazard-prone areas, population and size, Ahmedabad ranked as the 2nd most vulnerable city. This is attributed to the annual increase in migrant population &episodes of climate-hazards.*

Climate change can manifest as various hazards, including socio-natural hazards, which result from the interaction between human intervention and environmental degradation in natural ecosystems, potentially exacerbating their severity and frequency. Such disasters may have significant and far-reaching consequences. These impacts are sustained disproportionately across the country and even within a single community and individuals.

Heat stress is a major environmental stressor affecting these populations, with the potential to cause catastrophic consequences as India's summers become hotter due to climate change (C40 Cities Climate Leadership Group, C40 Knowledge Hub, 2019). Studies in this domain show that increased temperature also causes heat waves, flash floods, urban flooding, storms, and unpredictable weather patterns (Ghanekar, et al., 2021). The urban heat island effect, brought on by increased heat absorption and less ventilation in built-up areas, exacerbates the effects of heat stress. The consequences of heat stress are further compounded by the lack of ventilation, greenery, and clean water in informal settlements. Heat waves have a range of impacts, including increased morbidity and mortality, reduced labour productivity, and damage to infrastructure such as roads and rail lines.

With unique social, spatial, and environmental concerns, each city necessitates local and contextualized responses. Hence, the role of local governments and grassroots organizations is of prime significance. The future of people's lives and livelihoods in urban regions will depend significantly on actions taken, or not taken, to address climate change in the next decade (Bicknell, Dodman, & Satterthwaite, 1972).

1.2 Ahmedabad- An Overview

Ahmedabad, one of the fastest-growing cities and economic centres of Gujarat, lies 53 meters above sea level and spans over an area of 505 km^2. Ahmedabad's urban population increased by 51% from 2001 to 2011 compared to the state of Gujarat entirely, and urban land grew by 136% between 2007 and 2017 in the city (Census of India, 2011). Most of the city's topography is flat, except for some hillocks in the north (Thaltej-Jodhpur Tekra). On a scale of 2 to 5, in order of increasing vulnerability to earthquakes, it falls in seismic zone 3.

In a recent study conducted by MoEF[2], Ahmedabad ranks as the 2nd most climate-vulnerable city in India. The climate of Ahmedabad is hot and semi-arid with moderate rainfall that is conducive to heat waves.

The city has taken pioneering steps toward addressing the challenges of climate change, including the implementation of the Heat Action Plan (HAP). The Ahmedabad Municipal Corporation (AMC) announced the creation of a HAP in response to a catastrophic heat wave that killed 1344 citizens in May 2010 (Urban Sustainability Exchange, n.d.). In addition, the city has implemented several programs, such as the Slum Networking Project and BSUP, aimed at improving the overall well-being of its vulnerable population.

The city of Ahmedabad experiences four main climate stressors, including heat stress, localized and overland flooding, water scarcity, and water and vector-borne diseases, according to a report by the Global Resilience Partnership. Its location in the semi-arid region and growing urbanization make it particularly vulnerable to these climate stressors.

Heat stress is one of the most pressing issues in Ahmedabad, especially with the maximum temperature soaring up to 48°C (highest recorded in 2016) in the summer months. Especially for vulnerable groups like children, the elderly, and outdoor laborers, this creates a risk of heat exhaustion and heat stroke. Additionally, the city's reliance on groundwater, which is diminishing due to rising demand and decreased recharge, exacerbates the effects of heat stress. Water scarcity-related issues have so become more frequent, particularly in low-income communities. Inadequate drainage systems and the city's location on the Sabarmati River exacerbate the concerns of localized and overland flooding, which leads to loss of life and damage to infrastructure and property. This, in turn, increases the risk of water and vector-borne diseases, particularly in areas with poor sanitation, inadequate waste management, and stagnant water. The combination of these factors means that Ahmedabad frequently experiences outbreaks of diseases such as dengue fever, chikungunya, and malaria, particularly during the monsoon season, and heat exhaustion during summer.

Managing these challenges require a comprehensive approach that prioritizes the needs of vulnerable communities and addresses the underlying factors that contribute to their vulnerability.

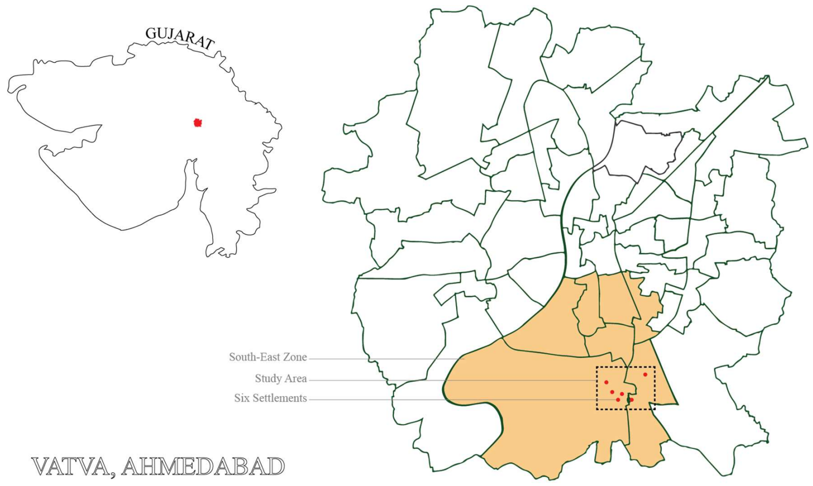


Figure 1.1 Ahmedabad Ward Map

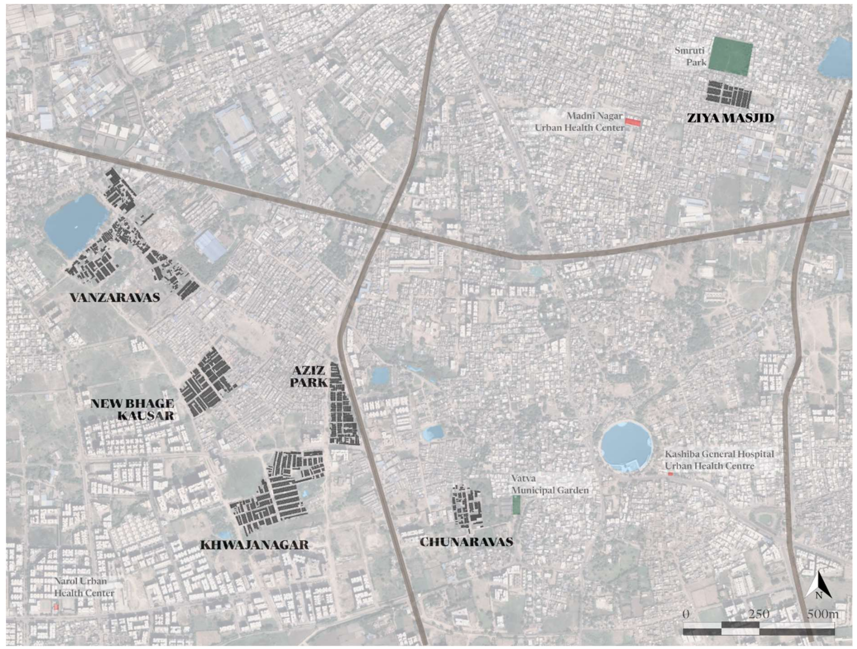


Figure 1.2 Six study areas in Vatva

1.3 Aim and Objective

The study aims to evaluate the vulnerability of six low-income settlements in Vatva to the impacts of heat stress and identify effective climate response strategies to enhance the heat resilience of these communities.

Objectives:

- Create a framework of vulnerability indicators for the climate stressors
- Evaluate and compare vulnerability to extreme heat with participation from the community
- Assess the existing adaptation techniques on-site and around the world
- Strategy recommendations for supporting vulnerable communities to build resilience to heat stress

1.4 Scope and Limitations

This study provides a comprehensive understanding of differential vulnerability among the six settlements of Vatva, offering a framework that can be utilized to assess the vulnerability of other settlements in similar climatic contexts. By drawing comparisons between the settlements, the study highlights the most vulnerable areas that require primal attention. Moreover, the assessment of various dimensions of vulnerability provides insight into whether improvements should focus on reducing exposure and sensitivity or enhancing capacity.

However, one of the primary limitations of this study in low-income settlements is the inadequate availability and sharing of real-time and historical data. The manual data collection method used in the study is time-consuming, requires significant labour, and is prone to errors. The constraints of the study timeline made it challenging to study the long-term changes in demographics, infrastructure, and population dynamics. Additionally, reliance on self-reported data introduces bias and inaccuracies. Due to the study's restricted access to particular settlement areas and use of convenience sampling, the results may not be completely depictive of the larger community.

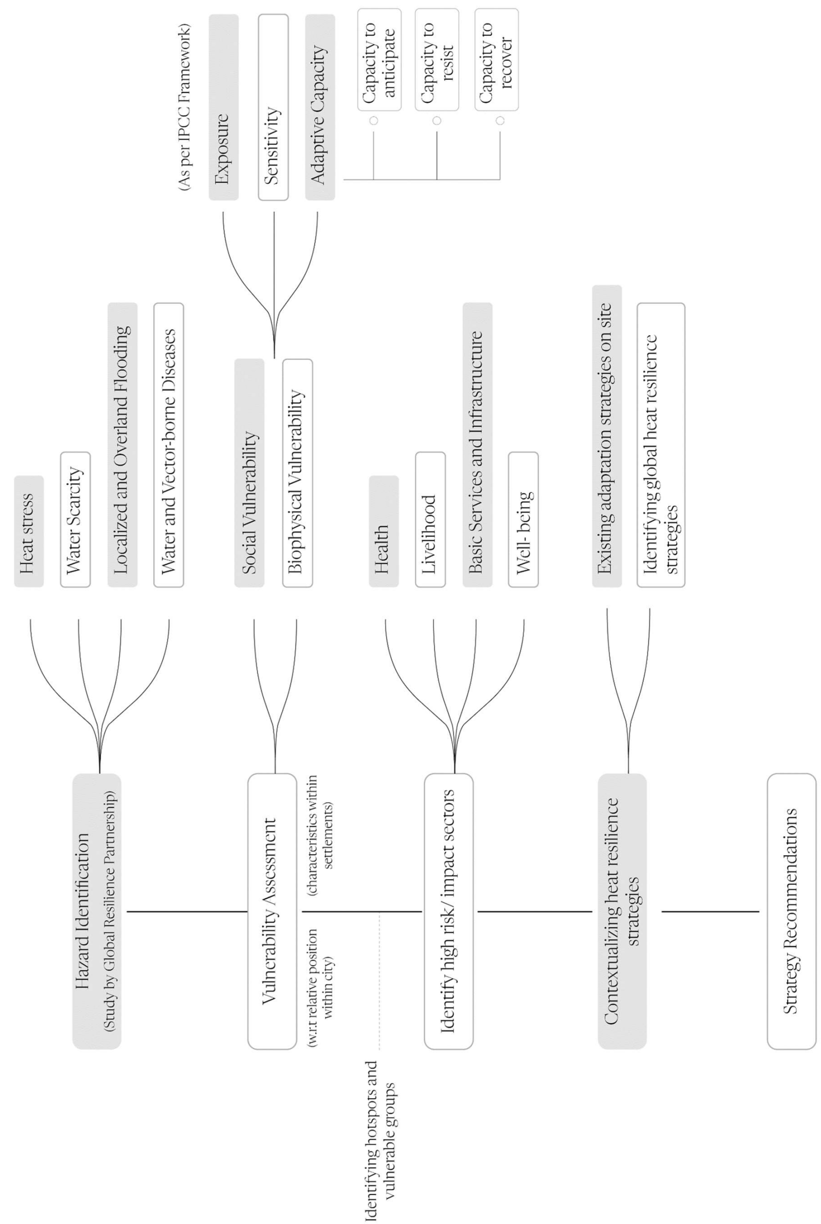


Figure 1.3 Study Framework

2.

BACKGROUND

2.1. Introduction to Vatva

Between 1970 to 1990, there was a notable emergence of the industrial sector in the south-eastern regions of the city. During this period, most of the land in Vatva, was used for agriculture and industry. The establishment of the Gujarat Industrial Development Corporation (GIDC) in 1969 created substantial employment opportunities, resulting in an influx of inter and intra-state migrants.

The surge in employment opportunities in this region, was accompanied by a subsequent increase in the demand for housing. The TP Schemes proposed in 2012 provided opportunities for private investors to invest in the development of this area. As a result, industries began constructing low-cost informal housing to accommodate the influx of migrants and the labour force. Over time, this area experienced a proliferation of informal and low-rise settlements, resulting in severe overcrowding.

The study primarily focuses on six low-income settlements namely, Aziz Park, Khwajanagar, New Bhage Kausar, Zia Masjid, Chunaravas, and Vanzaravas. These areas recently, have been incorporated within the limits of AMC, and therefore, the systems and services of the city have not yet extended to these regions. The land use of the study region is characterized by sparse vegetation, unvegetated empty land plots, formal residential areas, and dense informal settlements, all of which contribute to an urban microclimate that features higher local land surface and air temperatures. During summer, the land surface temperature in these settlements ranges from 42-47°C, while in winter, it ranges from 27-31°C. These temperatures are significantly higher than the other parts of the city (Avashia, Garg, & Dholakia, 2021). Moreover, the study region falls within a high subsidence zone, indicating unplanned groundwater extraction. Due to a lack of basic infrastructure and healthcare options, groundwater depletion, high temperatures, and the socio-economic abilities of the households in this region, it presents a crucial area for study and intervention.

