Assessing and Managing Loss and Damage

Local-level evidence to inform global-level action in Gujarat

PART II

Systems Adaptation Scenario: Developing Adaptation Pathways and Assessing Adaptive Capacities and Limits



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UNEP - Copenhagen Climate Centre (CCC)

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Transitions Research

Gujarat Institute of Development Research

Report submitted by:

ICLEI South Asia in partnership with Transitions Research and GIDR

Acknowledgements

This report, "Assessing and Managing Loss and Damage: Local-level evidence to inform global-level action in Gujarat, Part - II on Systems Adaptation Scenario: Developing Adaptation Pathways and Assessing Adaptive Capacities and Limits," has been prepared as part of the ongoing efforts towards developing a City-Level Loss and Damage Assessment and Management Framework in India that supports municipal governance systems in identifying, assessing, and managing climate-induced risks and residual economic and non-economic loss and damage.

We extend our sincere gratitude to the government officials from the Ahmedabad Municipal Corporation (AMC) and the Surat Municipal Corporation (SMC), and to other parastatals consulted during the preparation of this report, for their support in data sharing and valuable insights. We are particularly grateful to the community representatives, civil society organisations, and local institutions in Ahmedabad and Surat for sharing their lived experiences and insights on climate risks, challenges, and adaptation practices, which greatly enriched the qualitative dimensions of this study.

We acknowledge the support of our funding and knowledge partners, the UNEP Copenhagen Climate Centre and the Danish Institute for International Studies, for their continued commitment to advancing the assessment, reporting on, and addressing of climate-related losses and damages at the city level.

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Report Submitted by

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When citing this report or using excerpts, users are requested to include the full citation as provided here: ICLEI South Asia. (2026). Assessing and managing loss and damage: Local-level evidence to inform global-level action in Gujarat (Part II).

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Abbreviations

ACCCRN	Asian Cities Climate Change Resilience Network
AMC	Ahmedabad Municipal Corporation
AMTS	Ahmedabad Municipal Transport Service
AUDA	Ahmedabad Urban Development Authority
BAU	Business As Usual
BRTS	Bus Rapid Transit System
C&D	Construction and Demolition waste
C-CIQ	Comprehensive-Climate Impact Quantification
CATSIM	Catastrophe Simulation Model
CBOs	Community Based Organizations
CFS	Climate Fragility Statement
CGE	Computable General Equilibrium
COD	Cost of Damage
COI	Cost-of-Illness
CPCB	Central Pollution Control Board
CRCAP	Climate Resilient City Action Plan
CRVA	Climate Risk and Vulnerability Assessment
DALY	Disability-Adjusted Life Years
DaLA	Damage and Loss Assessment
DEM	Digital Elevation Model
ELD	Economic Loss and Damage
FGDs	Focus Group Discussions
FY	Fiscal Year
GAM	Generalized Additive Model
GCM	Global Climate Models
GCC	Gross Cost Contracting
GDCR	General Development Control Regulations
GIDC	Gujarat Industrial Development Corporation
GIDM	Gujarat Institute of Disaster Management
GSDMA	Gujarat State Disaster Management Authority
GSRTC	Gujarat State Road Transport Corporation
HAP	Heat Action Plan
HHs	Households
ICAT	Initiative for Climate Action Transparency
IMD	India Meteorological Department
IO	Input-Output

IPCC	Intergovernmental Panel on Climate Change
L&D	Loss and Damage
LPCD	Liters per Capita per Day
LST	Land Surface Temperature
MCDA	Multi-criteria decision analysis
MLD	Megaliters per Day
MRF	Material Recovery Facility
NAPCCHH	National Action Plan for Climate Change and Human Health
NASA	National Aeronautics and Space Administration
NDMA	National Disaster Management Authority
NELD	Non-Economic Loss and Damage
NPV	Net Present Value
NRW	Non-Revenue Water
PDNA	Post-Disaster Needs Assessment
PLFS	Periodic Labour Force Survey
PTSD	Post-Traumatic Stress Disorder
RCP	Representative Concentration Pathway
RTO	Regional Transport Office
SAPCC	State Action Plan on Climate Change
SCCT	Surat Climate Change Trust
SMC	Surat Municipal Corporation
SSP	Shared Socioeconomic Pathways
STP	Sewage Treatment Plant
SWM	Solid Waste Management
TPD	Tons Per Day
TTPs	Tertiary Treatment Plants
UPHCs	Urban primary health centers
VSL	Value of Statistical Life
WTP	Willingness-to-Pay
WTP	Water Treatment Plant


nerability & Risk Profile in Surat

Executive Summary

Indian cities are increasingly exposed to intensifying climate risks, including extreme heat, intense rainfall, urban flooding, cyclonic disturbances, water scarcity, disease outbreaks, and cumulative stress on physical and social systems. Ahmedabad and Surat, two of India's fastest-growing urban centres, provide a critical context for examining how climate-induced Economic Loss and Damage (ELD) and Non-economic Loss and Damage (NELD) unfold within dense and interdependent urban environments.

This report forms Part II of the study **Assessing and Managing Loss and Damage: Local-level Evidence to Inform Global-level Action in Gujarat, India**. Building on the retrospective assessments and vulnerability profiles established in Part I, the present report examines systems adaptation scenarios by evaluating adaptive capacities, identifying limits to adaptation, and developing prospective pathways to reduce future climate-induced losses and damages. Part II operationalizes a forward-looking methodology for assessing residual and future losses, building on the retrospective L&D assessment and vulnerability baseline established in Part I. Key contributions include: operationalizing a city-specific ELD/NELD classification that captures impacts beyond disaster assessment templates; integrating climate projections with local impact functions and sectoral vulnerabilities; systematically identifying hard and soft limits to adaptation; and demonstrating feasible quantification approaches for both economic and non-economic impacts using illustrative case studies despite data constraints.

This report employs a mixed-methods approach combining quantitative, qualitative, and spatial analyses. The methodology integrates: (i) a systematized ELD/NELD framework adapted from the national Post-Disaster Needs Assessment (PDNA) guidelines and tailored to the city context (Chapter 2); (ii) observational climate trend analysis (1970–2024) validated against Gujarat State Action Plan for Climate Change (SAPCC) projections, coupled with downscaled Representative Concentration Pathway (RCP) 2.6, 4.5, and 8.5 scenarios (Chapter 3); (iii) sectoral risk assessment using hazard–exposure–vulnerability logic to map current and future city-level impacts (Chapter 4); and (iv) structured identification of adaptation limits and illustrative quantification of residual losses through case studies (Chapters 5–6). Qualitative insights from stakeholder consultations and focus group discussions (FGDs) are systematically integrated with quantitative analysis throughout.

L&D Classification Framework

The report first establishes a city-level L&D classification informed by secondary research, national and state disaster-assessment methodologies, consultations with government departments, community stakeholders, and an analysis of historical climate-induced events between 2000 and 2025. While aligned with the national PDNA guidelines and the Gujarat Institute of Disaster Management (GIDM)

assessment and reporting methods, the classification is tailored to Ahmedabad and Surat and organized across three domains: social, productive, and infrastructure systems.

Stakeholder consultations revealed that several non-economic losses, such as psychosocial distress, displacement, gender-based vulnerabilities, ecological degradation, and erosion of social cohesion, remain insufficiently captured due to data gaps and the absence of standardized valuation methods. To address these gaps, the report expands the L&D framework to incorporate these cross-sectoral and community-specific dimensions. It also presents four illustrative valuation cases: damage to infrastructure, income loss, health-related impacts, and loss of life. These demonstrate feasible approaches for estimating both economic and non-economic impacts despite data constraints. These cases highlight the importance of improving access to disaggregated datasets, integrating socio-economic and hazard-exposure information, and adopting valuation methods suited to both market and non-market losses.

Climate Trends and Future Projections

A comprehensive assessment of historical climate patterns and future projections for both cities is undertaken to project future climate risks and impacts. Using long-term IMD datasets (1970 to 2020 for Ahmedabad and 1972 to 2024 for Surat), the analysis confirms consistent warming trends, higher rainfall variability, and increasing frequency of heatwaves, floods, droughts, and cyclonic events. These observed patterns are cross-validated with projections from the Gujarat SAPCC (2021).

Future climate projections based on downscaled RCP 2.6, 4.5, and 8.5 scenarios for the periods 2011-2040 and 2041-2050 indicate rising mean temperatures, a growing number of hot days and nights, and heightened rainfall variability. Together, these trends point to escalating risks across infrastructure, services, health, and livelihoods. While these datasets provide valuable directional insights, the report acknowledges inherent limitations of city-level downscaling, particularly the inability of global climate models to reflect micro-climatic variations, urban heat island effects, drainage-system behaviour, or short-duration extreme events that often cause the most severe damage.

Climate Impacts: ELD and NELD

Drawing from these climatic trends, the report examines the implications for both ELD and NELD. High surface temperatures and recurrent flooding contribute to damage to infrastructure, disruptions in transport and trade, reduced labour productivity, and heightened economic vulnerability among informal workers and low-income settlements. Non-economic losses manifest through long-term health effects, educational disruption, displacement, psychosocial distress, and diminished community resilience, particularly among groups such as informal workers, sanitation staff, slum residents, and street vendors. These impacts demonstrate that climate risks in urban environments extend far beyond physical damages and increasingly affect human development outcomes.

Urban Climate Risks and Sector-wise Vulnerability Assessments

Building on the climatic scenarios, the report undertakes a sector-wise prospective loss and damage (L&D) assessment for Ahmedabad and Surat. It evaluates vulnerabilities across water supply, sewerage, solid waste management, transport, public health, education, and related urban systems. Using the Climate Fragility Statement (CFS) methodology, which integrates hazard likelihood with potential consequences, the analysis identifies priority sectors and high-risk areas requiring targeted adaptation interventions.

Although both cities have implemented several adaptation initiatives through Heat Action Plans, Resilience Strategies, Master Plans, and Disaster Management Plans, the assessment reveals critical gaps. These include limited integration of climate-risk information into planning instruments, insufficient mechanisms for tracking recurrent losses, and continued underrepresentation of non-economic impacts.

Existing strategies largely remain sectoral and infrastructure-centric, highlighting the need for more comprehensive, data-driven, and community-centred adaptation planning.

Limits to Adaptation and Adaptive Pathways

The report identifies both hard and soft limits to adaptation across urban sectors in Ahmedabad and Surat. Hard limits arise from physical, technological, and environmental constraints, while soft limits stem from institutional capacity, governance challenges, financial constraints, and behavioural barriers. It presents an analytical framework for projecting future L&D under RCP 4.5 and 8.5 scenarios by linking these adaptation limits to residual climate risks.

Two case studies, heat-related health impacts in Ahmedabad and flood-induced infrastructure losses in Surat, demonstrate that even with robust adaptation measures, substantial residual losses persist. These illustrative cases demonstrate how future economic and non-economic losses can be quantified and mapped. This highlights the need for strengthened preparedness, risk reduction, and long-term investment in resilient urban systems.

Inherent limitations include: (a) data constraints—observational health and informal-sector income data are sparse and unevenly distributed; (b) model uncertainty—global climate models cannot reliably represent urban microclimates, short-duration extreme events, or compound hazards at ward level; (c) NELD methodology—valuation approaches for non-market impacts (mental health, cultural loss, social cohesion) remain contested and context-specific, and some dimensions are retained as qualitative indicators rather than monetized; (d) attribution challenges—isolating climate-induced losses from secular development trends and other stressors in retrospective events is difficult; and (e) socio-economic scenarios—future population and economic growth are drawn from limited sources and may not reflect rapid urbanization or demographic shifts. All projections and scenarios should be interpreted as indicative trends rather than precise forecasts.

Way Forward

The conclusion emphasizes the need for a structured, city-level institutional framework for continuous L&D assessment and integration into urban planning and budgeting. A structured, city-level L&D assessment system is important for embedding climate-risk-informed decision-making into urban planning and fiscal frameworks. It emphasizes the importance of establishing dedicated L&D reporting within local governance structures, improving horizontal and vertical coordination across state, district, and city institutions, and integrating L&D considerations into development plans, resilience strategies, and disaster management plans. Enhancing spatial data systems, standardizing reporting formats, and developing a city-level L&D information portal are critical to strengthening analytical capability and tracking climate-induced losses.

Building on these insights, the next stage of work will focus on developing the City-Level Loss and Damage Assessment and Management Framework, enabling cities to be better equipped to quantify, manage and mitigate future climate risks.

1. Introduction

This report is Part II of the 'Assessing and Managing Loss and Damage, Local Level Evidence to Inform Global Level Action in Gujarat, India'. Part I of the report focused on retrospective Loss and Damage (L&D). Its primary aim was to establish city-level baselines for Ahmedabad and Surat through a high-level analysis of existing policies, institutional mechanisms, and past experiences in managing climate-induced losses and damages, assessing climate-related hazards and disasters over the last 50 years. It examined their impacts on urban infrastructure, public health and safety systems, social structures, and the local economy, thereby providing an evidence base for evaluating how past events have shaped the cities' current vulnerability and adaptive capacity. It covered vulnerability, exposure, and risk profiles for the cities by assessing their current risks and weaknesses, thereby establishing a baseline for evaluating future adaptation scenarios.

The Part II report focuses on two essential components: adaptive capacities and limits to adaptation for urban systems and affected communities. It further delves into establishing the prospective scenarios for addressing losses and damages that happen when adaptation or mitigation measures fail or reach their limit, in a changing climate scenario, thereby addressing ex-ante L&D. These residual losses and damages refer to the negative, often irreversible impacts of climate change that occur despite mitigation and adaptation efforts. The report also takes into account ground realities by factoring in stories and opinions gathered from the field through stakeholder engagement, including workshops with government departments and civil society organizations, as well as community engagement. The insights from these, along with secondary datasets, are used to address information gaps and present a holistic scenario. The data on climate scenarios and adaptation strategies draws from the Climate Resilient City Action Plans (CRCAP) for Ahmedabad and Surat. However, these strategies respond to existing conditions of heat, extreme precipitation, and resulting flooding, thereby providing a base case for understanding the adaptation limits based on adaptive capacities.

Due to limitations in the resolution of climate models, a prospective hyper-local assessment of climate impacts at the ward and neighbourhood level is challenging to achieve, thereby resulting in limitations to the evaluation at the community scale for future scenarios. The analysis, therefore, relies on the hot-spot identification based on the existing situation. However, SSP population projections provide a high-level indication of the population numbers that might be impacted by future climatic conditions.

This assessment report aims to inform city authorities and parastatals about the potential future economic and non-economic L&D their cities may face, as well as the financial impacts they will need to prepare for. This will affect the city's liveability, GDP, and overall competitiveness from a resilience perspective.

Further, our assessment, presented in this report, will form the basis of the governance structure and community participation in disaster management, informing the roles and responsibilities of the Urban Disaster Management Authority (UDMA) as per the latest Disaster Management (Amendment) Act, 2025[1]. The Authority, when formed, is to be chaired by the Municipal Commissioner, with the District Collector as Vice-Chair.

1.1 Conceptual Framework and Key Definitions

Adaptation refers to adjustments in socio-ecological systems in response to actual or expected climate stimuli, serving to moderate harm or exploit opportunities (IPCC AR6). Residual impacts are consequences of climate change that persist despite adaptation efforts, occurring when adaptation reaches its limits. L&D encompasses both economic losses (monetisable impacts on income, services, assets) and non-economic dimensions (life, health, cultural heritage, ecosystem integrity, social cohesion) that arise from climate variability and change, particularly when they exceed adaptive capacity or occur where adaptation is not feasible or implemented. The distinction between adaptation and L&D is important for planning: effective adaptation reduces but does not eliminate L&D. This report focuses on the residual L&D that remains even under robust adaptation scenarios, as a basis for informing resilience and financial planning at the city scale.

1.2 Rationale and Objectives

This report presents a structured approach to developing adaptation pathways and assessing adaptive capacities and limits for Ahmedabad and Surat's climate-related risks. Drawing on retrospective L&D assessments and current risk and vulnerability profiles covered in the previous report, the study analyses city-specific adaptation strategies using a systems-of-systems approach that recognizes interdependencies (e.g., water-energy-food-health nexus, cascading infrastructure failures). Adaptation pathways are conceptualized as sequences of management choices over time, acknowledging that adaptation options differ in effectiveness, feasibility, and limits across time horizons and socio-economic contexts (following Haasnoot et al., 2013; Ray et al., 2023). The 'systems adaptation scenario' framework maps how different adaptation strategies interact, where they reach limits, and what residual losses remain—providing a basis for anticipatory action and resilience investment. Combining this analysis with the findings of the participatory stakeholder engagement and climate modelling, the study identifies the hard and soft limits of adaptation strategies for various urban sectors. This work will support the development of a city-level L&D assessment methodology that can be integrated into the existing governance and reporting mechanisms.

The study is guided by the following research questions:

1. Understanding and Classifying L&D - How can historical climate-induced ELD and NELD be systematically classified and partially quantified at the city level, aligning with national disaster frameworks while capturing locally salient impacts?

2. Climate Risk Assessment under Current and Future Scenarios - What are the observed trends and projected future patterns of hazard intensity (extreme heat, rainfall, floods) for Ahmedabad and Surat across multiple climate scenarios, and which population and assets are exposed?

3. Adaptation Pathways, Limits, Residual Losses and Future Loss & Damage Estimation - Where do adaptation limits arise (physical, institutional, financial, behavioural) and what residual losses persist under climate scenarios where adaptation strategies are fully implemented?

4. Institutional Integration and Urban Decision-Making - How can city governments

1Government of India. (2025). Disaster Management (Amendment) Act, 2025 (Act No. 10 of 2025). Ministry of Home Affairs. https://ndma.gov.in/sites/default/files/PDF/DM-Amendment-Act-2025.pdf

institutionalize L&D assessment and integrate it into planning, budgeting, and resilience frameworks to better anticipate and respond to residual impacts?

1.3 Structure of the report

The methodology in this study adopts a mixed-method approach, combining quantitative, qualitative, and spatial analyses to assess climate risks through retrospective analysis, sectoral risk assessment, and projected future climate models, supported by extensive stakeholder consultations. This approach enables a comprehensive understanding of the L&D classification, adaptation capacities, adaptation limits, and illustrative cases that project future L&D.

Chapter 2 presents the classification of L&D, distinguishing between Economic L&D (ELD) and Non-Economic L&D (NELD). The categorization aligns with the district-level loss assessment templates of the NDMA and State Disaster Management Authorities, while expanding their scope to capture urban systems, cross-cutting sectors, and non-economic impacts specific to city contexts. This section outlines the approach for estimating L&D from past climate events, using illustrative cases for ELD and NELD.

Chapter 3 presents spatial climate risk analysis of Ahmedabad and Surat, using historical climate trends and projecting future scenarios for these cities. Historical climate hazards from 1970 to 2024 were compiled from IMD datasets, municipal records, and disaster management plans to identify recurring events, including heatwaves, floods, and extreme rainfall. Long-term trend analysis reveals a consistent warming trend and rising rainfall variability, validated against the Gujarat SAPCC, 2021. In Ahmedabad and Surat, LST mapping and the identification of existing hotspots and vulnerable groups are used to map heat hotspots and flood-prone areas. Future climate projections were developed using downscaled NASA data under RCPs 2.6, 4.5, and 8.5 scenarios for a mid-term horizon (2050). While these spatial analyses provide valuable insights for exposure mapping, limitations persist due to coarse model resolution, absence of urban micro-climate parameters, and incomplete representation of socio-economic drivers.

Chapter 4 presents a city-level assessment of ex-ante climate-induced risks, sectoral vulnerabilities, and adaptation strategies for Ahmedabad and Surat, linking observed trends and projected climate scenarios to urban system fragility. The analysis covers key urban sectors, water supply, drainage and stormwater management, solid waste management, transport, health, and education. Each sectoral matrix links hazards to prospective ELD and NELD and identifies adaptation interventions aligned with city action plans such as CRCAP, Heat Action Plans, and Master Plans.

Chapter 5 identifies hard and soft limits to adaptation across sectors in Ahmedabad and Surat, distinguishing between technical-physical constraints and institutional-financial barriers that pose limitations to adaptation actions. It provides the analytical basis for estimating residual L&D.

Chapter 6 outlines the methodological approach for projecting future L&D under evolving climate scenarios for Ahmedabad and Surat, translating adaptation limits into measurable future risks. It integrates historical exposure data, sectoral vulnerabilities, and climate projections (RCP 4.5 and 8.5) to estimate residual economic and non-economic losses and damages. The analytical framework follows six phases to link adaptation strategies with their limits systematically. Two city-specific case studies operationalize this framework: heat-related health losses in Ahmedabad and flood-related infrastructure damages in Surat. Both cases demonstrate that while adaptation substantially reduces projected losses, residual damage persists, highlighting the need for a robust assessment of residual losses and damages that combines tangible and intangible dimensions.

The insights from this study will inform and help build on the subsequent report on the city-level L&D assessment framework.

2.

Economic and Non-economic Loss and Damage (ELD and NELD)

This chapter establishes a conceptual foundation for understanding L&D by distinguishing between ELD and NELD. These categories provide the analytical lens for assessing urban vulnerabilities, which will be applied in later chapters when examining city-level sectoral impacts.

2.1 Overview of ELD and NELD classification

The classification of L&D is grounded in secondary research, a review of existing governments' disaster assessment methodologies, and primary stakeholder engagements with governmental and non-governmental actors. Drawing from various sources, the list of L&D categories presented here reflects both established classifications and evolving understandings from the field.

A critical methodological consideration is avoiding double-counting when losses span multiple sectors. For example, a flood that damages school infrastructure (ELD—partial damage to building) and displaces households (NELD—displacement) must be recorded separately by sector but tagged to the same event. At the aggregation level, losses are summed across sectors but not recounted. Where possible, infrastructure interdependencies (Section 2.4) should be mapped to identify cascading impacts; however, secondary or indirect losses should be recorded separately from direct damages to avoid artificially inflating total estimates. When data permit, economic valuation of direct damages should be clearly distinguished from indirect macroeconomic losses (e.g., supply-chain disruption) to enable transparent accounting.

The list of economic and non-economic losses and damages at the city level has been consolidated after an extensive review of data on recent (2000-2025) and recurring climate-related events in the city to understand the types of impacts experienced. The global, national, and state disaster assessment methodologies are used to guide a preliminary framework of comprehensive economic and non-economic L&D categories. These have been further tailored to the local context by considering city-specific vulnerabilities, populations at risk, and past disaster outcomes. The latest GIDM manual (2024)[2] adopted from the national PDNA framework[3], which is currently adopted in Gujarat for post-disaster damages and recovery needs assessment at the district level, has been

2 Gujarat Institute of Disaster Management. (2024, July). Training Module on Post Disaster Needs Assessment (PDNA) (ISBN 978-81-946379-7-4). Gujarat Institute of Disaster Management.
3 National Institute of Disaster Management. (2019). Standard operating procedures: Post-disaster needs assessment India [PDF]. Ministry of Home Affairs, Government of India. https://nidm.gov.in/PDF/pubs/sop_pdna.pdf

further modified from a city's perspective and tailored to the local context. Broadly classifying the L&Ds as per IPCC reports:

- **Economic Losses and Damages (ELDs):** Monetizable losses (e.g., income, infrastructure).
- **Non-Economic Losses and Damages (NELDs):** Intangible or hard-to-quantify impacts (e.g., displacement, migration, mental well-being, life loss).

The classification of ELDs and NELDs has also been improved through secondary research, building on the framework developed by Puig (2023), which distinguishes between economic and non-economic impacts of climate-related events. This framework was also informed by key contributions from literature on L&D, including works of Bharadwaj et al. (2024), Boyd et al. (2017), and Van der Geest & Warner (2015). The consolidated classification was developed after reviewing all studies on L&D assessment and has been further organized into three broad categories, differentiated across various sectors as outlined in the GIDM manual adopted for Gujarat: -

- **Social** - Health, Education, Housing, Culture and Heritage, Environment
- **Productive** - Trade and Services, Manufacturing, Tourism
- **Infrastructure** - Water Supply and Sanitation, Electrical and Communications, Transport

The classification into these sectors provides a framework aligned with existing disaster assessment templates for assessing climate-related impacts. However, it must be acknowledged that this categorization, while practical, does not fully capture the entire spectrum of losses and damages identified through stakeholder consultations, focus group discussions (FGDs), and field assessments, primarily due to data limitations and the focus on policy-relevant domains. In particular, while the present framework includes an 'Environment' sector, the assessment would benefit from explicit integration of ecosystem services loss as a cross-cutting theme. Ecosystems provide regulating services (flood reduction, heat mitigation through urban greening, water filtration), supporting services (nutrient cycling, pollination), and cultural services (recreation, aesthetic, spiritual value). Climate impacts such as prolonged drought, waterlogging, and extreme heat can degrade urban forests, wetlands, and green spaces, reduce these services, and compound adaptive capacity.

Consequently, several critical dimensions of L&D, particularly those that are non-economic, cross-sectoral, or community-specific, are therefore presented as cross-cutting themes to provide a more comprehensive overview of city-level L&D dynamics (Sections 2.2 and 2.3). Where feasible, ecosystem service impacts should be identified and, where valuation data exist (e.g., from national or state studies on urban greening), monetary estimates should be included. Otherwise, qualitative or semi-quantitative indicators (e.g., hectares of green cover lost, species richness change) should be documented.

To enhance international comparability and situate this framework within global L&D typologies, Section 2.3.1 provides a crosswalk between the Gujarat city-level categories (Social/Productive/Infrastructure) and established NELD meta-categories. Serdeczny et al. (2016) and Tschakert et al. (2019) identify key domains: (1) Life and health; (2) Territory and cultural heritage; (3) Ecosystem integrity and biodiversity; (4) Identity and social cohesion; (5) Knowledge and ways of living; and (6) Agency and capability to act. The present framework captures these domains within and across sectoral columns, though with some contextual adaptation. For example, loss of traditional knowledge (identified in FGDs) is mapped to both the Environment sector and cross-cutting themes, while identity and social cohesion losses appear under Housing and cross-sectoral themes. This mapping helps readers compare the findings with other city or national assessments.

Moreover, certain losses, such as increased inequality, food insecurity and malnutrition, human rights violations, and the loss of traditional knowledge, are not currently captured within existing assessment frameworks. However, these issues have emerged as recurring and

interconnected themes across both cities, as evident from stakeholder consultations and field insights. Importantly, malnutrition is not limited to children, but is increasingly observed among adults as well, reflecting broader systemic vulnerabilities related to food access, livelihoods, and health. These dimensions underscore the limitations of conventional sectoral classifications and highlight the need for integrated, equity-focused assessment approaches that account for social, cultural, and non-economic aspects of L&D alongside physical and infrastructural impacts.

2.2 Economic Loss and Damage (ELD)

A matrix for ELD is developed to systematically assess and document the economic impacts of disasters or disruptions across key sectors. It captures both losses and damages, disaggregated into Social, Productive, and Infrastructure service sectors, providing a comprehensive overview of sectoral vulnerabilities. Economic Impacts have been categorised into losses and damages.

Economic L&D represent reduced income, increased costs, or financial strain caused by the disruption. These are categorized as:

- **Decline in Output / Revenue Loss:** Reduction in productivity, service delivery, or business earnings due to disaster.
- **Higher Operating Cost:** Increased cost of providing services or running operations under emergency or disrupted conditions.
- **Unexpected Expenses:** Unforeseen expenditures such as temporary relocation, emergency procurement, or crisis mitigation.

To estimate reversible economic L&D , a counterfactual baseline—representing conditions had the climate event not occurred must be defined. For example, 'Decline in Output/Revenue Loss' is calculated as: (Baseline Revenue – Actual Revenue During Event) × Duration. Baseline revenue is typically derived from: (a) average revenue for the same season/ period in prior years (3–5 year average); (b) sector-wide or municipality-wide economic data (GDP, sectoral output); or (c) expert judgment where baseline records are unavailable. When constructing counterfactuals for informal sectors (street vendors, small businesses), household surveys or proxy data (e.g., daily wage rates, average daily sales) are necessary, which introduces additional uncertainty. For all loss estimates, the counterfactual assumption should be explicitly stated.

ELD refers to tangible physical and equipment-related impacts. These are classified as:

- **Infrastructure (Total/Partial):** Damage or destruction of physical infrastructure (e.g., buildings, roads, utilities).
- **Equipment:** Loss or damage to machinery, tools, teaching aids, medical instruments, etc.

Indicators are drawn from multiple sources (e.g., PDNA framework adopted in the GIDM training manual, GSDMA manual, secondary literature, and FGD/CBO inputs). These indicators are meant for local validation and quantification (costs, counts, locations). Colour-shading indicates the primary source of the indicators, and cells highlighted as priority ELD/ NELD, are the ones that were frequently cited during stakeholder engagement and have been taken into consideration for economic valuation to estimate L&D for past events as illustrative cases.

2.2.1 Uncertainty in ELD Estimation:

Key sources of uncertainty in ELD estimates include:

1. Missing or delayed reporting: Small businesses, informal traders, and low-income households often do not report losses to authorities; official estimates typically capture only 50–70% of actual damage.
2. Valuation assumptions: Unit costs (e.g., repair cost per square foot of housing, replacement cost for equipment) are often adapted from national norms rather than based on local market prices, introducing systematic bias.
3. Cascade and interdependency effects: Damage to one infrastructure (e.g., power) cascades to others (e.g., water treatment, transport); total loss is greater than the sum of sectoral damages, yet often under-counted without explicit modelling of interdependencies.

4. Temporal factors: Whether to apply discount rates to losses occurring over multiple periods, and at what rate, significantly affects present-value estimates.

Where possible, ELD estimates should be presented with ranges (low/central/high) or sensitivity analyses to reflect these uncertainties. For illustrative cases (Section 2.6), qualitative statements on robustness (e.g., 'estimate robust to ±10% variation in unit costs' or 'highly sensitive to missing informal-sector data') should accompany monetary figures.

Methodology for ELD Matrix Construction:

The template for the matrix can be accessed here: Link(https://docs.google.com/spreadsheets/d/13oBs-Ay1pq6KrEf6jkIWdj23SMArBfuF/edit?gid=1194134034#gid=1194134034)

Each cell in the table represents a potential loss or damage category. For each category, the following information should be documented:

Data Source: Administrative records (municipal, revenue, health, education departments), post-disaster assessments (PDNA, municipal disaster reports), peer-reviewed literature, or stakeholder consultations (FGDs, interviews).

Estimation Method: Direct observation (e.g., infrastructure inventory surveys), imputation (using comparable units or expert judgment where primary data is absent), or model-based projection (e.g., damage functions).

Confidence Level: Entries marked as 'high confidence' indicate data collected or validated from multiple sources; 'moderate confidence' indicates estimation from limited sources or surveys; 'low confidence' indicates data inferred from literature or expert judgment.

The color-coding indicates primary source: blue = secondary literature/PDNA framework, orange = field-based (FGDs, CBO inputs), green = combined/validated. Cells requiring primary data collection for future assessments are noted.

The categorization of economic losses and damages across sectors provides a comprehensive view of how climate-induced impacts translate into direct and indirect costs at the city level. By disaggregating L&D into losses (e.g., operating costs, revenue decline, unexpected expenses) and **damages** (e.g., infrastructure and equipment impacts), the framework captures both the immediate financial disruptions and the longer-term depreciation of assets and services. This cross-sectoral structure helps identify critical linkages, for instance, how urban flooding simultaneously increases public health expenditure, damages transport and water infrastructure, and disrupts trade and services, revealing the interconnected nature of urban systems under climate stress.

However, several limitations constrain the current ability to measure and attribute L&D with precision at the city scale. City-level data on asset loss and revenue impacts are rarely disaggregated by hazard type, making it difficult to isolate climate-induced losses from routine operational costs. Institutional responsibilities and reporting formats vary widely between departments (e.g., health, water supply, transport), leading to fragmented datasets and incompatible valuation approaches. Losses experienced by small enterprises, informal workers, and low-income households often go unrecorded in official assessments. While this framework aligns with district-level disaster assessment templates, certain domains fall outside the operational purview of city administrations, requiring coordination with state and regional agencies.

This framework thus serves as a foundational step toward developing a comprehensive, evidence-based city-level L&D assessment methodology aligning with local governance capacities, ensuring that climate-related L&D and adaptation gaps are systematically captured and assessed.

2.3 Non-economic Loss and Damage (ELD)

2.3.1 Conceptual Grounding

Non-economic losses and damages are dimensions of climate impacts that lack direct market prices and include impacts on life, physical and mental health, cultural heritage, social cohesion, knowledge systems, and ecosystem integrity. Recognizing NELD is essential because:

(1) total climate impact cannot be captured by economic valuation alone; (2) vulnerable populations often experience disproportionate NELD (e.g., indigenous communities losing sacred sites); and (3) NELD may trigger social upheaval, conflict, or irreversible system changes.

To organize NELD assessment in a systematic manner, this study adopts a recognition-response framework aligned with Serdeczny et al. (2016) meta-categories while remaining grounded in the Gujarat context:

Table 1: Crosswalk table between the Gujarat city-level categories (Social/Productive/Infrastructure) and established NELD meta-categories

NELD Domain	Sub-categories (this study)	Example Losses in Ahmedabad/Surat
Life and Health	Mortality, morbidity (disease, injury), malnutrition, mental health, reproductive health	Heat-related deaths, waterborne disease outbreaks, anxiety/PTSD from recurrent flooding
Territory & Cultural Heritage	Loss of cultural sites, sacred spaces, historical landmarks, sense of place, livelihood spaces	Inundation of temples, loss of traditional markets, and damage to heritage structures
Ecosystems & Biodiversity	Species loss, habitat degradation, ecosystem services decline, aesthetic/recreational loss	Loss of urban green spaces, wetland degradation, and declining bird populations
Knowledge & Practices	Loss of traditional/indigenous knowledge, loss of rituals, loss of occupational practices	Displacement of artisans, interruption of seasonal practices (festivals), loss of oral histories
Identity & Social Cohesion	Social fragmentation, erosion of community bonds, identity loss (for groups tied to place/ heritage), and increased social tension	Out-migration breaking social networks, gender-based violence in temporary shelters, and community conflict over resource scarcity
Agency & Capability	Reduced capacity to make decisions, loss of dignity, restriction of human rights, loss of livelihoods	Displacement limiting choice of residence/ livelihood, forced dependency on government assistance, restrictions on movement during disasters

In the Gujarat assessment, three measurement approaches are systematically employed, appropriate to each NELD domain and data availability:

This matrix is designed to systematically capture non-economic climate impacts, disruptions, and systemic stressors across social, productive, and infrastructure sectors. While economic damages are often quantifiable, non-economic losses encompass critical but less tangible dimensions such as well-being, equity, inclusion, and institutional resilience.

2.3.2 Measurement Approaches for NELD: Qualitative, Semi-Quantitative, and Selective Valuation

A. Qualitative Recognition Approach

For NELD dimensions where numerical metrics are inappropriate or infeasible (e.g., loss of cultural identity, dignity), qualitative documentation is prioritized. Methods include:

- Narrative documentation: Community testimonies, key informant interviews, and focus group discussions (conducted in both cities) are coded thematically to identify patterns in NELD experiences (e.g., recurring mention of psychosocial trauma, loss of ritual spaces, restricted mobility).
- Participatory mapping: Community members identify valued sites (cultural, spiritual, recreational) on maps and indicate which have been lost, damaged, or become inaccessible due to climate events.
- Archival & historical research: Documented loss of heritage sites, traditional practices, cultural landscapes through historical records, news archives, municipal heritage inventories.

These qualitative findings are presented as thematic narratives, supported by representative quotes or case examples, and are not aggregated into indices for simplicity and to avoid false precision.

B. Semi-Quantitative Scoring Approach

For NELD domains where rough prioritization is needed but full monetization is inappropriate, semi-quantitative scoring is used:

- Frequency-based scoring: NELD items mentioned in FGDs are tallied (how many communities, stakeholders, or FGD sessions reported each impact type). High frequency indicates greater prevalence, though not absolute magnitude.
- Severity scaling: Trained assessors (or community members) score each NELD type on a 1–5 scale (1 = minimal concern, 5 = severe/irreversible) based on described impacts. Mean scores are computed with confidence intervals to reflect disagreement.
- Participatory ranking: In workshops, stakeholders use participatory tools (ranking cards, pairwise comparisons) to weigh the relative importance of different NELD domains, revealing locally-defined priorities.

Semi-quantitative scores are presented transparently (with sample sizes, methodologies, confidence ranges) and used for internal prioritization or visualization (e.g., bar charts showing "NELD domains by relative community concern"), but NOT converted to monetary units unless specifically justified.

C. Selective Economic Valuation for Specific NELD

For selected NELD types where economic valuation is feasible and ethically appropriate, valuation methods are applied. These are limited to domains where (i) monetary valuation has established precedent in public health or environmental economics; (ii) ethical concerns are manageable (e.g., transparent acknowledgment of limitations); and (iii) data are available or can be reasonably estimated. Key examples for Ahmedabad and Surat:

i. Loss of Life and Health (NELD):

- **Approach 1** – Value of Statistical Life (VSL): Used primarily for policy guidance on risk mitigation investment. VSL represents the societal willingness to pay to reduce mortality risk by a small amount. For India, VSL estimates range from USD 0.3–1.2 million depending on income and study methodology. For Ahmedabad/Surat, a conservative domestic estimate (e.g., USD 0.5 million per life, or ~INR 4 crore) is applied only in illustrative case studies (Section 2.6.4) with extensive caveats.
- **Approach 2** – Disability-Adjusted Life Years (DALYs): Preferred for health impact quantification. DALYs combine years of life lost (YLL) due to premature mortality and years lived with disability (YLD). For heat-related mortality in Ahmedabad, YLL is calculated as: YLL = deaths × life expectancy at age of death. For each DALY lost, a cost-of-illness (COI) or cost-per-DALY values (from health sector studies or WHO guidance) is applied. India-specific DALY costs range from INR 50,000–500,000 per DALY, depending on sector and income level.

ii. Mental Health and Psychosocial Impacts (NELD):

- Where baseline mental health data exist (e.g., prevalence of post-traumatic stress disorder [PTSD] or depression in flood-affected communities), two approaches are used:
  - **Cost-of-Illness (COI) approach**: Estimated healthcare costs + productivity loss (days of work lost, reduced wage-earning capacity) associated with diagnosed mental illness. India-specific COI for major depression is approximately INR 20,000–50,000 per person per year.
  - **Contingent Valuation or Willingness-to-Pay (WTP) surveys:** Individuals are asked about their willingness to pay to avoid or mitigate specific mental health impacts. WTP estimates are then aggregated across the affected population.

iii. Cultural Heritage & Ecosystem Services (NELD):

- **Replacement/restoration cost method:** Where cultural sites or ecosystems can be

restored, the cost of restoration (e.g., temple reconstruction, mangrove replanting) serves as a proxy for loss value. This captures at least the material dimension of loss, though not the intangible cultural meaning.

- **Travel cost or hedonic pricing:** For ecosystem services loss (e.g., loss of urban parks), revealed preference methods infer value from property prices or recreation travel costs in comparable areas. Interpreted cautiously as partial, lower-bound estimates.

D. Ethical Caveats and Transparency Standards

The selective use of economic valuation for NELD requires explicit acknowledgment of ethical issues:

- Not all NELD should or can be monetized. Some losses (e.g., irreversible biodiversity, sacred heritage) are uniquely valued by cultures and cannot be fairly represented by money alone. The study does not attempt to monetize loss of cultural identity, spiritual significance, or traditional knowledge.
- Valuation does not equate to reversibility. A monetary estimate of the loss of a sacred site does not imply that compensation in cash would restore the site's value or meaning to affected communities.
- Distributional justice: Monetized NELD estimates can mask differential impacts on vulnerable groups. Where feasible, NELD metrics should be disaggregated by income, gender, caste, ethnicity, or occupational group to show who bears losses.

In the present study, the applied approach is as follows: Life loss is quantified using VSL or DALY methods for illustrative purposes only (Section 2.6.4), with substantial qualifications. Health impacts are valued using COI + DALY where health data permit (Section 2.6.3). Mental health, cultural heritage, and ecosystem service losses are primarily recognized qualitatively and semi-quantitatively; selective economic valuation is applied only where secondary data and community input support it, with transparency about assumptions and limitations.

2.3.3 Operationalizing Mental Health and Psychosocial NELD Measurement

Mental health impacts from climate hazards, including anxiety, depression, PTSD, and community trauma, are significant but often invisible in formal assessments. In Ahmedabad and Surat, FGD stakeholders frequently cited psychosocial distress, insecurity, and fear of recurrent disasters. Measurement approaches include:

A. Screening Indicators (Proxy Measures)

Where full mental health assessments are infeasible, proxy indicators are used:

- **Perceived stress scale (PSS):** Simple 4–10-item self-report questionnaire asking respondents to rate stress levels on a scale of 0–4. Can be administered in surveys or FGDs; scoring is straightforward.
- **Activity limitation:** Number of days respondents report being unable to work, care for the household, or engage in normal activities due to emotional distress or fear.
- **Sleep disruption:** Prevalence of reported sleep loss or nightmares related to flooding/heat fears; measured via household survey or health facility records.

These proxy indicators do not constitute a clinical diagnosis but provide quantifiable data on the prevalence of distress.

B. Semi-Quantitative Community Reporting

In FGDs, participants are asked to describe:

- Changes in community dynamics post-event (e.g., "increased conflicts," "reduced social gathering," "increased out-migration").
- Coping strategies adopted (e.g., "reliance on alcohol," "isolation," "increased religious practice").
- Observed changes in vulnerable groups (e.g., "increased child labor," "more girls not attending school," "increased domestic violence").

Responses are coded thematically and frequency-tabulated to indicate which psychosocial impacts are most commonly reported.

C. Health Facility Data

Where available, municipal health facilities or NGO clinics can provide:

- Outpatient visits for mental health complaints pre- and post-event.
- Prescriptions for anti-depressants, anti-anxiety medications.
- Referrals to mental health specialists.

Comparing trends before/after major climate events provides a data-driven signal of mental health burden, albeit incomplete (many affected persons do not seek care).

D. Qualitative Narratives

In-depth interviews or focus group discussions yield detailed narratives on the lived experience of psychosocial impacts: fear, grief over loss, community fragmentation, loss of hope or agency. These are documented, coded for themes, and presented alongside quantitative signals to provide texture and context.

Application in this study: Given time and resource constraints, FGD thematic analysis on psychosocial impacts is the primary method. The frequency of mentions and representative testimonies are documented. Where health facility records or household survey data on activity limitation are available, these supplement the narrative evidence. Valuation (via COI or WTP for mental health recovery) is applied selectively in illustrative cases (Section 2.6) with substantial qualifications regarding data quality and ethical considerations.

2.3.4 Participatory Approaches to Cultural Heritage and Social Cohesion NELD

Cultural heritage, sense of place, and social cohesion are particularly difficult to value yet essential for understanding total L&D. Participatory methods complement economic valuation:

A. Participatory Mapping & Ranking of Valued Sites

- Communities identify cultural, recreational, religious, or economically significant sites on maps (temples, community markets, parks, water bodies, burial grounds).
- Participants assess which sites have been damaged, inundated, become inaccessible, or lost due to climate events over the past 10–20 years.
- In a second round, participants collectively rank the cultural/social significance of each site using pairwise comparisons or numerical scoring, weighted by importance to different community groups (e.g., women, youth, elderly, specific castes or religious groups).
- Results are presented as 'loss of valued sites by significance level' and disaggregated by community group to reveal differential impacts.

B. Narrative Coding of Social Cohesion Loss

- Focus group discussions and interviews capture narratives of how climate events disrupt or strengthen social bonds (e.g., "After the 2024 flood, families from the neighbourhood did not return; the community feel is lost" vs. "The disaster brought us closer; we support each other now").
- Codes include: migration/displacement of key community members, erosion of neighbourhood interactions, emergence of conflict (e.g., resource competition, blame), gender-based violence, or conversely, emergence of mutual support networks.
- Frequency and intensity of coded themes are tabulated to provide a semi-quantitative summary.

C. Multi-Criteria Decision Analysis (MCDA) for NELD Prioritization

- In structured workshops, stakeholders rate different NELD impacts on multiple criteria (severity of impact, number of people affected, reversibility, importance for livelihoods and identity) using numerical scales (1–5).
- An aggregated score per NELD type is computed, helping prioritize which losses to focus on for response and recovery.
- MCDA is transparent about stakeholder diversity: if different groups prioritize differently (e.g., women prioritize health/education NELD; informal workers prioritize livelihood NELD), this is explicitly documented.

D. Ecosystem Services Valuation - Participatory Approach

- Communities identify ecosystem services they depend on or value (urban forests for cooling/shade, water bodies for recreation/ livelihood, parks for physical health and mental relaxation).
- They assess changes in ecosystem condition (e.g., "25% of trees in the park were uprooted in the storm," "water body is now polluted and we no longer use it").
- Where secondary data exist (e.g., economic value of urban greenery from published studies), these are adapted to the local context with community input.
- Results are presented as 'loss of ecosystem services by type and magnitude,' with a community narrative explaining why these losses matter.

Application in this study: FGD and stakeholder workshop outputs on cultural sites, social cohesion, and ecosystem services are documented using the approaches above. Semi-quantitative and narrative findings are presented in Section 2.3 and cross-referenced with illustrative cases. Monetary valuation of cultural heritage is applied only where community and expert consultation strongly support it (e.g., replacement cost of a temple), with explicit acknowledgment of limitations

2.3.5 Equity and Disaggregated NELD Assessment

Climate impacts and losses are not uniformly distributed; marginalized populations (women, low-income households, informal workers, religious minorities, scheduled castes) often experience disproportionate NELD. To capture this, the assessment disaggregates NELD by social group where data permit:

Gender-Specific NELD:

- Women often face distinct NELD: increased domestic violence in temporary shelters (documented in post-flood reports), inability to attend schools/health clinics due to shame or mobility restrictions, an unpaid care burden (managing children and the elderly in adverse conditions), and reproductive health complications during disasters.
- FGDs with women's groups, separate from mixed groups, reveal gender-specific impacts not always mentioned in mixed settings.
- Indicators include: female-headed households disproportionately affected by housing loss, women's livelihood loss in sectors like informal food/beverage trade, differential health impacts (e.g., higher malnutrition among girls in some studies).

Caste, Religion, and Occupational Group-Specific NELD:

- Scheduled Caste (SC) and Scheduled Tribe (ST) populations may face caste-based discrimination in post-disaster relief distribution, affecting trauma recovery and rebuilding.
- Religious minority groups may experience loss of sacred sites or community spaces selectively.
- Occupational groups (e.g., street vendors, informal sanitation workers, fisherfolk) face livelihood loss that cascades into food insecurity and loss of occupational identity.
- The assessment documents which NELD impacts are concentrated in specific groups and, where feasible, quantifies affected population numbers by group.

Presentation: In Section 2.3, results tables, and in Chapters 4–6, NELD findings are disaggregated by gender and occupational group where data are available, and these disaggregations are visually indicated with footnotes or sub-rows. This ensures that gender and equity dimensions are not erased in aggregate statistics.

The template for NELD has been developed, and can be accessed here: Link: https://docs.google.com/spreadsheets/d/13oBs-Ay1pq6KrEf6jkIWdj23SMArBfuF/edit?gid=1490636250#gid=1490636250

The ELD and NELD matrix for Ahmedabad and Surat has been developed, and can be accessed here: Link: https://docs.google.com/spreadsheets/d/1Twc9o8Sem058MqIGyAuIB8gGtDmKZr3GlZB2I-suERE/edit?gid=1521729263#gid=1521729263

The matrix of non-economic losses and damages illustrates how climate-induced hazards, such as extreme heat and flooding, affect human wellbeing, social cohesion, culture, and environment beyond measurable economic costs. These impacts manifest as loss of life, health deterioration, education disruption, displacement, erosion of cultural heritage, and ecosystem degradation, underscoring that climate shocks extend far beyond economic losses. The cross-cutting domains reflect the interconnected nature of vulnerabilities within an urban system, where, for example, flooding simultaneously disrupts schooling, damages cultural landmarks, and degrades local water bodies, compounding psychosocial stress within affected communities.

However, several limitations constrain the systematic assessment of non-economic L&D at the city level. Many intangible losses, such as trauma, dignity, cultural value, or biodiversity decline, lack standardized metrics or valuation methods. City departments rarely track qualitative or perception-based indicators (e.g., stress, displacement, identity loss), making it difficult to attribute these to specific climate events. Health, education, environment, and housing intersect across institutional boundaries; their impacts are diffuse and cumulative, not easily isolated within single departmental mandates. While this categorization aligns with district-level disaster assessment frameworks, many domains fall outside the functional jurisdiction of city administrations, requiring inter-agency coordination.

These include human rights violations, gender-based violence, increased violence against vulnerable groups, increased hunger, loss of social cohesion and community resilience, and social inequality. Unlike economic losses, there are no universally accepted methodologies for quantifying non-economic damages at urban or sub-district scales.

It is also vital to acknowledge that although the parameters and indicators for recording L&D have been outlined in the PDNA framework, there are no templates available for recording NELD thereby keeping these losses outside the remit of formal L&D assessments.

While this matrix aims to complement the L&D assessment by capturing the full spectrum of human and environmental consequences of climate hazards, integrating both tangible and intangible losses, it is largely focused on urban flooding and does not capture ELD and NELD related to extreme heat and droughts, although there may be some overlaps. A unified framework embedded in policy will help quantify L&D at the city level.

Sections 2.5 and 2.6 will illustrate the economic estimation of L&D from past events for 2 ELD and 2 NELD cases and detail some economic estimation methods.

2.4 Infrastructure Interdependencies

Across cities globally, there is no accepted general definition of interdependencies since these may vary based on geographic context, size, and location, and the type of climate hazard impacting the city i.e., flooding, extreme heat, droughts. Megacities with large populations and compact high densities serviced by concentrated infrastructure may experience different types of impacts in comparison to mid-size cities with medium densities serviced by spread out infrastructure. Quantification of the damages due to the impacts of extreme climatic events allow the city administration to make a case for developing strong infrastructure to the decision makers and enhances the investment attractiveness of the city.

The list of critical infrastructure identified by global cities include the following:

1. Energy; 2. Transport; 3. Water Supply; Drainage (waste water, storm water, sewage); 4. Telecom; 5. Buildings; 6. Coastal Infrastructure; 7. Industry; 8. Waste; 9. Public Works; 10. Gas Supply; 11. Energy Management; 12. Health; 13. Economy (trade, tourism, and financial services); 14. Parks and Recreation.

Infrastructure insurance companies are increasingly looking at instruments that take infrastructure risks into consideration to minimize their exposure. Approaches such as the 'Risk Pool for Infrastructure Protection and Recovery' are being considered to complement

the traditional insurance approaches.

It is noteworthy that approaches such as infrastructure interdependencies take into consideration the cascading impact of infrastructure systems on the rest of the urban systems and their disruption due to extreme climatic events. Following is an example of extreme precipitation on the urban infrastructure systems in a city.

supply stops"), (ii) expert judgment from municipal engineers, and (iii) post-event reports documenting cascading failures.

- Example: A flood inundates the sewage pumping station (direct damage to wastewater infrastructure)→loss of power to the pumping station→overflow of sewage→contamination of local water wells → health impacts in the surrounding neighborhood.

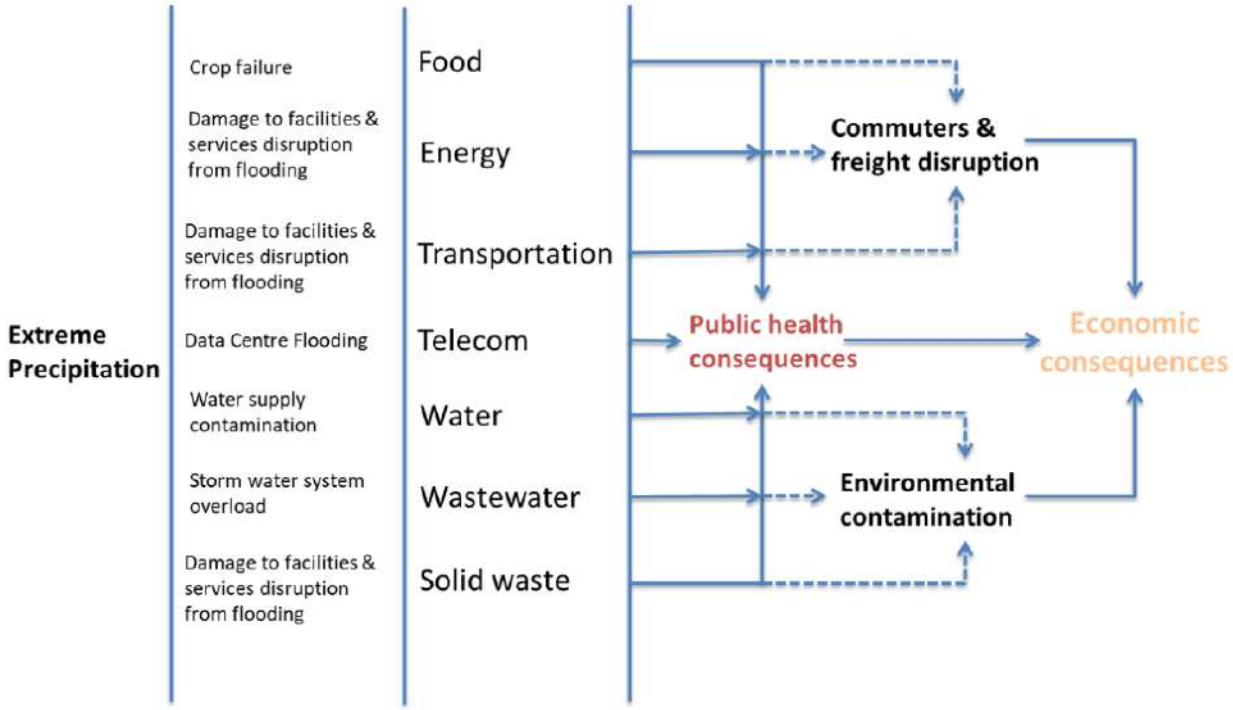


Figure 1: Infrastructure Interdependencies due to urban flooding

2.4.1 Methodology for Mapping Infrastructure Interdependencies:

Infrastructure systems in Ahmedabad and Surat are interconnected; disruption to one often cascades to others. To systematically identify and document interdependencies:

A. Dependency Matrix Development

- A simple matrix is constructed with infrastructure systems (water, power, transport, communication, waste) as both rows and columns.
- For each intersection, the degree of dependency is assessed (strong/moderate/weak/none) based on: (i) operational data from utility agencies (e.g., "power pump depends on grid electricity; if grid fails, water

B. Network Visualization

- Interdependencies can also be visualized as a network diagram, with systems as nodes and causal links as edges. Edge thickness or color intensity indicates the strength of dependency.
- Criticality is identified: which system failures pose the greatest risk to overall urban function? (E.g., power failure affecting water treatment > damage to single street vendor C. Temporal Cascading Interdependencies unfold over time; immediate cascades (hours) differ from longer-term effects (days to weeks). Documentation includes timing: e.g., power outage→water supply reduction within 4 hours→health impacts emerge over days.

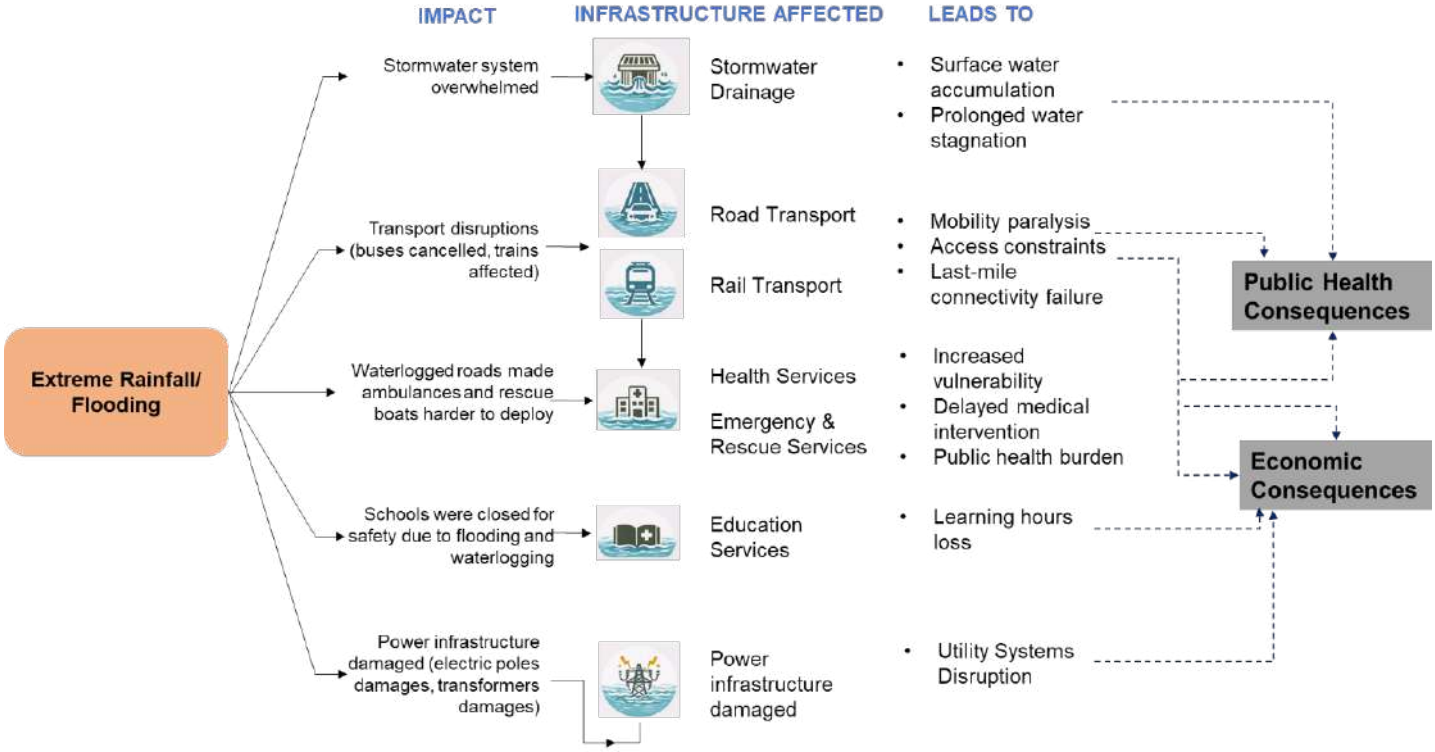


Figure 2: Example of Infrastructure Interdependencies

Example Surat: Cascading Impacts of Extreme Rainfall and Flooding on Urban Infrastructure

A preliminary case of infrastructure interdependencies is presented in Figure 2. This illustrates the cascading effects of extreme rainfall and flooding on interconnected urban infrastructure systems. Extreme rainfall overwhelms the stormwater drainage system,[4] leading to persistent waterlogging.

As drainage capacity is exceeded, transport systems are directly affected. Road transport experiences mobility paralysis due to inundated streets, while rail transport operations are disrupted by flooded tracks and signalling systems.[5] These mobility constraints limit last-mile connectivity and restrict access to essential services.

Flooded road networks further impede emergency and rescue operations, delaying ambulance deployment[6] and reducing response efficiency. Health services face increased vulnerability due to both physical inaccessibility and operational stress during peak demand. Simultaneously, schools and educational institutions are closed[7] for safety reasons, resulting in learning hour losses.

Power infrastructure damage, including impacts on electric poles, transformers, and substations, amplifies system-wide disruption. Power failures contribute to utility system interruptions and reduces the operational capacity of health facilities, transport systems, and communication networks.[8]

4 The Times of India. (2025, June 26). Surat sees pause in rain, but flood woes continue as city remains submerged. https://timesofindia.indiatimes.com/city/surat/surat-sees-pause-in-rain-but-flood-woes-continue-as-city-remains-submerged/articleshow/122054475.cms

5 The Times of India. (2025, June 24). Monsoon's first big strike: 9 inches rainfall in 10 hours brings Surat to its knees; traffic disrupted. https://timesofindia.indiatimes.com/city/surat/monsoons-first-big-strike-brings-surat-to-its-knees/articleshow/122032856.cms

6 The New Indian Express. (2025, June 25). Surat's rescue failure leaves heart patient stranded in flooded street for 30 minutes. https://www.newindianexpress.com/nation/2025/Jun/25/surats-rescue-failure-leaves-heart-patient-stranded-in-flooded-street-for-30-minutes

7 The Economic Times. (2024, August 28). Surat weather: Schools shut, trains affected as heavy rains lash Gujarat city. https://economictimes.indiatimes.com/news/india/surat-weather-schools-shut-trains-affected-as-heavy-rains-lash-gujarat-city/articleshow/112851447.cms

8 The New Indian Express, "Over 1,000 evacuated as Gujarat lashed by heavy rain; nine dams overflow, power, roads hit," The New Indian Express, June 19, 2025,https://www.newindianexpress.com/nation/2025/Jun/19/over-1000-evacuated-as-gujarat-lashed-by-heavy-rain-nine-dams-overflow-power-roads-hit

These interconnected failures propagate into broader disruptions in healthcare and emergency services, elevate public health risks, increase vulnerability, and contribute to a higher disease burden. At the macro level, service interruptions, reduced productivity, and infrastructure damage collectively result in significant economic consequences.

2.5 Estimating Loss and Damage for Past Events

City-level assessment highlights the need for a structured approach for L&D assessment during climate events. This approach can help cities to adopt and estimate and, where possible, monetize L&D using historical climate event data. The estimation integrates participatory validation, structured data collection and estimation methods tailored to different types of impacts.The classification of losses and damages for illustration is grounded in the framework developed by Puig (2023)[9], which distinguishes between economic and non-economic impacts of climate-related events. This framework has been further informed by key contributions from recent literature on loss and damage, including works by Bharadwaj et al. (2024)[10], Boyd et al. (2017)[11], and Van der Geest & Warner (2015)[12]. Drawing from these sources, the list of L&D categories presented here reflects both established classifications and evolving understandings from the field.

Stakeholder Consultation, validation, and community knowledge are critical to identifying locally relevant and underreported L&Ds, especially non-economic impacts. City officials can ensure more grounded and inclusive assessments by actively engaging diverse local actors and affected communities. To demonstrate this step, a series of FGDs was conducted with community-based organizations (CBOs) in Ahmedabad and Surat. The most critical and commonly reported losses during the stakeholder engagement in both cities are illustrated below.

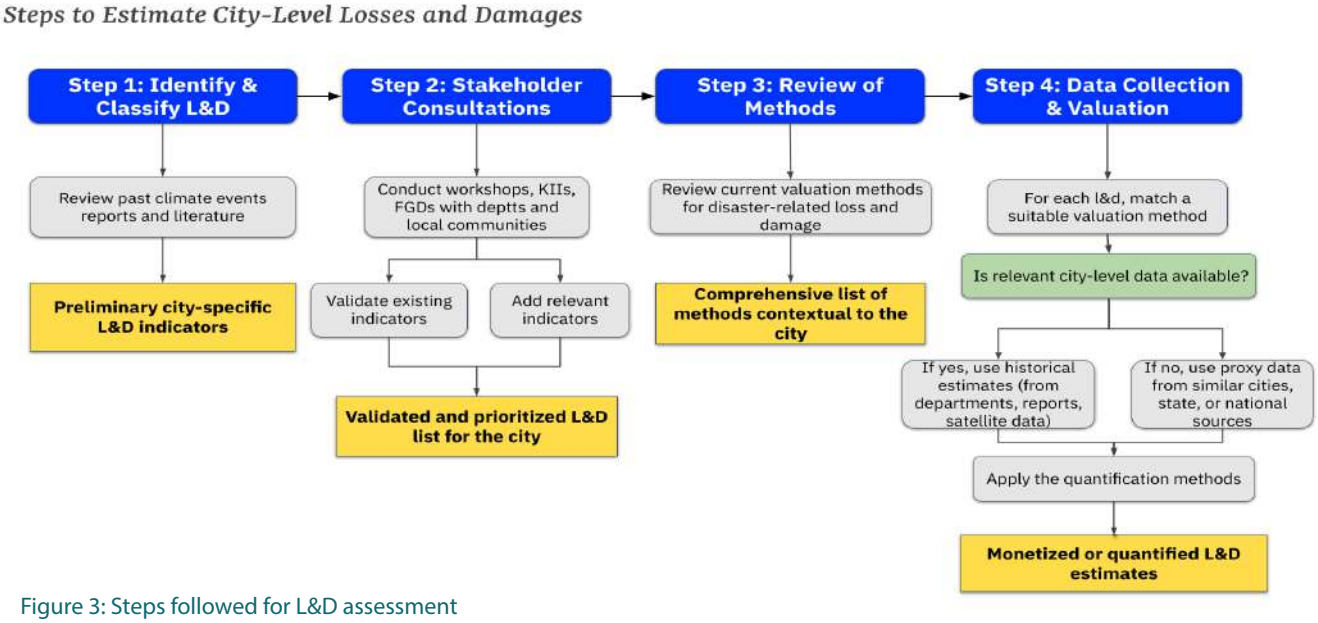


Figure 3: Steps followed for L&D assessment

9 Puig, D. (2023) Assessing climate change-driven losses and damages. A guidance note. Copenhagen, Denmark: UNEP Copenhagen Climate Centre and Initiative for Climate Action Transparency (ICAT). https://climateactiontransparency.org/assessing-climate-change-driven-losses-and-damages/

10 Bharadwaj, R, Karthikeyan, N and Pichandi, K (2024) Comprehensive Climate Impact Quantification (C-CIQ): an approach to co-developing policy and programmatic responses for climate risk management. IIED, London. http://pubs.iied.org/22491iied

11 Boyd, E., James, R.A., Jones, R.G., Young, H.R., Otto, F.E., A typology of loss and damage perspectives. Nat. Clim. Chang., 2017, 7 (10), 723–729. https://doi.org/10.1038/nclimate3389

12 Van Der Geest, K., & Warner, K., 'Editorial: Loss and damage from climate change: emerging perspectives. In Inderscience Enterprises Ltd.', Int. J. Global Warming (Vol. 8, Issue 2, pp. 133–135), (2015), http://collections.unu.edu/eserv/UNU%3a3245/Emerging_perspectives_on_Loss_and_damage.pdf

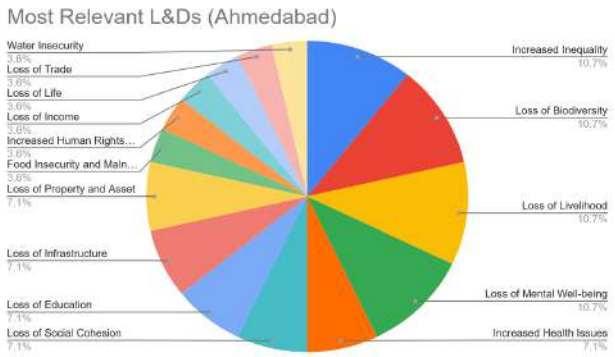


Figure 4: Most Recurring or Relevant Losses in Ahmedabad

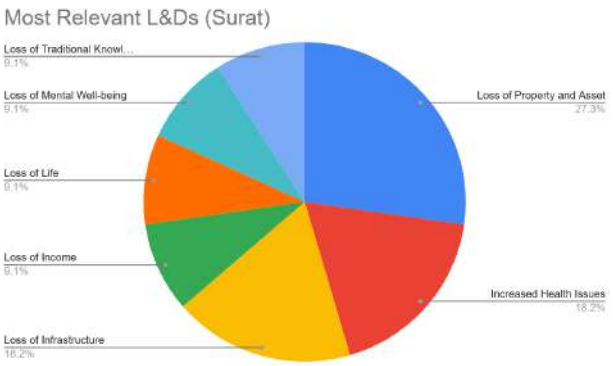


Figure 5 Most Recurring or Relevant Losses in Surat

Based on insights shared by the CBOs, the following L&D were identified and prioritized as the most relevant for the two cities. Following the flow from the table and the matrix in the preceding sections, it is important to note that the highlighted losses are not captured in any existing assessment frameworks. However, they consistently emerge as recurring themes across both cities, underscoring their significance in understanding the full scope and lived realities of L&D.