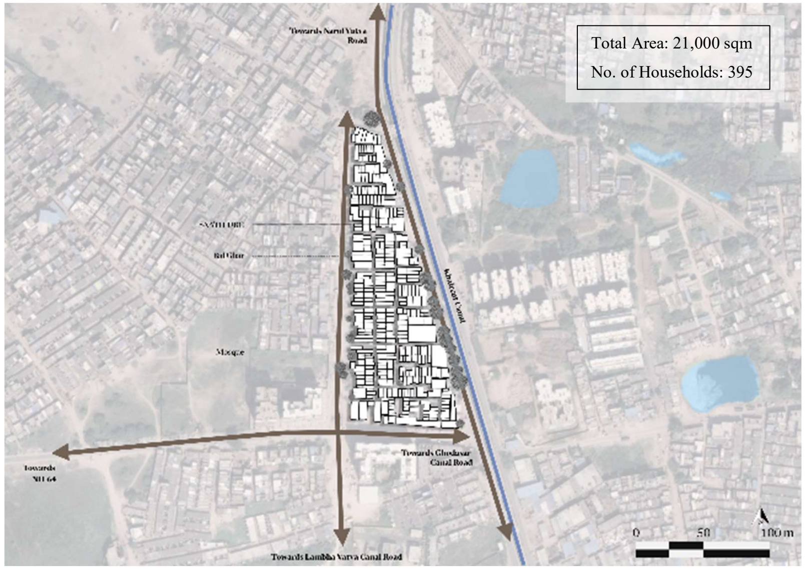


Figure 2.1 Site A- Aziz Park

Figure 2.2 Site B- New Bhage Kausar

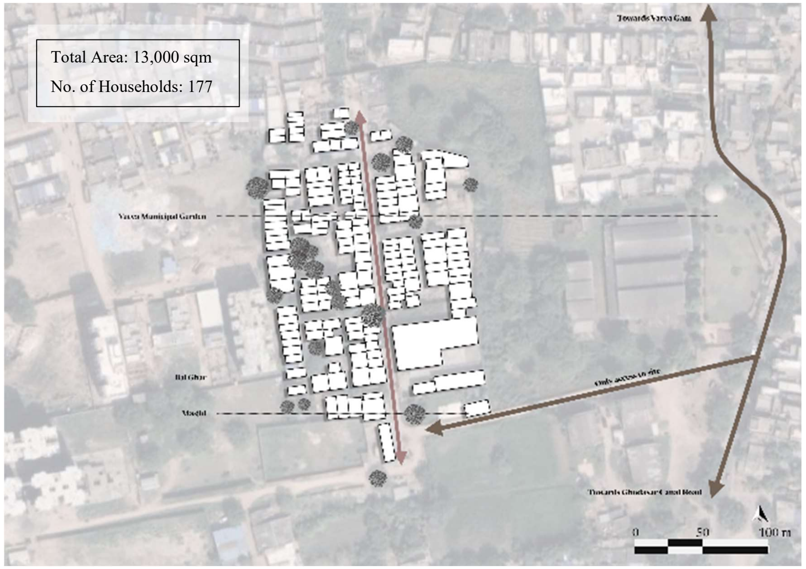


Figure 2.3 Site C- Chunaravas

Figure 2.4 Site D- Zia Masjid

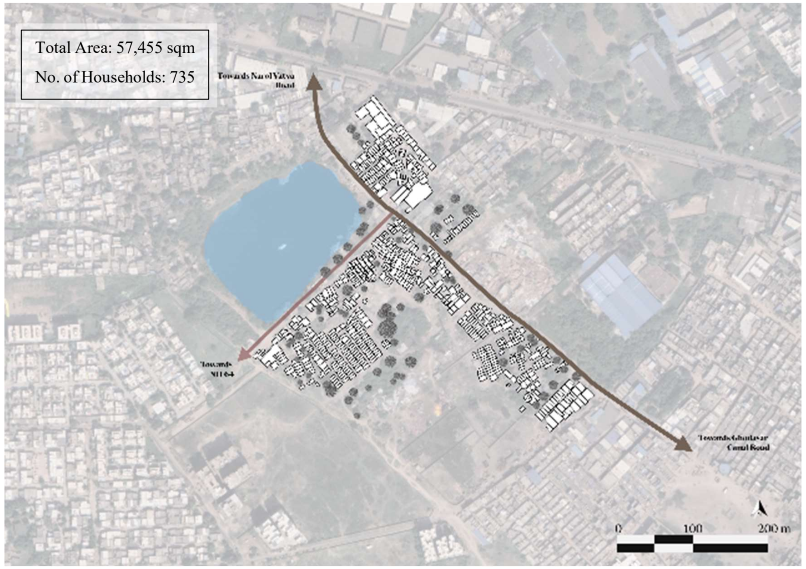


Figure 2.5 Site E- Vanzaravas

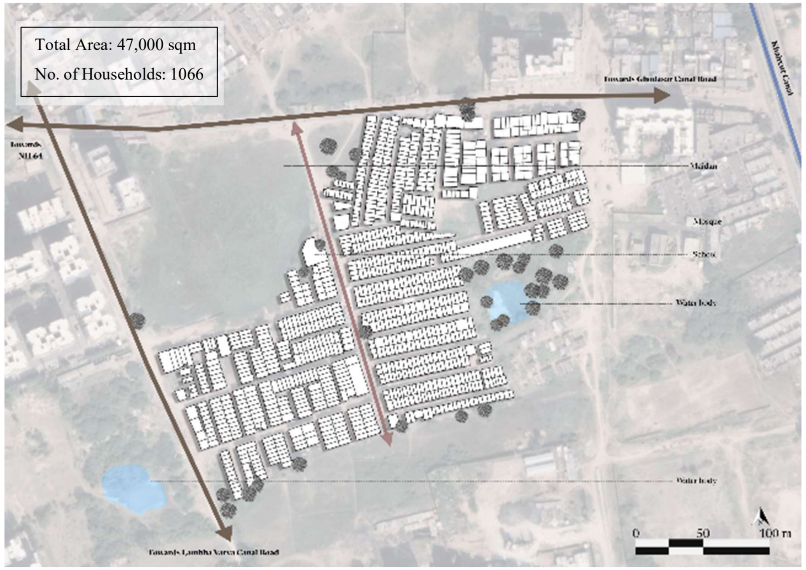


Figure 2.6 Site F- Khwajanagar

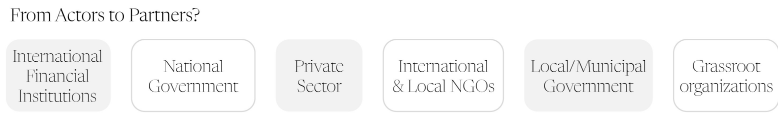
2.2. Vulnerability assessment and resilience strategies

Urban vulnerability, made up of several components, is complex and integrates aspects of social and biophysical vulnerability. The study engenders a tool for the vulnerability assessment of informal settlements for their climate change adaptation and mitigation plans. Urban informal settlements witnessed a significant increase in vulnerabilities, and hence, investing in reducing climate risk for low-income and marginalized people and concentrating efforts there could deliver the highest gains in well-being in urban areas (Pörtner, et al., 2022). The IPCC Third Assessment Report defines vulnerability as a system's susceptibility to withstand harmful consequences of climate change, especially climate variability, and extremes. Further, the level of vulnerability is determined by its exposure, sensitivity, and capacity to cope, resist and adapt to the magnitude, character, and rate of climate variation. These three dimensions provide insight into direct and indirect or intangible aspects of vulnerability. Exposure is the extent to which a system is subjected to climate variations. Sensitivity refers to the degree to which a system is directly or indirectly affected by climate-related stimuli. Adaptive Capacity deals with the capability of a system to accustom to climate variability and extremes to minimize possible harm, take advantage of possibilities, or deal with the effects (Pörtner, et al., 2022). These factors are often shaped by an actor's access to rights, resources, and assets (Pelling, 2003).

The implementation of climate resilience measures is crucial in supporting vulnerable urban populations to mitigate the effects of heat exposure. Strategies to address these various dimensions of vulnerability range from opting for thermal insulation, passive cooling and ventilation or providing natural vegetation. Apart from their positive environmental impacts, these measures also contribute to lower energy consumption for cooling, and improve the thermal comfort of slums in the hot summer months.

Among local administrations, adaptation to climate change demands local expertise and capacity. This calls for a context-specific study to understand vulnerability and risk at the localized level. This evaluation assesses the potential impacts of extreme heat in the settlements and offers key inputs in building resilience strategies. Unlike the usual homogeneous characterization of vulnerable groups, basing the actions on contextualized assessments reduces the risk of misdirected efforts (Pillai & Dalal, 2023). The gathered bottom-up data is then synthesized with an analysis of future climate projections and local hazards.

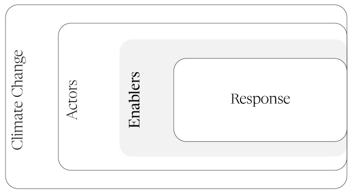
2.3. Players in the process- Role of NGOs



The Ministry of Environment, Forest and Climate Change (MoEFCC) is the primary governmental agency addressing climate change at the national level, while the Climate Change Department operates at the state level, implementing relevant policies and programs. Together they coordinate the country's endeavours to meet its international climate change commitments. While there are no government agencies at the local level dedicated to this issue, a variety of stakeholders, including financial agencies, private sector entities, international and local NGOs, local governing bodies, and grassroots organizations are involved in a city's climate change initiatives (Refer to Annex 1).

The SAATH Charitable Trust is a grassroots-level NGO operating in Ahmedabad dedicated to improving the lives of low-income communities in the sectors of education, health, and infrastructure. The organization works for and with the inhabitants of these settlements in a bottom-up approach to identify and address their issues encouraging active participation from the community. This study explores the potential benefits of combining these sectoral initiatives with an adaptation framework, providing a co-benefit approach to resilience-building in vulnerable communities.

Global interests have frequently spurred cooperative actions between these state and non-state entities, marginalizing and overlooking vulnerable groups. In this context, local NGOs have a stronger position than other political actors to produce, accumulate, and transfer knowledge to address information asymmetries in local decision-making, promote empowerment and infrastructure sustainability, and weaken patronage and dependency systems. This gives them a competitive advantage over the other actors in the hierarchy (Pelling, 2003).



3.

METHODOLOGY

The study follows a methodology based on a qualitative research design process. Based on the pragmatism paradigm, the research involves a mixed-method study to document and analyse the ground reality as accurately as possible.

Through this framework, the study answers the following questions:

- When is the highest risk?
- Where and who faces the highest risk?
- What are the risks associated with heat?
- How to reduce the risk to heat stress?

Objectives	Data/ Evidence to be collected	Tools for data collection
Identify the most pressing climate stressor in the settlements	- Demographic data - Climate & weather related data - Impacts of the stressors on the community - Community challenges and coping mechanism	- Literature Review - Semi-structured interviews - GIS
Vulnerability Assessment	- Exposure to climate events - Sensitivity to climate events - Adaptive Capacity to climate events	- Surveys - GIS - Spatial typology mapping
Classifying loss and damage based on impact areas or sectors	- Impact assessment	- Household survey
Recommending heat resilience strategies	- Existing adaptation strategies on site - Global strategies to build heat resilience	- Literature Review - Case study

Table 3.1 Research Methodology

This study employs a holistic approach to address the root causes of climate stressors in Ahmedabad, identifying pertinent solutions and prioritizing them accordingly. The initial stage involves narrowing down to one of the four climate stressors in Ahmedabad, followed by conducting interviews to identify context-specific parameters affecting vulnerability to the climate stressors. A comprehensive vulnerability assessment is then carried out to understand the impacts and responses of settlements to these stressors. Subsequently, a matrix of solutions adapted to similar contexts is developed, and finally, solutions are prioritized based on the differential vulnerability of these settlements.

3.1 Framework for vulnerability assessment

An essential step in identifying critical weaknesses in a system, actors, or strategies is vulnerability assessment. To comprehend risk and risk-generating components, this multi-level assessment identifies the vulnerability of the settlements concerning their relative position in the city and the unique characteristics within the community that contributes to it. The study follows a participatory approach using parameters outlined by the IPCC. Vulnerability could manifest in various forms and therefore, the assessing parameters consider socio-economic (livelihood), biophysical, and institutional or infrastructure-related factors. A baseline evaluation of heat stress and its impacts are achieved through interviews, scientific literature, and reports. This is strengthened by recent studies on population and urban growth, past weather information, community experiences through interviews and surveys, and projections from climate models. It investigates its effects on various sectors, including health, sustainable livelihood, economic productivity, and basic services. The study follows a human-centric model to assess “when, where, and to what extent people are exposed to urban heat and further assess the impact of heat exposure on their comfort, performance, well-being, and health” (Nazarian & Lee, 2021).

3.1.1 Climate Projections and Spatial Context

Beyond the scope of a single weather event, climate variability refers to changes in the mean state of the climate and other statistics about it. In this analysis of heat stress, the temperature is used as the primary climate variable (Vasudha Foundation, 2022).

Over the last decade, a change in the patterns can be observed with the early onset and prolonged duration of summer months.

Temperature Variability:

The mean temperature in the city ranges between 35°C and 40°C during the summer months.

	March	April	May	MAM
Observed monthly max. temp (Celsius)	35.8	38.7	39.6	38
Projected (2030s)	36.8	40.2	41.8	39.6
Observed monthly warm days	9	10	10	10
Projected (2030s)	34	40	42	39

Table 3.2 Observed and projected maximum temperatures and number of warm days in summer

	December	January	February	DJF
Observed monthly min. temp (Celsius)	14.5	12.9	14.9	14.1
Projected (2030s)	14.4	13.2	15.1	14.2
Observed monthly cold days	4	22	24	16
Projected (2030s)	1	2	17	7

Table 3.3 Observed and projected minimum temperatures and number of cold days in winter

An increasing trend can be observed in the mean maximum temperature and number of warm days during summer, and May being the hottest month. The projection shows an increase of 1-2°C in the mean maximum temperature, and the number of warm days is increasing drastically.

An increasing trend can be observed in the mean minimum temperature and a decrease in the number of cold days, with January being the coldest month.

Apart from decadal variability of the air temperature, heat waves can be attributed to other factors that contribute to the heat island effect. These include increased air pollution, an increase in impervious area and waste heat or external energy inputs, and a lack of vegetation cover and water bodies.

To identify the spatial distribution of areas of high heat vulnerability within the community, a 10x10 meter grid of points was overlaid onto the plan. Each point was then assigned a score ranging from 0 to 4 in increasing order of vulnerability based on the type of land or roof material at that location. Areas with greenery such as trees or water bodies were assigned a score of 0, while areas with concrete were assigned a score of 1. Tar roads were given a score of 2, unvegetated sandy soil was assigned a score of 3, and tin roofs were given the highest score of 4. The resulting map of heat hotspots, generated through this process, presents the most vulnerable areas within the communities (Figure 3.1).

The sparse vegetation, dense habitations, presence of materials with low specific heat capacities, and growing energy consumption increasing anthropogenic heat make these settlements a hotspot for climate-related issues.

Given the continued projections of extreme heat, the study reflects on the landscape of heat stress in low-income settlements by examining heat risks, proposed or implemented strategies, and the structuring of finances for implementation.

3.1.2 Built Typology

The built typology study assesses the physical characteristics of housing and infrastructure that contribute to vulnerability. The typologies are categorized based on the physical attributes such as building materials, kitchen and toilet access, fenestrations, floors, and building use. This helps in identifying and prioritizing the most vulnerable households in terms of the physical factors and high-risk areas within settlements.

To classify the different building typologies identified on the site, the factors that influence thermal comfort are taken into account. The building use determines how the spaces are utilized and for how long. While certain houses may have verandas, others only have a single porous facade, limiting the potential for cross-ventilation. Furthermore, the absence of planning in informal settlements leads to inconsistent building orientations, affecting indoor thermal comfort. The selection of roof materials also has a significant impact on heat transfer, exacerbating the issue.

These identified typologies are mapped for the six settlements to identify the most prevalent typology and analyse any existing patterns.

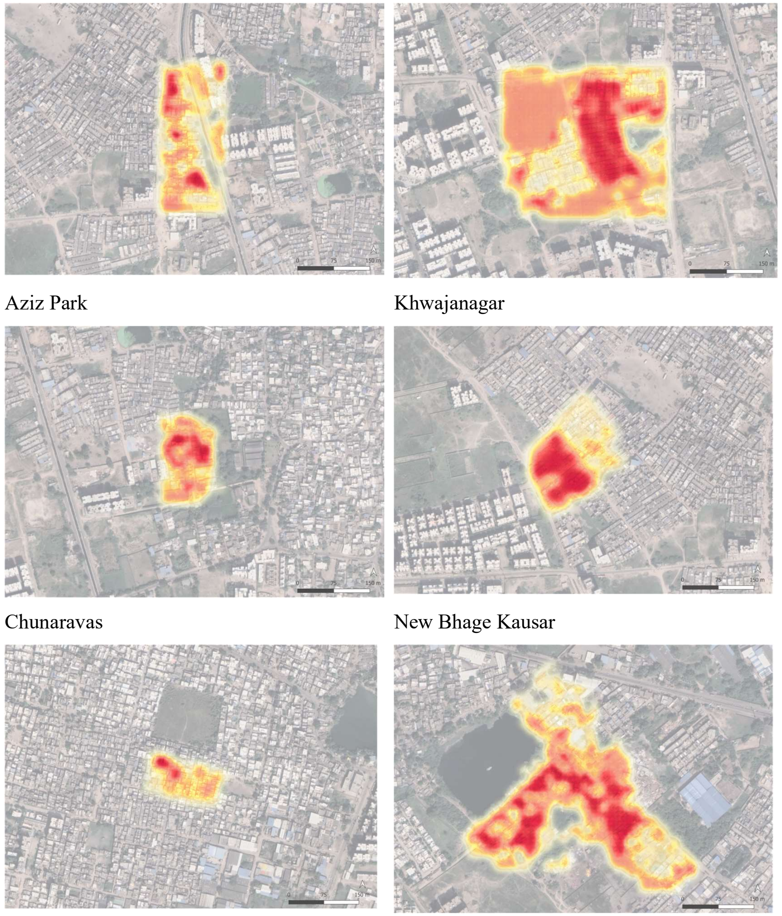


Figure 3.1 Heat Hotspot Map

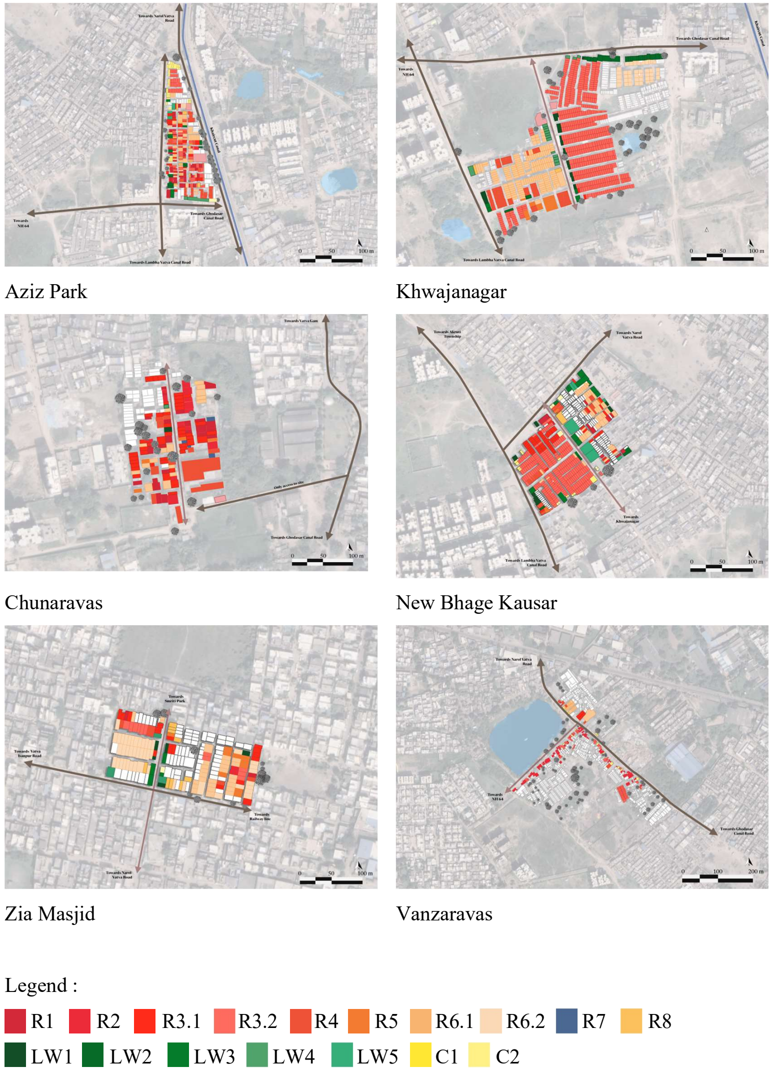


Figure 3.2 Built Typology Mapping

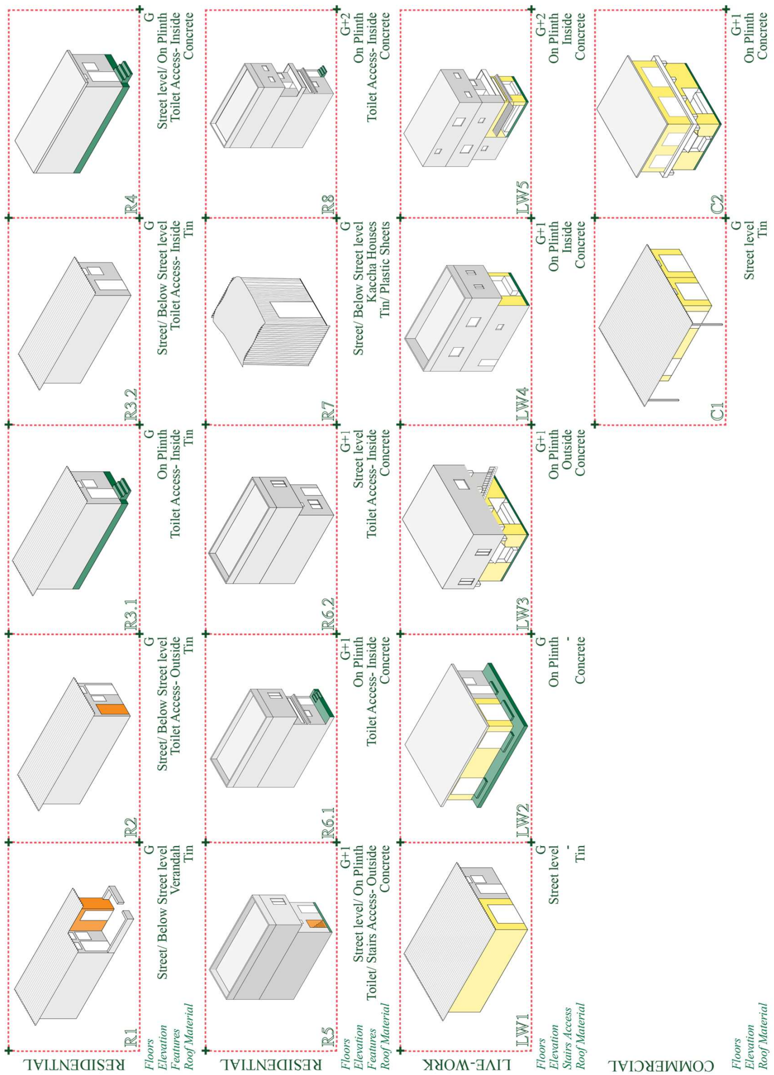


Figure 3.3 Identified Building Typologies

3.1.3 Participatory Process to Vulnerability Assessment

The various dimensions of vulnerability are assessed through qualitative methods. An insight into the community's challenges with climate change is achieved through a multi-level stratified sampling.

For the initial level of sampling, the study employed semi-structured interviews to understand the experiences of inhabitants and households have had with climate change. This provided insights into various factors and parameters affecting the vulnerability of the inhabitants and the resultant loss and damage.

The interviews with community members reveal that heat stress and localized flooding represent the most pressing concerns, with flooding predominantly caused by poor infrastructure. The impact of extreme heat is further compounded by water scarcity and pre-existing health conditions. A combination of inadequate housing materials, poor ventilation, lack of green areas, cooking with chulhas, and dense living conditions render these communities particularly vulnerable to the adverse effects of heat. Residents are often not provided with sufficient warning signals during heat waves, and even among those who receive warning messages, many lack the necessary education to fully comprehend them. The absence of shaded and green spaces nearby obliges residents to remain indoors during periods of extreme heat. For many residents, air conditioning and coolers are financially out of reach, and fans are often the sole source of relief during periods of extreme heat. Some residents even avoid using coolers to minimize their electricity expenses. Moreover, despite having access to medical facilities, heat exhaustion is often treated at home, and people do not seek appropriate medical care for heat-related illnesses as they would for other health conditions and diseases. (Refer to Annex 2.1)

Inferring from the regional context, the interviews, and the literature, a set of indicators was determined to study the three dimensions of vulnerability.

Vulnerability dimensions	*Factors*	*Tools*
Exposure	• Spatial distribution/ Urban Morphology- Land use & land cover profile, building typology (building material, type & position of buildings w.r.t the street) • Population density • Context- water supply, drainage & sanitation, access to infrastructure- schools, hospitals & markets • Seasonal frequency and weather pattern trends • Aggravating/ additional factors • Economic Activity- outdoor work during peak hours	- Mapping - Spatial analysis - Reports
Sensitivity	• Household demographics- Age (dependent members) & gender distribution, education, underlying health status and chronic conditions • Livelihood/ economic activity- income • Material possessions/ assets	- Survey
Adaptive Capacity	• Social Capital- access to help and resources through social ties, information sharing and connections to institutions • Previous experience with hazards- likely to take preventive measures • Local governance mechanisms • Awareness	- Survey - Interviews

Table 3.4 Vulnerability parameters

Settlement	Total no. of households	Identified households (typology)	Surveyed households
Aziz Park	401	349	45
Khwajanagar	1067	914	98
New Bhage Kausar	568	457	50
Chunaravas	173	123	30
Zia Masjid	216	148	28
Vanzaravas	735	173	28

Table 3.5 Household Survey Sampling

These broader parameters help to investigate the extent of risk the households are exposed to. For a user-oriented perspective of climate-related challenges, the vulnerability factors were rendered, in the form of a questionnaire in English and Gujarati, the regional language. The pilot survey improved the conciseness and efficacy of the questions. Based on the takeaways from the pilot, the questionnaire was modified and finalized.

While the first stage of sampling aided in narrowing down the main impact factors and climate stressors, the next stage, aimed to determine the sample size of the survey. Based on the literature review, research timeline, and availability of labour, a sample size between the ratio of 1:7 and 1:10 was finalized. The six settlements house a total of 3164 households. In total 279 households were identified for the survey out of 2164 households whose typologies were identified across all six study areas.

For the following stage of sampling, the total number of surveys of each settlement was divided amongst the vulnerable household typologies in ratios of 1:7 and 1:10, depending on the dominance of the typologies (Refer to Annex 2.2).

The stratified sampling is followed by a stage of convenience sampling where households of each typology are selected randomly based on the availability and willingness of the residents. The data was collected by the students, field officers and volunteers.

3.2 Case Study Matrix

Broadly, the results of the survey indicate that, in all six settlements examined, less than half of the population implements adaptive measures to mitigate the effects of heat stress. The strategies currently employed are primarily focused on household and behavioural levels and do not encompass broader, community-level interventions or passive cooling strategies. These measures include the use of mechanical cooling devices such as fans and coolers, hanging of wet cloth on doors and windows, sleeping on verandas, spending time outdoors under shaded areas such as otlas and trees, and sprinkling water on terraces and streets.

For the final stage of this methodology, case studies on resilience strategies from around the globe were conducted to investigate the measures taken to deal with heat stress. They were selected based on comparable economic and climatic conditions as that of Vatva. A comprehensive analysis of the strategies implemented across various scales includes their associated costs and the institutional frameworks that supported their implementation. By examining these factors, the range of adaptation methods used to combat heat stress in different regions can help in contextualising strategies for the low-income settlements of Vatva.

The impacts of heat stress can be observed and mitigated across all scales. Around the globe, a combination of climate-related resilience strategies is implemented across the household, street, and community levels. Most of the existing interventions adopted by the community members are on an individual or behavioural scale. Residents usually modify the patterns of their movements or usage of spaces and take precautionary methods. In cases where the cultural context permits, people also opt for lighter clothes to escape the heat.