Estimating losses using appropriate methods strengthens the credibility of city assessments and enables informed decision-making for resource allocation, risk reduction, and compensation planning. Table 3 below lists commonly used L&D estimation methods. This reference list was compiled through a comprehensive review of existing literature, a list of methods relevant to city-level L&D estimation, and was grouped into quantitative, qualitative, and integrated approaches. Here, quantitative methods include econometric and statistical techniques for assessing and analysing data on L&D indicators, providing numerical insights and measurable outcomes. Qualitative methods in the assessment include tools and approaches such as participatory assessments, narrative textual analysis, storytelling, and descriptive frameworks to explore individual-level impacts and capture the context and subjective experiences of L&D. Studies that combine both quantitative and qualitative methods to evaluate climate-induced L&D are categorized under integrated or mixed-method approaches.

Table 2: The List of Most Relevant L&Ds in Ahmedabad and Surat

Name of Loss	Classification
Increased Health Issues	NELD
Loss of Mental Well-being	NELD
Loss of Infrastructure	ELD
Loss of Property and Asset	ELD
Loss of Income	ELD
Loss of Life	NELD
Increased Inequality	NELD
Loss of Biodiversity	NELD
Loss of Livelihood	NELD
Loss of Social Cohesion	NELD
Loss of Education	ELD
Food Insecurity and Malnutrition	ELD
Increased Human Rights Violations	NELD
Loss of Trade	ELD
Water Insecurity	ELD
Loss of Traditional Knowledge	NELD

Quantitative tools are commonly used to assess disaster impacts, particularly for estimating direct and indirect damage costs. Direct damage is often measured using damage functions that link hazard parameters to monetary values (e.g., cost per square foot of housing). Market price methods are also popular for their simplicity and applicability across sectors in quantifying impacts on resources traded in markets (for example, timber, fuelwood, cork, and other forest products). Both direct and indirect damage costs, such as supply chain disruptions, reduced production, and accumulated debt, are estimated

Table 3: Reference List of Key Methods

Key Existing Methods		
Quantitative	**Qualitative**	**Integrated or Mixed**
1. Damage Functions 2. Economic modelling a. Integrated Assessment Method b. Computable General Equilibrium model c. Input-output model d. Attribution-based method e. Vulnerability Curves f. Index-based Approaches 3. Market price method 4. Production function approach 5. Surveys 6. Hedonic pricing method 7. Travel cost method 8. Replacement Cost 9. Contingent valuation method 10. Choice experiment method 11. Prevention Cost Method 12. Opportunity Cost Method 13. Cost-Benefit Analysis 14. Risk mitigation cost Method	1) Values-based Approach 2) Ranking Method 3) Narrative Method 4) Story-telling 5) Artistic Analysis 6) Scenario Creation 7) Place-based Valuation 8) Relational Approach 9) Visual Mapping	1) Multi-criteria decision analysis (MCDA) 2) Climate Change Risk and Vulnerability Assessment (CRVA) 3) Comprehensive-Climate Impact Quantification (C-CIQ) tool

using tools such as surveys, econometric models, input-output models, and Computable General Equilibrium (CGE) models. Input-output models and CGE models help estimate regional and economic impacts post-disaster. Valuation of losses such as environmental degradation, health effects, and social disruptions employs economic valuation techniques to estimate the impacts of disasters that lack direct market prices. Methods like revealed and stated preferences, including hedonic pricing, travel cost, contingent valuation, and choice modeling, are used to capture these non-market impacts by assessing individual willingness to pay (WTP) or accept compensation (WTA).

Qualitative methods for measuring L&D focus on capturing the nuanced, context-specific perceptions, experiences, and values associated with NELDs. Through approaches such as interviews, FGDs, storytelling, and participatory techniques, these methods prioritize local perspectives, emotional connections, and cultural variability, offering a comprehensive understanding of what communities value and how they navigate trade-offs in the face of climate impacts.

Mixed-method approaches, combining qualitative tools like interviews and FGDs with quantitative analysis, are commonly used to assess climate change impacts and losses. Frameworks such as the C-CIQ, MCDM, and CRVA provide structured, community-centered methods for evaluating economic and non-economic losses. From the longlist collated in Table 3, methods may be shortlisted based on:

- **Feasibility,** given data and time availability
- **Relevance** to the priority L&Ds identified during stakeholder consultations

Appropriateness for the type of impacts (economic and non-economic): To illustrate this, the guide provides examples of four priority L&D indicators selected for Ahmedabad and Surat, with two economic and two non-economic indicators. These categories -- loss due to increased health-related issues, loss of income, loss of infrastructure, and loss of life -- were chosen based on their reported relevance during stakeholder consultations. They reflect both the cities' recent experiences with heatwaves and urban flooding, as well as the feasibility of accessing supporting data. Table 4 outlines suitable methods and tools for each. These methods serve as practical entry points for cities aiming to quantify both economic and non-economic impacts.

To generate credible, policy-relevant estimates of L&D, cities need to match appropriate valuation methods to the best available data. The following section presents four illustrative cases of monetary estimation for the selected L&D: Damage to Infrastructure, Loss of Income, Loss due to Health-Related Impacts, and Loss of Life. These examples demonstrate a range of approaches from direct physical damage valuation (e.g., infrastructure) to economic assessments of disrupted livelihoods (e.g., income loss). In contrast, the estimates of health-related impacts and loss of life aim to quantify non-economic losses in financial terms. These methods focus on the measurable monetary aspects of such impacts, while acknowledging that not all dimensions, particularly intangible or irreversible ones, can be fully captured in monetary terms.

Table 4: List of key methods for selected L&Ds for Ahmedabad and Surat

L&D Category	Common Methods
Damage to Infrastructure	Damage Functions Replacement Cost Method Market Price Method **Tools:** PDNA (Post-Disaster Needs Assessment) DaLA (Damage and Loss Assessment) HAZUS-MH (for scenario-based infrastructure loss)
Loss of Income	Input-Output (IO) Models Computable General Equilibrium (CGE) Models Production Function Approach Survey-based Income Loss Estimation **Tools:** CATSIM (Catastrophe Simulation Model) for macroeconomic simulations Sector-wise exposure mapping with local income/wage data

L&D Category	Common Methods
Loss due to Increased Health Issues	Cost-of-Illness (COI) [Economic Modeling Method] Statistical Health Models [Attribution-based Method] Revealed Preference (Health-related Behavior) [Travel Cost/Hedonic Pricing] DALY (Disability-Adjusted Life Years) [Damage function]
Loss of Life	Value of Statistical Life (VSL) [Contingent Valuation Method] Willingness-to-Pay (WTP) Surveys [Contingent Valuation Method] Human Life-Years Lost [Cost-Benefit Analysis]

2.5.1 Scope and Data Sources:

Past events selected for illustrative L&D estimation are identified based on: (1) severity and impact coverage in municipal records and news media; (2) availability of granular impact data (infrastructure damage, health outcomes, livelihood disruption); and (3) representation of both recurring events (annual monsoon flooding, summer heatwaves) and rare events (e.g., 2024 August flooding in Ahmedabad, and 2019 Cyclone Vayu in Surat).

Time period covered: 2000–2025 for historical event inventory (Chapter 3); focus on 2015–2024 for quantified L&D estimates where data are more reliable.

Data sources prioritized: (i) Municipal disaster reports and PDNA assessments (highest priority, official); (ii) NGO/civil society reports and monitoring data (secondary); (iii) newspaper archives and social media (tertiary, cross-validated); (iv) household surveys and FGDs (for undocumented informal losses).

Uncertainty and data gaps: For each case study, the quality and completeness of data are assessed (indicated in methods box). Where critical data are missing, interpolation, assumptions, or expert judgment are used, with transparent documentation of reasoning.

2.6. Illustrative Cases of Monetary Estimation for Selected L&D

2.6.1 Damage to Physical Infrastructure (ELD)

Loss of physical infrastructure refers to the physical damage or destruction of public and private infrastructure, such as roads, bridges, health centers, schools, electricity and water systems, and housing that require repair or replacement as a result of the flood. For illustration, potential damage to government schools in Nanpura, Surat, is estimated under a modelled 4-day flood scenario triggered by the release of 400,000–500,000 cusecs of water from the Ukai Dam.

Data Collection and Damage Estimation:

The estimation of infrastructure losses involves the following steps:

- Identify and categorize infrastructure types damaged during the flood using official damage assessment reports, government disaster bulletins, newspaper archives, or post-disaster needs assessments (PDNAs). Categories may include (but are not limited to):
  - Roads and bridges
  - Health facilities and schools
  - Housing and shelters
  - Public utilities (water pipelines, electrical infrastructure)
- Extract the reported quantity of damage per infrastructure type. This could include the length of road damaged (in km), the number of buildings affected, or the number of utility connections disrupted.
- Assign standard unit replacement or repair costs for each infrastructure type using publicly available costing schedules or published government norms.

Quantification and Monetization:

The total direct loss is calculated using a

replacement cost method, applying the following formula:

Total Loss $_{infrastructure}$ = $1\sum n$ (Qi × Ci)

Where:

- Qi = Quantity of damage to infrastructure type *i*
- Ci = Unit cost of repair or replacement for infrastructure type *i*
- n = Total number of distinct infrastructure categories included

The estimation of monetary loss to public infrastructure is illustrated by taking the example of government schools in Ward Nanpura, Surat, based on data from the TARU-led flood risk mapping report prepared under the ACCCRN initiative.[13] The report models a 4-day flood scenario involving the release of 400,000–500,000 cusecs of water from the Ukai dam, combined with high tides of 2.5-3 meters, representing a severe but plausible monsoon-season event for Surat.

Using the flood depth maps from this simulation, government school buildings located in zones where water depth exceeds 1–1.5 meters are identified. This threshold is based on established disaster literature and post-disaster assessment experience, which suggests that buildings exposed to such depths typically incur significant structural and internal damage (Pistrika et al., 2014, Wüthrich et al., 2024).[14,15]

Using the flood depth contours and mapped locations of schools, five government schools are identified within the high-risk zones. These are considered damaged for the purpose of estimating loss. To estimate the total monetary loss, standard government rates for repair and reconstruction, drawn from the Kerala PDNA 2018,[16] are applied, using ₹7.3 lakh per classroom and ₹23,000 per toilet or urinal as unit cost benchmarks.

Total Loss $_{Govt\ Schools}$ = No. of Classrooms * Cost per Classroom + No. of Toilets * Cost per toilet = 47.5*730000 + 52.5*23,000 = 35,882,500

The estimated monetary loss from flood-related damage to government school infrastructure in the ward amounts to **approximately ₹3.59 crore.**

Methods Box: Infrastructure damage estimation – Surat government school's case

Objective: Estimate monetary loss to government school buildings in Ward Nanpura, Surat, under a modeled 4-day flood scenario (400,000–500,000 cusecs release from Ukai Dam + tidal surge 2.5–3 m).

Data and Methods:

1. Flood extent mapping: Depth contours

Table 5: Details of government schools in the flood zone in Nanpura, Surat

Sl. No.	Name	Zone	No. of Classrooms	No. of Toilets	Year of Establishment
1	NAGAR PRIMARY SCHOOL-19	Central	7	6	1919
2	NAGAR PRIMARY SCHOOL-20	Central	11	6	1919
3	NAGAR PRIMARY SCHOOL-17	Central	11	15	1978
4	NAGAR PRIMARY SCHOOL-18	Central	9	15	1978
5	NAGAR PRIMARY SCHOOL	-	9.5	10.5	-
Total			**47.5**	**52.5**	

13 Rajasekar, U., Shah, P., & Ramirez, J. A. (2015). Flood Risk Profile: Surat. Taru Leading Edge, India.

14 Pistrika, A., Tsakiris, G., & Nalbantis, I. (2014). Flood Depth-Damage functions for built environment. Environmental Processes, 1(4), 553–572. https://doi.org/10.1007/s40710-014-0038-2

15 Wüthrich, D., Korswagen, P. A., Selvam, H., Oetjen, J., Bricker, J., & Schüttrumpf, H. (2024). Field survey assessment of flood loads and related building damage from the July 2021 event in the Ahr Valley (Germany). Journal of Flood Risk Management. https://doi.org/10.1111/jfr3.13024

16 United Nations Development Programme. (2018, December 12). Post-Disaster Needs Assessment – Kerala. United Nations Development Programme. https://www.undp.org/publications/post-disaster-needs-assessment-kerala

derived from TARU/ACCCRN flood risk simulation model (Mazumdar et al., 2015). Mapped grid resolution ~30 m; depth values extracted for school locations.

2. Exposure definition: Schools identified as 'damaged' if located in zones with water depth > 1–1.5 m, based on engineering literature (Pistrika et al., 2014), indicating a typical structural damage threshold.
3. Asset inventory: School addresses, building footprints, number of classrooms, and facilities (toilets, offices) extracted from municipal education department records and verified through field visits (2024).
4. Valuation: Unit replacement costs sourced from Kerala PDNA 2018 (INR 7.3 lakh per classroom, INR 23,000 per toilet), adapted to the Gujarat context with ±15% adjustment factor reflecting regional cost differences (assumption: Kerala and Gujarat construction costs similar; sensitivity testing shows ±25% variation in unit costs leads to ±25% variation in total estimate).
5. Formula: Total loss = Σ (No. classrooms × cost/classroom) + Σ (No. toilets × cost/toilet)

Limitations:

- Model-based depths are subject to hydrodynamic uncertainty (model parameterization, rainfall input variability).
- Damage threshold (1–1.5 m) is literature-based, not validated for Surat building types; actual damage may differ.
- Repair vs. replacement distinction not made; estimate assumes partial repair at 70% of replacement cost (sensitivity: ±20%).
- Indirect losses (disruption of schooling, temporary classroom setup, teacher reassignment) not included.
- Informal settlement schools, private schools not included (data unavailability).

Confidence Level: MODERATE. Driven by model uncertainty and reliance on literature damage thresholds; should be treated as indicative order-of-magnitude estimate rather than precise forecast."

2.6.2 Loss of Income (ELD)

To estimate loss of income at the city level, short-term income losses are quantified during an urban flooding event in Ahmedabad in August 2024.

Analytical Framework and Assumptions:

1. This estimation uses a retrospective, event-based approach to quantify short-term income loss during the August 2024 urban flood in Ahmedabad.
2. The projected population of Ahmedabad is used as 7,18,17,731 for 2021.[17]
3. According to the Ahmedabad Climate Resilient City Action Plan, based on data from the Ahmedabad Municipal Corporation, approximately 4.3% of the city's area is prone to urban flooding or waterlogging, and an estimated 9.5% of the city's population is affected.[18] For the purpose of this calculation, it is assumed that flooding has disrupted the workplaces of the affected population, thereby impacting their ability to work and earn. Therefore, 9.5% of the working population is considered as flood-affected workers in estimating income loss.
4. Employment category shares and average daily wages are derived from the PLFS Quarterly Bulletin (July–September 2024). Due to the lack of city-specific labour data, these national-level proxies are applied for Ahmedabad.
5. The analysis focuses on self-employed and casual laborers, as they are most likely to face income disruption during short-term flood events. Regular salaried workers are excluded under the assumption that income continuity is more likely.

17 Ahmedabad Municipal Corporation; ICLEI – Local Governments for Sustainability, South Asia. (2023, July). Ahmedabad Climate Resilient City Action Plan – Toward a Net Zero Future. https://southasia.iclei.org/wp-content/uploads/2024/01/AMC-CRCAP-EXEC-SUMMARY_06JULY2023_compressed.pdf

18 United Nations Development Programme & United Nations Environment Programme. (2025, May 9). Urban flood recovery strategies in the cities of Ahmedabad, India, and Port Louis, Mauritius: Flood recovery learnings. SDG Local Action. https://sdglocalaction.org/flood-recovery-learnings/

6. A uniform assumption of 3 workdays lost is applied, based on local rainfall records and media reports on the duration of flood-related disruption.
7. The resulting income loss estimate represents the higher end of the possible range, as it is based on broad proxies and does not capture variations across different wards, occupations, or coping capacities.
8. For more precise estimation, it is recommended to integrate flood exposure maps with disaggregated worker and workplace data at the ward or city zone level.

To estimate loss of income by livelihood group i:

$\text{Income Loss}_i = N_i \times W_i \times D_i$

Where:

- N_i = Number of affected workers in group i
- W_i = Average daily wage of group i
- D_i = Number of workdays lost due to the disaster for group i

Step 1: Estimate total flood-affected population

$N_{affected_pop} = 7{,}181{,}773 \times 0.095 \approx 6{,}82{,}268$

Step 2: Estimate flood-affected working-age population (15+ years)

$N_{\text{working age}} = 6{,}82{,}268 \times 0.75 = 5{,}11{,}701$

where the percentage of the population between 0-14 years is 25% in India in 2023.[19] This national average is used as a proxy for the 75% of the working-age population in Ahmedabad.

Step 3: Estimate the number of workers in different activities

The PLFS categorizes different activity statuses for the working population as follows:

i. All self-employed people
ii. Regular wage / salaried workers
iii. Casual labourers
iv. Unemployed
v. Not in the labour force

Based on the percentage of distribution from the PLFS data,[20] the number of workers affected in the self-employed and casual workers categories is estimated as:

The number of workers in the self-employed category:

$N_{\text{Self-employed}} = 5{,}11{,}701 \times 0.175 \approx 89{,}548$

And the number of daily wage earners/casual labourers:

$N_{\text{daily wager}} = 5{,}11{,}701 \times .046 \approx 23{,}538$

Step 5: Calculating Income Loss for Daily Wage Earners

Based on the July–September 2024 PLFS, the average daily earnings in urban Gujarat are estimated as follows: casual laborers earn around ₹ 498/day, regular salaried workers approximately ₹ 796/day, and self-employed individuals about ₹ 818/day.[21,22,23] These average wages are used as a proxy for the average wage (W_i) for the days of flood in August 2024.

It is assumed that the number of workdays lost (D_i) due to flooding was 3, based on newspaper reports of the flooding and the rainfall data of Ahmedabad.

Therefore,

$\text{Income Loss}_{\text{daily wagers}} = \{(23{,}538 \times 498) + (89{,}548 \times 818)\} \times 3 = 25{,}49{,}16{,}564$

Thus, the estimated income loss for daily wage

19 World Bank. (n.d.). Population ages 0 – 14 (% of total population) – India (Indicator SP.POP.0014.TO.ZS). https://data.worldbank.org/indicator/SP.POP.0014.TO.ZS?locations=IN

20 Ministry of Statistics & Programme Implementation. (2024). Quarterly Bulletin PLFS, July–September 2024. https://mospi.gov.in/sites/default/files/publication_reports/QuarterlyBulletinPLFS_July_September_2024.pdf

21 Wikipedia. (n.d.). Income in India. In Wikipedia. https://en.wikipedia.org/wiki/Income_in_India

22 National Herald India. (2019, July 18). Gujarat's regular, casual workers earn less than 19 top states. National Herald India. https://www.nationalheraldindia.com/india/gujarats-regular-casual-workers-earn-less-than-19-top-states

23 Labour & Employment Department, Government of Gujarat. (2024, October 3). Minimum wages in Gujarat w.e.f. 01-10-2024 to 31-03-2025 (Notification No. 3/525/2024). https://rajconjnd.com/xl-rajconsultancy/upload/news/rajconsultancy-398.pdf

workers due to the August 2024 urban flood in Ahmedabad is approximately ₹25,49,16,564 (₹25.49 crores).

Please note that this aggregate estimate represents the higher end of potential income loss for casual laborers and self-employed individuals in the city, as it is based on broad proxy assumptions for the affected workforce and related parameters. For greater precision, it is recommended to overlay work zone and flood maps with disaggregated worker and workplace distribution data at the city or ward level to better capture the differentiated impacts of flood events on the working population.

Methods Box 2.6.2: Income Loss Estimation – Ahmedabad August 2024 Flood

Objective: Estimate short-term income loss to the working population affected by urban waterlogging and flooding during the August 2024 heavy rainfall in Ahmedabad.

Event Overview:

Continuous heavy rainfall (> 100 mm/day) over 2–3 days in early August 2024 led to urban waterlogging in low-lying wards (primarily east and south-central Ahmedabad), disrupting transport, markets, and business operations. The event lasted 48–72 hours; recovery to near-normal conditions took ~1 week. Official reports documented ~40–50 deaths, extensive vehicle traffic disruption, and market closures (see event timeline in Annex).

Step 1: Identify Affected Population

Flood-prone zone definition: Using AMC's flood vulnerability maps (CRCAP 2023), wards/zones with flood depth > 0.5 m or waterlogging for >12 hours are classified as affected. These zones cover ~4.3% of the city area and include slums, low-lying commercial areas, and informal markets.

Population in flood-prone zones: From the 2021 Census and AMC data, ~9.5% of Ahmedabad's 2021 population (~71.8 million) is residing in flood-prone zones ≈ 6.8 million persons.

Subset to working population: Assuming 60% of the population is in the working age (15–65 years) and ~45% are economically active (labor force participation), and the affected working population ≈ 1.8 million workers.

Affected by current event: Not all workers in flood-prone zones were able to work during the 2–3-day event. Assumptions about disruption vary by sector:

- Formal sector (office, factory workers; 25% of affected workers): Limited disruption if workplaces were not in inundated zones or were located outside the flood zone. Assumption: 50% of formal workers experienced >50% reduction in work days. Disrupted formal workers ≈ 225,000.
- Informal sector (street vendors, daily laborers, transport workers; 60% of affected workers): High disruption due to water inundation, transportation barriers, and market closure. Assumption: 80% experienced complete (100%) disruption during the 3-day event. Disrupted informal workers ≈ 864,000.
- Trade and services (shop owners, service providers; 15% of affected workers): Moderate disruption; small shops closed, large stores partially operated. Assumption: 70% experienced >50% disruption. Disrupted workers ≈ 189,000.

Total workers experiencing income loss ≈ 1,278,000 (central estimate; range: 800,000–1,600,000 depending on disruption assumptions).

Step 2: Estimate Daily Income Loss Per Worker

- Formal sector workers: Average monthly salary (Census/PLFS data): INR 25,000–30,000. Daily wage ≈ INR 1,200 (assuming 22 working days/month). Income loss per disrupted day = INR 1,200.
- Informal sector workers (street vendors, manual laborers, transport workers): Daily earnings vary (INR 300–800/day based on occupational subcategory). Use conservative average: INR 500/day.
- Trade and services (small shop owners, service providers): Estimated daily earnings INR 800–1,500; use median INR 1,000/day.

Weighted average daily income loss (across all

sectors): (225,000 × 1,200 + 864,000 × 500 + 189,000 × 1,000) / 1,278,000 ≈ INR 617/worker/day

Step 3: Estimate Duration of Income Loss

Direct disruption period: 2–3 days of complete/near-complete disruption (August 1–3, 2024).

Extended recovery period: Partial disruption for 3–5 additional days as markets reopened, transport normalized, but demand remained depressed (customers still dealing with personal crisis, assessment of damage). Assume 50% income for these days.

Total disrupted income-days: 2.5 (full disruption) + 2.5 × 0.5 (partial disruption) = 3.75 income-days lost per worker (range: 2.5–5 days depending on sector recovery speed).

Step 4: Calculate Total Income Loss

Total Income Loss = Affected workers × Average daily income × Days disrupted

= 1,278,000 × INR 617 × 3.75 ≈ INR 2,950 crore (±45% depending on parameter uncertainty)

Central estimate: ~INR 2,950 crore (USD ~355 million)

Sensitivity Analysis:

- Low estimate (conservative assumptions): 800,000 workers × INR 450/day × 2.5 days = INR 900 crore
- High estimate (extensive disruption): 1,600,000 workers × INR 800/day × 5 days = INR 6,400 crore

Limitations & Caveats:

1. Informal sector income data are sparse. Daily earnings for street vendors and casual laborers are estimated from limited surveys; the actual range may be ±50%.
2. The disruption duration assumption is critical. Actual disruption depends on household-specific factors (distance from flood zone, occupation type, available savings); the assumption of 3.75 days is illustrative. Sensitivity testing shows doubling or halving this assumption changes the total estimate by ±50%.
3. Multiplier effects excluded. Total economic loss is likely larger than direct income loss due to supply-chain disruption, business failure, and deferred consumption; this estimate captures only direct income loss to workers, not broader macroeconomic effects.
4. Recovery dynamics underspecified. The assumption of linear recovery over 3–5 days is a simplification; actual recovery is heterogeneous (some workers recover faster, others face prolonged disruption).
5. Not all income loss is permanent L&D. Many workers recovered income in the following weeks as markets reopened; the loss is a temporary disruption. However, households dependent on daily income (informal workers) who lack savings experience this as immediate material deprivation.

Data Quality Assessment: MODERATE-TO-LOW. Dependent on sector-level assumptions and limited primary income data; should be treated as an order-of-magnitude estimate with substantial uncertainty ranges provided.

2.6.3 Increased Health-related Issues (NELD)

To quantify the indicator loss due to increased health-related issues from a climate event, an illustrative example focusing on children, one of the most affected groups, and the impact of heatwaves is presented. Specifically, the health impacts of heatwave events in Ahmedabad between March and June 2024 are examined. During this period, 18 heatwave days were recorded. Using available data, the excess number of pediatric emergency cases is estimated to be attributable to these heatwaves as a basis for quantifying the monetary value of the health-related loss.

Analytical Framework and Assumptions:

1. For retrospective estimation, when historical data are available, the number of heatwave days in past years can be compared with corresponding emergency case records, and excess cases can be estimated by subtracting the average from non-heatwave periods. To support this, a Generalized Additive Model

(GAM) with a quasi-Poisson distribution and log link is used to estimate the non-linear relationship between temperature and pediatric emergency visits (Heo et al., 2018).[24] For future projections, modeling approaches are required to estimate potential impacts under different heatwave scenarios using projected exposure data.

2. Pediatric emergency case counts from reporting units across India are used, as documented in the 2024 NPCCHH report.[25] These serve as proxies since reliable state-level data for Ahmedabad was unavailable.
3. Reference (baseline) temperatures for Ahmedabad (March–June 2024) are based on historical daily mean data from 1991–2021 (27.2 °C, 31.2 °C, 33.0 °C, and 31.9 °C, respectively), and heatwave days are defined as those with maximum temperatures >40 °C.[26]
4. Based on public hospital data from Gujarat, the direct costs for pediatric emergency visits to include the most common basic services are considered—Registration (₹10), Drip with infusion (₹30), CBC lab test (₹30), ECG (₹45), X-Ray (₹80)—totaling ₹195 per case.[27]
5. Available public health center data is used, and the cost of treatment in public hospitals is applied to estimate the health-related economic burden. To account for cases treated in private healthcare facilities, it is recommended to incorporate data and estimates on the share and cost differential of private-sector utilization.

Increased Health-Related Issues (NELD) – Monetary Estimation using Cost-of-Illness

Methods Box 2.6.3: Health Impact Valuation – Heat-Related Morbidity in Ahmedabad (Illustrative)

Objective: Estimate monetary value (in terms of health costs + productivity loss) from heat-related morbidity during peak summer months (May–June) in Ahmedabad.

Background: Ahmedabad has experienced repeated heatwaves (>42°C) resulting in heat exhaustion, heat stroke, and exacerbation of chronic diseases. Medical camps operated by AMC and NGOs have recorded cases; deaths have been documented (Figure 12, p. 68: 68 deaths in 2015). Non-fatal heat morbidity is far more common but underreported.

Step 1: Estimate Heat-Attributable Health Burden

A. Exposure-response function (Temperature–Health Relationship):

- Use established epidemiological relationships between ambient temperature (or heat index) and health outcomes (morbidity/mortality).
- From Indian studies (Kinney et al., 2020; Hajat & Kosatsky, 2010), the relationship is typically non-linear: health effects increase sharply above a threshold temperature (~35–38°C depending on local acclimatization).
- For Ahmedabad, the threshold ~ 40°C is based on HAP and local data.
- Quantify: For each degree above threshold, morbidity increases by ~2–5% (literature-based estimate; specific for Ahmedabad unavailable, so borrowing from regional studies).

B. Exposure data (temperature and affected population):

- Days with T > 40°C in May–June 2023: 35 days (IMD data); average daily max temperature on high-heat days ~42°C, i.e., 2°C above threshold.
- Exposed population: All of Ahmedabad during these days, but vulnerable subpopulations at higher risk: outdoor workers (street vendors, construction, sanitation), elderly (>65 years), low-income households without AC/cooling.

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24 Heo, S., Bell, M. L., & Lee, J. (2018). Comparison of health risks by heat wave definition: Applicability of wet-bulb globe temperature for heat wave criteria. Environmental Research, 168, 158–170. https://doi.org/10.1016/j.envres.2018.09.032

25 Patel, P., Shamra, T., Thakur, M., Joshi, S., Ahuja, S., & Shrivastava, A. (2024). Report of heat-related activities conducted in India in 2024 (Report, National Programme on Climate Change & Human Health (NPCCHH), National Centre for Disease Control). Ministry of Health & Family Welfare, Government of India. https://ncdc.mohfw.gov.in/wp-content/uploads/2024/12/Report-of-Heat-Related-Activities-2024_NPCCHH.pdf

26 Climate Data Org. (n.d.). Ahmedabad, Gujarat Climate: Average Temperature & Weather Data [Web page]. https://en.climate-data.org/asia/india/gujarat/ahmedabad-2828/

27 Surat Municipal Institute of Medical Education & Research. (2024). Hospital service charges. Surat Municipal Corporation.

- Vulnerable population estimate (from Census and HAP): ~800,000 persons (outdoor workers + elderly + low-income).
- Assume baseline annual heat-related morbidity (outpatient visits, clinic consultations) in vulnerable population: ~40,000 cases (estimate from HAP post-event surveys and clinic reports; range 25,000–60,000 depending on screening sensitivity).

C. Attributable cases:

- Under 2°C elevation above baseline threshold, and assuming ~3% increase in cases per degree (mid-range of literature), attributable morbidity increases ≈ 2°C × 3% = 6%.
- Attributable cases ≈ 40,000 × 6% = 2,400 additional heat-related morbidity cases during May–June 2023 (range: 1,500–4,000 depending on exposure-response function elasticity).

Step 2: Estimate Cost-of-Illness (COI)

A. Direct medical costs:

- Outpatient visit (primary health center): INR 200–500 (consultation + basic diagnostics).
- Inpatient treatment (heatstroke, complications): ~30% of cases require hospitalization; average 3-day stay in government hospital @ INR 3,000–5,000/day = INR 10,000 per hospitalized case.
- Average medical cost per case (weighted): 70% outpatient × INR 300 + 30% inpatient × INR 10,000 = INR 3,210 per case.

B. Indirect costs (productivity loss):

- Days of work/activity loss per case: outpatient cases ~1–2 days; hospitalized cases ~7–10 days. Average ~2.5 days per case.
- Productivity loss valued at average daily wage: INR 500 (vulnerable pop. predominantly informal workers).
- Indirect cost per case: 2.5 days × INR 500 = INR 1,250 per case.

C. Total cost per case (COI):

- COI = Direct medical + Indirect = INR 3,210 + INR 1,250 = INR 4,460 per case.

Step 3: Calculate Total Health-Related NELD

Total NELD (health) = Attributable cases × COI per case

= 2,400 cases × INR 4,460 = INR 1.07 crore (~USD 1.3 million)

Sensitivity Analysis:

- Low estimate: 1,500 cases × INR 3,500 = INR 52.5 lakhs
- High estimate: 4,000 cases × INR 5,500 = INR 2.2 crores

Alternative metric – DALY burden:

- If assuming average case results in 0.05 DALY loss (e.g., 2 days of reduced activity = 2/365 years × disability weight of 0.1), total DALY burden ≈ 2,400 × 0.05 = 120 DALYs.
- Using India-specific value of INR 1,00,000 per DALY averted/lost, DALY-based estimate of health burden ≈ INR 1.2 crore (similar order of magnitude to COI estimate).

Limitations & Caveats:

1. The exposure-response function is borrowed from literature. Ahmedabad-specific function would require long-term health and temperature data; uncertainty range ~±50%.
2. Only direct health outcomes are included. Indirect effects (e.g., reduced nutrition intake, dehydration leading to chronic disease exacerbation) are not quantified.
3. Valuation method (COI) captures financial costs but not suffering. A person experiencing heat exhaustion faces disruption, fear, and reduced well-being that are not captured in INR.
4. Informal health-seeking behavior is underestimated. Many heat-related illnesses are managed at home with home remedies, traditional healers, or are not reported to clinics; the official count likely underestimates the true burden by 50–70%.
5. Vulnerable population definition is approximate. The actual heat risk is more nuanced (not all outdoor workers are equally

at risk; some elderly people with AC are low-risk).

Data Quality: LOW-TO-MODERATE. Based on a literature-borrowed exposure-response function and rough population estimates, it should be interpreted as illustrative of order-of-magnitude and methodological approach rather than a precise estimate. Confidence interval: ±50%

Statistical Model:

A Generalized Additive Model (GAM) with a quasi-Poisson distribution and log link function is used:

$\log(E(Y_t))=\alpha+s1(Temp_t)+s2(Rainfall)+\gamma DOW_t$

Where:

- Yt: number of pediatric emergencies on day t
- $Temp_t$: ambient maximum temperature on day t
- s1, s2: smooth functions (natural splines) capturing non-linear effects of temperature and rainfall
- DOWt: categorical variable for day of the week
- α: model intercept

Estimation:

After fitting the GAM model in R, excess pediatric emergency cases are estimated by comparing predicted counts at actual daily temperatures with those at monthly average baseline temperatures. For each day, excess cases are calculated as:

$\text{Excess Cases}_t = Y_{t,baseline} \times (Y_{t,baseline}/Y_{t,actual} - 1)$

Where $Y_{t,actual}$ is the predicted case count at the observed temperature, and $Y_{t,baseline}$ is the predicted count if the temperature had remained at the monthly average. Summing across heatwave days yields a total excess of 43,776 cases.

Monetize Using Cost of Illness (COI):

$\text{Total Cost}_t = \text{Excess Cases}_t \times \text{Cost} = 43{,}776 \times 195 = 85{,}37{,}320$

Thus, over the 18 heatwave days, the monetary impact of excess pediatric emergency cases amounted to approximately ₹85.37 lakh.

2.6.4 Loss of Life (NELD) – Monetary Valuation Using Value of Statistical Life (VSL) – ILLUSTRATIVE ONLY

ETHICAL PREAMBLE

The monetization of loss of life is ethically contentious and should be understood as a limited accounting tool, not a moral statement. A monetary valuation of a human life does not imply: (a) that a life 'costs' that amount or can be 'compensated' in cash; (b) that lives of wealthier persons are worth more than poorer persons (though VSL methods often incorporate income, inadvertently creating this effect); or (c) that loss of life is economically recoverable. The following exercise is illustrative only, and shows how public sector practitioners estimate the value of marginal mortality risk reduction when allocating prevention budgets. It is NOT appropriate for determining compensation, and it does NOT replace the primacy of preventing loss of life through adaptation and resilience measures.

Loss of life is among the most severe and irreversible consequences of climate-related disasters, yet it is also one of the most ethically and methodologically contested forms of loss to quantify, particularly in monetary terms. To demonstrate a city-level approach to quantifying the monetary value of loss of life, excess mortality is analyzed during the May 2010 heatwave in Ahmedabad (Azhar et al., 2014).[28]

Analytical Framework and Assumptions:

1. Excess mortality is estimated by comparing observed deaths during the 2010 heatwave period with average deaths from comparable non-heatwave years (2009 and 2011), based on Azhar et al. (2014).
2. It is assumed that the deviation in mortality is primarily attributable to the heatwave, with other factors held constant.
3. The economic value of life loss is estimated using the Value of Statistical Life (VSL) method. VSL is one of the most commonly used methods in public policy that represents the amount society is willing to pay to reduce the risk of one death.
4. Two VSL estimates are applied: ₹14.42

million (top-down macroeconomic scaling) and ₹44.69 million (bottom-up hedonic wage approach).

5. Each death is treated as a full statistical life lost, without adjustments for age or comorbidities, consistent with standard VSL applications.
6. This approach is retrospective and does not project future mortality or changing vulnerability patterns.

Quantification Approach:

Data on heatwave-related mortality from Azhar et al. (2014) is used to demonstrate the quantification of loss of life.

Step 1: Define the event period

- Full-month assessment: May 1–31, 2010
- Peak event: May 19–25, 2010

Step 2: Obtain observed mortality during the event period.

- May 2010 deaths: 4,462
- May 19–25, 2010 deaths: 1,515

Step 3: Calculate expected mortality based on average for May in 2009 and 2011:

- May average deaths (2009 & 2011): 3,118
- May 19–25 average deaths (2009 & 2011): approx. 714.5

Step 4: Compute excess deaths

Excess Deaths = Observed - Expected

- For May 2010: 4,462-3,118 = 1,344 excess deaths
- For peak period (May 19–25): 1,515-714.5 = 800.5 excess deaths

Monetization Approach: Value of Statistical Life (VSL)

VSL is the most commonly used method in public policy which represents the amount society is willing to pay to reduce the risk of one death.

Select an appropriate VSL range: Based on economic valuation studies from India, two estimates of the Value of Statistical Life (VSL) were identified: ₹14.42 million, derived from a top-down approach using macroeconomic scaling methods for Surat (WRI India, 2021), and ₹44.69 million, estimated through a bottom-up hedonic wage analysis based on primary data from Ahmedabad (Majumder et al., 2018).[29,30]

Apply the formula: Total Life Loss =Number of Deaths during peak period × VSL

Calculate economic loss

- **Considering VSL = ₹ 14.42 million**

800 × 14.42 million = ₹11,536,000,000 (₹1,153.6 crore)

- **Considering VSL = ₹ 44.69 million**

800 × 44.69 million = ₹35,752,000,000 (₹3,575.2 crore)

Methods Box 2.6.4: Value of Statistical Life (VSL) estimation for illustrative purposes

Objective: Provide an illustrative monetary estimate of loss of life from heat-related deaths in Ahmedabad (2015 heat wave), using VSL methodology, to show order-of-magnitude context for L&D assessment.

Background: In May–June 2015, Ahmedabad experienced an extreme heatwave, with temperatures exceeding 46°C. Official reports documented 68 heat-related deaths (data from AMC); however, it was likely underestimated, and the true count may be 150–300 based on excess mortality analysis.

29 Majumder, A., Madheswaran, S., & Institute for Social and Economic Change. (2018). **Value of Statistical Life in India: A Hedonic wage approach**. The Institute for Social and Economic Change, Bangalore. Link: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.isec.ac.in/wp-content/uploads/2023/07/WP-407-Agamoni-Majumder-and-Madheswaran-Final.pdf#:~:text=Using%20hedonic%20wage%20approach%2C%20the%20VSL%20estimated,(VSI)%20is%20INR%201.67%20million%20($0.02%20million).&text=Their%20study%20is%20based%20on%20the%20primary,million%20and%20a%20VSI%20of%20INR%204%2C876

30 Health Risk Assessment and Value of Statistical Life for Emissions Effects for Surat City https://www.suratmunicipal.gov.in/Content/Documents/Departments/AQMCell/HealthRiskAssessmentSuratCity.pdf?ver=5055



Step 1: Estimate Heat-Attributable Deaths

Official reported deaths: 68

Literature-based under-reporting factor: 1.5–3x (many heat deaths are misattributed to dehydration, cardiac complications, respiratory exacerbation). Use midpoint: 2x.

Estimated 'true' heat-attributable deaths: 68 × 2 = ~136 deaths (range: 68–204 depending on under-reporting assumptions).

Step 2: Estimate Value of Statistical Life (VSL)

VSL represents the aggregate willingness of society to pay to reduce mortality

This guide lays the foundation for cities to estimate climate-induced losses and damages through practical, data-informed methods. The examples show that even with constrained data, meaningful estimates can be developed using transparent assumptions and locally relevant techniques. To advance this work, cities can prioritize expanding access to disaggregated data, improving integration between hazard exposure and socio-economic datasets, and adapting valuation methods to reflect both market and non-market impacts. Strengthening these capabilities will enhance the accuracy, credibility, and utility of future L&D assessments.

3.

Climate Trends and Projections

Understanding past and future climate trends forms the foundation for assessing climate-induced losses and damages in urban systems. This section provides a comprehensive analysis of historical climate patterns, observed changes, and projected future scenarios for Ahmedabad and Surat.

The assessment begins with an examination of major climate-induced disasters, including heatwaves, floods, droughts, and cyclones compiled from district disaster management plans, state-level climate risk indices, and historical event databases. This analysis highlights recurring hazards and temporal patterns that have shaped each city's exposure and vulnerability.

Subsequently, a detailed trend analysis of air temperature and rainfall has been undertaken using long-term datasets from the India Meteorological Department (IMD), covering 1970–2020 for Ahmedabad and 1972–2024 for Surat. The findings indicate consistent warming trends and increasing rainfall variability, with results cross-verified against projections from the Gujarat State Action Plan on Climate Change (SAPCC, 2021) to ensure coherence between observed and modeled patterns.

The section further explores future climate projections based on downscaled Representative Concentration Pathway (RCP) scenarios, RCP 2.6 (low emissions), RCP 4.5 (medium emissions), and RCP 8.5 (high emissions) as outlined in the Gujarat SAPCC (2021). These are analyzed for the short-term (2011–2040) and mid-term (2041–2070) horizons. The projections indicate rising mean temperatures, increased frequency of hot days and nights, and higher rainfall variability, underscoring the urgency for adaptive planning and resilient urban systems.

Building on the observed trends and projected scenarios, the analysis identifies areas of high exposure under current conditions and anticipates risks in the future in subsequent chapters.

3.1 Ahmedabad

3.1.1 List of Historical Disaster Events

Based on past trends, key climate risks were identified for Ahmedabad. Historical climate data from IMD (1970–2020), Gujarat SAPCC 2021, State Disaster Management Plan (Gujarat 2016-17) and District Disaster Management Plan (Ahmedabad 2021), along with insights from scenario projections, were used to validate these findings and corroborate the results. Table 6 below presents a snapshot of climate-related hazards historically recorded in Ahmedabad district.

Table 6: History of climate-related hazards in Ahmedabad district

Year	Hazards			
	Heat Wave	Flood	Drought	Cyclone
2000				
2001				
2002				
2003				
2004				
2005				
2006				
2007				
2008				
2009				
2010				
2011				
2012				
2013				
2014				
2015				
2016				
2017				
2018				
2019				
2020				
2021				
2022				

Source: Disaster Management Plan for Ahmedabad District, 2021

Key observations:

- Ahmedabad faces a very high risk of extreme heat events and urban flooding[31], as identified by Gujarat's Composite Risk Index[32].
- Recurring heatwaves during summer months have been observed consistently over the past decade, with increasing frequency and intensity.
- The city is vulnerable to flash floods, particularly during water discharge from the Sabarmati River and Dharoi Dam.
- Urban flooding risk is exacerbated by high-intensity rainfall events and inadequate drainage systems in several low-lying urban areas.
- Future climate projections indicate a continued rise in average temperatures, increased frequency of heatwaves, and more intense extreme rainfall events, further amplifying urban climate risks.

3.1.2 Climate Trends

Air Temperature Trend Analysis

Annual and seasonal temperature trends for Ahmedabad from 1970 to 2020 were analyzed using data from the Indian Meteorological Department (IMD). The analysis focused on annual, maximum, and minimum temperatures, as well as the frequency of hot and cold days and nights.

- Average Annual Temperature: Increased by 0.15°C per decade during 1970–2020 (Figure 6)
- Average Maximum Temperature: Increased by 0.06°C per decade.
- Average Minimum Temperature: Increased by 0.26°C per decade.

31 Gujarat State Disaster Management Plan Volume 1 2016-17, GSDMA.
32 Prepared by Gujarat State Disaster Management Authority (GSDMA), as a part of the State Disaster Management Action Plan 2016-17

- Hot Days and Nights: From 1951 to 2019,[33] the city recorded an increase of 12–18 hot days and 18–24 hot nights, along with a decrease of 1–4 cold days and 8–12 cold nights (Table 7).
- Hot Years: Frequency of hot years per decade increased from 3 (1970–1980) to 8 (2011–2020). Between 1970 and 2020, 25 hot years[34] were recorded with temperatures above the average air temperature of 27.6°C.
- Recent Trends: Since 2014, average air temperatures have consistently risen by +0.30°C to +0.50°C, indicating a continued warming trend.

Implications:

Without effective mitigation measures, rising air temperatures may raise land surface temperature and heat index, leading to more frequent heatwaves. This could adversely affect public health, water and energy demand, and municipal service delivery and finances

Rainfall Trend Analysis

Analysis of rainfall from 1970 to 2020 indicates notable variations in both volume and intensity (Figures 8 & 9):

- Average Annual Rainfall: 800 mm, increasing by 12 mm per decade (a total rise of about 60 mm from 1970 to 2020).
- Average Number of Rainy Days: 34 days per year, showing a decreasing trend. Between 2015 and 2020, rainy days reduced by nearly 50%, averaging 18–19 days per year (Figures 8 & 9)
- Extreme Rainfall Events: Between 1970 and 2020, 10 years[35] recorded single-day rainfall exceeding 50% of the annual total, indicating a rise in short-duration, high-intensity rainfall events.
- Recent Years: In 2017 and 2020, Ahmedabad recorded very high rainfall within just 15 rainy days[36] — 1,161 mm in 2017 and 975 mm in 2020.
- Observed Urban Flooding: Certain city areas are more prone to flooding and waterlogging due to reduced stormwater carrying capacity and low infiltration rates, especially during extreme rainfall events.

Implications:

Increased rainfall coupled with fewer rainy days raises the risk of urban flooding, waterlogging, and stress on stormwater infrastructure, particularly in low-lying areas with inadequate drainage and infiltration capacity.

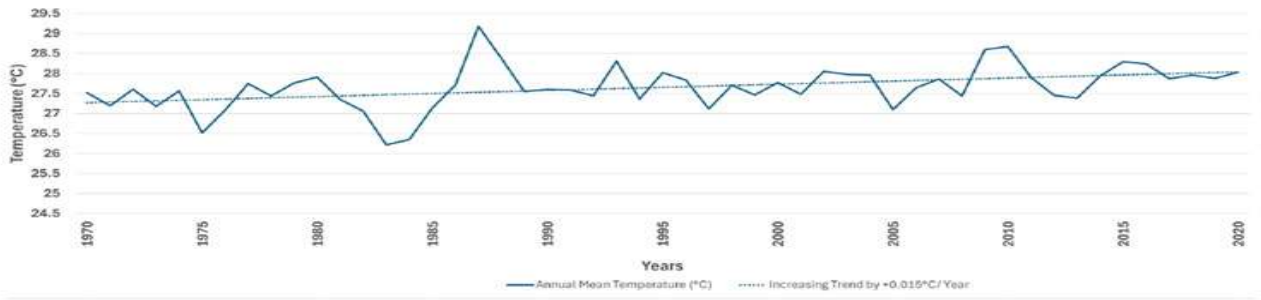


Figure 4.1 Average air temprature trend in Ahmedabad (1970 - 2020)
Source - Analysed by ICLEI South Asia, based on data received from IMD from year 1970 to 2020

Figure 6: Average Air Temperature trend in Ahmedabad (1970-2020)

33 Gujarat Climate Change Department. (2021). Gujarat State Action Plan on Climate Change (SAPCC 2021). Government of Gujarat. https://climatetracker.gujarat.gov.in/uploads/images/SAPCC/Gujarat%20State%20Action%20Plan%20on%20Climate%20Change_compressed.pdf

34 Years with hotter average air temperatures compared to mean are considered hot years.

35 Extreme rainfall in a day (more than 400mm) was recorded in 1975, 1976, 1977, 1985, 1990, 1994, 1997, 2000, 2005 and 2014.

36 As per Ahmedabad District Disaster Management Plan, in 2017, 10,000 people (2,081 families) were affected due to intense rainfall in the district. More than 950 houses were damaged and 20 people died.

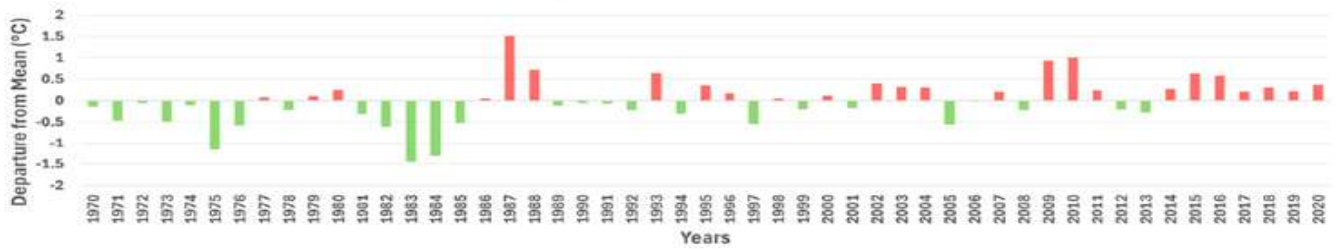


Figure 4.2 Anomalies in average air temperature in Ahmedabad (1970 to 2020)
Source - Analysed by ICLEI South Asia, based on data received from IMD from year 1970 to 2020

Figure 7: Anomalies in average air temperature in Ahmedabad (1970 - 2020)

Table 7: Temperature trend based on SAPCC (Gujarat 2021) and analysis from IMD data from 1970 - 2020

Temperature Trend (1951 to 2019 as per SAPCC)	Specifics (Ahmedabad City)
Change in Maximum Temperature	Increase by 0.5 to 1°C. (Increase by 0.3°C based on analysis from IMD data from 1970 to 2020 for Ahmedabad city)
Change in Average Temperature	Increase by 0.5 to 1°C (Increase by 0.75°C based on analysis from IMD data from 1970 to 2020 for Ahmedabad city)
Change in Minimum Temperature	Increase by 0.5 to 1°C (Increase by 1.3°C based on analysis from IMD data from 1970 to 2020 for Ahmedabad city)
Change in Number of Hot Days	Increase by 12 to 18 days
Change in Number of Hot Nights	Increase by 18 to 24 nights
Change in Number of Cold Days	Decrease by 0 to 4 days
Change in Number of Cold Nights	Decrease by 8 to 12 nights
Change in Heatwave Events	Increase by 4 heatwave events per year

Table 8: Rainfall trend based on SAPCC (Gujarat 2021) and analysis from IMD data from 1970 to 2020

Rainfall Trend (1951 to 2019)	Specifics (Ahmedabad City)
Change in Precipitation	Increase by 100 mm to 200 mm. (Increase by 60 mm based on analysis from IMD data from 1970 to 2020 for Ahmedabad city)
Extreme Rainfall Event	Increase by 3 to 4 events
Change in Extreme Wet Event	Increase by 1 to 2 events

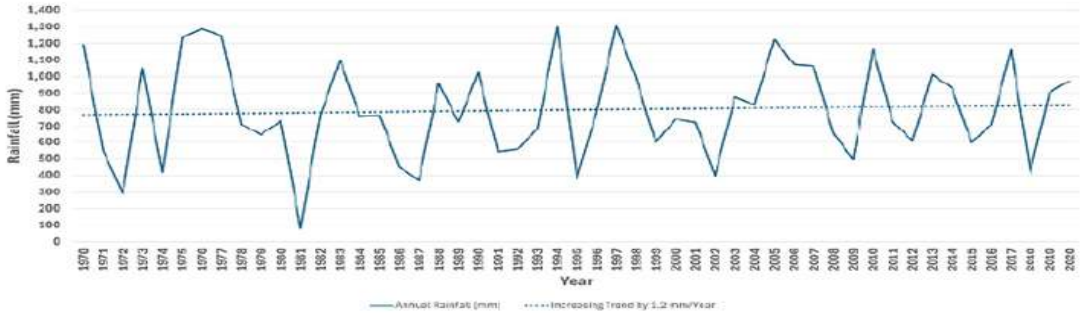


Figure 4.3 Annual rainfall trend in Ahmedabad (1970 to 2020)
Source - Analysed by ICLEI South Asia, based on data received from IMD from year 1970 to 2020

Figure 8: Annual rainfall trend in Ahmedabad (1970 to 2020)

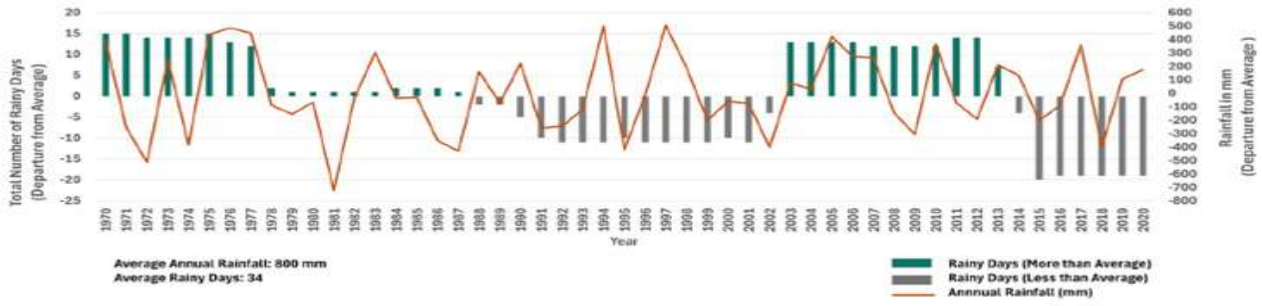


Figure 4.4 Anomalies in annual rainfall and rainy days (1970 to 2020)
Source - Analysed by ICLEI South Asia, based on data received from IMD from year 1970 to 2020

Figure 9: Anomalies in annual rainfall and rainy days (1970 to 2020)

3.1.3 BAU Climate Scenarios (based on downscaled RCP models)

3.1.3.1 Methodological Details

Data and Downscaling Approach:

Observed Climate Data:

- Source: Indian Meteorological Department (IMD)
- Variables used: Daily precipitation and daily temperature (maximum, minimum, and mean) at 0.25° × 0.25° resolution (1951–2019).
- IMD gridded datasets serve as the observed baseline for analysis

Climate Model Projections:

- Models used: Five CMIP5 Global Climate Models — BNU-ESM, CESM1-CAM5, GFDL-ESM2M, MPI-ESM-LR, and NorESM1-M — in gridded format at ~0.5° × 0.5° resolution.
- Projection period: 1951–2100; historical reference period: 1971–2000.
- RCP scenarios analyzed: RCP 2.6, RCP 4.5, and RCP 8.5, representing a range from low- to high-emission futures.
- Future time slices assessed:
  - Near-term (2011–2040)
  - Mid-term (2041–2070)
  - Far-term (2071–2100)

Bias correction: It is not mentioned in the SAPCC document. Assuming without bias correction, model biases in baseline climate are projected forward, potentially amplifying errors.

Limitations of the document:

- Downscaling resolution (~50 km) is coarse for city-scale impacts. Microclimatic variations (urban heat island, local drainage patterns, intra-city temperature gradients) are not captured. Heatwave intensity in dense urban cores is likely higher than what the model suggests.
- GCMs represent large-scale climate dynamics well but struggle with extreme events and local forcing. The probability of tail-end extreme events is often underestimated.
- No internal variability or cascading effects. Models do not capture, for example, feedback between vegetation loss (due to heat stress) and further temperature increase, or interaction between heat and monsoon patterns.

The Gujarat SAPCC (2021) includes climate projections from three RCP scenarios, RCP 2.6, RCP 4.5, and RCP 8.5, which reflect high, medium, and low efforts to curb emissions, respectively. These scenarios are modeled for short-term (2011 to 2040), mid-term (2041 to 2070), and long-term (2071 to 2100) periods. Given that the target year for the Net Zero Climate Resilient City Action Plan for Ahmedabad is 2070, short-term and mid-term climate scenarios are considered for further analysis. Details of climate projections derived from SAPCC (Gujarat 2021) are shown in Tables 9 and 10.

Table 9: Future climate projection trends-based on RCP 2.6, 4.5 and 8.5 scenarios

Future Trend	RCP 2.6 (2011-2040)	RCP 2.6 (2041-2070)	RCP 4.5 (2011-2040)	RCP 4.5 (2041-2070)	RCP 8.5 (2011-2040)	RCP 8.5 (2041-2070)
Temperature						
Average Maximum Temperature	Increase by 1 to 1.5 °C	Increase by 1 to 1.5 °C	Increase by 1 to 1.5 °C	Increase by 1.5 to 2 °C	Increase by 1 to 1.5 °C	Increase by 2 to 3 °C
Average Mean Temperature	Increase by 0.5 to 1 °C	Increase by 1 to 1.5 °C	Increase by 1 to 1.5 °C	Increase by 1.5 to 2 °C	Increase by 1 to 1.5 °C	Increase by 2 to 3 °C
Average of Minimum Temperature	Increase by 0.5 to 1 °C	Increase by 1 to 1.5 °C	Increase by 1 to 1.5 °C	Increase by 1.5 to 2 °C	Increase by 1 to 1.5 °C	Increase by 2 to 3 °C
Frequency of Hot Days	Increase by 15 to 20 days	Increase by 30 to 35 days	Increase by 25 to 30 days	Increase by 35 to 40 days	Increase by 30 to 40 days	Increase by 50 to 60 days
Frequency of Hot Nights	Increase by 30 to 35 nights	Increase by 40 to 45 nights	Increase by 35 to 40 nights	Increase by 60 to 65 nights	Increase by 50 to 60 nights	Increase by 100 to 110 nights
Frequency of Cold Days	Decrease by 22 to 24 days	Decrease by 28 to 29 days	Decrease by 22 to 24 days	Decrease by 32 to 34 days	Decrease by 22 to 24 days	Decrease by 34 to 36 days
Frequency of Cold Nights	Decrease by 24 to 26 cold nights	Decrease by 24 to 26 cold nights	Decrease by 20 to 22 cold nights	Decrease by 28 to 30 cold nights	Decrease by 26 to 28 cold nights	Decrease by 34 to 36 cold nights
Projected Number of Heatwave Days per Year	Increase by 0 to 5 days	Increase by 5 to 10 days	Increase by 5 to 10 days	Increase by 20 to 25 days	Increase by 5 to 10 days	Increase by 25 to 30 days
Rainfall scenario						
Average Precipitation	Increase by 0 to 20mm	Decrease by 0 to 20mm	Increase by 0 to 20mm	Increase by 20 to 40mm	Increase by 20 to 40mm	Increase by 40 to 60mm
Extreme Precipitation Wet Events	Decrease by 0 to 0.25 events	Decrease by 0 to 0.25 events	Decrease by 0 to 0.25 events	Increase by 0 to 0.25 events	Increase by 0 to 0.25 events	Increase by 0 to 0.25 events

Table 10: Climate Scenario Statements for Ahmedabad

Climatic Condition	Climate Scenario Statements
Change in Temperature	Temperature in Ahmedabad is expected to further increase by 1°C to 3°C by 2070 (RCP 2.6, RCP 4.5, and RCP 8.5 scenarios). Frequency of hot days is expected to increase by 15 to 60 days; frequency of hot nights is expected to increase by 30 to 110 nights by 2070 (RCP 2.6, RCP 4.5, and RCP 8.5 scenarios). Frequency of cold days is expected to decrease by 22 to 36 days; frequency of cold nights is expected to decrease by 20 to 36 nights by 2070 (RCP 2.6, RCP 4.5, and RCP 8.5 scenarios).
Extreme Heat Events	Heatwave events in Ahmedabad are expected to increase by 5 to 30 days by 2070 (RCP 2.6, RCP 4.5, and RCP 8.5 scenarios).
Change in Rainfall	Rainfall in Ahmedabad is expected to increase by 20 mm to 60 mm by 2070 (RCP 2.6, RCP 4.5, and RCP 8.5 scenarios).
Extreme Rainfall Events	Extreme rainfall events in Ahmedabad are expected to increase by 0 to 0.25 events by 2070 (RCP 2.6, RCP 4.5, and RCP 8.5 scenarios).

3.2 Surat

3.2.1 List of historical Disaster Events

Based on past trends, key climate hazards were identified. Information from the State Disaster Management Plan (Gujarat 2016-17), Surat District Disaster Management Plan (2024), and Disaster Management and Preparedness Plan 2024, as well as other research reports and stakeholder consultations, were used to validate the results. Table 11 below shows a snapshot of the history of climate-related hazards in Surat district.

Key observations:

- Surat is highly susceptible to urban floods and heatwaves, corroborated by Gujarat's Composite Risk Index[37].
- Frequent flooding has been observed along low-lying areas near the Tapi River and in neighborhoods with poor drainage infrastructure.
- Heatwave incidents have increased in recent decades, particularly impacting densely populated residential areas.

These historical patterns highlight the need for proactive adaptation and disaster preparedness planning, particularly for heat and flood-risk management.

3.2.2 Climate Trends

Air Temperature Trend Analysis

Annual and seasonal temperature trends for Surat from 1972 to 2024 were analyzed using data from the Indian Meteorological

Table 11: History of climate-related hazards in Surat district

Year	Hazards			
	Heat Wave	Heavy Rain	Flood	Cyclone
1990				
1994				
1998				
2001				
2002				
2003				
2004				
2005				
2006				
2007				
2008				
2009				
2010				
2011				
2012				
2013				
2014				
2015				
2016				
2017				
2018				
2019				
2020				
2021				
2022				

37 Gujarat State Disaster Management Authority (GSDMA), as a part of the State Disaster Management Action Plan 2016-17

Department (IMD). The analysis focused on minimum, mean, and maximum temperatures, as well as the frequency of hot days and nights.

- Average Annual Temperature: Increased by 0.10°C per decade over the period.
- Average Maximum Temperature: Slight decrease of 0.11°C per decade.
- Average Minimum Temperature: Increased by 0.19°C per decade.
- Hot Years: Frequency of hot years per decade increased from 5 (1972–1982) to 11 (2014–2024). Between 1972 and 2024, 30 hot years were recorded with temperatures exceeding the average air temperature of 27.8°C.
- Recent Trends: Since 2014, average air temperatures consistently rose by +0.15°C to +0.58°C, indicating a sustained warming trend.

Implications: Rising temperatures and increasing frequency of hot days and nights pose challenges to human health, energy demand, and urban infrastructure.