Figure 3.4 Case Study Matrix -1

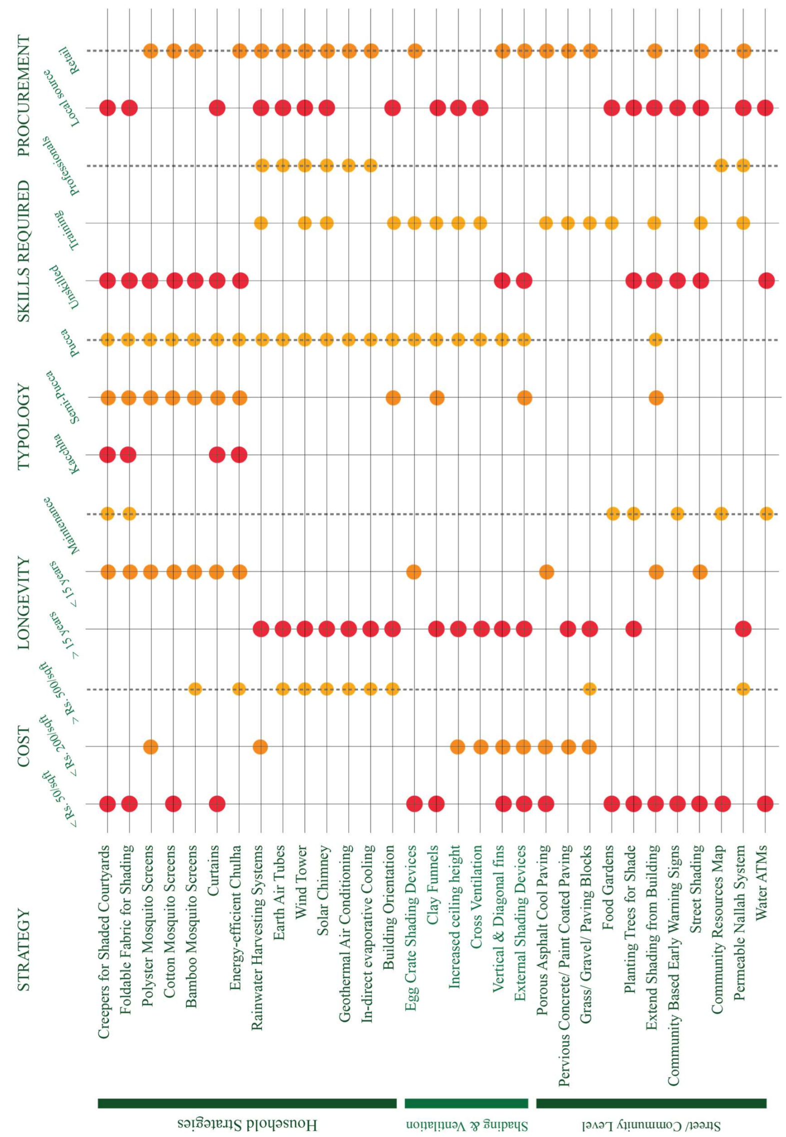


Figure 3.5 Case Study Matrix -2

The most common adaptation measures are retrofitted strategies that are cost-effective and implementable by the community. Painting the roofs and facades white, using curtains and mosquito screens, planting trees, and shading using fabric are most prevalent and replicated across different settlements. These informal settlements often lack regulatory frameworks or grassroots organizations working with them. It restricts their awareness of heat stress and limits their ability to cope with it. In the context of climate change in low-income settlements, MHT and cBalance have done extensive work with informal settlements in India by acting as conduits for enforcing heat resilience strategies. Adaptation at the household level has been through combining technological and community-led measures such as cool roofs, greening, passive cooling strategies, cool pavements, etc. (Asian Development Bank, 2022). Thermocol insulation, solar reflective white paint, ModRoof, and other paint, membrane, and tile-based roof retrofits have been the most viable options found in low-income settlements. Green roofs, although offering significant heat relief, are relatively expensive and have daily water requirements. There are examples of passive cooling techniques like fenestrations or external shading devices. Although building orientation and natural ventilation are the most preferred means to address heating, their impracticality in dense low-income settlements is a drawback. Vernacular architecture and materials have been shown to lower indoor temperatures but are not common as they are labour-intensive, and materials like tin or asbestos are economical. Concerning livelihood, people use shaded vending carts, cool auto rickshaws, and alternate sources of income that don't involve spending time outdoors during peak hours. At the neighbourhood scale, planting trees, shading using fabric, cool and permeable pavements, and access to drinking water have been the most discussed strategies. While other measures such as rainwater harvesting, solar chimneys, and wind towers are enforced, they are not as widespread due to the larger scale and higher cost implications. Further, community-based early warning systems and community resources maps are also prioritized.

The strategies realized through pilot or municipal, voluntary, and CSR models suggest a combination of transformative, incremental, and adaptive measures. Employing community-led measures that are contextually suitable eliminates chances of maladaptation and maximizes co-benefits.

4.

RESULTS AND DISCUSSION

[3] *In the domain of vulnerability assessment, a common approach is to utilize a 'vulnerability index' as a means of quantifying vulnerability. This index is a formative measurement, and the selected indicators need not exhibit internal correlation with each other. The indicators used in the analysis vary in terms of their units and scales. To address this, the UNDP's Human Development Index (UNDP, 2006) is employed to normalize the indicators. The value of each indicator is converted to a scale of 0 to 1, in order to standardize and make them comparable with one another.*

[4] *After computing the normalized scores, the index is constructed by assigning weights to the different indicators. The composite index developed by Iyengar and Sudarshan in 1982 calculates vulnerability rankings of settlements using multivariate data.*

4.1. Vulnerability dynamics and analysis

On the basis of the dynamics of vulnerability, the surveyed indicators were quantified and indexed for analysis (Giri, Bista, Singh, & Pandey, Climate change vulnerability assessment of urban informal settlers in Nepal, a least developed country, 2021). The study followed assessments based on the UNDP's Human Development Index[3] and Iyengar and Sudarshan Method[4] for differential vulnerability to quantify and compare vulnerability dynamics within and amongst the six settlements (Refer to Annex 3).

Higher exposure and sensitivity and relatively lower adaptive capacity increase the vulnerability of these settlements. The main elements of vulnerability dimensions frequently varied depending on the surveyed household's capacity for making decisions and financial status.

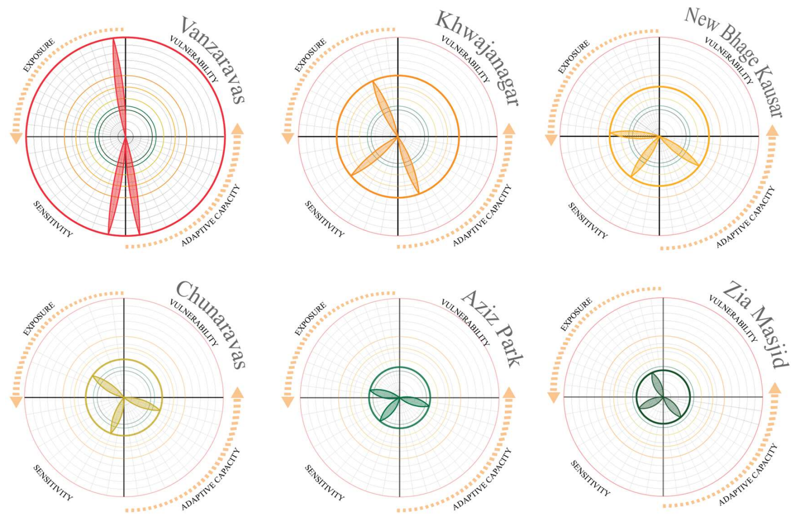


Figure 4.7 Degree of vulnerability and its parameters

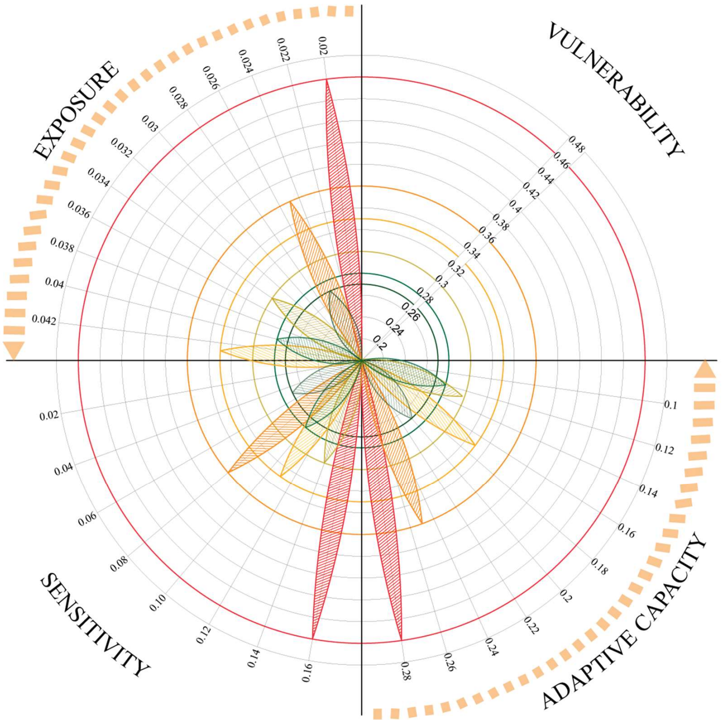


Figure 4.8 Comparison of the differential vulnerability of the six settlements

The households in Vanzaravas are the most vulnerable to heat stress and Zia Masjid, the least. Although spatially Vanzaravas is situated near a water body and is relatively less dense, the settlement ranks highest in all aspects of social, economic, and environmental sensitivity and lowest adaptive capacity. Khwajanagar ranks second most vulnerable to heat stress owing to its lower adaptive capacity. This is amplified by individual exposure resulting from outdoor work and inadequate transportation modes and moderate sensitivity due to lower literacy, lack of quality water, and higher population density. With the highest level of exposure, New Bhage Kausar stands next in vulnerability to heat stress. Lack of communal shaded areas, poor water quality, a lack of early warning systems,

and the adverse impacts of high temperatures on work have all contributed to the settlements' relatively high sensitivity and low adaptative capacity. Chunaravas is the fourth most vulnerable with moderate exposure and sensitivity and relatively high adaptive capacity. The shaded community spaces, early warning systems, and water motors facilitate households in coping with vulnerabilities stemming from a lack of separate kitchens, water scarcity, chronic conditions, outdoor labour, and tin roofs. Despite the households in Aziz Park being significantly exposed to heat stress from the presence of tin roofs, high population density, daily wage workers engaged in outdoor work, and indoor temperatures elevated by the use of chulhas, the community exhibits less vulnerability due to moderately low sensitivity and the presence of coping mechanisms. Contrary to the limited adaptive capacity of Zia Masjid, the households in the area demonstrated a notable resilience to extreme heat due to their lower levels of exposure and sensitivity. This can be attributed to the presence of pucca houses, a predominantly lower daily wage population, and fewer concerns related to health, water availability, power cuts, and access to cooling technologies. (Refer to Annex 3)

Primary causes of exposure to heat stress are the choice of roofing material, lack of cross-ventilation, and outdoor work environment. While households in the settlements may not be significantly exposed, they are inherently more vulnerable due to sensitivity, including illiteracy, high household density, pre-existing health conditions, power outages, and limited access to clean water. The presence of coping and resistance mechanisms to combat heat stress, including access to exhausts, water motors, cooling technologies, shaded community spaces, and early warning signs, is associated with a slight reduction in vulnerability to the impacts of heat stress.

The findings indicate that the vulnerability to heat stress is spatially, economically, and socially differentiated. The six settlements with similar characteristics revealed that their levels of vulnerability are stratified due to the varying extent of exposure, sensitivity, and adaptive capacity of their population. The settlements classified as the most vulnerable exhibited higher levels of exposure and sensitivity combined with lower adaptive capacity. The moderately vulnerable settlements showed high levels of exposure or sensitivity but also had higher adaptive capacity. In contrast, the least vulnerable settlement which was characterized by low adaptive capacity, was least affected owing to the lower levels of exposure and sensitivity.

4.2. Loss and Damage

Loss and damage caused by heat hazards are influenced by various social, economic, and geographic factors. The study findings reveal the economic and spatial implications of heat stress that are discernible across the sectors of health, livelihood, and basic services and infrastructure. The survey indicates that 72% of the inhabitants have been affected in one or more of these areas.

Primarily, extreme heat has significant effects on the physical health of individuals. Some common physiological responses to extreme heat include dizziness, heat rashes, dehydration, respiratory issues, heat exhaustion, and heat strokes. 75% of the surveyed population has reported cases of heat exhaustion. The elderly, children, and those with pre-existing health conditions, who constitute around a quarter of the total population, are more susceptible to these issues. More than 30% of the residents in these settlements are daily wage workers whose work involves working outdoors, increasing their direct exposure to heat. Heat and health issues are further aggravated due to improper garbage disposal systems when the residents burn their uncollected waste. Despite these challenges, heat-related illnesses are mostly treated with home remedies, unlike other health issues. As inferred from the interviews, the majority of inhabitants typically choose private healthcare facilities due to the poor reputation of the quality of healthcare offered in government hospitals. Conversely, only those who struggle financially turn to public hospitals or urban health clinics for medical attention.

The impact of heat stress extends to the livelihoods of the community, with self-employed individuals, daily wage workers, street vendors, and auto drivers finding it challenging to operate during peak hours, leading to reduced working hours and income. In these households, the storage of unsold goods presents a challenge, as the climatic conditions often contribute to the degradation and spoilage of these products. Some vendors temporarily discontinue their work during the peak summer months while those with a single source of income are compelled to work despite adverse climatic and health conditions. As a result, residents who typically walk to work are forced to pay for alternative forms of transportation that offer respite from the sweltering heat. Additionally, individuals employed in home-based activities experience reduced productivity due to overheating of their homes. Almost 1/3rd of the respondents have reported a loss in income during periods of extreme heat.

High indoor temperatures are a cause for concern for the well-being of individuals. Most of these residents cannot afford

cooling technologies and are unable to bear the heat, they resort to communal spaces or strategies to beat the heat. However, a lack of awareness regarding effective strategies to adapt to heat increases indoor temperatures. For instance, residents close their windows and doors to ward off mosquitoes, exacerbating indoor heat and causing breathing difficulties and palpitations during summer. Due to improper garbage collection, the waste is dumped in empty plots or burned. Moreover, to prevent damage or leakage of the tin roofs, plastic sheets are spread over the roofs, further increasing indoor temperatures.

Access to basic services and infrastructure is also affected during periods of extreme heat. The study found that the lack of access to clean and sufficient water and sanitation services led to increased vulnerability to heat stress, as residents were unable to stay hydrated, self-douse, or maintain adequate hygiene practices. In these settlements where individual cooling technologies are not affordable, such services and infrastructure are the only means to reduce sensitivity to heat.

While the risks associated with heat stress have been identified across various sectors, it is crucial to recognize that these sectors are not isolated systems but interrelated. The lack of access to basic services and infrastructure exacerbates health issues, decreasing economic productivity and income generation. This, in turn, perpetuates a cycle where the loss of income further limits opportunities to address health concerns or access alternative basic services. Therefore, comprehensive action is needed in each of these sectors to address the challenges posed by heat stress and ensure the resilience of vulnerable communities.