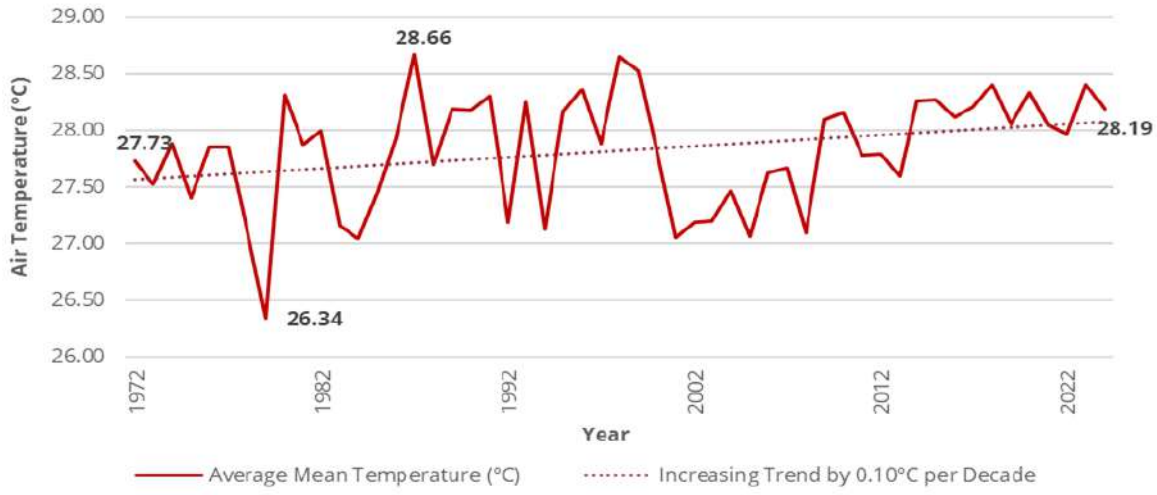


Figure 10: Average air temperature trend in Surat (1972-2024)

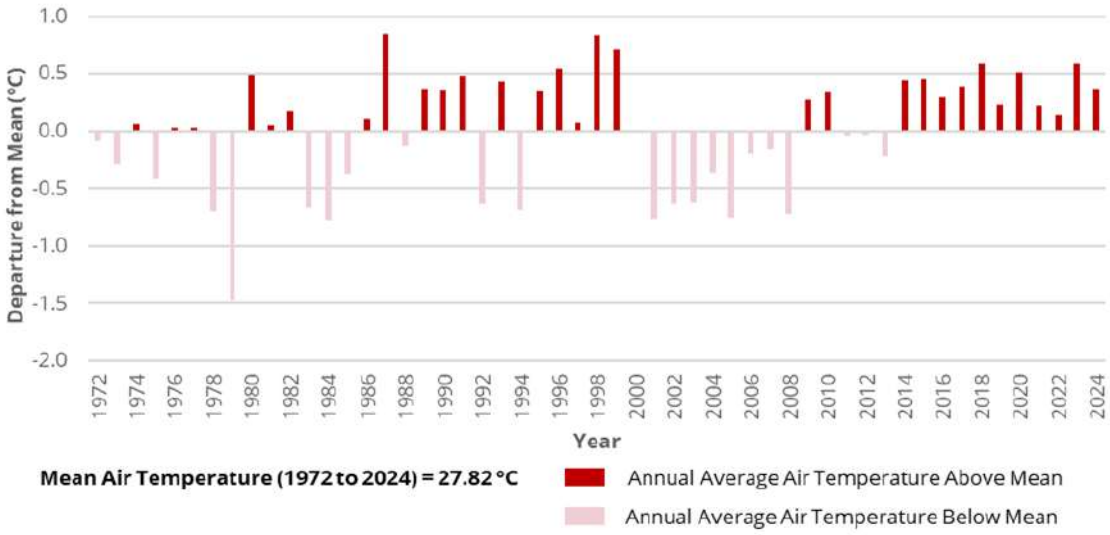


Figure 11: Anomalies in average air temperature in Surat (1972-2024)

Table 12: Temperature trend based on SAPCC (Gujarat 2021)

Temperature Trend (1951 to 2019 as per SAPCC 2021)	Observed Trend for Surat
Change in Maximum Temperature[38]	Has not increased between 1951 and 2019
Change in Average Temperature[39]	Increased by up to 0°C to 0.5°C
Change in Minimum Temperature[40]	Increased by up to 0.5°C to 1°C
Change in Number of Hot Days	Increased up to 0 to 6 days
Change in Number of Hot Nights	Increased up to 12 to 18 nights
Change in Number of Cold Days	Increased up to 8 to 12 days
Change in Number of Cold Nights	Decreased to 4 to 8 nights
Change in Heat Wave Events	Increased up to 4 to 4.2 events

Rainfall Trend Analysis

Analysis of rainfall from 1972 to 2024[41] indicates significant changes in both volume and intensity:

- Average Annual Rainfall: 1,186.2 mm, increasing at 19 mm per decade.
- Average Number of Rainy Days: 42 days per year, increasing by 2 days per decade. Between 2014 and 2024, there were six years with over 42 rainy days, and in four of these years, the total annual rainfall exceeded 1,186.2 mm.
- Extreme Rainfall Events: In some years, single-day rainfall reached 50% of the annual total, causing localized flooding.
- Observed Urban Flooding: Significant events occurred in 2002, 2006, and 2013, linked to heavy rainfall, insufficient drainage, and low soil infiltration capacity.

Implications: Increased rainfall intensity and frequency of extreme events exacerbate urban flooding and waterlogging, particularly in low-lying areas with inadequate stormwater management.

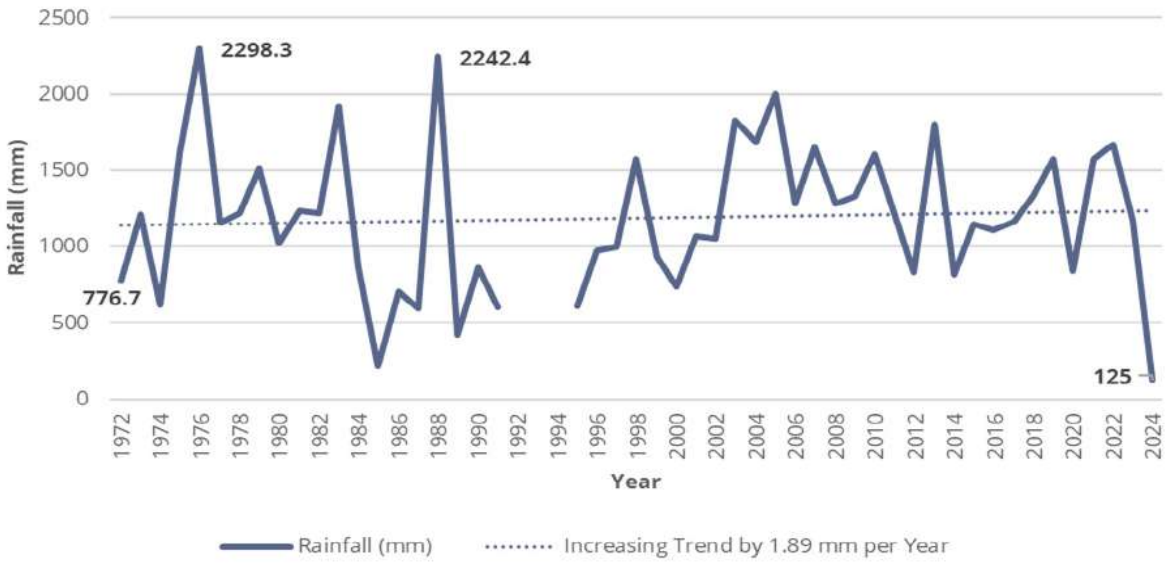


Figure 12: Annual rainfall trend in Surat (1972 to 2024)

38 Decrease by 0.07 °C based on analysis from IMD data for 1972 to 2024 for Surat city.
39 Increase by 0.46 °C based on analysis from IMD data for 1972 to 2024 for Surat city.
40 Increase by 0.98 °C based on analysis from IMD data for 1972 to 2024 for Surat city.
41 IMD rainfall records for 1992–1994 are unavailable; data discrepancies for 2024 were excluded from analysis.

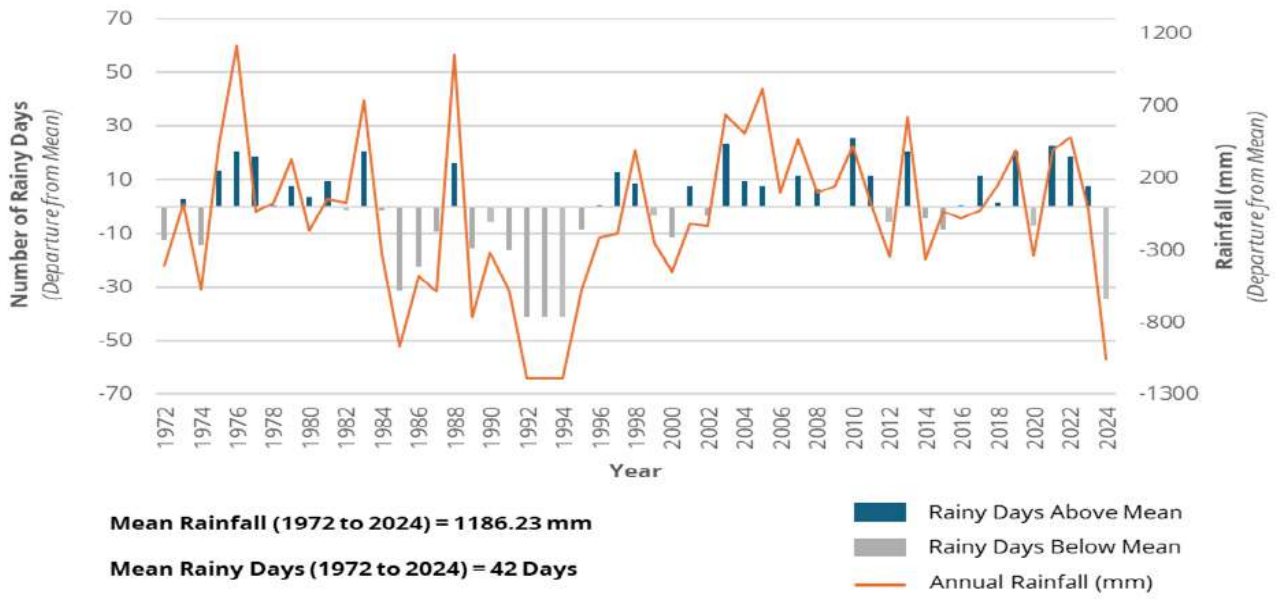


Figure 13: Anomalies in annual rainfall and rainy days for Surat city (1972-2024)

Table 13: Rainfall trend based on SAPCC (Gujarat 2021)

Rainfall Trend (1951 to 2019)	Observed Trend for Surat City)
Change in Precipitation	Increase by 100 mm
Extreme Rainfall Events	Increase by 4 to 5 events
Change in Extreme Wet Events	Increase by 4 to 5.5 events

3.2.3 BAU Climate Scenarios (based on downscaled RCP models)

Future climate projections were developed using RCP2.6 (low), RCP4.5 (medium), and RCP8.5 (high) emission scenarios for short-term (2011–2040) and mid-term (2041–2070) horizons.

Table 14: Future climate projection trends based on RCPs 2.6, 4.5, and 8.5 scenarios

Future Trend	RCP 2.6 (low emission pathway/scenario)		RCP 4.5 (mid emission pathway/scenario)		RCP 8.5 (high emission pathway/scenario)	
	2011 to 2040 (short term)	2041 to 2070 (mid-term)	2011 to 2040 (short term)	2041 to 2070 (mid-term)	2011 to 2040 (short term)	2041 to 2070 (mid-term)
Temperature						
Average Maximum Temperature	0.5 to 1 °C increase	1 to 1.5 °C increase	0.5 to 1 °C increase	1.5 to 2 °C increase	0.5 to 1 °C increase	2 to 3 °C increase
Average Mean Temperature	1 to 1.5 °C increase	1 to 1.5 °C increase	1 to 1.5 °C increase	1.5 to 2 °C increase	1 to 1.5 °C increase	2 to 3 °C increase
Average of Minimum Temperature	1 to 1.5 °C increase	1 to 1.5 °C increase	1 to 1.5 °C increase	1.5 to 2 °C increase	1 to 1.5 °C increase	2 to 3 °C increase
Frequency of Hot Days	20 to 30 days increase	30 to 35 days increase	25 to 30 days increase	40 to 45 days increase	30 to 40 days increase	50 to 60 days increase

Future Trend	RCP 2.6 (low emission pathway/scenario)		RCP 4.5 (mid emission pathway/scenario)		RCP 8.5 (high emission pathway/scenario)	
	2011 to 2040 (short term)	2041 to 2070 (mid-term)	2011 to 2040 (short term)	2041 to 2070 (mid-term)	2011 to 2040 (short term)	2041 to 2070 (mid-term)
Frequency of Hot Nights	35 to 40 days increase	45 to 50 days increase	30 to 40 days increase	65 to 70 days increase	30 to 40 days increase	100 to 110 days increase
Frequency of Cold Days	23 to 24 days decrease	28 to 29 days decrease	24 to 26 days decrease	34 to 36 days decrease	24 to 26 days decrease	34 to 36 days decrease
Frequency of Cold Nights	24 to 26 days decrease	28 to 29 days decrease	24 to 26 days decrease	32 to 34 days decrease	24 to 26 days decrease	34 to 36 days decrease
Projected number of Heatwave Days per year	0 to 5 increases	10 to 15 increases	5 to 10 increases	10 to 15 increases	5 to 10 increases	20 to 30 increases
Rainfall Scenario						
Average Precipitation	0 to 20 mm decrease	60 to 80 mm decrease	0 to 20 mm decrease	20 mm decrease to 20 mm increase	20 to 60 mm increase	40 to 60mm increase
Extreme Precipitation Wet Events	0.25 to 0.5 decrease	0.5 to 1 decrease	0.5 to 0.75 decrease	0.25 to 0.5 decrease	0.25 to 0.5 decrease	0 to 0.5 decrease

Table 15: Climate Scenario Statements for Surat

Climatic Condition	Climate Scenario Statements	Anticipated Risks
Change in Temperature	Temperature in Surat is expected to further increase by 0.5°C to 3°C by 2070 (RCP 2.6, RCP 4.5, and RCP 8.5 scenarios). Frequency of hot days is expected to increase by 20 to 60 days; frequency of hot nights is expected to increase by 35 to 110 nights by 2070 (RCP 2.6, RCP 4.5, and RCP 8.5 scenarios). Frequency of cold days is expected to decrease by 23 to 36 days; frequency of cold nights is expected to decrease by 24 to 36 nights by 2070 (RCP 2.6, RCP 4.5, and RCP 8.5 scenarios).	Temperature rise and more frequent hot days and nights are expected across all scenarios, increasing heat stress for residents.
Extreme Heat Events	Heatwave events in Surat are expected to increase by 5-30 days by 2070 (RCP 2.6, RCP 4.5, and RCP 8.5 scenarios).	Heatwave days are projected to increase, requiring robust heat action plans.
Change in Rainfall	Rainfall in Surat is expected to increase by 20-60 mm by 2070 (RCP 2.6, RCP 4.5, and RCP 8.5 scenarios).	Recent decades have seen more frequent but intense rainfall events, underscoring the need for robust stormwater management and climate-resilient urban planning.
Extreme Rainfall Events	Extreme rainfall events in Surat are expected to decrease by 0-0.5 events by 2070 (RCP 2.6, RCP 4.5, and RCP 8.5 scenarios).	Slight reduction in extreme events, but localized flood risk persists

3.2.3.1 Interpretation of Trends for Risk Assessment:

While absolute temperature and rainfall values are important, risk-relevant indicators are more useful for adaptation planning. Examples for Ahmedabad and Surat:

Heat-related risk indicators:

- Number of days per year with T > 40°C (health threshold): Observed trend shows increase from ~30 days/year (1970s) to ~50 days/year (2020s); projections suggest 80–120 days/year by 2050 (depending on RCP).
- Number of consecutive hot days (heatwave definition per IMD: ≥3 consecutive days with T > normalized max): Frequency and intensity increasing.
- Heat index (apparent temperature accounting for humidity): More relevant for health than dry-bulb temperature; typically, 3–5°C higher than dry-bulb in monsoon season.

Rainfall-related risk indicators:

- Number of days with rainfall > 100 mm/day (intense event threshold): Frequency increasing; recurrence interval decreasing.
- Coefficient of variation of annual rainfall: Increasing trend suggests greater rainfall variability, implying more frequent droughts and floods within the same year.
- Monsoon onset and withdrawal dates: Shifts in monsoon timing are already observed; implications for water supply and agriculture timing.

3.3 Spatial Mapping of existing and future climate risk projections

This assessment relies on hotspot identification based on current conditions, coupled with population projections derived from Shared Socioeconomic Pathways (SSPs) to estimate the potential scale of affected populations and infrastructure under future climate scenarios.

3.3.1 Methodology

Urban Heat

Urban heat hotspots were assessed by analyzing the LST for May, the hottest month, for both day and night. The urban heat assessment for Ahmedabad and Surat applied an integrated methodology combining historical temperature trend analysis, satellite-based surface temperature evaluation, and heat stress assessment (see Table 9.1). Historical air temperature trends were analyzed using daily and annual data from 1970 to 2020 for Ahmedabad and 1972 to 2024 for Surat, sourced from IMD stations, to evaluate changes in minimum, mean, and maximum temperatures. LST analysis was carried out through temporal, pixel-based statistical analysis of day and night satellite imagery—covering 2015, 2018, and 2021 for Ahmedabad, and 2016, 2020, and 2024 for Surat—to identify hotspot areas with consistently higher surface temperatures above 37°C and 41°C respectively, using LandSat8 (30m) for daytime and MODIS (500m–1km) for nighttime data. For Ahmedabad, the heat index or "feel-like" temperature was assessed using May 2021 data from AMC's 50 environmental sensors and 10 air quality monitoring stations, correlating air temperature and humidity as per NDMA's national heatwave guidelines. Additionally, heatwave[42] trends were analyzed for 2015–2021 by correlating monthly heatwave warning days with reported heat stroke cases and deaths during summer months.

Urban Flooding

The urban flood assessment for Ahmedabad and Surat employed a comprehensive approach that combined historical rainfall trend analysis, spatially mapping flood points, and health risk correlation (see Table 9.2). The impact of waterlogging and urban flooding was assessed by overlaying flood points and areas with layers of natural drainage patterns, the city's stormwater drainage network, and the road network.

42 Heat wave events: Heat wave event is said to occur when maximum temperature of a station reaches at least 400°C or more for plains and at least 300°C or more for hilly regions (IMD)

Historical rainfall patterns were analyzed using daily and annual data from 1970–2020 for Ahmedabad and 1972–2024 for Surat, obtained from IMD stations, to assess changes in annual rainfall, rainy days, and frequency of extreme rainfall events. Flood-prone and water-logged areas were identified through satellite imagery and Digital Elevation Model (DEM) analysis by overlaying natural contours, streamlines, flood points, stormwater and road networks, and built-up areas (from Google Earth). High-risk zones were defined within a 250 m buffer of 166 flood points in Ahmedabad and 46 in Surat, verified using stakeholder consultations and field-level information from AMC and SMC. For Ahmedabad, 30×30 m resolution LandSat 8 imagery (May 2021) supported spatial analysis. Further, flood-prone zones were overlaid with ward-level health data to correlate flood exposure with incidences of water- and vector-borne diseases using 2021 data for Ahmedabad and 2024 for Surat, sourced from the respective city health departments.

3.3.2 Ahmedabad

Urban Heat

Urban heat analysis in Ahmedabad indicates a rising trend in air temperature and land surface temperature, with daytime LST ranging from 29°C to 47°C, revealing prominent urban heat hotspots. The city's heat index ('feels-like' temperature) frequently exceeds 43°C, highlighting zones of high thermal discomfort and health risk. Increasing frequency of heatwave events has been observed, closely linked to higher incidences of heat-related illnesses and mortality, emphasizing the growing vulnerability of Ahmedabad's population to extreme heat. The 2010 heatwave in Ahmedabad resulted in a documented excess of ~1,300–1,344 deaths in May 2010, and subsequently, a Heat Action Plan was introduced in 2013 (later updated in 2019) to reduce such impacts. Heat drives acute heatstroke, dehydration, cardiovascular, and respiratory exacerbations. Further extreme heat intensifies urban service delivery, especially water supply, emergency healthcare infrastructure, solid waste disposal, processing and mobility (transport), which is further detailed in section 4.1 (Chapter 4).

Urban Areas Vulnerable to Extreme Heat Risk:

The city's most vulnerable areas are those with high LST and 'feels -like' temperature. Such areas include wards[43] like Amraiwadi, Bapunagar, Viratnagar, and industrial areas. Extreme heat may impact water and energy demand. As per Gujarat SAPCC (2021), the number of heatwave events has increased by 4 events from 1951 to 2019 and is expected to increase by 5-30 events by 2070. The actual increase depends on efforts to curb GHG emissions. This increase in heatwave events may have severe public health implications.

Hotspots with high surface temperature (>37°C) in Ahmedabad include:

- Newly developing areas, i.e., Science city, Gota/ Ognaj, Jundal, Nikol
- Small-scale industrial plots (Calico Mills, Piplaj Industries, Ready Mix, and Asphalt Hot Mix Plant)
- Major industrial areas and estates, i.e., Naroda, Odhav, Kathwada, and Vatva
- Ahmedabad Airport area and railway tracks
- Torrent power plant (particularly where fly ash is being dumped by a thermal power plant)
- Pirana dumpsite and scientific landfill site at Gyaspur
- Warehouses (FCI Kaligam, Railway and Metro Depot),
- Gujarat State Road Transport Corporation (GSRTC) depot and other parking areas

43 Ahmedabad Municipal Corporation, Thennarasan, M., Chaudhary, P., Khanama, V., Bhatt, R., Solanki, B., Zala, H., Nayak, V., Patel, R., Shah, A., Solanki, H., Mistry, V., Patel, J., Pandey, R. L., ICLEI South Asia, Makvana, A., Jose, A., Ghorpade, A. R., Karki, B., . . . Jain, P. (2023). Ahmedabad Climate Resilient City Action Plan (N. Indrasha, Ed.) [Report]. https://southasia.iclei.org/wp-content/uploads/2024/01/AMC-CRCAP-EXEC-SUMMARY_06JULY2023_compressed.pdf

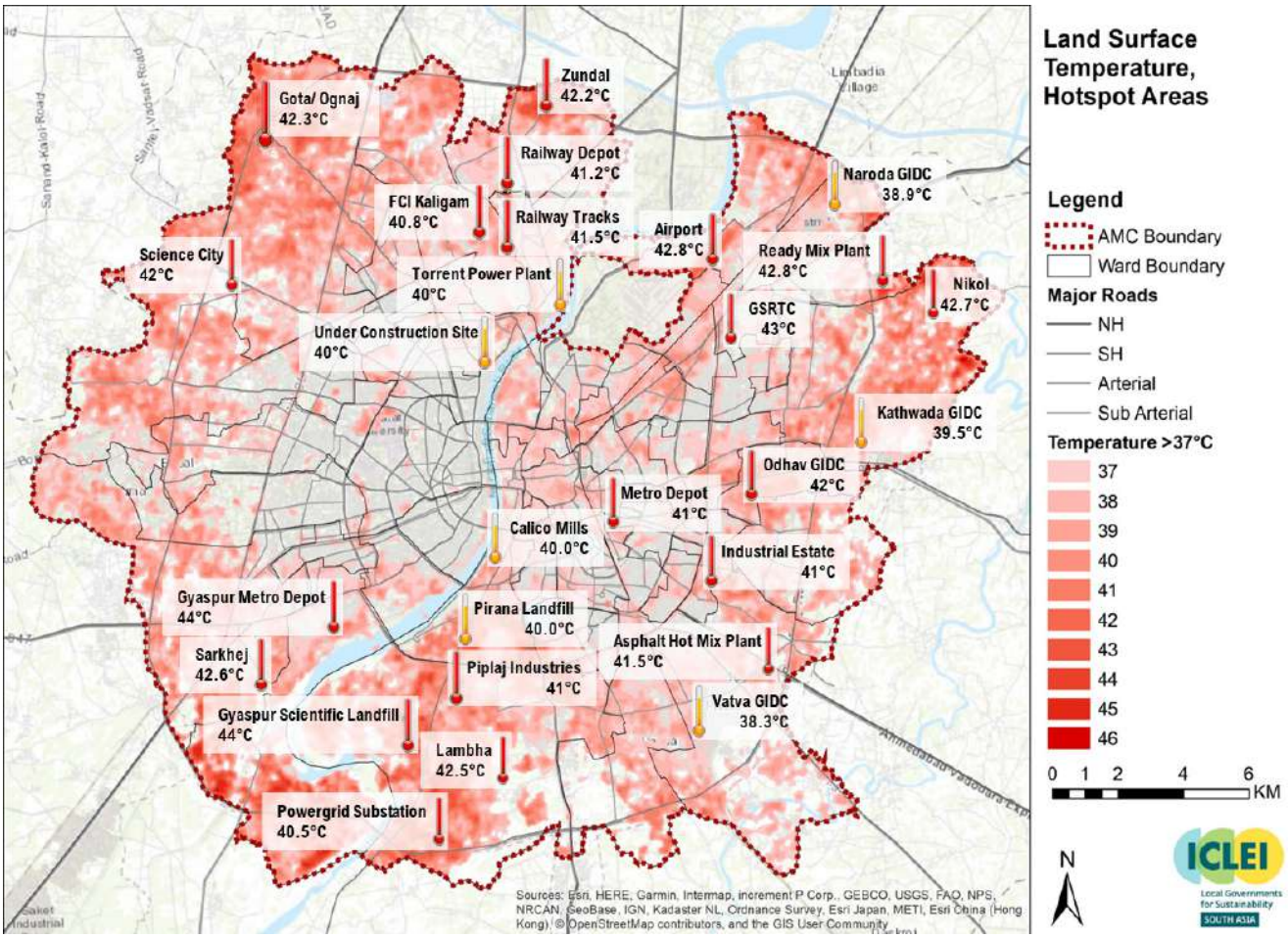
Land Surface Temperature Scenario:

LST varies from 29°C to 47°C during the day and from 26°C to 29°C at night.

Maximum LST during the day increased from 45°C in 2015 to 47°C in 2021, and minimum LST increased from 26°C in 2015 to 29°C in 2021.

67.9% of the total city area falls under hotspot areas, with LST more than the median of 37°C, impacting 59.9% of the population in 2021.

Maps 1: Land surface temperature hotspot areas, May 2021



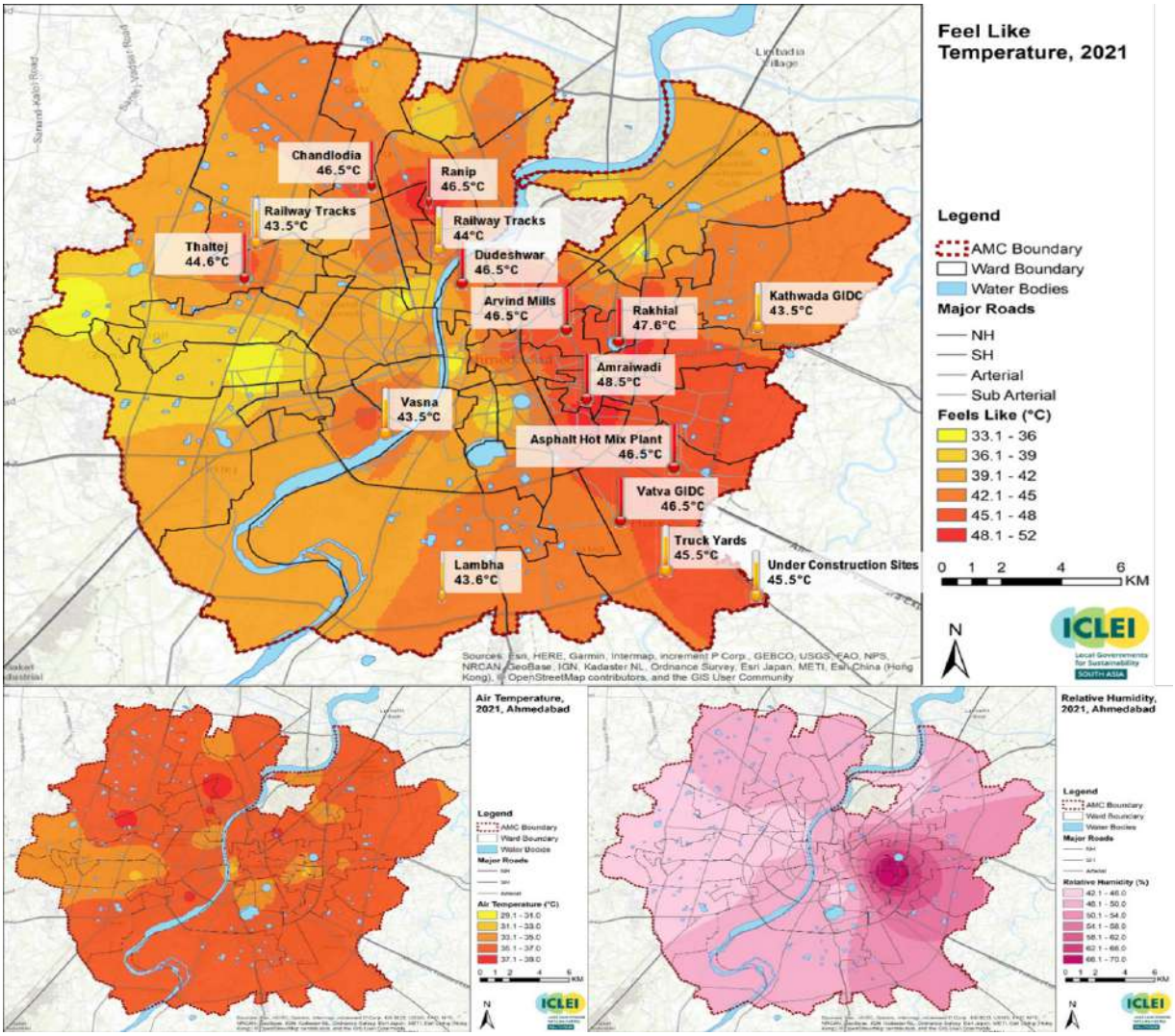
High heat index hotspots in Ahmedabad include:

- Newly developing areas with under-construction sites, i.e., Thaltej, Chandlodiya, Lambha, etc.
- Industrial areas or estates, i.e., Arvind Mills, Vatva GIDC, Kathwada GIDC
- Riverfront development near the Vasna area
- Other areas, i.e., hot mix plants and truck yards
- Railway tracks, with very little or no green cover, are usually observed.

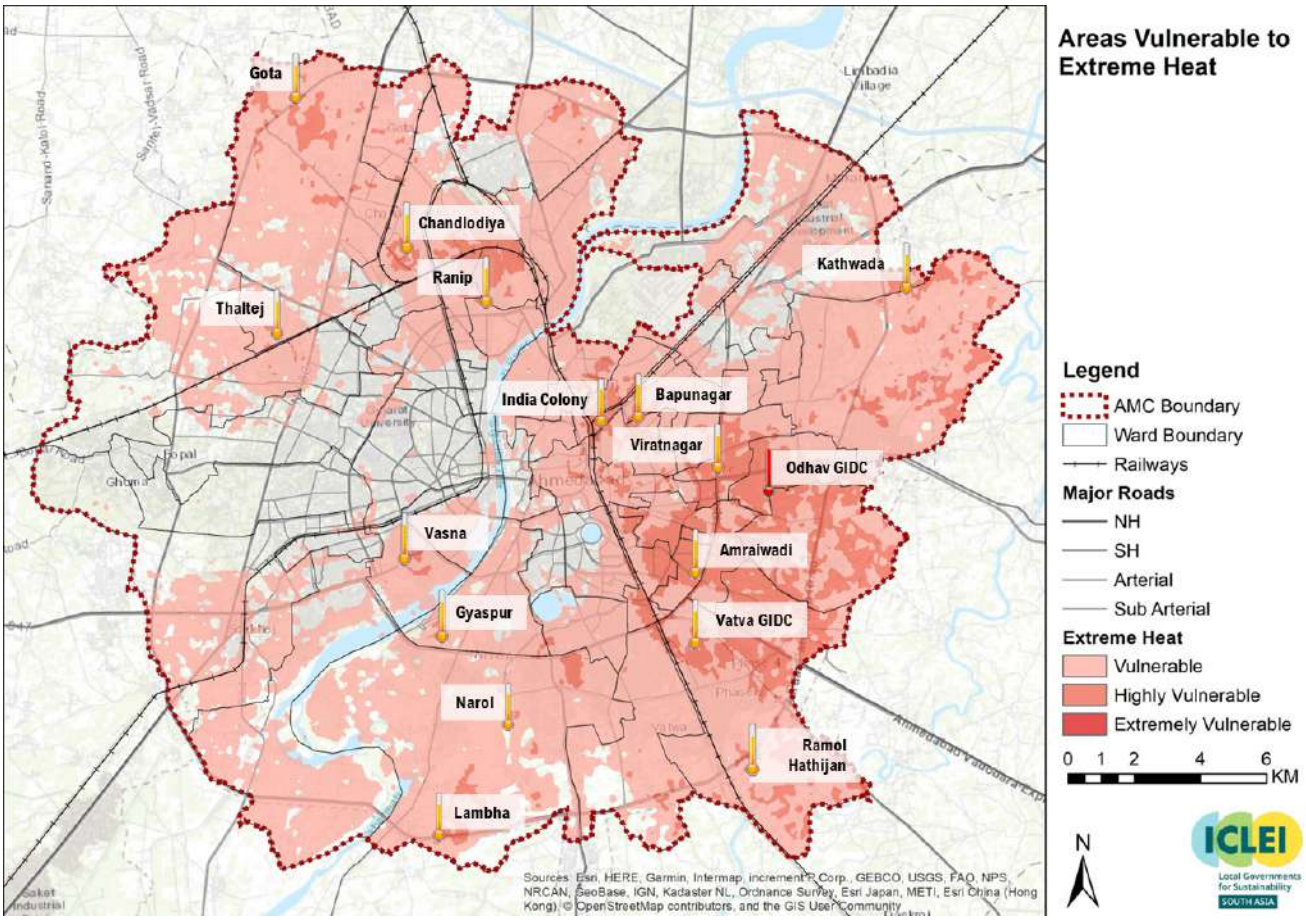
Extreme Heat Hotspots (impacted by high LST and high Feel-Like Temperature) in Ahmedabad include:

- Wards: Amraiwadi (39), Bapunagar (26), Viratnagar (25), Vasna (31), India Colony (22), Chandlodiya (02), Ranip (05), Thaltej (08), Gota (01), Lambha (46), Ramol-Hathijan (48).
- Industrial areas or estates, i.e., Odhav GIDC, Vatva GIDC, Kathwada GIDC, Narol
- Landfill site: Gyaspur and Pirana

Maps 2: Feel-like temperatures, Ahmedabad (May 2021)



Maps 3: Areas vulnerable to extreme heat hotspots



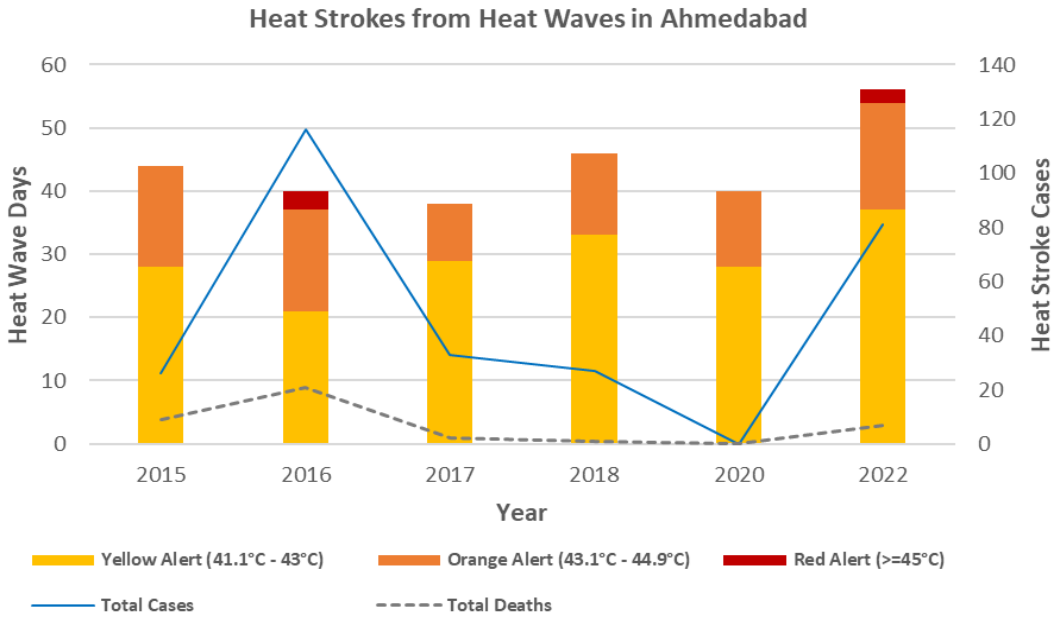


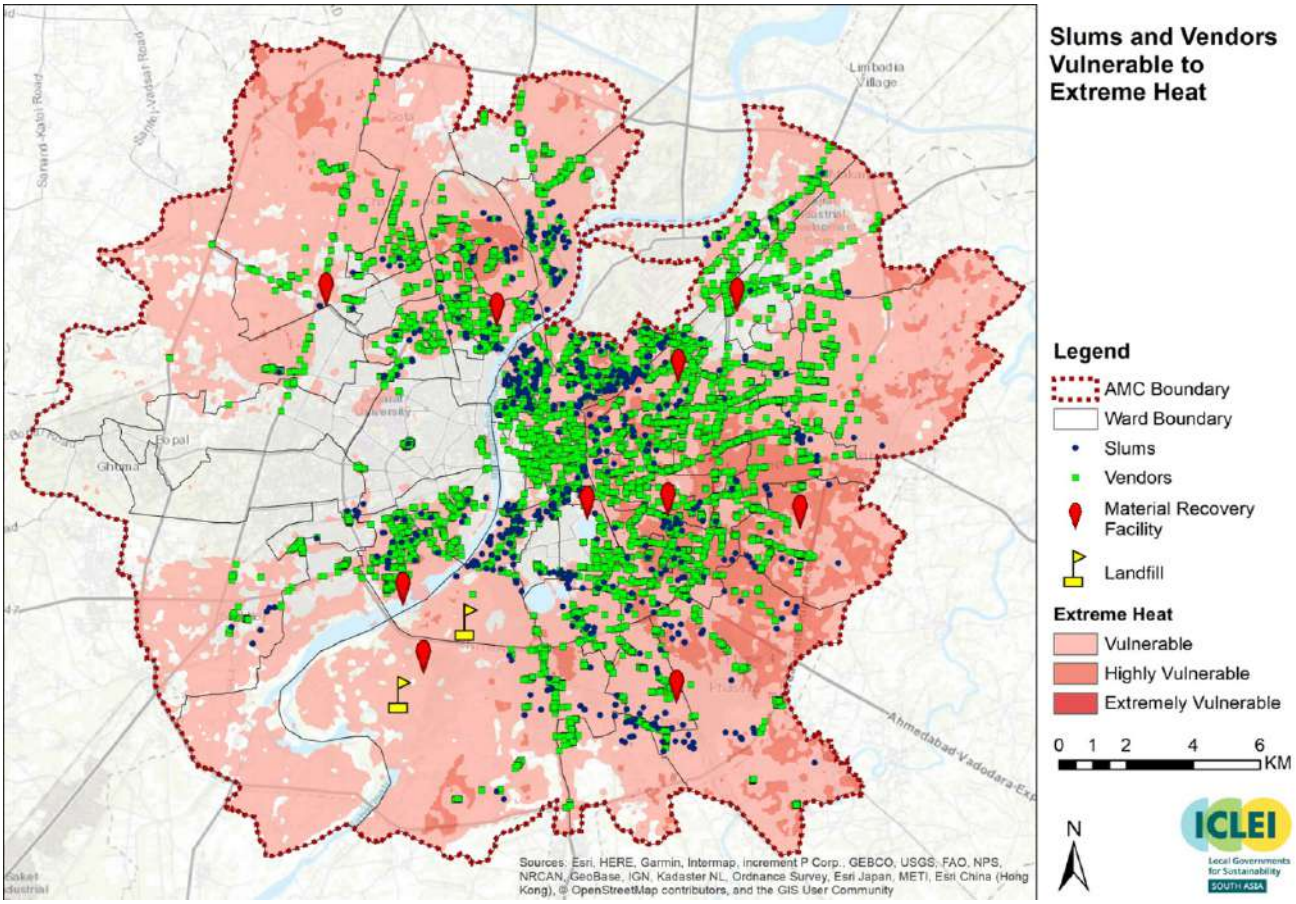
Figure 14: Heatwave warning days and heat stroke cases/deaths in Ahmedabad, 2015 to 2022

44 Areas impacted by urban heat include areas impacted by high surface temperature (>37OC) and/or high feel like temperature (>43OC). The classification of vulnerable, highly vulnerable, and extremely vulnerable areas is based on ArcGIS analysis using the 'weighted overlay' tool.

Population Groups Vulnerable to Extreme Heat Risk[45]

- Vulnerable population: 72.1% of the total population in the city (5.1 million people - 2.4 million females and 2.7 million males)
- Vulnerable population by age: Total 0.4 million children and 0.3 million elders
- Vulnerable population with special needs: 0.2 million people
- Vulnerable population with illiteracy: 1.1 million people
- Vulnerable population by income group: 0.7 million people living in slum localities (83.8% of the total slum population) and about 45,000 streetside vendors (73.1% of the total streetside vendors).
- Vulnerable population with poor workplace conditions: 770 workers at dumpsites and material recovery facilities (MRF) are impacted due to accelerated decomposition rates and potentially hazardous conditions in open dumpsites that increase the probability of landfill fires.

Maps 4: Population of slums and vendors vulnerable to urban heat risk[51]



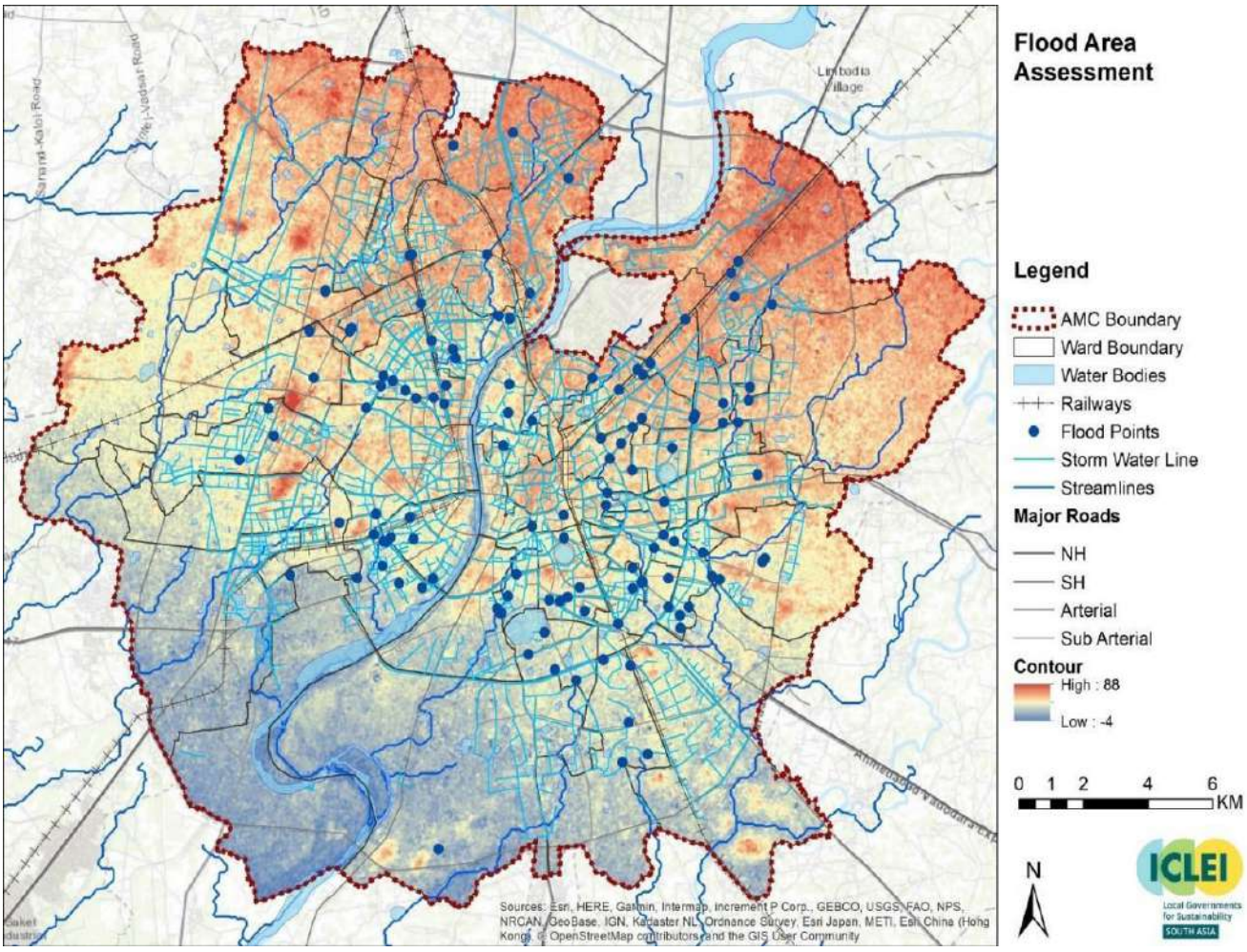
45 These values are estimated based on total population of identified hotspot areas; actual numbers may vary.

Urban Flood

Rise in extreme rainfall events and insufficient stormwater drainage leads to urban flooding. Vulnerable populations, such as the urban poor, are the most impacted due to poor living conditions and limited resources. The flood risk is assessed by analyzing rainfall trends, spatial analysis of waterlogged areas, and ward-level analysis of water-borne diseases, revealing areas most affected by flooding. Issues such as heavy siltation in stormwater drains and improper waste and sewage disposal exacerbate flooding, impacting health, mobility, and economic productivity. Some of the areas severely affected by waterlogging include Naranpura, India Colony, Indrapuri, Khokhra, Thakkarbapa Nagar, Isanpur, Bodakdev, Paldi, Maninagar, Vasna, S P Stadium, Saraspur, and Vatva. The city is experiencing an increase in urban flooding hazards due to intense rainfall occurrences. Residents within a 250 m radius of 166 waterlogged areas or flood points face elevated risks and are susceptible to severe health hazards.

Approximately 4.3% of the city's total area is affected by urban flooding or waterlogging, impacting around 9.5% of the city's population. Population Groups Vulnerable to Urban Flooding: Children, the elderly, women, and those with special needs are most impacted by urban flooding. Limited access to health facilities, emergency services, and urban services during floods mainly affect these groups. They also suffer from a lack of inclusive infrastructure and access to information. Urban poor living in compromised housing conditions and with limited access to health centers are susceptible to disease outbreaks. Approximately 9.5% of the city's population, i.e., 0.7 million (0.3

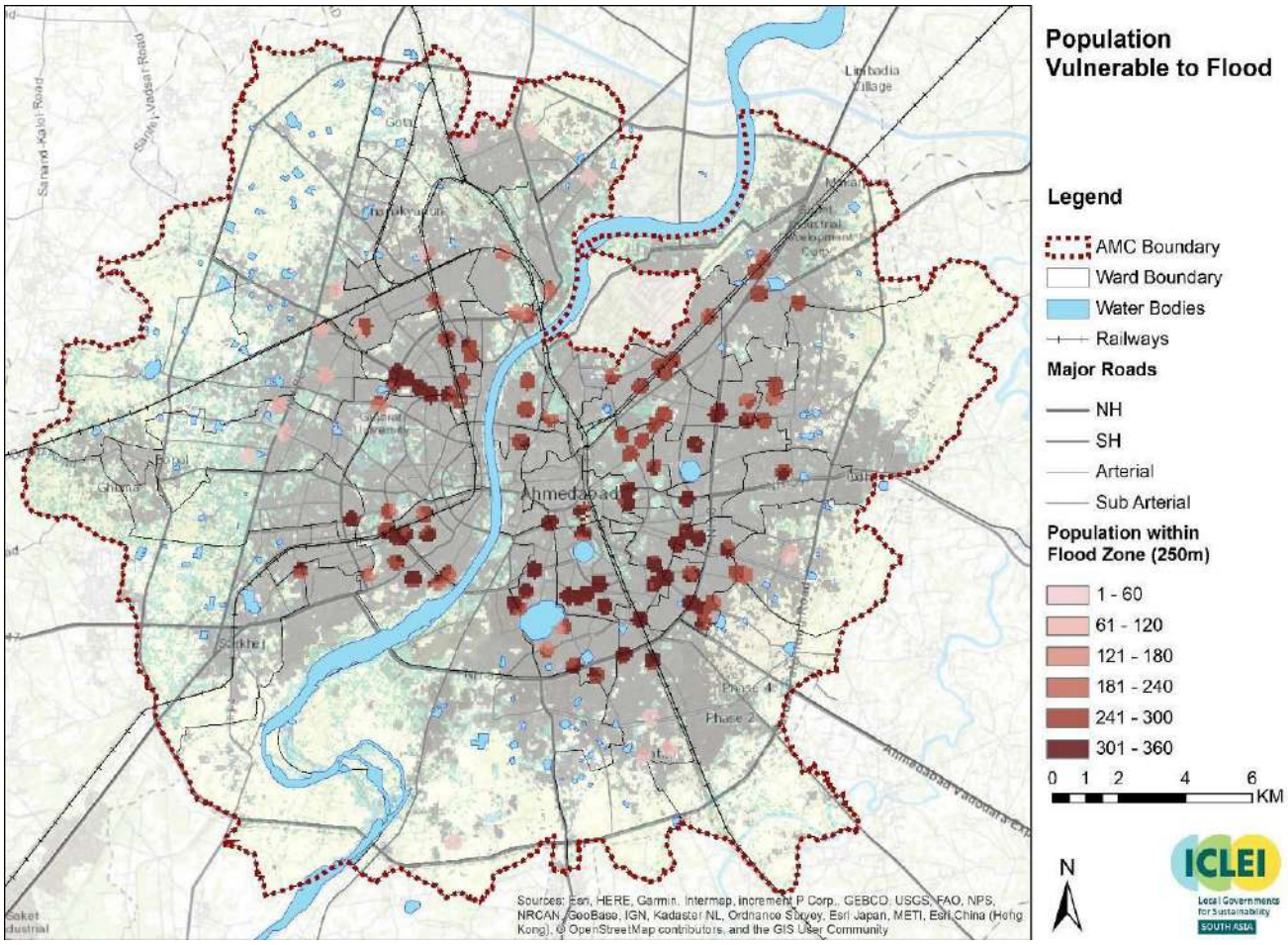
Maps 5: Flood prone area assessment in Ahmedabad



Population Groups Vulnerable to Urban Flood Risk[46]

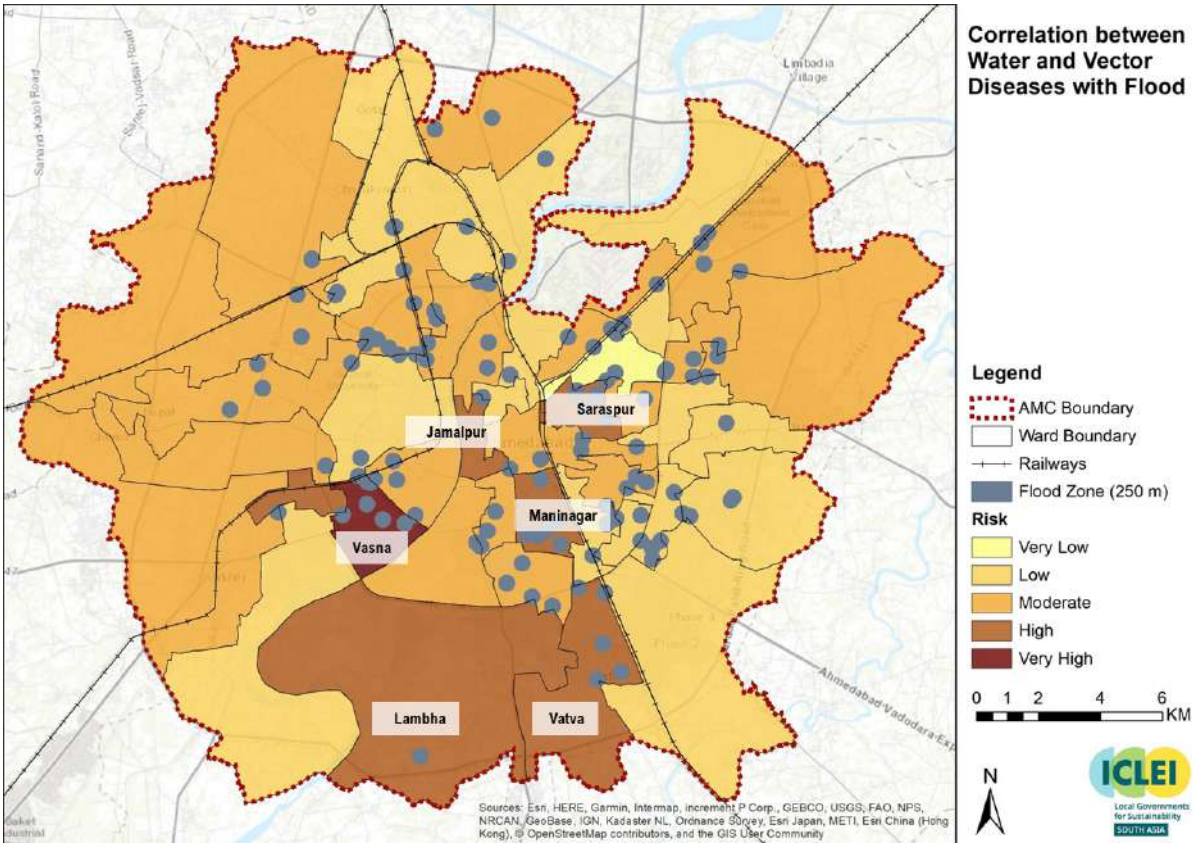
- Vulnerable population: 9.5% of the total population in the city (Total 0.7 million people – 0.3 million females and 0.4 million males).
- Vulnerable population by age: 55,000 children and 34,000 elders
- Vulnerable population with special needs: 20,000 people
- Vulnerable population with illiteracy: 0.2 million people
- Vulnerable population by income group: 88,000 people living in slum localities (10.5% of the total slum population) and 5,000 street-side vendors (9.2% of the total street vendors).
- Vulnerable population with poor workplace conditions: Urban flooding renders public infrastructure, such as roads, inaccessible, impacting the daily livelihood of street-side vendors and slum dwellers.
- Vulnerable areas: 4.3% of the city area
- Vulnerable wards: Naranpura (09), India Colony (22), Indrapuri (42), Khokhra (44), Thakkarbapa nagar (23), Isanpur (45), Bodakdev (19), Paldi (30), Maninagar (37), Vasna (31), S P Stadium (10), Saraspur (27) and Vatva (47)

Maps 6: Population vulnerable to urban flood risk in Ahmedabad

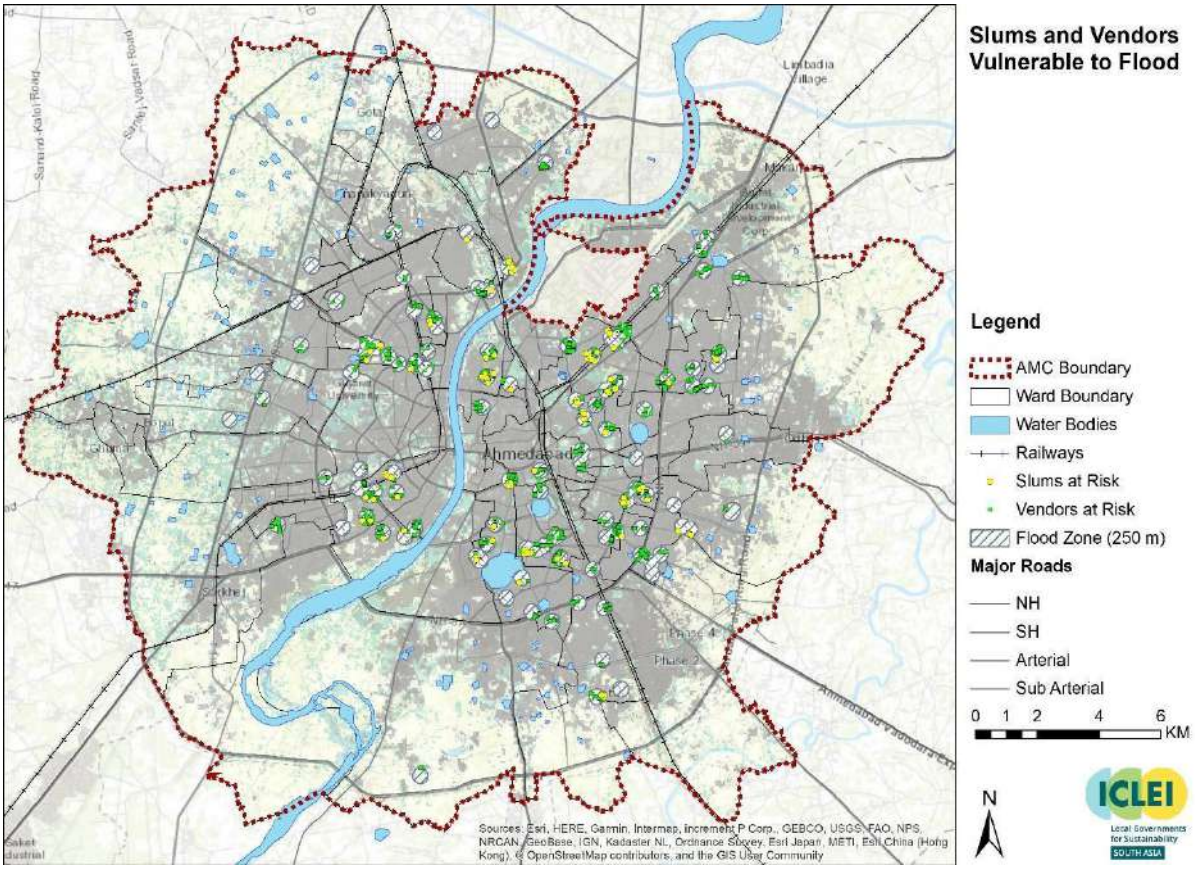


46 Numbers are estimated as per total population numbers; actual numbers may vary.

Maps 7: Flood-prone areas with a high incidence of water and vector-borne diseases



Maps 8: Slums and vendors impacted by urban flood risk



47 Classification based on disease incidence: Very Low: 1 – 10 cases; Low: 11 – 40 cases; Moderate: 41 – 90 cases; High: 91 – 180 cases; Very High: 181 – 276 cases.

million females, 0.4 million males) is vulnerable to urban flooding. Vulnerable areas encompass about 4.3% of the city's overall area.

3.3.3 Surat

Hotspots with high surface temperature (>41°C) in Surat include:

- **Critical election wards**[48]: Wards 4, 5, 6, 12, 13, 14, 15, 16, 17, 18, 19, 22, 23, 24, 25, 26, 27, 28, 29, 30
- **Critical areas:** Sagrampura, Salabatpura, Begampura, Haripura, Mahidharpura, Saiyadpura, Gopipura, Vadifalia, Sonifalia, Shahpore, TPS - 1 Lal Darwaja, TPS - 3 Katargam Gotalawadi, TPS - 4 Ashwanikumar Navagam, TPS - 7 Anjana, TPS - 8 Umarwada, Tunki, Karanj, Magob, Dumbhal, Limbayat, Dindoli, Bhedwad, Bhestan, Pandesara, Udhna, Bamroli, Majura, Puna, Parvat, Godadara, Unn, Sonari, Gabheni, Jiyav, Vadod, Bamroli (Part), Khajod, Abhava, Gaviyar, Bhatpor, Bhatha, Pardi Kande, Sachin, Talangpur, Rander Pal, Bhimpore, Dumas
- Major industrial areas, industrial estates and industries, i.e., Udhna GIDC, Pandesara GIDC, Katargam GIDC, food manufacturing and textile mills, Baroda Rayon Corporation and City Industrial Estate
- Surat airport area and shrimp farms
- Landfill site at Khajod

High LST is observed in industrial areas due to the pavement and roofing materials used. This has implications for the health of workers in industrial units. The Khajod landfill site also falls within a high LST area, which may adversely impact the health and productivity of its vulnerable workers. Urban heat conditions may also increase water demand. Wards with limited water supply that also experience urban heat conditions are especially vulnerable (i.e., wards 16, 17, 22, 23, 24, 25, 26, and 27).

The energy demand in buildings located in areas with high LST may also be higher due to increased need for space cooling. Maps 9 and 10 show the spatial distribution of vulnerable population groups, municipal schools, and Anganwadis impacted by urban heat. Details of the hotspot areas and vulnerable populations[49] getting impacted by high LST are shown here.

48 30 election wards have been considered for further analysis to identify vulnerable wards based on suggestions received from SMC officials during a Climate Core Team Meeting. Meanwhile, SMC's comprehensive complaint redressal system follows the boundaries of 134 administrative wards, which have been identified as vulnerable areas. The election wards were overlaid on the administrative wards to identify critical election wards based on complaints received for each administrative ward.

49 Population groups are categorized by age, gender, population with special needs, education and income group. Population density per unit area was estimated from WorldPop Open Data Source (2020 - raster file 100m X 100m resolution, https://hub.worldpop.org/geodata/summary?id=49804) and adjusted for 2024 appropriately. Since 2021 census has not been conducted, census 2011 information is considered and extrapolated appropriately to identify population by these categories for 2024.

Land surface temperature scenario:
LST varies from 27.1°C to 50.1°C during the day and from 26.1°C to 29.2°C at night

Hotspot areas and vulnerable population:
55.39% of the total city area; 64.7% of the population impacted in 2024

Population groups impacted by urban heat[50]:
Impacted population: 5.10 million people are exposed to high surface temperatures (2.19 million females and 2.91million males)

- Children and elderly: 0.45 million children and 0.15 million elders
- People with special needs: 61,177 people
- People with illiteracy: 1.17 million people
- By income group: 0.35 million people living in slum localities (91% of the total slum population) are exposed to high temperatures

Municipal markets: 63 (88.7% of a total of 71 municipal markets)

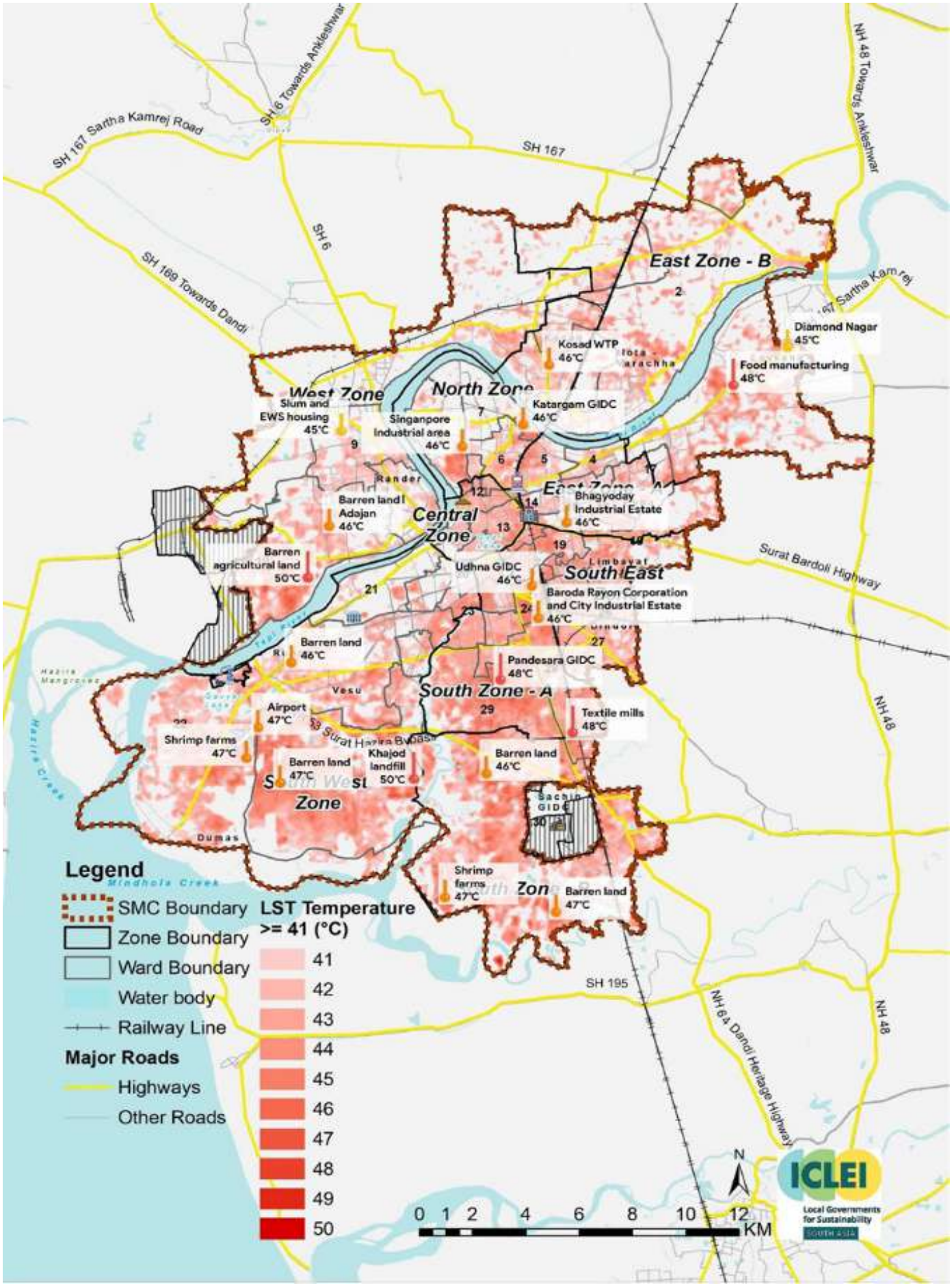
People with poor workplace conditions: 165 workers at dumpsites are impacted due to accelerated decomposition rates and potentially hazardous conditions in open dumpsites that increase the probability of landfill fires.