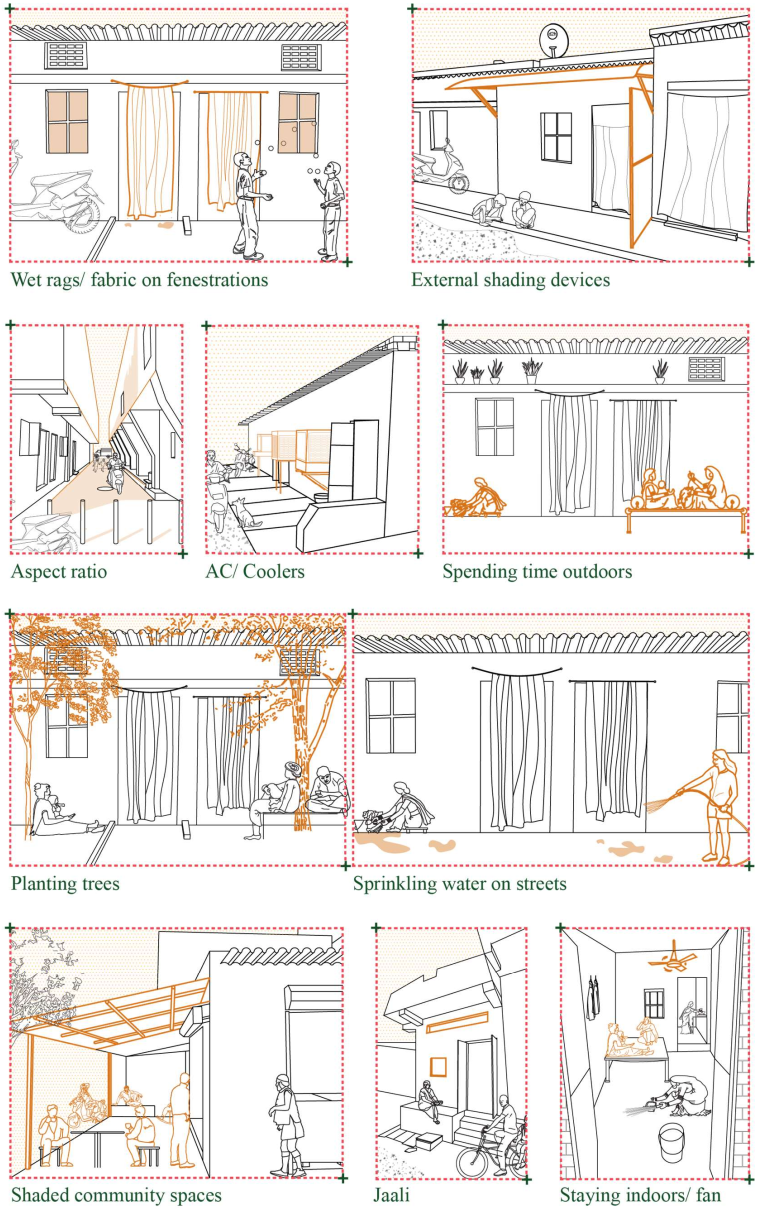


Figure 4.9 Existing adaptation strategies

4.3. Heat Mitigation and Adaptation Strategies

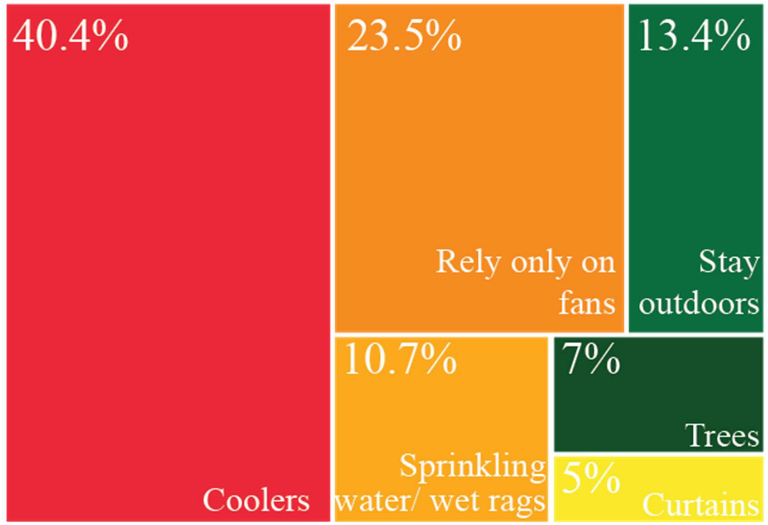


Figure 4.10 Adaptation strategy bifurcation across all six settlements

According to the survey results, a mere 43.7% of respondents reported adopting adaptive measures to alleviate heat stress. Among these respondents, 40.4% relied on coolers, while 10.7% opted for hanging wet clothes or sprinkling water on terraces and streets. Additionally, 13.4% spent time outdoors from noon till evening and slept on terraces or verandas, while 5% kept their fenestrations open and added curtains or fabric. A significant proportion of respondents (23.5%) relied solely on fans, while 7% utilized the shade of trees near their residences.

The existing practices to respond to heat stress are limited to short-term behavioural and household-level strategies. The interactions with the community also noted a prevalent trend in which the community members pooled their resources and worked collaboratively to enhance their infrastructure and systems without the involvement of external actors. This highlights the potential of participatory practices in strengthening the development of heat resilience within these communities.

Developing local adaptive capacities to lower user vulnerability, must align with local practices to improve the appropriateness and sustainability of proposed adaptation measures (Simpson et al., 2021). This calls for well-defined and holistic strategies based on the low cost of implementation, local materials, low-tech solutions, and passive strategies. The extent to which the systems and actors are vulnerable and the projected climate scenario presenting prolonged heat days indicate a need for long-term strategies.

The comparison and analysis of vulnerability and strategy (case study) assessment identifies the most feasible heat resilience strategies.

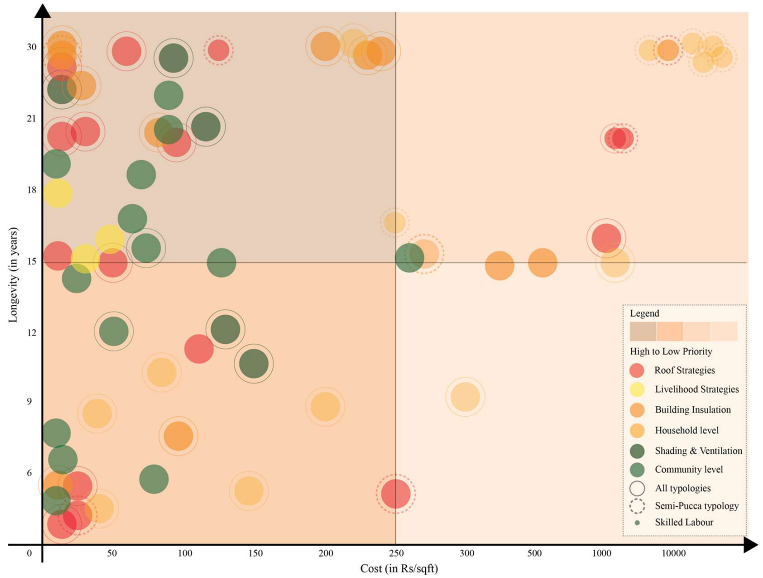


Figure 4.11 Pre-eminence matrix of identified strategies

The identified solutions (from Section 3.2) are compared to ascertain the most practical strategies. The scatterplot (Fig. 4.5) analyses the relation between the cost and longevity of the techniques and technologies. The overall trend denotes the cost-effectiveness of community-based solutions. This pre-eminence matrix reveals that almost half of the identified strategies are durable and those are applicable to various building typologies. The eminent solutions include cheaper roof alternatives, retrofitted roofs, livelihood strategies, and passive cooling strategies through ventilation and building insulation. Certain community-level strategies also demonstrate to be practical. The household-level strategies involving mechanical cooling options prove to be ambiguous, with a high cost of implementation, lower

longevity, or inapplicability to the range of typologies. On the contrary, the most durable solutions are expensive and require skilled labour, and do not apply to the different building typologies that exist on-site.

Deriving from the matrix, the most eminent community-based strategies are recommended for the geographic and economic context of Vatva. These are prioritized based on the following criteria:

- Impact on the settlement in areas of health, livelihood, and environment;
- Longevity and period of implantation
- Cost of implementation and
- Relevance to existing systems and strategies.

The recommended strategies are classified into three categories- Cool roofs and paving; passive cooling and community level strategies. Cool roofs and paving, primarily assist in reducing exposure of the households. Passive cooling strategies, realised through improving building ventilation and insulation, reduce the exposure and sensitivity. Finally, the community-level strategies focus on improving the capacity and reducing sensitivity of the households. These recommendations are tailored to the unique spatial and socio-economic context of Vatva and have the potential to have a significant and positive impact on the settlement.

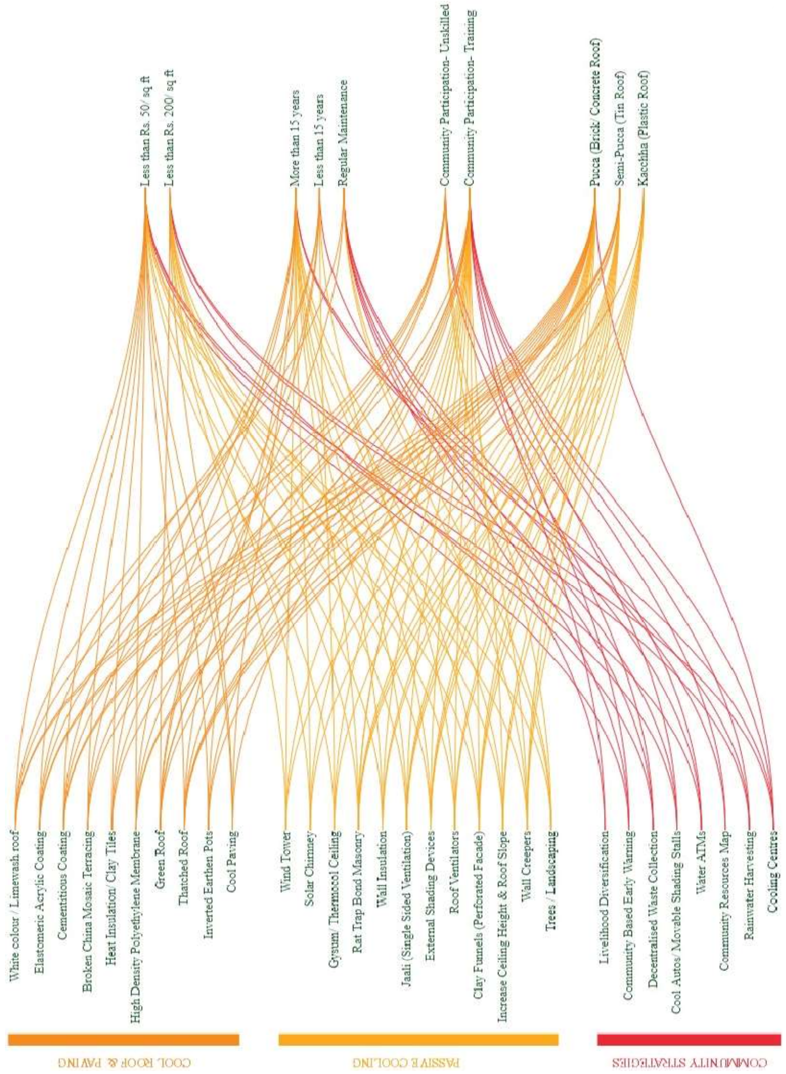


Figure 4.12 Recommended Strategies

4.3.1. Cool Roofs and Paving

In most urban areas, pavement and roofing constitute over 60% of the land's surface (Akbari, Menon, & Rosenfeld, 2009). The majority of the solar radiation is absorbed by these paved surfaces and rooftops, which raises the temperature of the roof and the surrounding air. To mitigate the adverse effects of this phenomenon, the first category of strategies focuses on cool roofs and paving. Cool roof options include multiple techniques such as painted or tiled roofs, membrane roofs, and special material roofs. Painted or tiled roofs include utilizing white or limewash paint, elastomeric acrylic or cementitious coatings, or the application of clay or concrete tiles, broken china mosaic, and white glazed tiles over existing roofs. The high reflectivity and emissivity of these materials will reduce the likelihood of heat being stored and transferred through the walls and roofs of the buildings. Alternatively, employing pre-fabricated sheeting materials such as high-density polyethylene membranes also increases thermal emittance. Some unique roof materials include retrofitting RCC roofs with inverted earthen pots to add a layer of air insulation or green roofs to protect the building from direct sunlight and reduce temperature through evapotranspiration (Ghanekar, et al., 2021). Moreover, thatched roofs using dry vegetation such as coconut and wheat husk, straw, and palm leaves, keep the buildings cool in summer and warm in winter owing to their high insulation properties (Rajasekar, Mishra, & Mehta, 2014).

4.3.2. Passive Cooling

These low-income settlements are characterized by building typologies, which often feature materials that increase indoor temperatures, random building orientations throughout the site, and single facades with limited fenestrations that reduce natural ventilation. Given these characteristics and the climatic conditions, thermal insulation and using solar radiating surfaces are more effective and feasible than relying on natural ventilation (Asian Development Bank, 2022). Therefore, the second category of interventions focuses on passive cooling strategies. This includes measures such as increasing ceiling height and increasing the roof slope to reduce the area receiving direct sunlight. The provision of roof ventilators and false ceilings using thermocol or gypsum boards improves both ventilation and insulation. Wall insulation using materials like rammed earth or extruded polystyrene improves thermal comfort by working on the principles of heat loss and gain through the building envelope (Rajasekar, Mishra, & Mehta, 2014). Additionally, construction techniques such as rat trap bond masonry improve insulation through the formation of cavities and the use of clay funnels to create perforated facades improves ventilation (Dabaieh, Zakaria, & Kazem, 2021).

Landscaping options include planting trees to shade the south, east and west openings or employing wall creepers. The provision of jaalis or window openings at two different levels for single-sided ventilation, and using external shading devices are other affordable options. These interventions aim to mitigate the effects of heat stress by improving the thermal comfort of residents while reducing their reliance on mechanical cooling systems.

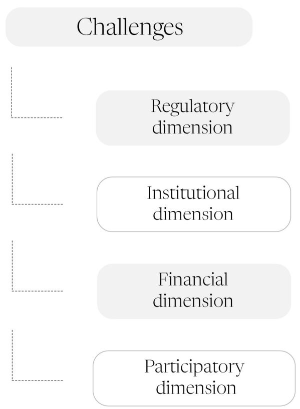
4.3.3. Community Level Strategies

To create thermally comfortable urban environments, it is essential to implement a range of strategies that address various factors contributing to heat stress. These include providing access to cooling centres, potable drinking water, rainwater harvesting systems, decentralized solid waste collection systems, and cool paving. Furthermore, raising awareness among the community is crucial, and this can be achieved by providing community resource maps and community-based early warning systems, such as auto drivers announcing heat alerts or warnings. Disseminating information about the increase in temperature and associated health issues and adaptation measures through local community groups is also imperative. In addition, livelihood-related strategies include livelihood diversification, cool autos, and movable shaded carts (Dey, 2017). These strategies are unskilled, affordable, and can be implemented by community members with basic training. They are easy to implement, as they require locally sourced materials and have short implementation periods while providing long-lasting benefits.

The most common challenges faced during the implementation of resilience strategies are due to the dependence on extended participation from the community, lack of financial resources, and absence of local adaptation policies. The interventions proposed in this study highlight the key areas that require targeted interventions to effectively reduce exposure and sensitivity or enhance the capacity of vulnerable communities to heat stress. Moreover, these strategies address the issues in sectors such as health, livelihood, well-being, and basic services, maximizing cross-sectoral benefits.

5.