Municipal schools in urban heat-susceptible areas: 325 schools out of a total of 382 schools

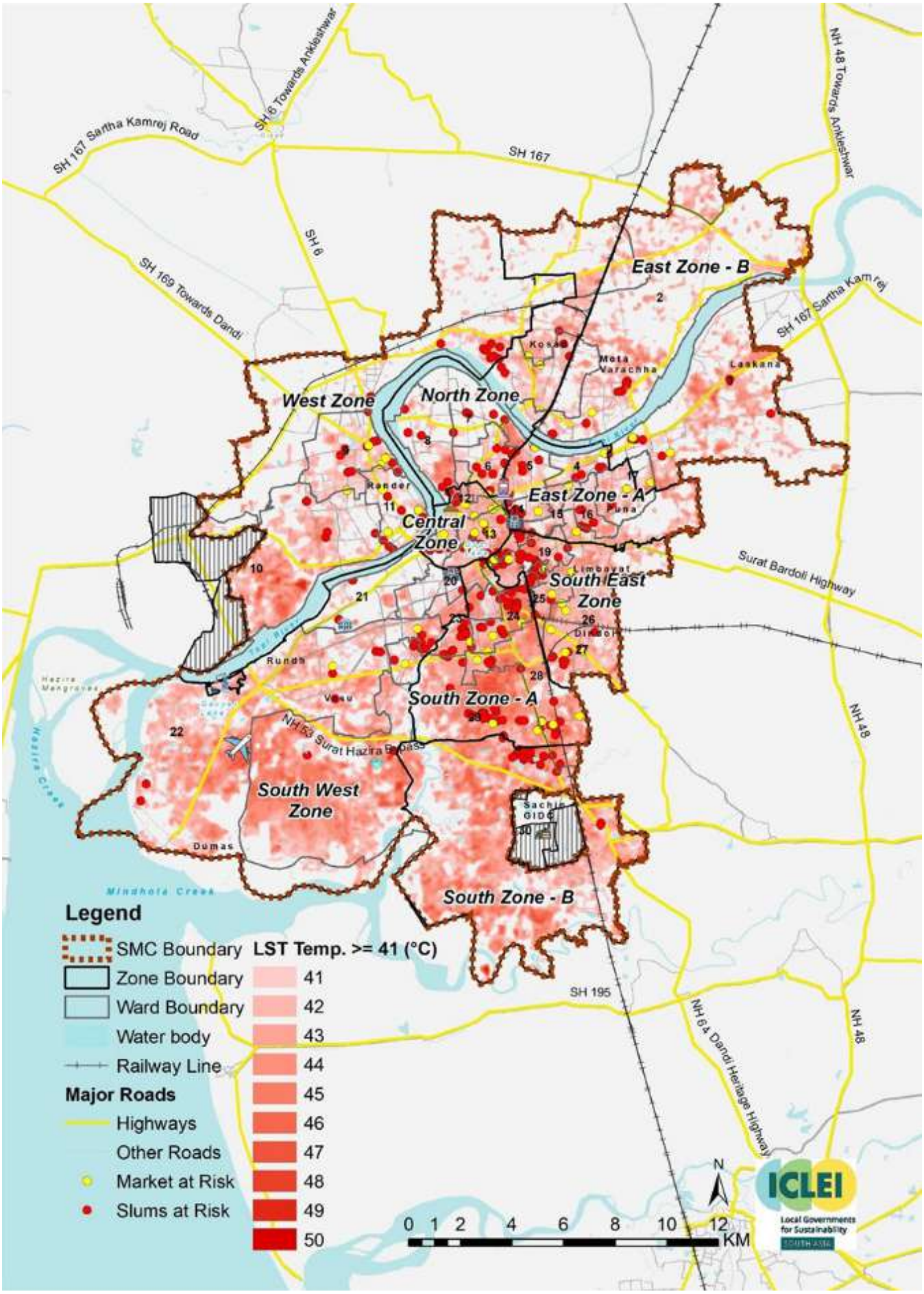
Anganwadis in urban heat-susceptible areas: 1,022 out of total 1,095

50 These values are estimated based on total population of identified hotspot areas; actual numbers may vary.

Maps 9: LST Hotspot areas in Surat (2024)



Maps 10: Areas vulnerable to extreme heat



The mapping reveals spatial variations in climate risks across the city. Certain wards and low-lying neighbourhoods are more susceptible to flooding and extreme heat, while areas with dense populations and critical infrastructure face higher potential economic and non-economic losses. By overlaying hazard maps with population and economic data, the assessment provides actionable insights into which areas may require prioritized interventions.

Urban Flood

The city is also prone to flash floods, especially in low-lying areas of the Tapi River, during heavy rainfall and periods of water discharge from the Ukai Dam. A majority of the flood points were observed to be closer to the river stretch, such as Katargam, Adajan, Rander, Utran, and the area near the railway station and the creeks, i.e., Simada Gam, Nana Varachha, Saroli, Magob, Parvat Patiya, Parvat Gam, Limbayat, Godadara, Pandesara, Azad Nagar, and Dindoli.

Heavy siltation in stormwater drains, solid waste disposal, and illegal encroachment of natural drains and creeks are major issues that cause flooding or waterlogging, impacting health and hygiene, mobility, and economic productivity. Stormwater flowing through sewerage lines during intense rainfall is also a critical issue. People residing within 250m buffer zones of flood points or waterlogged areas are susceptible. Some parts of Wards[51] 4, 5, 6, 7, 8, 9, 11, 13, 14, 17, 23, 24, 25, 26, and 27 are impacted by waterlogging.

Surat recorded 10,179 water and 950 vector-borne disease cases[52] during 2023-24. Urban primary health centers (UPHCs) in areas like Althan, Vesu, Rander, Adajan, Pal, Ichhapore, Puna, Hirabaug, Bhatena, Limbayat, Navagam Dindoli, Navanagar, Umarwada, Pandesara, Unn, Vadod, Vijayanagar, and Unngam recorded a large number of water-borne and vector-borne disease cases.

Urban flooding: Incidents in the city are increasing due to intense rainfall events. People residing within a 250m buffer zone of 46 waterlogged areas or flood points are vulnerable and may experience adverse health impacts. In 2023-34, 10,179 cases of water-borne and 950 cases of vector-borne diseases were registered, with a majority reported from wards impacted by flooding or waterlogging.

Hotspot areas and impacted population[53]

Area Impacted: 2.33 % of the total city area

Population impacted: 4.6% of the total city population (0.37 million people – 0.15 million females and 0.22 million males)

Children and elderly: 32,860 children and 10,953 elders

People with special needs: 4,381 people

People with illiteracy: 83,978 people

By income group: 0.12 million people living in slum localities (30.76% of the total slum population)

People with poor workplace conditions: Urban flooding disrupts critical public infrastructure, including roads, hindering access to emergency services and adversely impacting the livelihoods of street vendors and slum dwellers.

51 Election wards have been considered for analysis as suggested by SMC officials during a Climate Core Team Meeting.
52 Diarrhoea, Typhoid, and Hepatitis are considered water borne diseases, while dengue, chikungunya, and malaria are considered vector borne diseases.
53 Numbers are estimated as per total population numbers; actual numbers may vary.

Impacted wards[54]: Wards 4, 5, 6, 7, 8, 9, 11, 13, 14, 17, 23, 24, 25, 26, and 27

Impacted areas: Nanpura, Begampura, Saiyadpura, Nanavat, Rander, Rander, Adajan, TPS - 1 Lal Darwaja, TPS - 2 Nanpura, TPS - 3 Katargam Gotalawadi, TPS - 4 Ashwanikumar Navagam, TPS - 8 Umarwada, Tunki, Singanpore, Katargam, Fulpada, Kapadra, Dumbhal, Limbayat, Pal, Utran, Simada, Magob, Parvat, Godadara, Saniya Hemad, Saroli, Kumbhariya

Municipal schools in areas susceptible to urban flooding: 71 schools out of a total of 382

Anganwadi's in areas susceptible to urban flooding: 232 out of a total of 1095

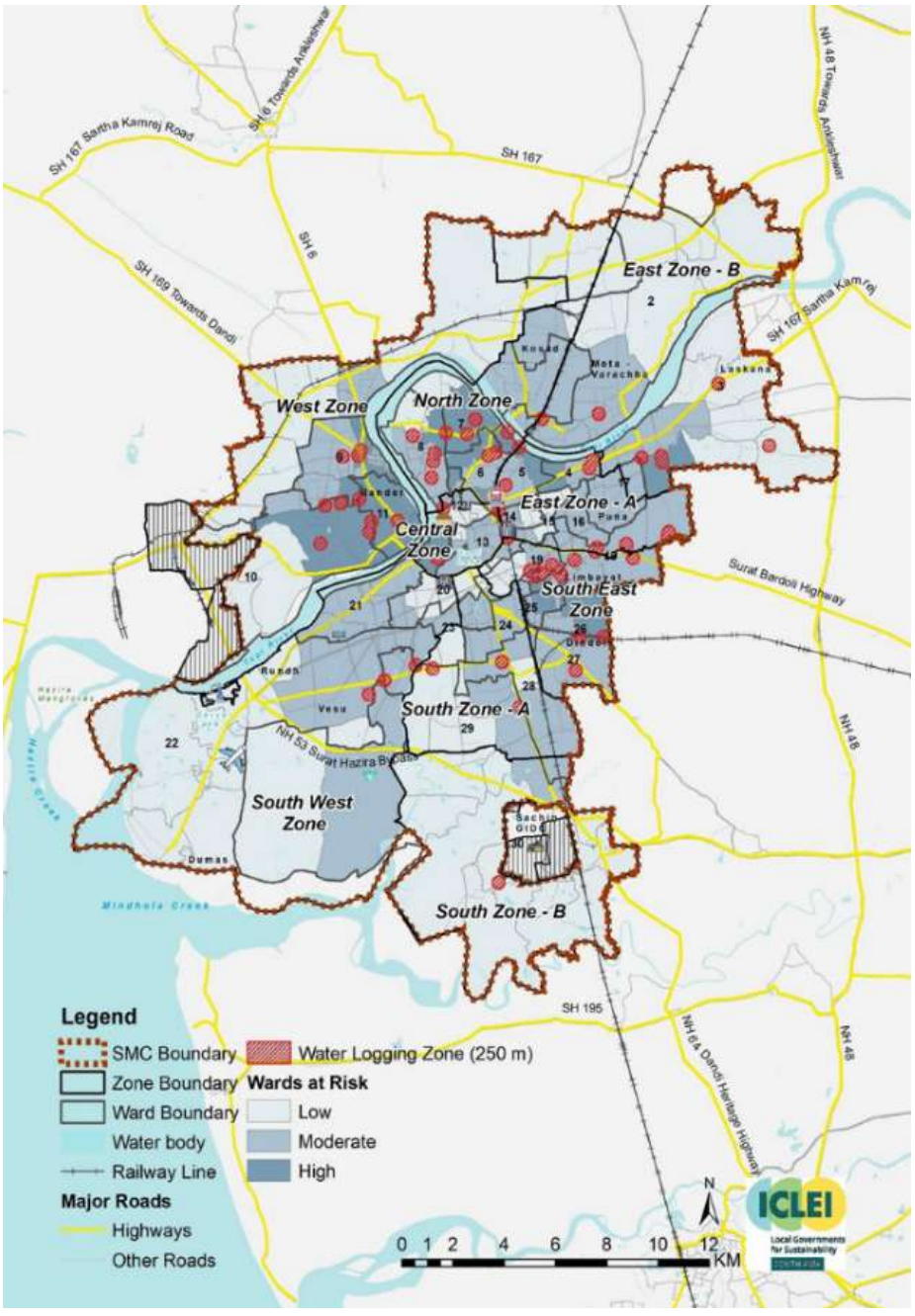
Implications for Loss and Damage (L&D)

The assessment of LST and urban flooding in Surat highlights the dual and compounding nature of climate risks, resulting in both economic and non-economic losses.

Economic Loss and Damage (ELD): High surface temperatures and recurring floods cause direct damage to infrastructure, including roads, schools, Anganwadis, markets, and drainage systems. Industrial and commercial zones experience productivity losses due to heat stress, while urban flooding disrupts transport, trade, and access to essential services. Recurrent repair and maintenance costs, damage to educational and health facilities, and reduced labor efficiency contribute to significant economic strain, especially in low-income and informal settlements**.**

Non-Economic Loss and Damage (NELD): Prolonged exposure to extreme heat

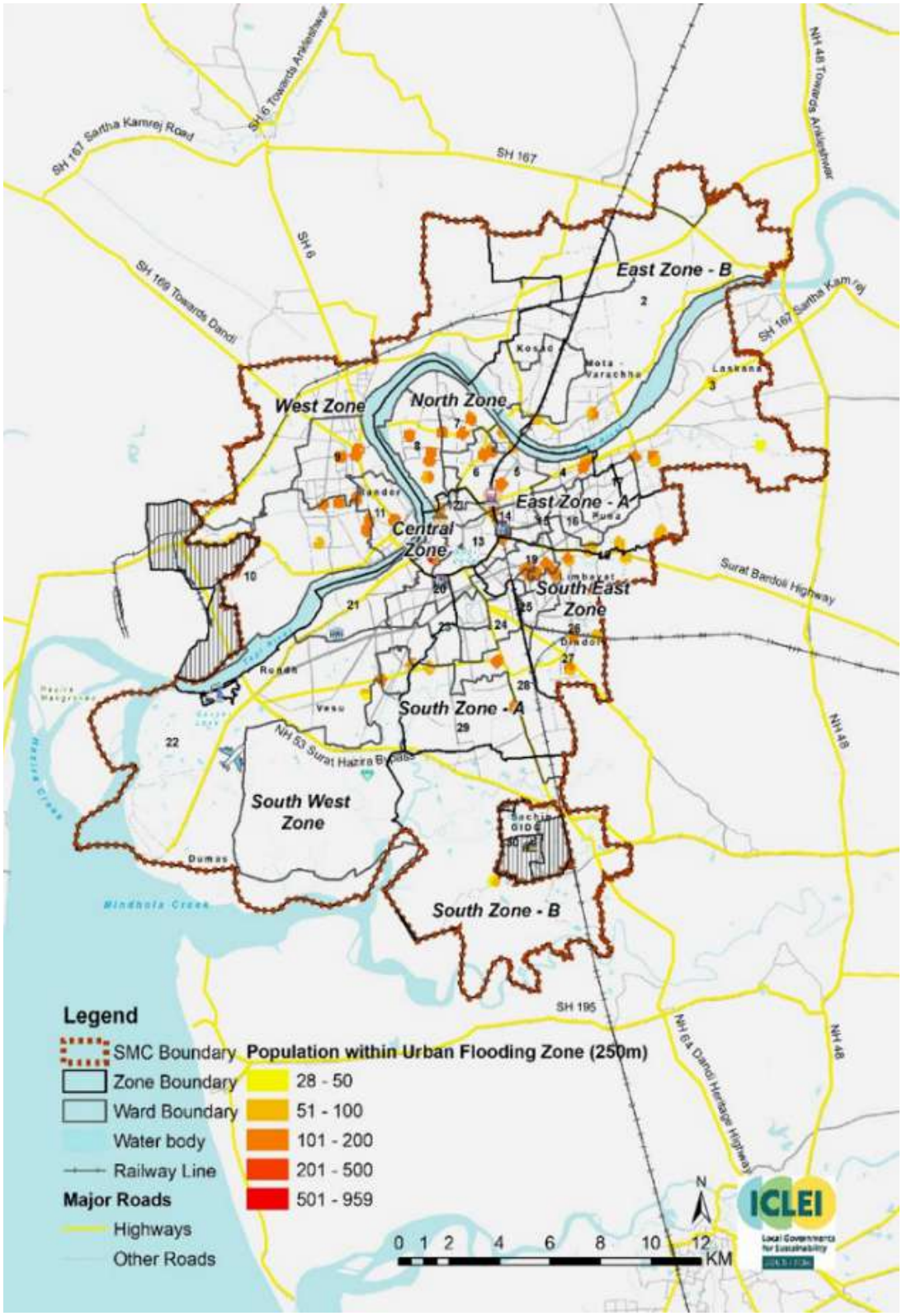
Maps 11: Flood-prone area assessment in Surat



54 30 election wards have been considered for further analysis to identify vulnerable wards based on suggestions received from SMC officials during a Climate Core Team Meeting. Meanwhile, SMC's comprehensive complaint redressal system follows the boundaries of 134 administrative wards, which have been identified as vulnerable areas. The election wards were overlaid on the administrative wards to identify critical election wards based on complaints received for each administrative ward.

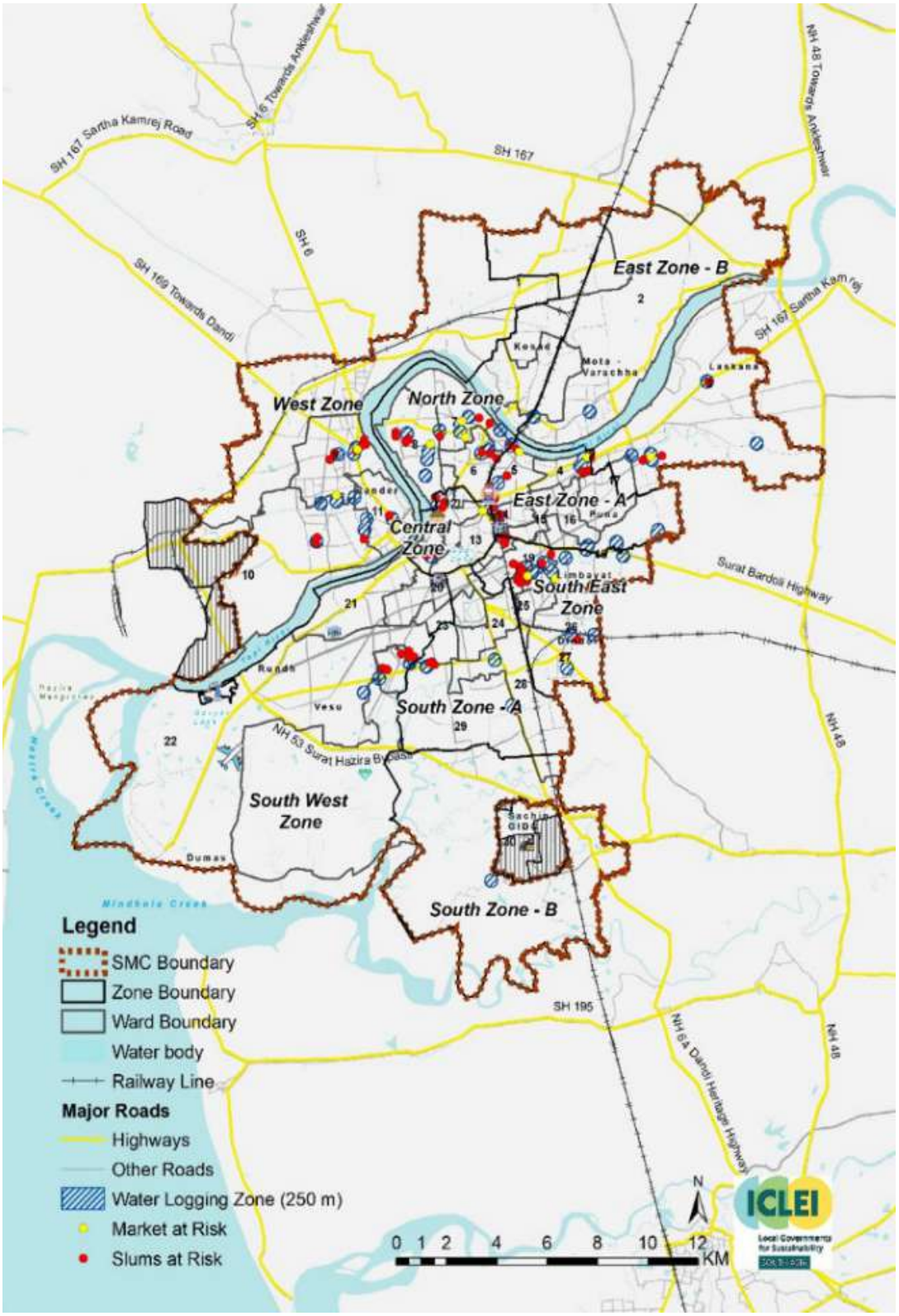
affects the health, well-being, and learning capacity of residents, particularly children, the elderly, and informal workers. Flood-induced displacement, school closures, and outbreaks of waterborne and vector-borne diseases increase psychosocial distress and reduce community resilience. Vulnerable groups—such as slum dwellers, sanitation workers, and street vendors—face heightened risks to health, safety, and livelihood security.

Maps 12: Population vulnerable to urban flooding risk in Surat

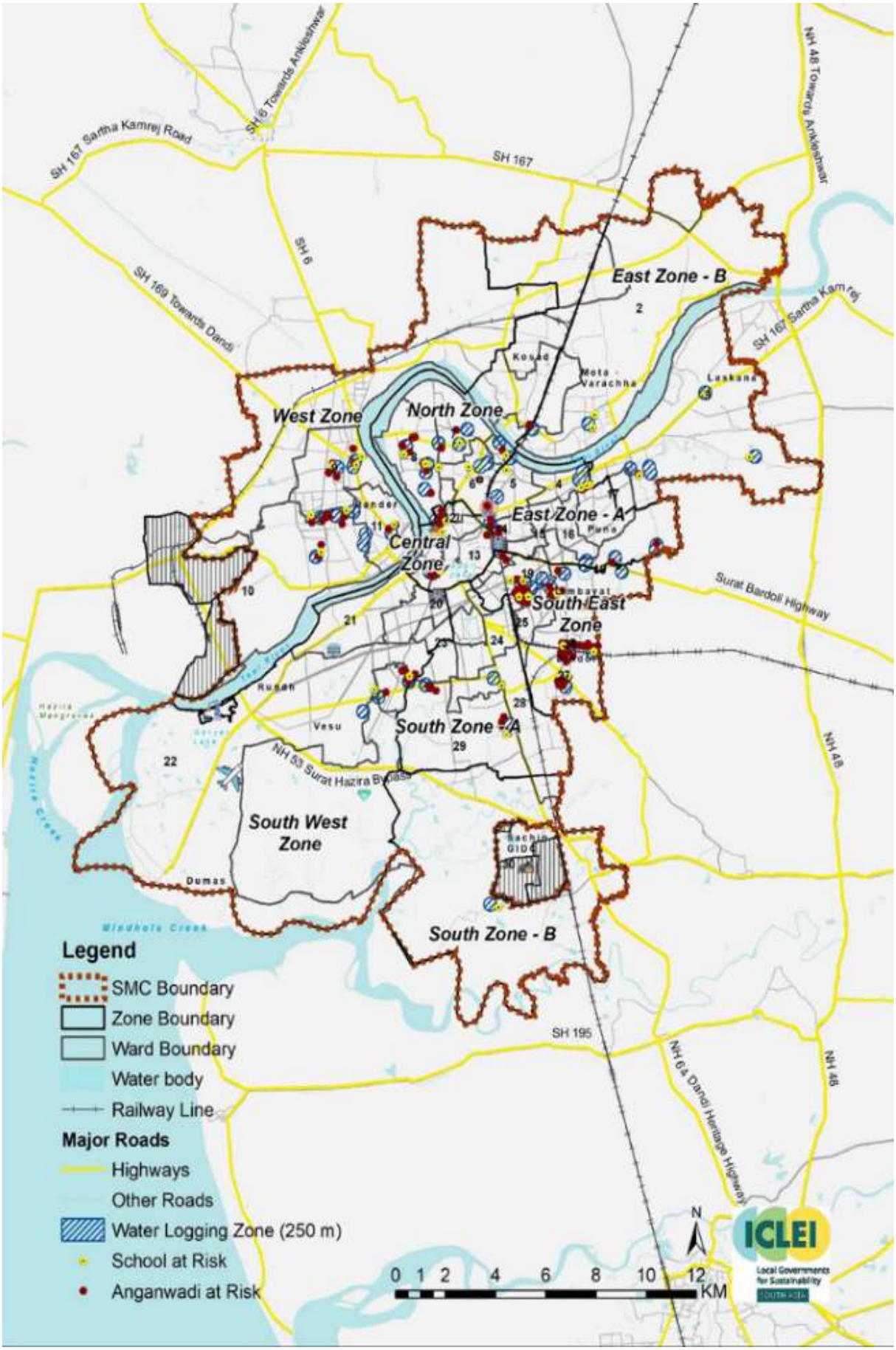


Overall, the interaction between urban heat and flooding hotspots demonstrates that climate-related losses in Surat extend beyond physical damage and include sustained impacts on human health, productivity, education, and social well-being, underscoring the need for integrated adaptation and risk-reduction strategies across sectors.

Maps 13: Slums impacted by urban flooding



Maps 14: Municipal schools and Anganwadis vulnerable to urban flooding



3.3.4 Mapping future risks

Mapping future climate risks involves a multi-layered approach that combines historical observations, climate model projections, and socio-economic data to provide an integrated view of vulnerabilities and potential impacts. Due to the limited spatial resolution of climate models, it is challenging to produce hyper-local projections at the city level.

The following maps illustrate projected spatial variations in temperature and precipitation across Gujarat for the year 2050, developed using downscaled climate projections from the WorldClim CMIP5 dataset[55] (v1.4), based on the NASA GISS-E2-R (GS) global circulation model. Three Representative Concentration Pathways (RCP 2.6, 4.5, and 8.5) were considered to represent low, moderate, and high greenhouse gas emission trajectories, respectively. The analyzed variables include:

- **Tn (Minimum Temperature)** – Monthly average minimum temperature (°C × 10),
- **Tx (Maximum Temperature)** – Monthly average maximum temperature (°C × 10), and
- **Pr (Precipitation)** – Monthly total precipitation (mm).

Global data were downloaded in GeoTIFF format, imported into ArcGIS, and clipped to the Gujarat state boundary. The raster layers were then converted to 1 km × 1 km grids and interpolated using Inverse Distance Weighting (IDW) and Kriging methods to generate continuous surface maps. These spatial analyses capture broad climate gradients:

- **Temperature projections** indicate a consistent increase in both minimum and maximum temperatures across Gujarat, with northern and interior regions warming more rapidly than coastal zones.
- **Precipitation projections** indicate higher rainfall variability, marked by increased monsoon intensity and spatial disparity, with southern Gujarat (including Surat) and central districts near Ahmedabad experiencing alternating wet and dry anomalies.

Such spatial visualizations help identify regional exposure zones and provide context for future urban climate risk assessments in Ahmedabad and Surat. In these two cities, heat stress and flooding risks are expected to intensify as populations grow and land-use changes.

Row 1: Projected Maximum Temperature (Tx) under RCP 2.6, 4.5, and 8.5 scenarios for the year 2050.

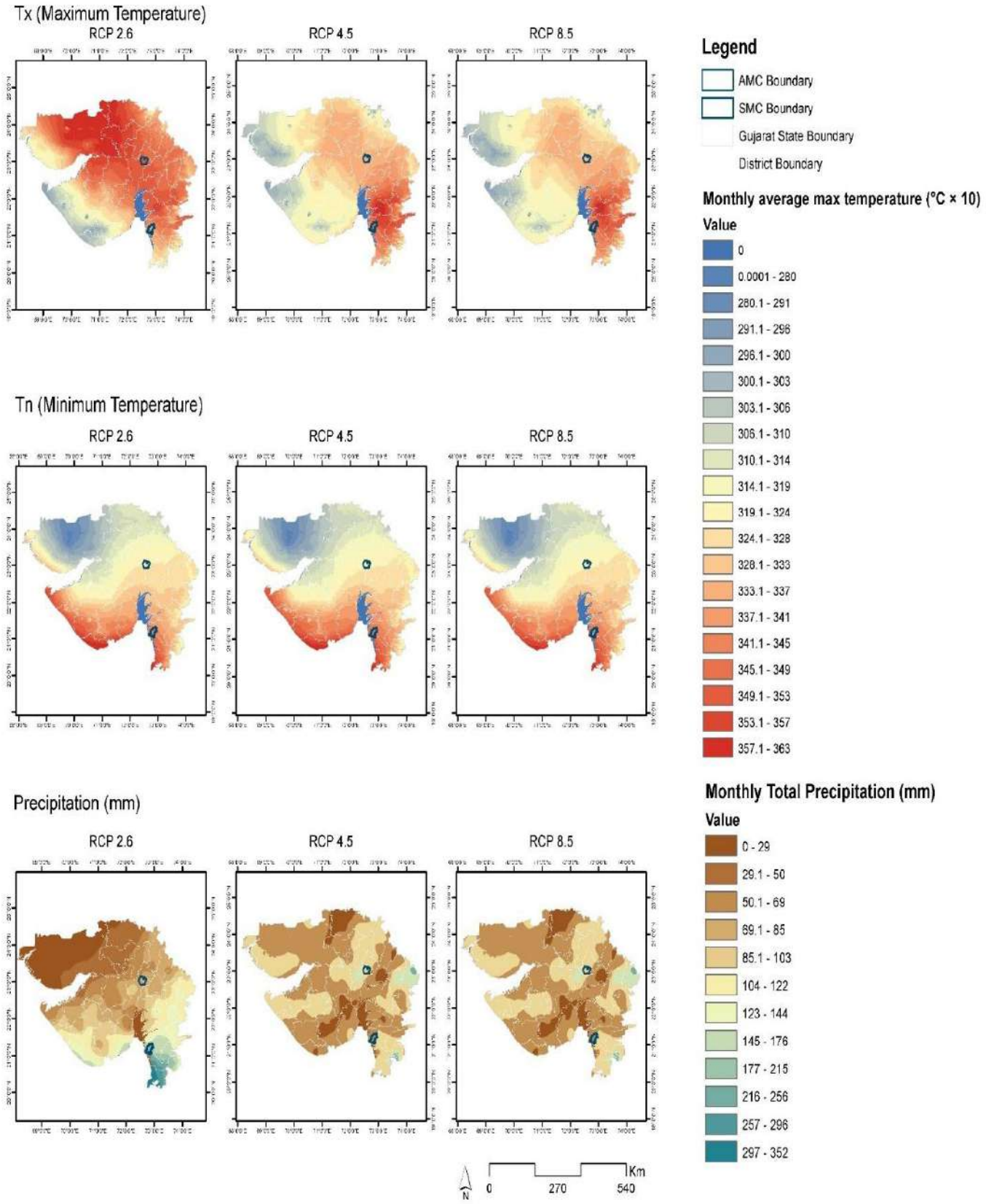
Note: Northern and central Gujarat show higher maximum temperatures (>40°C zones).

Row 2: Projected Minimum Temperature (Tn) under RCP 2.6, 4.5, and 8.5 scenarios for the year 2050.
Note: Warmer shades indicate higher average minimum temperatures; cooler zones appear in blue.

Row 3: Projected Precipitation (Pr) under RCP 2.6, 4.5, and 8.5 scenarios for the year 2050.

Note: Southern Gujarat and coastal districts show increasing precipitation gradients, indicating potential for high-intensity rainfall and urban flooding.

55 WorldClim. (n.d.). Downscaled CMIP5 data, 30 second spatial resolution. https://www.worldclim.org/data/v1.4/cmip5_30s.html



Maps 15: Future RCP scenarios mapping in Ahmedabad and Surat, Gujarat (ICLEISA, 2025)

Limitations of City-Level Climate Risk Mapping

While these maps offer valuable insights into Gujarat's future climate trends, several limitations must be acknowledged for a detailed city-scale climate risk assessment. Even after downscaling, global climate models (GCMs) operate at 5km grids, which cannot fully capture micro-climatic variability within dense urban areas like Ahmedabad or Surat. Each GCM uses distinct physical and statistical assumptions; RCP pathways represent idealized global emission futures, not localized behavior. Urban heat island effects, built-up density, albedo variations, vegetation cover, and anthropogenic heat emissions are not explicitly represented in GCM-based temperature projections. Flooding in Surat and Ahmedabad depends on drainage design, river regulation (Tapi and Sabarmati), and tidal backflow, which global precipitation datasets cannot simulate. Monthly or seasonal averages, and temporal changes mask short-duration extreme events (e.g., cloud bursts or heat spikes) that cause the most damage, and cannot be accounted for in future projections. Integrating socio-economic exposure data (such as population density, land use, and infrastructure) with biophysical risk layers remains a methodological challenge.

Therefore, these maps should be viewed as indicative spatial trends rather than precise forecasts. For local adaptation planning and ground-based monitoring, additional local data are unavailable to translate regional projections into actionable city-level insights for Ahmedabad and Surat.

4.

Urban Climate Risks and Adaptation Strategies: Methodological Framework

4.1 Sectoral Risk Assessment Methodology

Risk is understood as the intersection of hazard (the likelihood and intensity of climate events), exposure (population and assets in harm's way), and vulnerability (susceptibility of exposed elements to damage). This framework is applied consistently across all sectors.

Hazard Assessment:

- Derived from Chapter 3 climate projections; specify which hazards affect each sector (e.g., the water sector affected by heat and rainfall variability; the transport sector affected by flooding and extreme heat).
- Assign qualitative hazard probability (low/medium/high) based on observed frequency
- Assign hazard intensity (magnitude of temperature increase, rainfall depth, inundation extent) based on climate scenarios.

Exposure Assessment:

- Population: Number of residents, workers in hazard-prone zones (derived from spatial risk mapping, Chapter 3).
- Assets: Value of infrastructure (water pipes, roads, schools, hospitals) in hazard zones, based on municipal asset inventories.
- Services: Number of persons dependent on services (water supply hours, hospital beds, school enrolment) that may be disrupted.
- Data source: Municipal records, Census, satellite imagery, field surveys.

Vulnerability Assessment:

- Biophysical: Technical susceptibility of infrastructure (e.g., is water treatment plant designed for >100-year flood? Are buildings heat-resistant?).
- Socio-economic: Coping capacity of population

(income, savings, social networks, access to insurance).