CONCLUSION

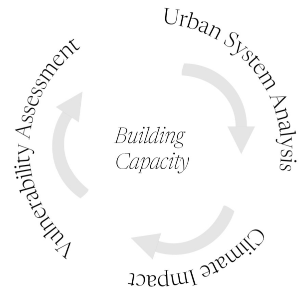


The study assesses the extent of vulnerability of six informal settlements in Vatva to heat stress caused by climate variability and anthropogenic activities. The inhabitants of Vanzaravas, Khwajanagar, and New Bhage Kausar are more vulnerable to extreme heat than those in Chunaravas, Aziz Park, and Zia Masjid. The spatial, environmental and socio-economic vulnerability of these settlements is attributed to higher exposure or sensitivity and low adaptive capacity. The adoption of tin roofs, extended outdoor work hours, and sparse vegetation cover are common causes of increased exposure to heat stress. Furthermore, underlying characteristics including poor literacy rates, high household densities, heat-related work disruptions, and restricted access to water, all increase vulnerability to the effects of extreme heat. Overall, the study has shown that the degree of vulnerability is stratified even amongst these low-income settlements. The participatory approach followed by an index-based approach to vulnerability assessment, facilitates better operationalisation and captures even minute differences across settlements. This highlights the need for a comprehensive vulnerability study to assess variations in risk and loss and damage to implement apt differential resilience protocol. The adverse effects of heat stress are pervasive, affecting multiple sectors such as health, livelihood, well-being, and basic services and infrastructure. Of these sectors, health,

and livelihood are most profoundly impacted, with limited access to basic services exacerbating the negative effects in these areas.

The present adaptation strategies implemented on-site are limited to short-term and individual-level measures. However, considering future climate projections, it is imperative to introduce long-term adaptation and mitigation strategies. In the context of informal settlements, that is characterized by their dense and unplanned built systems, low-cost retrofitted strategies at the household level and community-level interventions that complement the existing systems are the most efficient options. The creation of shaded communal spaces at the community level, provision of thermal insulation at the household level, spreading awareness through community-based early warning systems, and upgradation of existing systems for basic services at the institutional level aid in building heat resilience. Building resilience to climate change requires bottom-up strategies and involvement from local communities. A community-led approach will enable people to anticipate and overcome the effects of climate change as it is based on their priorities, needs, knowledge, and capacities.

To adapt to climate resilience, local guidelines and programs must be established, given the rapidly growing number of informal settlements. Linking the strategies to existing policies and systems, partnering with other institutions for CSR or funding options, and providing micro-finance options can contribute to the economic feasibility of the interventions.



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ANNEXURES

Annexure 1: Literature Review

i) ***Climate Change in Indian Context***

Climate change refers to the long-term changes in temperature, precipitation, wind patterns, and other measures of climate that occur over several decades, primarily caused by human activities. It has a wide range of negative impacts such as rising sea levels, severe weather events, displacement, increase in spread of diseases and disruptions to ecosystems and agriculture. India ranks 5th in the Global Climate Risk Index, that analyses the extent of impact by weather-related events. With urbanisation at the forefront, major policies and plans focus on urban development and economic growth, with climate change action being a mere co-benefit. Moreover, urbanisation creates varied vulnerability partly through informality. This enhances exposure and susceptibility of the physical systems and inhabitants to climate-related risk.

1) Urban India and Climate Change

The chapter discusses the evolution of India's climate change action and its governance characteristics. With the momentum of climate change aiming to reduce energy consumption, and urbanization, that demands energy consumption taking place simultaneously, it questions the idea of using development as the entry point for climate change strategies. The nascent climate actions, although present at the national and state level, lacks local level understanding. When the state and non-state actors come together in play, their actions have often been pertaining to a globally oriented motivation, excluding the vulnerable groups in picture. The chapter further indicates that the future trajectory requires linking local development policies to climate goals. It emphasises on creating links between the complex systems within a city rather than project-based outcomes.

2) IPCC Assessment Report- Climate Change 2022: Impacts, Adaptation and Vulnerability
3) Reframing the Problem of Climate Change: From Zero Sum Game to Win-win Solutions

ii) ***Ahmedabad***

The climate of Ahmedabad district is hot and semi-arid with marginally moderate rainfall and might experience a projected increase in quantum of rainfall and mean temperature. The city also attracts migrants with plethora of job opportunities leading to formation of slums and informal settlements. The four main climate stressors experienced are heat waves, localised flooding, water scarcity and water and vector borne diseases. Moreover, the city has been a pioneer in undertaking measures towards addressing these challenges of climate change such as the Heat Action Plan. Moreover, it also has a lot of programmes working towards the

betterment of city such as the Slum Networking Project, BSUP, etc.

1) Classification of Informal Settlements Based on their Susceptibility to Climate Change

The study assesses climate susceptibility to key climate stressors of the different typologies of informal settlements in Ahmedabad. The major climate related hazards experienced in Ahmedabad are heat waves, localised and overland flooding, water scarcity and increased incidence of water and vector-borne diseases. Vulnerability to each of the climate stressors has been assessed based on 3 major factors- exposure, susceptibility and adaptive capacity (based on IPCC). Further, based on each of the climate stressors, a set of indicators are used to quantify the level of vulnerability to draw comparisons between the various typologies. Based on the information gathered through surveys and secondary sources, policy recommendations at household, community and municipality level are suggested. Although the study focuses on community participation and the need to address the different settlements within a city distinctly, the classification needs to be on the basis of geographic location and socio-economic background rather than the typology of housing.

2) Climate Change and Environment Action Plan of Ahmedabad District

The plan explores the sectoral impact of climate change. Strategies through each of these sectors and sub-sectors, aim to address the SDGs. To achieve this, the plan proposes an institutional set-up and guidelines to monitor and evaluate at the block, ULB, cluster and ward level. But for these short to long term strategies recommended, it also emphasises on the need of policy level intervention or need to align with existing framework.

3) Ahmedabad Slum Free City Action Plan
4) Assessing Vulnerability to Extreme Heat Among Residents of Urban Slums in Ahmedabad, India
5) Ahmedabad Heat Action Plan

iii) ***Vulnerability and Disaster & Risk Management***

The impacts of climate change vary across time and space. Therefore, an assessment of vulnerability both post and pre-disaster becomes essential to address these issues and identify apt adaptation measures. Vulnerability could manifest in various forms and hence the assessing parameters need to consider socio-economic (livelihood), biophysical and institutional or infrastructure related factors. Although, each geographic or cultural might require tailor-made set of parameters, IPCC outlines three broad dimensions of vulnerability- exposure, sensitivity and adaptive capacity. The current plans focus more on disaster response and lacks understanding of local systems and capacity.

1) ACCCRN- Semarang Climate Change Resilience Strategy, Indonesia

ACCCRN, with an aim of creating a replicable base of action to build climate resilience, worked in Semarang, providing a good case of implementing climate change responses in complex governance systems. With a participatory approach, it involved stakeholders at different levels such as government officials, NGOs and academicians. Due to the lack of capacity and planning, even after decentralisation, the local government was unable to handle the impacts of floods, droughts and landslides. These have led to economic losses, social network and social capital. The project initially started with an assessment of vulnerability and adaptive capacity of different areas of the city. The core aim was to incorporate the strategies with the 5-yr development plans. This ensured financing from the annual city funding cycle. It proposes sector-wise strategies such as rainwater harvesting, incorporating climate change in education curriculum, establishment of climate change centres, etc. These were then prioritised based on cost and benefit.

2) Mapping Vulnerability: Disaster, Development and People

The book examines the relationship between vulnerability and disasters in the context of development. It argues that disasters are not just natural phenomena, but are also shaped by social, economic, and political factors. The book explores the ways in which people and communities become vulnerable to disasters, and how development policies and practices can contribute to this vulnerability. The first part provides an overview of the concept of vulnerability and its relationship to disasters and development. The second part examines the ways in which different groups of people, such as women and children, are particularly vulnerable to disasters. The final part looks at the ways in which development policies and practices can be used to reduce vulnerability and improve disaster resilience. The book draws case studies from Asia, Africa and Latin America.

3) Climate change vulnerability assessment of urban informal settlers in Nepal, a least developed country

The study focuses on three strands of vulnerability- natural hazards, politico-economic and ecological resilience. Through the framework outlined by IPCC, vulnerability is quantified and assessed through exposure, sensitivity and adaptive capacity and compared between the settlements in hilly and plain regions. The index-based system was used to capture even the minute difference across the comparison units and simplicity. The study highlights the differential nature of

vulnerability which makes it important to alter the assessment paraments as per the context.

The main factors contributing to settlement vulnerability are a lack of resources, low employability, insufficient income, poor sanitation, and food insecurity. Major underlying factors that have been found include a lack of safety networks, medical facilities, and education. It is crucial to improve basic infrastructure through programmes that integrate education, public health, solid waste management, sanitation, food security and employment.

4) The Vulnerability of Cities: Natural Disaster and Social Resilience

The book highlights the importance of participatory approaches in urban areas and community response to disasters. It gives an introduction to the basic concepts of vulnerability, hazard, risk and disasters to narrow down the factors of vulnerability to socio-political, financial and physical structure of the society. In an example, the author highlights the role of legislation in increasing the vulnerability of certain households. This makes a strong argument to incorporate the political context and governance to understand the influence of legislation in creating conditions of risk.

Further, he outlines the importance of community participation in policy making that leads to the failure of the political structures in addressing disaster risk.

To enhance social resilience to disasters:

- Local organisations should work with formal organisations to reduce vulnerability
- Community-level action should be recognized within the political structure to increase community participation in decision making.

5) Climate Vulnerability Assessment for Adaptation Planning in India using a Common Framework

6) Vulnerability, risk and adaptation: A conceptual framework

7) Measuring Vulnerability to Natural Hazards

iv) *Informal Settlements and Climate Change*

Cities with higher job churning potential, act as magnets for inter and intra state migrants. This influx of population has led to a rise in informal and low-rise settlements. The lack of awareness and access to basic facilities and services make them more vulnerable. Climate change exacerbates their challenges as they're often located in hazard-prone areas and lack capacity to protect themselves against climate related events. 'The greatest gains in wellbeing in urban areas can be achieved by prioritising investment to reduce climate risk for low-income and marginalised residents and targeting informal settlements (IPCC, 2022).' Due to the lack of legal status or database of the land or its inhabitants, the government services do not reach them, limiting the effectiveness of climate change mitigation and adaptation efforts.

1) ACCCRN City Vulnerability Analysis Report for Indore and Surat
2) Climate Change Impacts on Urban Poor: A Study on Slum People in Dhaka City

This article presents the findings of a study on the impacts of climate change on the urban poor, specifically focusing on slum dwellers in Dhaka City, Bangladesh. The study used both quantitative and qualitative methods to gather data from a sample of slum dwellers, and found that the majority of respondents reported experiencing negative impacts from climate change, such as increased flooding and water scarcity. The article also discusses the lack of access to basic services and resources, such as sanitation and safe housing, among slum dwellers, which exacerbates the impacts of climate change. Some of the major impacts experienced by these inhabitants are damaging of shelter and household assets, water scarcity and pollution, diseases and loss of work and income. Overall, the study highlights the urgent need for interventions to address the vulnerability of urban poor communities to climate change.

v) ***Institutional Framework***

In India, the Ministry of Environment, Forest and Climate Change (MoEFCC) is the primary government agency responsible for addressing climate change. It is responsible for developing and implementing policies and programs related to climate change mitigation and adaptation, as well as coordinating the country's efforts to meet its international climate change obligations. The National Action Plan on Climate Change (NAPCC) was launched in 2008 to provide a framework for addressing climate change in the country. The NAPCC also established the National Adaptation Fund for Climate Change, which provides funding for adaptation projects in vulnerable communities. While such frameworks are at the national and state level, the local governments are simply used as conduits for implementation and not involved in the planning process.

1) Climate Change Policy in India and Goal 13

The commentary asses the existing Indian policies at various levels and highlights opportunities and challenges in incorporating resilience strategies within the policy framework. The growing population and the development that follows, recognizes climate change as a risk multiplier that disproportionately affects the vulnerable and poor urban population. IPCC, in its 5th assessment report outlines a framework for climate-centric solutions to work in conjecture with urban issues of inequality, employment and poverty. SDG 13, although with a wide scope focusing on incorporating adaptation and mitigation goals in development policies, leaves out

significant domains. Further, it points out that vulnerability and adaptive capacity are socially differentiated and temporal yet the approach has often been mainstreaming of national policies under international pressure. This calls for a more context-specific study than a sectoral approach. Urban governance in India is fragmented and the multiple stakeholders are involved in the planning process leading to lack of ownership of larger issues. The current superficial results can be attributed to the centralised top-down governance approach. State actors often prioritise development and economic growth to comply with NAPCC and yielding climate outcomes becomes a secondary co-benefit. Local government simply becomes an implementation agent with no scope for innovation.

There seems to be a need to link local level short-run priorities to the national level long-run strategic plans to build a coherent framework to reduce vulnerability and risk. This bottom-up approach would be a major shift considering India’s current urban management paradigm in the climate context.

2) Gujarat State Action Plan on Climate Change

The plan, which addresses several elements of climate change through multiple sectors, was created by the state's climate change department in partnership with other institutions. In accordance with the Sustainable Development Goals of the UN, the state's action plan aspires to create a sustainable and climate-resilient future. Agribusiness, water, health, forests and biodiversity, sea level rise and coastal infrastructure, energy efficiency and renewable energy, urban development, and green jobs are just a few of the subject groupings that constitute Gujarat's top goals. The strategies outlined includes encouraging public engagement, attracting business investment, as well as legislative changes and public funding. For environmental conservation, Gujarat has given particular focus to the usage of solar, wind, and electric cars.

3) Mainstreaming Climate Actions in Indian Cities: Case Study of Rajkot

Annexure 2.1: Interviews

Interviews were conducted with residents, settlement leaders, and field officers from SAATH Charitable Trust to obtain a comprehensive understanding of the climate stressors and contextual factors impacting and impacted by climate-related events in Vatva. The primary goal of these interviews was to establish a baseline assessment of the situation. Qualitative data was collected from each settlement and transcribed for analysis.

Aziz Park:

Health- The monsoon season brings with it the risk of water and vector-borne illnesses such as dengue and malaria, while summers are associated with health problems such as headaches, low blood pressure, and skin issues. The residents often rely on home remedies to alleviate their symptoms, but in cases of emergency, they seek medical assistance. Private clinics are in close proximity, but their services are often unaffordable for the low-income residents. Alternatively, the government clinics and hospitals, namely Vatva Gam and Akriti, are accessible throughout the year and are preferred due to their affordability.

Water Scarcity- Residents in the community receive water from the AMC between 6am-8am, with concerns regarding water quality during the initial few minutes of supply. However, in cases where there are issues or damages to the water infrastructure, water supply may be interrupted for a prolonged period of 2-3 days, with the situation worsening during summer months. To address these concerns, residents often file complaints at the AMC office. Some households have installed water motors reSsulting in uneven distribution. In cases of water scarcity, residents resort to purchasing water from private bore wells. To mitigate water scarcity, residents have adopted a self-sufficient approach and pre-emptively store water, rather than sharing information and resources within the community.

Flooding and water-logging- During the monsoon season, the houses are frequently inundated as they are situated below street level and are devoid of adequate infrastructure. Consequently, the roads become waterlogged, making it difficult for the residents to navigate the area. As the majority of the inhabitants are daily wage earners, such as auto-rickshaw drivers, vendors, and laborers, the waterlogging results in a loss of income. Restricted mobility due to flooded roads hinders their access to resources, leading to an increase in the cost of everyday essentials. Additionally, households that rely on traditional cooking methods using chulha are unable to cook during this period, and the stored food and water may not be sufficient.

Heat- The residents seek shade under trees, use coolers and hang wet rags on fenestrations to seek relief from the heat. Mostly, heat-related health issues are treated with home remedies.

Capacity- Despite having received education, they face challenges in securing employment. Additionally, they are unable to address basic housing needs, such as repairing leaky roofs during rainfall, due to lack of social and financial support. These individuals have also reported not receiving any formal warnings or information related to potential hazards. They express a sense of neglect from the government and a feeling of discrimination based on their caste.

Khwajanagar:

Health- The monsoon season poses a significant health threat to the community, as water and vector-borne diseases such as dengue and malaria are prevalent. The private clinics within the settlement and SG Hospital, are the most commonly visited healthcare providers. However, government clinics and hospitals such as Vatva Gam and Akriti, which are affordable, are also preferred. Unfortunately, due to the lack of proper waste collection systems, burning garbage is a common practice among residents.

Water Scarcity- Residents in the community receive water from the AMC between 6am-8am. If it was not provided in the morning, it's provided in the evening in a similar time slot. A lot of households also depend on private water supply that don't hold accountability on days when water is not supplied.

Flooding and water-logging- During the monsoon season, the houses are frequently inundated as they are situated below street level and are devoid of adequate infrastructure. In addition, the roads in the settlement become waterlogged, making mobility a challenge. The lack of proper sanitation facilities also exacerbates the situation as latrine water fills up in their homes. The majority of the residents are daily wage laborers, and the loss of income due to the flooding or difficulty in reaching their workplace adds to their struggles. The restricted mobility also hinders their access to resources and leads to an increase in the prices of essential goods. In response to the flooding, some residents are forced to temporarily or permanently relocate from the settlement, while those who own multi-story homes move to higher floors. Flooding also poses health risks as cases of illnesses and injuries are observed during this period, and the lack of access to emergency medical services can exacerbate the situation. Furthermore, instances of crime have been reported during this challenging period.

Heat- The residents of this settlement have limited options to mitigate the effects of heat, with coolers being their only source of relief.

Capacity- The lack of appropriate warning systems and infrastructure, as well as essential services, remains a concern. As a result, individuals or groups of households often rely on pooling their resources to make necessary modifications to their homes or streets. Moreover, the absence of Bal Mandir or Anganwadi have a significant impact on the children's future prospects.

Chunaravas:

Health- During the monsoon season, residents in the settlement are at a risk of contracting vector-borne illnesses such as dengue and malaria due to increased mosquito/fly infestation caused by muddy kaccha streets. In addition, residents commonly experience health issues such as fainting, nausea, and stomach-related problems. Limited access to healthcare exacerbates these issues as there are no clinics or hospitals within or in close proximity to the settlement, with the nearest healthcare facility being Kashiba Hospital. Furthermore, the few clinics that are available do not operate full-time, closing by 1 pm, necessitating residents to travel long distances for medical attention. The narrow streets in the settlement pose challenges for ambulance access, further complicating emergency medical situations. Moreover, the lack of proper waste management services leads to residents resorting to littering waste on the streets, contributing to hygiene issues.

Water Scarcity- Previously, they received water from the AMC supply between 6 am and 8 am. However, for the past two months, the supply has been reduced to only one hour, from 6 am to 7 am. In some cases, the water pressure from taps located outside the house is better than the ones inside, leading the residents to rely on their motor. In situations where there is no water supply at all, the residents resort to purchasing water jugs. Alternatively, they lodge a complaint with the municipality, following which the authorities send a supply of water.

Flooding and water-logging- During the monsoon season, the settlement experiences severe flooding, which inundates the houses and leads to waterlogging on the streets. The subsiding of water on the streets leaves behind a muddy and slippery surface, posing a significant risk of injury. Moreover, the absence of food or shops within the settlements exacerbates the difficulties faced by the inhabitants during this time.

Heat- Due to the lack of access to AC or coolers, a majority of individuals tend to seek refuge indoors or under the shade of trees during periods of extreme heat.

Capacity- In situations of flooding and water logging, individuals often resort to cleaning and draining water from their homes, as evacuation options are limited. Those living in kaccha/ semi-pucca houses construct brick retention walls to prevent water from entering their homes.

New Bhage Kausar:

Health- The prevalent health concerns in this area relate to vector-borne diseases, fever and cold. In addition, a portion of the population has pre-existing health conditions that require medical attention. Access to healthcare is primarily through the Kashiba Hospital.

Water Scarcity- Residents in the community receive water from the AMC between 6am-4pm. However, during summer, the volume of water supplied is noticeably lower in comparison to the rest of the year.

Flooding and water-logging- During monsoon, the streets become inundated with water due to the lack of proper street infrastructure. However, the waterlogging does not seep into the houses to a significant extent. Pressure lines are installed to push the excess water towards the gutters. The waterlogging persists for a period of 8-10 days before subsiding. As a result, vehicles are unable to navigate through the inner streets, compelling people to wade through the water for work.

Heat- In summer, individuals often resort to using fans and coolers to alleviate the heat. Those who lack access to AC or coolers may seek out shaded public areas for relief.

Vanzaravas:

Health- During monsoon, garbage disposal and presence of open gutters becomes a critical issue, leading to the spread of diseases such as vector-borne illnesses, fever, and cold. To seek medical attention, individuals typically visit Akruti Urban Health Centre, LG (known for having better doctors), or Kashiba Hospital.

Water Scarcity- Although the water quality is good, the current water supply schedule of 6:30-7:30 or 8am is inadequate due to insufficient flow. This causes inconvenience to the community members, particularly daily wage earners while rushing to work.

Flooding and water-logging- During heavy rainfall, the lake tends to overflow, inundating the streets and houses. This exacerbates the issue of dumped garbage on the streets, which enters households and compounds the negative impacts of the flooding. People to construct brick walls to prevent water from entering. The residents highlighted the need for proper road infrastructure to alleviate the issue of waterlogging. Despite complaints being filed with the AMC, no action has been taken to address this problem. As a result, the community faces difficulties in accessing necessary resources during waterlogging.

Heat- Certain households have coolers installed. The felling of trees has resulted in a lack of shaded areas, therefore, people seek shelter indoors for relief.

Capacity- During floods, Narol Gam School serves as an evacuation centre for the residents.

Zia Masjid:

Health- During monsoon, there is a higher incidence of mosquito-borne diseases in the area. In an effort to combat this, the AMC uses mosquito repellent smoke to control the spread of these diseases. However, the nearest urban centre is located 1-1.5km away, making it difficult for residents to access emergency healthcare. Additionally, in case of emergencies, the ambulance can only access the main street.

Water Scarcity- The households are only able to access water for a mere 1.5 hours per day. Sometimes the water supply is available only on alternate days. As a result, they resort to storing water for up to two days in order to meet their needs.

Flooding and water-logging- Insufficient street infrastructure for proper gutter lines causes bathroom gutter water to overflow and flood homes during the monsoon season. Low-level houses are particularly vulnerable to flooding. Despite the lack of an evacuation plan, community members often rely on one another to protect their belongings by moving them to higher ground or neighbouring homes.

Heat- To mitigate the impact of heat in houses with tin roofs, residents often fix white thermocol to the roof to reduce heat absorption.

Annexure 2.2: Survey

The questions for the survey were formulated in the categories of demographics, heat stress, flooding, diseases and health, water scarcity and response mechanisms. It aimed at gathering insight on the issues, the causes, their adaptation and resultant loss.

To obtain a comprehensive understanding of the living conditions of individuals with varying economic and spatial backgrounds, the typologies were sampled at ratios of 1:7 and 1:10 for the surveys.

Settlement / *Typology*	**Aziz Park**	**Khwajanagar**	**Chunaravas**	**Zia Masjid**	**Vanzaravas**	**New Bhage Kausar**
R1	6		3	2	8	3
R2	3		3	2	3	2
R3.1	3	2	3	3	3	6
R3.2	8	54	6	3	8	25
R4	8	11	3	3	3	3
R5		3	3	3		3
R6.1	8	16	3		3	
R6.2		6	3	6		
R7	1		3			
LW1				3		3
LW2	3	3				2
LW3	3	3		3		3
LW4	2					

Annexure 3: Case Study

Strategy		Location	Cost & Funding	Longevity	Typology	Ease Of Implementation: Skill Required	Ease Of Implementation: Procurement
Roof							
Solar Reflective White Paint		Pilot and Implementation : Jodhpur, Surat, Ahmedabad, Bhopal	Rs. 0.5-40/ sq ft By MHT under Cool Roofs Program (HAP)	Up to 5 years; Application of single coat every 2-3 years	Tin/ metal, brick, concrete roofs	Community participation- Unskilled/ No training required	Can be locally sourced
Membrane Cool Roof	PVC or Bitumen -based	Pilot and Implementation : Jodhpur, Surat, Ahmedabad, Bhopal	Rs. 20-55/ sq ft	Around 10-15 years	Kuccha and semi-pucca houses	Community participation- Training required	Retail
	High Density Polyethylene	Pilot and Implementation : Hyderabad	Rs. 13/ sq ft CSR by Dupont India	Around 15- 30 years			
Modular Roofs (ModRoof)		Pilot and Implementation : Ahmedabad, Delhi, Surat, Bhopal, Ranchi & Jaipur	Rs. 1000/ sq ft MHT partner with ReMaterials and provides microloans	Around 15-20 years with minimal maintenance (every 5-6 years)	Kuccha , pucca and semi-pucca houses - Dismantlable alternative to RCC roofs	Community participation- Training required	Retail
Wood Wool Panels		Pilot and Implementation : Pune, Bangalore	Rs. 65/ sq ft By Consultancy cBalance; Funded by Ashden Cooling Fund	Over 30 years	Kuccha and semi-pucca houses	Community participation- Training required	Retail
EcoBoard		Pilot and Implementation : Pune, Bangalore	Rs. 35/ sq ft By Consultancy cBalance; Funded by Ashden Cooling Fund	Around 15-20 years	Kuccha and semi-pucca houses	Community participation- Training required	Retail
Alufoil		Pilot and Implementation : Pune, Bangalore	Rs. 93/ sq ft By Consultancy cBalance; Funded by Ashden Cooling Fund	Around 15-20 years	Kuccha and semi-pucca houses	Community participation- Training required	Retail
Water filled PET bottles		Pilot and Implementation : Pune, Bangalore	Rs. 10-15/ sq ft By Consultancy cBalance; Funded by Ashden Cooling Fund	Seasonal	Roof structures that can take a uniform load of 1kg/ sq ft	Community participation- Unskilled/ No training required	Can be locally sourced
Bamboo Mat Roof			Rs. 50/ sq ft	Around 15-20 years		Community	Retail

	Pilot and Implementation: Ahmedabad, Surat	MHT partner with Eco-Shelter and provides microloans		Kuccha and semi-pucca houses	participation- Training required	
Thermocol Ceiling	Existing Strategies by Community: Ahmedabad	Rs. 35/ sq ft	Around 3-5 years	Semi-pucca houses	Community participation- Unskilled/ No training required	Can be locally sourced
Extruded Polystyrene ceiling insulation	Pilot and Implementation: South Africa	Rs. 123/ sq ft By GBCSA; Funded by British High Council under Carbon Programmes.	Around 35-50 years	Semi-pucca houses	Community Participation for unskilled tasks and external implementation actors	Locally produced material
Inverted Earthen Pot	Rajasthan	Rs. 18/ sq ft	More than 10 years	Pucca houses	Community participation- Training required	Can be locally sourced
Cellulose Fibre	Indore	Rs. 125/ sq ft		Pucca houses	Community participation- Training required	Can be locally sourced
Green Roofs	Pilot and Implementation: Pune, Bangalore, Delhi, Bhopal & Ranchi	Rs. 250/ sq ft By GBCSA; Funded by British High Council under Carbon Programmes.	Daily Maintenance	Semi-pucca houses	Community participation- Training required	Can be locally sourced
"Air Lite" Ventilators	Pilot and Implementation: Ahmedabad, Delhi, Surat, Bhopal, Ranchi & Jaipur	Rs. 3000/ piece MHT partner with Eco Footprints and provides microloans	Around 10-20 years	Kuccha and semi-pucca houses	Community participation- Training required	Retail
Dormer Windows	Pilot and Implementation: Pune, Bangalore	Rs. 2500/ sq ft By Consultancy cBalance; Funded by Ashden Cooling Fund	Around 10-20 years	Corrugated steel/tin/cement roofs	Community participation- Training required	Retail
Walls & Materials						
Light Colour Paint on Facades	Existing Strategies by Community: Cairo	Rs. 0.5- 40/ sq ft	Up to 5 years; Application of single coat every 2-3 years	Kuccha and semi-pucca houses	Community participation- Unskilled/ No training required	Can be locally sourced
Green walls with climbers	Existing Strategies by Community: Cairo	Rs. 20- 200/ sq ft	Daily Maintenance	Kuccha and semi-pucca houses	Community participation-	Can be locally sourced

					Unskilled/ No training required	
Vertical Green Systems – HDPE	Pilot Study: Nigeria	Rs. 530/ sq ft	Around 10-15 years with plant replacement every year	Pucca houses	Community Participation for unskilled tasks and external implementation actors	Retail
Vertical Green Systems – Bamboo		Rs. 400/ sq ft				
Plastic Bottle filled with sand/ water in Wall Construction	Pilot Study: Nigeria	Rs. 10-15/ sq ft	More than 30 years	Semi-Pucca houses (Aluzinc sheet roof, bamboo ceiling, ceramic tile floor)	Skilled labours from community	Can be locally sourced
Compressed Agro Based Panels for Roofs & Walls	Pilot and Implementation: Bhopal, Ahmedabad	Rs. 25/ sq ft MHT partner with Strawcture Eco & Eco-board and provides microloans	Around 20 years	Kuccha , pucca and semi-pucca houses	Community participation- Training required	Retail
Puff Sheet and Honeycomb Panels for Roofs & Walls	Pilot and Implementation: Bhopal, Ahmedabad	Rs 89/ sq ft	Around 20 years	Kuccha , pucca and semi-pucca houses	Community participation- Training required	Retail
Building Insulation (Mineral wool, extruded/ expanded polystyrene, polyurethane foam and vermiculite)	Simulation & Recommendation: Surat, Indore	Rs. 10-30/ sq ft	More than 20 years	Pucca and semi-pucca houses	Community participation- Training required	Retail
Earth Berm Structures	Simulation & Recommendation: Surat, Indore		Around 30-50 years	Pucca and semi-pucca houses	Community Participation for unskilled tasks and external implementation actors	Can be locally sourced
Vernacular Architecture: Rammed Earth Foundation, Ferro-cement layer for wall, Coconut fibre insulation,	Workshops & Implementation: North Bangladesh	By local NGO; Funded by Shanti-Partnerschaft Bangladesh	Around 30-50 years depending on maintenance	Low-income houses	Community participation- Training required	Can be locally sourced

Straw mixed in mud for strength and bamboo						
Construction Materials: Adobe and rammed earth walls combined with a wood and lightweight concrete roof with vegetal fibre	Experimentation & Test Simulation: New Delhi		Around 30-50 years depending on maintenance	Low-income houses	Community participation- Training required	Can be locally sourced
Rat Trap Bond Masonry	Simulation & Recommendation: Surat, Indore		More than 30 years	Pucca and semi-pucca houses	Community participation- Training required	Can be locally sourced
Other household strategies						
Creepers grown in courtyards to cover roofs	Existing Strategies by Community: Dhaka	Rs. 20- 200/ sq ft	Daily Maintenance	Houses with courtyards	Community participation- Unskilled/ No training required	Can be locally sourced
Space Shading using Foldable Fabric	Existing Strategies by Community: Cairo	Up to Rs. 30/ sq ft	*N.A.*	Houses with courtyards	Community participation- Unskilled/ No training required	Can be locally sourced
Mosquito Screens – Polyester	Existing Strategies by Community: Cairo, Ahmedabad	Rs. 200/ sq ft	Around 7-10 years	Kuccha, Semi-Pucca & Pucca houses	*N.A.*	Can be locally sourced
Mosquito Screens – Cotton		Rs. 45/ sq ft				
Mosquito Screens – Bamboo		Rs. 300/ sq ft				
Fenestrations or Curtains	Existing Strategies by Community: Cairo	Rs. 50-100/ sq ft	Up to 10 years depending on maintenance	Semi-Pucca & Pucca houses	*N.A.*	Can be locally sourced
Energy-efficient Chulha	Pilot and Implementation: Ahmedabad	Rs. 1500 onwards/ household CSR by Philips; TERI	Up to 15 years	Kuccha, Semi-Pucca & Pucca houses	*N.A.*	Retail
Rainwater Harvesting Systems using flexible agricultural pipes, recycled tyres and big tanks	Pilot and Implementation: South Africa		More than 15 years	Pucca houses	Community Participation for unskilled tasks and external implementation actors	Can be locally sourced

Earth Air Tubes	Implementation: Persia		More than 30 years	Pucca houses	Skilled Labour	Can be locally sourced
Wind Tower	Implementation: Persia		More than 30 years	Pucca houses	Skilled Labour	Can be locally sourced
Solar Chimney	Simulation & Recommendation: Surat, Indore		More than 20 years	Pucca houses	Community Participation for unskilled tasks and external implementation actors	Can be locally sourced
Geothermal Air Conditioning	Implementation: Pakistan	Rs. 20,000-40,000/ household	Around 25-50 years	Pucca houses	Skilled Labour	Retail
In-direct evaporative Cooling	Implementation: India	Rs. 72,000-1,00,000/ unit	Around 30-50 years	Pucca houses (mid to high income)	Skilled Labour	Retail
Building Orientation	Simulation & Recommendation: India, South Africa, Cairo	*N.A.*	*N.A.*	Semi-Pucca & Pucca houses	Community participation- Training required	*N.A.*
Windows & Shading						
Egg Crate Shading Devices	Implementation: Jordon		More than 5 years	Pucca houses	Community participation- Training required	Can be locally sourced
Clay Funnels	Pilot Study: Cairo	Rs. 4-8/ sq ft	Around 30-50 years	Traditional houses with red brick walls & RCC roofs	Skilled labours from community	Locally produced material
Cross Ventilation/ Increased ceiling height	Test Simulation: Iran, Pakistan		Around 30-50 years	Pucca houses	Community participation- Training required	Can be locally sourced
Window Shading (Vertical & Diagonal fins)	Test Simulation: Kolkata, Naples, Hanoi	Rs. 35-150/ sq ft	More than 10 years	Pucca houses	Community participation- Unskilled/ No training required	Can be locally sourced
External Shading Devices (Sunshades, awnings, louvres, bamboo screens, jaali)	Simulation & Recommendation: Surat, Indore	Rs. 35-150/ sq ft	More than 20 years	Semi-Pucca & Pucca houses	Community participation- Unskilled/ No training required	Can be locally sourced
Livelihood						
Cool Auto Rickshaw	Pilot and Implementation: Bhopal		Around 5-8 years	*N.A.*	Community participation- Training required	Can be locally sourced

Movable Stalls with Shading		Existing Strategies by Community: Cairo		Around 3-5 years	*N.A.*	Community participation- Training required	Can be locally sourced
Livelihood Diversification		Existing Strategies by Community: Bangladesh	*N.A.*	*N.A.*	*N.A.*	*N.A.*	*N.A.*
Individual/ Behavioural responses							
Sprinkling Water on Streets		Existing Strategies by Community: Ahmedabad, Cairo	*N.A.*	*N.A.*	*N.A.*	*N.A.*	*N.A.*
Household Activities held Outdoors		Existing Strategies by Community: Ahmedabad, Dhaka	*N.A.*	*N.A.*	*N.A.*	*N.A.*	*N.A.*
Self-dousing		Existing Strategies by Community: Ahmedabad, Africa	*N.A.*	*N.A.*	*N.A.*	*N.A.*	*N.A.*
Changing to lighter clothes		Existing Strategies by Community: Africa	*N.A.*	*N.A.*	*N.A.*	*N.A.*	*N.A.*
Street/ Community level							
Cool Paving	Asphalt with light aggregates	Test Simulation: Albania	Rs. 30-110/ sq ft	Around 7-20 years	*N.A.*	Community participation- Training required	Can be locally sourced
	Porous asphalt		Rs. 30-110/ sq ft	Around 7-10 years			
	Pervious Concrete		Rs. 50-130/ sq ft	Around 15-20 years			
	Paving blocks		Rs. 30-130/ sq ft	More than 20 years			
	Grass/ Gravel pavers		Rs. 45-400/ sq ft	More than 10 years			
	Paint coated		Rs. 0.5- 40/ sq ft	Around 7-10 years			
Food Gardens		Pilot and Implementation: South Africa	Rs. 50-60/ sq ft	Daily Maintenance	*N.A.*	Community participation- Training required	Can be locally sourced

Planting Trees for Shade	Existing Strategies by Community: South Africa, Ahmedabad, Cairo	Between Rs. 0 to Rs. 149-251/ tree	Daily Maintenance	*N.A.*	Community participation- Unskilled/ No training required	Can be locally sourced
Extend shading from building façade and provide seating	Existing Strategies by Community: Cairo		More than 10 years	Semi-pucca & Pucca houses	Community participation- Unskilled/ No training required	Can be locally sourced
Community Based Early Warning Systems	Recommended: Ahmedabad		*N.A.*	*N.A.*	Community participation- Training required	*N.A.*
Street Shading	Existing Strategies by Community: Ahmedabad, Cairo	Rs. 50/ sq ft	Temporary structures or up to 30 years	*N.A.*	Community participation- Training required	Can be locally sourced
Community Resources Map	Recommended: Ahmedabad		Updated every 3-5 years	*N.A.*	Skilled Labour	*N.A.*
Permeable Nallah System	Proposed strategies: Bhopal		More than 10 years	*N.A.*	Community participation- Training required	Can be locally sourced
Water ATMs/ Access to potable drinking water	Implementation: Gujarat, Rajasthan, Maharashtra and Delhi	Rs. 5-8/ litre Waterlife & local government under PPP model & CSR by Parimal Group in Ahmedabad	Regular Maintenance	*N.A.*	Community participation- Unskilled/ No training required	Can be locally sourced

Annexure 4: Vulnerability Index

UNDP's Human Development Index

Each parameter of vulnerability is evaluated in a different unit and scale. Hence, the survey results of these parameters are normalized between a score of 0 and 1. The variables that are directly proportional to vulnerability, such as exposure and sensitivity are standardized using the formula:

$$x_{ij} = \frac{X_{ij} - \underset{i}{Min}\{X_{ij}\}}{\underset{i}{Max}\{X_{ij}\} - \underset{i}{Min}\{X_{ij}\}}$$

The variables of adaptive capacity, that are inversely proportional to vulnerability are standardized using the following formula:

$$y_{ij} = \frac{\underset{i}{Max}\{X_{ij}\} - X_{ij}}{\underset{i}{Max}\{X_{ij}\} - \underset{i}{Min}\{X_{ij}\}}$$

Exposure Assessment

Survey Result:

Settlement	*Built land cover*	*Population Density*	*Tin/plastic roofs*	*Chulha*	*Cross ventilation*	*Daily wage workers*	*Mode of transport*
Aziz Park	62	0.15	57	7.5	80.8	68.9	66.2
Khwajanagar	54.5	0.16	62	1	65.1	51.9	51.4
Zia Masjid	75.6	0.14	26	0	92.4	48.3	41.4
Chunaravas	45.6	0.12	73	15	69.9	84.3	39.2
Vanzaravas	47.5	0.11	83	11	44.4	54.3	54.3
New Bhage Kausar	65.5	0.16	78	0	90.5	70.5	55.7

Normalised Score:

	Built land cover	*Population Density*	*Tin/plastic roofs*	*Chulha*	*Cross ventilation*	*Daily wage workers*	*Mode of transport*	*Exposure Index*
	E1	*E2*	*E3*	*E4*	*E5*	*E6*	*E7*	
Aziz Park	0.546	0.8	0.544	0.5	0.758	0.573	1	0.1
Khwajanagar	0.296	1	0.632	0.066	0.431	0.101	0.451	0.06
Zia Masjid	1	0.6	0	0	1	0	0.081	0.06
Chunaravas	0	0.2	0.825	1	0.531	1	0	0.08
Vanjaravas	0.063	0	1	0.733	0	0.168	0.561	0.05
New Bhage Kausar	0.663	1	0.912	0	0.96	0.616	0.612	0.1

Sensitivity Assessment

Survey Result:

	No kitchen	*High household density*	*Water scarcity*	*Water Quality*	*Season dependent*	*Illiteracy*	*Power cut*	*Pre-existing health conditions*	*House Ownership*
Aziz Park	45	77.5	60	50	12.5	23.6	40	35	40
Khwajanagar	6	79	56.5	56.5	18	11.9	50	7	54.5
Zia Masjid	25	54	42	17	17	40.2	29	4	20.8
Chunaravas	63	77	81.5	78	30	21.2	74	59	7.4
Vanjaravas	57	75	100	86	64	26.7	96	14	20.5
New Bhage Kausar	38	69	41	76	48	18.1	100	24	33.3

Normalised Score:

	No kitchen	*High household density*	*Water scarcity*	*Water Quality*	*Season dependent/ Work affected*	*Illiteracy*	*Power cut*	*Pre-existing health conditions*	*House Owner-ship*	*Sensitivity Index*
	S1	S2	S3	S4	S5	S6	S7	S8	S9	
Aziz Park	0.684	0.94	0.322	0.478	0	0.413	0.155	0.564	0.692	0.48
Khwajanagar	0	1	0.263	0.572	0.107	0	0.296	0.054	1	0.37
Zia Masjid	0.333	0	0.017	0	0.087	1	0	0	0.284	0.21
Chunaravas	1	0.92	0.686	0.884	0.34	0.329	0.634	1	0	0.64
Vanjaravas	0.895	0.84	1	1	1	0.523	0.943	0.182	0.278	0.73
New Bhage Kausar	0.561	0.6	0	0.855	0.689	0.219	1	0.364	0.549	0.53

Adaptive Capacity Assessment

Survey Result:

	Community spaces for shade	*Early warning signs*	*Prior experience to heat waves*	*AC/cooler*	*Water motor*	*Exhaust fan/chimney*
Aziz Park	27.5	22.5	100	12.5	37.5	20
Khwajanagar	6	0	69	44	24	1
Zia Masjid	0	12.5	75	46	37.5	4
Chunaravas	44	55.5	100	4	37	4
Vanjaravas	7	0	0	14	43	0
New Bhage Kausar	0	10	89	41	52	0

Normalised Score:

	Community spaces for shade	*Early warning signs*	*Prior experience to heat waves*	*AC/cooler*	*Water motor*	*Exhaust fan/chimney*	*Index*
	A1	A2	A3	A4	A5	A6	
Aziz Park	0.38	0.59	0.00	0.80	0.52	0.00	0.37
Khwajanagar	0.86	1.00	0.31	0.05	1.00	0.95	0.72
Zia Masjid	1.00	0.77	0.25	0.00	0.52	0.80	0.57
Chunaravas	0.00	0.00	0.00	1.00	0.54	0.80	0.38
Vanjaravas	0.84	1.00	1.00	0.76	0.32	1.00	0.81
New Bhage Kausar	1.00	0.82	0.11	0.12	0.00	1.00	0.5

Iyengar and Sudarshan Method:

Each of these parameters are then assigned weights as they do not equally affect vulnerability. This is calculated using the following formula:

$$\overline{y_i} = \sum_{j=1}^{K} w_j x_{ij}$$

where, the weight *w* is determined by

$$w_j = c \Big/ \sqrt{\operatorname{var}_i(x_{ij})}$$

and the constant c,

$$c = \left[\sum_{j=1}^{j=K} 1 \Big/ \sqrt{\operatorname{var}_i(x_{ij})} \right]^{-1}.$$

Vulnerability Ranking

	Vulnerability	*Exposure*	*Sensitivity*	*Adaptive Capacity*
1. Vanjaravas	0.46	0.0215	0.1606	0.2835
2. Khwajanagar	0.36	0.0258	0.0814	0.252
3. New Bhage Kausar	0.33	0.043	0.1166	0.175
4. Chunaravas	0.3	0.0344	0.1408	0.133
5. Aziz Park	0.28	0.043	0.1056	0.1295
6. Zia Masjid	0.27	0.0258	0.0462	0.1995