- Institutional: Governance capacity for emergency response and recovery.
- Data source: Municipal performance data, household surveys (PLFS, Census), institutional reviews, FGDs.

Risk Calculation:

- Risk typically expressed as: Risk = Hazard Probability × Exposure Magnitude × Vulnerability Severity.
- For qualitative assessment: Low/Medium/High assigned to each component; combined into overall risk (LLL = Low, HHH = High).
- For semi-quantitative: Numerical scores (1–5) assigned, multiplied, and interpreted (e.g., score >12 = High Risk).
- Climate Fragility Statement (CFS; used in CRCAP) scores represent this integrated risk per sector.

Scenario design:

- Current (2023–2024): Based on observed hazards and existing infrastructure/ governance state.
- Future (2050): Based on projected climate hazards + assumed adaptation measures in place + unchanged socio-economic conditions (BAU socio-economic scenario).
- With adaptation: Same as future, but assumes full implementation of planned adaptation measures; residual risk after adaptation is highlighted.

Each sectoral table follows this structure:

- Column 1 (Parameter): Infrastructure/service element.
- Column 2 (Existing): Current state and capacity.
- Column 3 (Future Demand): Projected needs by 2050.
- Column 4 (Climate Fragility Statement): Integrated hazard–exposure–vulnerability risk assessment; risk score (1–20; higher = more fragile).
- Column 5 (Climate Impacts): Specific hazards and consequences.
- Column 6 (Possible ELD/NELD): Illustrative losses and damages if a hazard occurs with current or future infrastructure.
- Column 7 (Planned Adaptation Strategies): Existing and planned measures to reduce risk; residual risk after full adaptation implementation noted.

Urbanization and climate change are deeply intertwined. Rapid urban growth is not merely a demographic trend; it fundamentally reshapes land use, infrastructure, and social systems. As highlighted by UN-Habitat (2020), cities face rising pressures to provide affordable housing, reliable transport, adequate water and energy, and equitable access to services. Poorly managed expansion can exacerbate sprawl, congestion, and social exclusion, while amplifying vulnerability to natural hazards. The dense clustering of people, infrastructure, and assets increases exposure to climate risks such as heatwaves, flooding, and air pollution. Understanding these dynamics is essential for assessing sector-specific vulnerabilities and informing climate risk analysis.

This chapter will delve into the city-level risk assessment of Ahmedabad and Surat, linking the climate projections under various BAU scenarios and identifying the risks at the city level due to rapid urban growth, infrastructure gaps, and resource dependencies, which create varying degrees of vulnerability across water supply, sewerage, solid waste management, transport, and health and education sectors.

City-specific prospective loss and damage are presented for Ahmedabad and Surat. Building on the climate scenarios outlined earlier, it examines urban dynamics such as population growth, water demand, sewerage, solid waste management (SWM), transport, and the health and education sectors. The assessment provides a baseline of current and projected trends, enabling the identification of sectoral vulnerabilities unique to each city. By analyzing demographic and infrastructural factors, this chapter lays the groundwork for the subsequent climate risk assessment and adaptation strategy prioritization.

This analysis is done through a systematic

climate risk assessment using the Climate Fragility Statement (CFS). Each CFS evaluates risk by combining two pivotal factors: likelihood, the probability of a hazardous event occurring, and consequence, the magnitude of impacts on urban systems and population groups should the event materialize. By integrating sectoral vulnerabilities with the probability and severity of climate hazards, such as extreme heat and intense rainfall, this approach enables structured identification and prioritization of high-risk areas and sectors, forming the foundation for targeted adaptation strategies in subsequent chapters.

4.2 Ahmedabad: Sector-wise assessment

The sectoral assessment data drawn from the Ahmedabad CRCAP,[56] summarised in Tables 16-22, provides an integrated analysis of potential climate-induced impacts on Ahmedabad's critical urban systems, which include water supply, drainage and stormwater management, solid waste management, and urban transport (Ahmedabad Climate Resilient City Action Plan – Toward a Net Zero Future). Drawing on historical climate patterns and projected future scenarios, the assessment combines insights on existing vulnerabilities, anticipated stressors such as extreme heat and urban flooding, and compounded climate risks to identify fragility statements within each sector. It further correlates these identified risks with potential ELD and NELD, thereby encompassing both physical infrastructure impacts and broader socio-environmental implications. The assessment also proposes sector-specific adaptation actions designed to enhance resilience, ensure uninterrupted service delivery, and minimize anticipated losses under projected climatic conditions through 2050.

The risk scoring framework[57] for each sector is based on two interlinked dimensions: likelihood, representing the probability of a climate hazard occurring, and consequence, representing the severity of its impact on urban systems and communities. Likelihood is determined by the expected frequency and intensity of future climate hazards, while consequence depends on the vulnerability and adaptive capacity of affected sectors and population groups. The detailed methodology underpinning this risk assessment is presented in Table 9.3 (Annexures).

The results (Table 9.3) indicate that for Ahmedabad, intense precipitation and urban flooding typically cause more significant disruptions than heat stress across most infrastructure systems. Water-related assets, including distribution networks, treatment plants, and sewerage systems, are particularly at risk, as both flooding and extreme heat can impair their functionality. Solid waste management systems are especially flood-sensitive, whereas heat stress presents moderate but recurrent operational challenges.[54]

Limitations:

Ahmedabad has adopted multiple resilience and adaptation measures through instruments such as the Ahmedabad Heat Action Plan 2018, Ahmedabad CRCAP 2070, Revised Development Plan 2021 by AUDA, the Comprehensive General Development Control Regulations (CGDCR), and the City Disaster Management Plan. These frameworks collectively address themes like water resource management, public health protection, green infrastructure, disaster preparedness, and sustainable urban planning. These adaptation strategies are derived from current climate risks and ongoing urban initiatives. However, uncertainties remain regarding how future climate risks will interact and affect urban systems. Due to modeling limitations, the full extent of benefits from each action could not be quantified. The proposed actions have been endorsed by the city and validated under the Ahmedabad Net Zero Climate Action Plan 2070, though their effectiveness may be limited by evolving

56 Ahmedabad Municipal Corporation; ICLEI – Local Governments for Sustainability, South Asia. (2023, July). Ahmedabad Climate Resilient City Action Plan – Toward a Net Zero Future.
57 Refer Table 9.3 Critical urban systems and climate fragility statements for Ahmedabad (Annexure)

climate conditions, political, financial, & technical feasibility, and assumptions on ELD and NELD. Some of the other limitations include:

Gaps in retrospective L&D assessment: Although the city's climate plans acknowledge extreme heat, flooding and other hazards, they lack quantified data on actual ELD and NELD (e.g., displacement, health impacts, ecosystem degradation). Separating damages caused specifically by climate change (vs. man-made hazard exposure, urban development, or poor maintenance) is technically difficult. Assessments face the usual attribution gaps without robust counterfactual baselines and modeling. It is hard to say how much damage is "climate-induced" and therefore eligible for L&D responses and compensation.

Gaps in risk-data integration and planning tools: Climate risk information (hazard, vulnerability, exposure) is weakly integrated into city planning, financial budgets and decision-making, limiting adaptive measures' effectiveness. Sectoral assessments are often isolated, without sufficient analysis of cascading or cross-sector impact, such as how flooding in drainage can disrupt transport or water supply systems. Furthermore, post-flood recovery practices in Ahmedabad show recovery activity, but there is a gap in translating measured damages into targeted finance requests for L&D (insurance, grants, adaptation investments) at the city scale.

Gaps in adaptation actions implementation and infrastructure assumptions: Many adaptation actions (e.g., cool roofs and green infrastructure) have been identified, yet their cost-effectiveness, feasibility, and operational performance are not fully evaluated or publicly documented. Infrastructure vulnerability assessments often assume the current state of networks and facilities, but do not sufficiently incorporate future upgrades, maintenance deficiencies, or policy changes, which may alter risk profiles significantly. There is a limited focus on demand-side adaptation (e.g., reducing heat exposure, behavioural change, and decentralised storage) and a stronger emphasis on large infrastructure upgrades, which may leave gaps in protecting vulnerable populations.

Water Sector

The water supply sector faces increasing exposure to urban flooding and extreme heat, threatening both availability and infrastructure (Table 16). Projected temperature rise and rainfall variability may reduce groundwater recharge, increase evaporation, and stress distribution networks. Flooding of intake wells (e.g., near the Sabarmati and French wells) risks contamination and service disruptions, while heat accelerates pipeline wear and energy demand. Economic losses include infrastructure damage (pipelines, treatment units, pumps), higher energy and treatment costs, supply disruptions, and revenue loss. Non-economic losses include limited access to safe water, waterborne diseases, stress from recurrent failures, ecosystem degradation, and inequities affecting low-income areas. Adaptation measures in the city's resilience plan include WTP expansion, GIS-based monitoring, source diversification (Narmada Canal, recharge zones), and leakage/pressure control (Table 16). However, these focus more on infrastructure than demand management or decentralized systems, with limited quantification of climate-related losses. Data gaps on asset-level vulnerabilities and compounded impacts of events, flood, and heat, hinder comprehensive risk estimation.

Table 16: Water Sector Climate Risk Projection for Ahmedabad

Water Sector			
Parameter	**Existing (2023–24)**	**Future Demand (2050)**	**Climate Fragility Statement[58]**
Water Demand & Supply Continuity (Per Capita Supply)	**Existing supply:** 1,690 MLD Water source: 90% from bulk water purchases [60] from Narmada Canal (75%) and Mahi River (15%), and 10% from groundwater. **Coverage:** 96% of households and 85% of slums. Water is supplied for 2.5 hrs daily. Per capita water supply is 170 LPCD with and 25% NRW The city targets to reduce NRW to below 20%.	**Projected water demand**[61] by 2050: 2,453 MLD, which may lead to source stress. Future need for implementation of policies for rationalizing water tariffs for industrial and commercial consumers	Rising ambient temperatures, particularly during extreme heat events, increase water demand, while limited water availability leads to higher groundwater extraction, especially in summers and reduced overall resources; wards facing both extreme heat and drinking water issues are more vulnerable, and intense rainfall causing urban flooding further disrupts compromised water distribution systems, threatening public health. **Risk score:** 16 (High)
Treatment Capacity	3 WTPs of cumulative 1,750 MLD	The city is expanding its treatment capacity by over 1,100 MLD through 3 new and upgraded WTPs, serving an additional 4.5 million people by 2040. So far, AMC has proposed for adequate infrastructure to meet the water demand until 2030.	Treatment gaps exposes population to unsafe water **Risk score:** 16 (High)
Groundwater Status	Groundwater extraction over-exploited[63] (152.79%); meets 10% of city demand. City sinking[64] 12–25 mm/year due to over-withdrawal, mainly in Ghuma–Bopal. Water table depth[65]: 1–24 m; shallow (1–4 m) in the southeast and central zones. High iron, fluoride, chloride, nitrates in groundwater[62]; nitrate from fertilizers, sewage, industry	Extraction level may increase further in the future if the water supply source is not diversified	Increased dependence on groundwater when surface water systems do not suffice during floods or extreme heat. **Risk score:** 16 (High)

Increasing rainfall intensity and urban heat are straining Ahmedabad's drainage infrastructure. Historical data show rising rainfall (~12 mm/decade), with projections indicating an additional 20–60 mm by 2070. Combined with fewer rainy days and intense rainfall, this leads to higher runoff, flooding, submerged pumping stations and treatment plants, and sewage overflow. Economic losses include damage to drains, pumps, and sewer lines; increased O&M; downtime of treatment plants; lost revenue; business disruption; and emergency response costs.

58 The climate resilience and fragility of urban systems were assessed by examining the service levels and baseline situation of urban infrastructure in the city, especially the direct and indirect impacts of the identified climate hazards (i.e., urban heat, urban flood). Risks associated with climate fragility were assessed by determining the likelihood of their occurrence and potential consequences. For example, an increase in heat conditions could affect water consumption patterns, while urban flooding could lead to water contamination in areas where the water supply network is already compromised. The risk assessment exercise involved in-person discussions with key officials of AMC through Climate Core Team meetings and focused group discussions with vulnerable populations.

59 Adaptation strategies and actions for the sector are aligned with the Ahmedabad Climate Resilient City Action Plan – Toward a Net Zero Future (2023), which was developed with the suggestions and inputs of Ahmedabad city officials involving sectoral departments. These measures have been further refined based on insights from Focus Group Discussions (FGDs), one to one consultation, workshops involving parastatal bodies, district emergency operation center, fire department and NGOs/CBOs.

60 AMC purchases water from Narmada Canal at the rate of INR ~3.14 per kl, with 10% increase in price per year i.e., the city is spending around INR 4 million per day for bulk water purchases. Higher dependency on surface sources may further increase the costs of sourcing water in future without source diversification.

61 Water demand is projected based on population, considering 95% network coverage and 25% NRW as per BAU as assessed in Ahmedabad Climate Resilient City Action Plan – Toward a Net Zero Future.

Water Sector		
Climate Impacts	**Possible ELD/NELD**	**Planned adaptation strategies[59]**
Urban Flooding: increased risk of water contamination[61] at source due to mixing of hazardous substances from contaminated stormwater or wastewater disposal **Extreme Heat:** Increased water demand and groundwater extraction. Risk of water supply shortages without NRW reduction & source diversification in the future.	**Economic Losses (ELD):** High operating cost (tanker/bottled water distribution, extra chemicals for treatment, intensive groundwater pumping, increased potable water production) **Economic Damages:** Partial/total damage to water supply infrastructure – pipelines, treatment plants, pumping stations, mains, storage tanks, distribution networks, pumps **Non-Economic Losses/Damages (NELD):** Reduction in safe, reliable water-supply coverage[62] (fall in % of households with direct connections), disproportionate burden on vulnerable groups (women) for water access, environmental contamination of water resources disposal sites, and resulting health impacts. Environmental degradation, loss of ecosystem services, and reduced local resilience	**Reform policy and regulatory frameworks for water resilience:** Develop a local water resource and groundwater recharge action plan with policies for a 24x7 metered water supply. Promote treated wastewater reuse by regulating groundwater extraction. Water supply zones will be demarcated, supported by robust NRW studies and the replacement of old pipelines with DI networks. SCADA and smart meter-based systems will enhance real-time monitoring and management. Water ATMs will be provided in heat-vulnerable and slum areas to ensure equitable access to safe drinking water.
Urban Flooding: Inundation of low-lying pump houses, valve chambers, mains; contamination ingress; service outages and disruption from flooding. Contamination of source		Implement policies to promote treated wastewater reuse, thereby limiting groundwater extraction. Increase treatment capacity to serve newly merged developing areas.
Urban Flooding: Intense rainfall leads to high runoff and limited infiltration in paved urban areas. **Urban Heat:** Over-extraction during heatwaves to meet rising water demand for cooling and domestic use.		Provide efficient supply and equitable access to quality water by limiting groundwater extraction and policy measures. Monitoring of RWH structures implemented by builders as per GDCR.

Non-economic losses include loss of ecosystem services, health risks (waterborne/heat-related diseases), loss of cultural heritage, and reduced well-being, especially for slum populations. Further, CRVA from the Ahmedabad CRCAP shows that around 10.9%[66] of sewage pumping stations lie in flood-prone areas, affecting ~0.3 million slum residents and 16,000 vendors.[65]To address this, the city has planned/initiated key adaptation strategies that include lake interlinking, sponge city interventions, upgradation, expansion and rehabilitation of sewage and drainage network, and installation of new STPs. Despite limited zone-wise runoff and catchment modeling, analysis of flood return periods, downtime data, and non-economic impact metrics remain constrained, hindering informed investment and full damage assessment.

62 23% respondents in Ahmedabad reported worsening access due to contamination, water scarcity (18%), irregular supply (14%). Furthermore, in response to extreme weather events, such as heatwaves or water shortages, 9% of households reported having to purchase drinking water.

63 Report on Dynamic Ground Water Resources of Gujarat State as on March 2023. Ahmedabad Urban Area (including Ahmedabad City) is classified as "over-exploited", with extraction levels reaching 152.79%

64 Ahmedabad sinking 12-25 mm annually: Reports | DeshGujarat. (2023, January 17). DeshGujarat. https://deshgujarat.com/2023/01/17/ahmedabad-sinking-12-25-mm-annually-reports/

65 Information collected from BISAG, Department of Science and Technology, Gujarat as a part of preparation of 'Ahmedabad Climate Resilient City Action Plan – Toward a Net Zero Future'

Table 17: Wastewater Sector Climate Risk Projection for Ahmedabad

Drainage infrastructure (wastewater and stormwater management)			
Parameter	**Existing (2023–24)**	**Future Demand (2050)**	**Climate Fragility Statement[58]**
Wastewater recycle and reuse	Sewage generation in 2024: 1,320 MLD.[65] STPs: 18 STPs of 1367 MLD.[67] Sewage network coverage: 98% of total HHs (3,500 km sewerage network length) Treated wastewater is disposed in Sabarmati and Khari Rivers. 25% (337 MLD) of total sewage generated is reused for irrigation. 150 MLD Tertiary Treatment Plants (TTPs) proposed under the GRCP for industrial reuse.	Projected sewage generation by 2050: 1,962 MLD.[68] Additionally, 9 to 10 STPs[69] and expansion of the drainage network by approximately 2,079 km in new urban areas would be required by year 2050. Currently, infrastructure has been proposed to meet the demand until 2030.	Increased urban flooding worsens sewage network failures, disrupting treatment operations and degrading water quality and public health. Risk score: 16 (High)
Sludge and Septage Management	Sludge generated: 35 to 40 tonnes per day. Sludge treatment: 100 TPD capacity sludge treatment (or hygienization) plant, to convert sludge into good-quality manure.		
Stormwater network and allied infrastructure	Stormwater Network Coverage: 55% of the city area and 36% of the total road network (980 km of stormwater network length). Stormwater Pumping Stations: 34 Total Catchpits: 67,753[72] Disposal of Stormwater: Sabarmati River, Gota-Godhavi Canal, Kharicut Canal and nearby lakes. Waterlogging points: 166	Additionally, 21 SPS[73] is required and an expansion of stormwater network by approximately 535 km in new urban areas would be required by year 2050.	Extreme urban flooding can overwhelm drainage systems, causing blockages, prolonged waterlogging, higher pumping costs, and increased risks of waterborne and vectorborne diseases. Risk score: 15 (High)

Urban floods and extreme heat increasingly compromise solid waste operations. Floods obstruct waste collection and transportation, inundate landfills, and compromise leachate systems, while extreme heat accelerates organic waste decay, increases odor and fire risk, and intensifies worker health stress. Economic losses include damage to SW collection vehicles, transfer stations, and processing units; emergency clean-up costs; blocked drains[74]; operational delays; public health burdens. NELD includes worker exposure to extreme heat, spread of diseases within communities, ecosystem contamination (impact on ecological

64 Ahmedabad sinking 12-25 mm annually: Reports | DeshGujarat. (2023, January 17). DeshGujarat. https://deshgujarat.com/2023/01/17/ahmedabad-sinking-12-25-mm-annually-reports/

65 Information collected from BISAG, Department of Science and Technology, Gujarat as a part of preparation of 'Ahmedabad Climate Resilient City Action Plan – Toward a Net Zero Future'

66 Ahmedabad Municipal Corporation; ICLEI – Local Governments for Sustainability, South Asia. (2023, July). Ahmedabad Climate Resilient City Action Plan – Toward a Net Zero Future. Ward level complaints related to the sewerage network and treatment were analysed spatially to identify critical wards and correlated with urban flood risk areas. Sewage Pumping Stations (SPS) were spatially marked and overlaid to identify critical SPS that may be impacted by urban floods or stagnation.

67 Information collected from STP department, AMC as a part of preparation of 'Ahmedabad Climate Resilient City Action Plan – Toward a Net Zero Future' in 2023

68 AMC has 60 septage sucker machines for collection and disposal of septage. Wastewater demand is projected based on population and water supply projections.

Drainage infrastructure (wastewater and stormwater management)		
Climate Impacts	**Possible ELD/NELD**	**Planned adaptation strategies[59]**
Urban Flooding: Submergence of wastewater recycling plants, treatment plants and pumping stations. Intense rainfall can rapidly exceed sewer system capacity, causing wastewater to surge from manholes, sewer lines to collapse, or become blocked, and untreated sewage to be discharged directly into streets and surface waters.	Economic losses: Unexpected expenses- Septic tank clean-up, sewer network clean-up. Higher operating costs of pumps and increased energy use. Economic Damages: Partial/total damage to sewerage infrastructure[70]: collection systems, lift-stations, treatment plants, drainage system, outfalls, unexpected expenses in repairing and upgrading stormwater drain lines Non-Economic Losses/Damages (NELD): Increase in vector-borne & water-borne diseases[71]	100% efficient sewage collection and treatment. 'Treated Sewage Reuse and Recycle Action Plan' to promote reuse of treated wastewater for industry, irrigation, power plants, and plantations. Rehabilitate old sewage network, improvisation in network design, dual membrane technology, construction of TTPs, decentralised wastewater treatment and dual plumbing system through GDCR for projects with 20,000m^2 built up area or more
Urban Flooding: Water quality degradation[61] due to contamination from leakages from damaged/improper containment facilities at the treatment plant. This may further lead to public health risks.		100% sludge and septage management
Urban Flooding: Heavy rainfall and accumulation of solid waste in stormwater networks cause blockages and waterlogging, leading to mixing of stormwater and wastewater. Waterlogging disrupts the commuting of people and poses public health risks. Impervious urban surfaces (roads, pavements) increase runoff, putting more stress on the drainage network.		Adopt green-city planning to minimize runoff and flooding by improving stormwater management, restoring natural drains, and creating rain gardens in flood-prone areas to boost water retention. Reserve land in town-planning schemes for parks, urban forests, and green islands to serve as a city-wide sponge for stormwater.

services), cultural space degradation, and loss of livelihoods in the informal sector. Ahmedabad's CRCAP promotes source segregation, reuse/recycling, and improved collection/disposal systems, amongst others, to address the issues at source generation. However, there is minimum data available at city scale on equipment failure, damage to SWM infrastructure due to heat and floods, sanitation worker's health costs, or informal sector losses, limiting efficient adaptive planning and system resilience.

69 Projection based on population for the year 2050 from 'Ahmedabad Climate Resilient City Action Plan (2023)'

70 19% households reported damage to sanitation infrastructure during flooding event in Ahmedabad

71 During household surveys conducted in Ahmedabad, respondents reported that rising temperatures, irregular rainfall, and frequent extreme weather events have led to a marked increase in heat-related illnesses (reported by 61% of households), as well as respiratory diseases (25%), outbreaks of water-borne (18%) and vector-borne diseases (18%) such as diarrhoea, dengue, and malaria. Specific symptoms such as fever and dizziness were reported by 68% of households during heat events and 20% during floods.

72 There are 67,753 catch pits in Ahmedabad, of which 12,398 are in west zone. Despite the most catch pits, this zone is highly vulnerable to flood, particularly the Naranpura, Navrangpura, Sabarmati, Amraiwadi, Paldi, and Vasna areas as per information received from drainage department of AMC.

73 Projection based on population for the year 2050 from 'Ahmedabad Climate Resilient City Action Plan (2023)'

74 As a part of preparation of 'Ahmedabad Climate Resilient City Action Plan', CCRS complaints related to littering, indiscriminate waste dumping and blockage of drains and manholes were analysed and correlated with urban flood risk areas to identify vulnerable wards. 14 out of 48 wards are experiencing water logging issues and are receiving complaints related to solid waste dumping.

Table 18: Solid Waste Management Sector Climate Risk Projection for Ahmedabad

Solid waste management			
Parameter	**Existing (2023–24)**	**Future Demand (2050)**	**Climate Fragility Statement[58]**
Waste collection	Solid Waste Generation: 4,100 TPD[75] Household Coverage: 100% Waste collection: • Door-to-door collection: 1,700 MT • Community bins: 700 MT • Cradle bins: 600 MT • C&D waste: 1000 MT • Kitchen waste: 90 MT • Offal waste: 10 MT	Projected MSW generation by 2050[76]: 9,348 TPD	Rising temperatures accelerate waste decomposition and heighten the risk of landfill fires at open dumpsites, exposing workers to heat stress and reduced productivity, while heavy rainfall worsens drainage blockages and increases leachate flows, contaminating land, surface water, and groundwater. Risk score: 16 (High)
Treatment and processing	Waste Treated: 3,600 TPD Disposal: Pirana (dumpsite), Gyaspur (landfill) Existing waste treatment plants[71]: • Waste to compost: 1,500 MT • MRF: 1,000 MT • Waste to energy[77]: 1,000 MT • C&D: 1,000 MT • Waste to Bio-CNG: 500 MT • Plastic waste[78] management plant: 200 MT		

The transport network is vulnerable to flooding and extreme heat. Waterlogging damages roads, signals, rail links, and vehicles, and hinders commute and accessibility to emergency services, while extreme heat degrades road surfaces and endangers transport workers. Economic losses include infrastructure (road) repair costs,[80] service disruptions (BRTS, AMTS, freight), longer travel times, higher fuel costs, and business interruption. Non-economic losses include reduced access to vulnerable groups, heat-induced health issues, weakened mobility rights, and social cohesion. The CRCAP highlights that 117 BRTS and 2,820 AMTS stations lie in heat-risk zones,

75 Information collected from SWM department, AMC

46 Projection based on population for the year 2050 from 'Ahmedabad Climate Resilient City Action Plan (2023)'

77 1,000 TPD waste to energy plant (11 MW) by JITF Urban Infrastructure Pvt. Ltd.

78 100 TPD plastic waste management facility by NEPRA and 100 TPD plastic waste management facility by Eco Vision Environmental Resources LLP

79 Chopda, M., & Malek, Prof. A. M. (2018). Contamination of Groundwater Quality Due to Municipal Solid Waste Disposal – A GIS Based Study. International Research Journal of Engineering and Technology (IRJET) https://www.irjet.net/archives/V5/i4/IRJET-V5I41068.pdf. The study highlights groundwater in areas like Behrampura, Nagma Nagar, Faisal Nagar, and Chhipakuva is highly contaminated, with sulphates, chlorides, and conductivity levels exceeding BIS and WHO limits. The water is unsafe for drinking, and measures like clay liners and monitoring wells are recommended to prevent further contamination.

Solid waste management		
Climate Impacts	**Possible ELD/NELD**	**Planned adaptation strategies[59]**
Urban Flooding: Flooded roads hinder waste transportation, leading to waste accumulation and informal dumping that heighten public health risks. Contaminated floodwaters mixed with waste increase exposure to vector- and water-borne diseases, while flood-carried waste clogs drains and pump stations, worsening urban flooding.	Economic Damages: Partial/total damage to solid waste infrastructure: transfer stations, trucks, disposal/composting sites	Minimize solid waste generation and maximize reuse and recycling: • Towards zero waste wards and zero plastic waste, • Promote eco-parks: MRFs, manufacturers of alternate materials, and recyclers • Legacy waste management
Urban Flooding: Contamination of groundwater due to leachate flow[79] Urban Heat: Waste decomposition at landfills or nuisance spots and burning of waste due to methane emissions pose public health risks, especially to dumpsite workers and neighbourhoods living near landfills or nuisance spots. Heat increases worker illnesses, leading to productivity loss.		

with 37 major junctions in flood/heat-prone areas. Spatial analysis shows several high-risk stations and traffic junctions exposed to both flood and heat hazards. Complaints of potholes, open or raised manholes, and poor road quality correlate strongly with urban flood–prone zones, with six of 48 wards[81] showing the highest incidence. Proposed measures include non-motorized connectivity. Despite data on service downtime, losses due to connectivity issues, indirect losses, and non-economic impacts like construction and sanitation worker health are not reported, hindering targeted, climate-resilient investments.

80 Parmar, J. (2025, June 28). 4,669cr down the drain as Ahmedabad's roads crumble. The Times of India. https://timesofindia.indiatimes.com/city/ahmedabad/4669cr-down-the-drain-as-ahmedabads-roads-crumble/articleshow/122134949.cms

81 As a part of preparation of 'Ahmedabad Climate Resilient City Action Plan', spatial analysis of BRTS, AMTS, and Metro stations has been conducted. Access is computed by using road network grids and population coverage within 400 m walking distance from AMTS and BRTS stations and 800 m walking distance from metro stations as per URDPFI guidelines.

Table 19: Transport sector climate risk projection for Ahmedabad

Transport			
Parameter	**Existing (2023–24)[82]**	**Future Demand[83]**	**Climate Fragility Statement[58]**
Transport systems (NMT, road network)	Total road network: 3,225 km Length of footpath: 1,248 km Public Transportation: AMTS Stations: 4,968 BRTS Stations: 200 Metro Stations: 33 Accessibility[84] of Public Transport Stations: 93.7% of the total population can access AMTS and BRTS stations within 400m, and metro stations within 800m Fleet Size of Public Transport[85]: 0.12 per 1000 people (Inadequate) AMTS: Operates 133 routes covering 3,730 km with 645 buses, serving 0.32 million passengers/day. BRTS: Runs on a 133 km dedicated corridor with 18 routes and 374 buses, serving 0.19 million passengers/day.	Registered private vehicles increased from 2.38 million (2009–10) to 3.9 million (2021–22), a 65% rise over a decade and a 4.23% annual increase. Four-wheelers increased over threefold, and two-wheelers doubled. Auto-rickshaws rose from 40,944 (2011) to 0.17 million (2021). With these trends, the number of registered private vehicles may increase and worsen vehicular congestion.	Rising extreme heat will increase the demand for comfortable public transport while adversely impacting pedestrians, cyclists, and two-wheeler commuters—especially at major junctions—thereby increasing dependence on personal vehicles. Extreme rainfall will further deteriorate road infrastructure, particularly damaged sections, and intense waterlogging during heavy rains will worsen congestion, connectivity, and overall mobility. Extreme heat risk score: 16 (high) Urban flooding risk score: 9 (medium)

82 Information collected from AJL, BRTS, AMTS & roads department, AMC as a part of preparation of 'Ahmedabad Climate Resilient City Action Plan'

83 The percentage increase in vehicle registration was calculated using data from the VAHAN National Register, an integrated online database maintained by the Ministry of Road Transport and Highways (MoRTH), Government of India. The VAHAN portal records on registered vehicles across India, providing updated information on vehicle types, ownership, and growth trends

84 As a part of preparation of 'Ahmedabad Climate Resilient City Action Plan', spatial analysis of BRTS, AMTS, and Metro stations has been conducted. Access is computed by using road network grids and population coverage within 400 m walking distance from AMTS and BRTS stations and 800 m walking distance from metro stations as per URDPFI guidelines.

85 Adequate fleet size for public transport is 0.6 per 1,000 people as per SLBs for Public Transport, MoUD, GOI. Fleet size is considered based on passenger transport units (seating capacity) of AMTS, BRTS, and Metro.

Transport		
Climate Impacts	**Possible ELD/NELD**	**Planned adaptation strategies[59]**
Urban Flooding: Impacts accessibility to healthcare and emergency services due to waterlogging, increases traffic congestion and detours leading to larger trip lengths Urban heat: Reduction in ridership in public transport due to discomfort. More heat-related illnesses among commuters and transport workers. More emissions if people shift to private vehicles; urban heat island intensification	Economic Losses & Damages (ELD): Damage to road surfaces,[86] bridges, and bus depots; disruption of freight and passenger services.[87] Non-Economic Losses & Damages (NELD): Reduced mobility, loss of access to essential services, and increased commuter stress	Develop climate-resilient, low-carbon, and inclusive transport infrastructure by upgrading roads and transit systems to withstand extreme heat and flooding, integrating flood-resilient designs and permeable surfaces, and expanding green, electric, and non-motorized transport to reduce emissions and strengthen adaptive capacity.

86 Samachar, G. (2025, July 1). Smart city or pothole city? 13 areas of Ahmedabad riddled with potholes, repairs after monsoon. Gujarat Samachar. https://english.gujaratsamachar.com/news/gujarat/smart-city-13-areas-of-ahmedabad-ridden-with-potholes-repairs-to-begin-after-monsoon

87 UrbanNews. (2025, June 27). Ahmedabad commuters stranded overnight as monsoon floods damage expressway route. Urban Acres. https://urbanacres.in/ahmedabad-commuters-stranded-overnight-as-monsoon-floods-damage-expressway-route/

Table 20: Environment Sector Climate Risk Projection for Ahmedabad

Environment Sector (Focus on Urban Greening and Biodiversity)			
Parameter	**Existing (2023–24)**	**Future Demand**	**Climate Fragility Statement[58]**
Urban Greening and Biodiversity	Tree cover[88] in the city: Increased from 10% in 2021 to 12.5% in 2024 due to focused urban greening initiatives such as Mission Million Trees Tree survival rate: Increased from 60% in 2023 to 84% in 2024. Per capita green cover: Increased from 6.8 m^2 per person in 2021 to 8.4 m^2 per person in 2024 Total population accessible[89] to parks & gardens: 83.5% Total Parks and Garden: More than 300 parks and gardens. Urban Forests and Oxygen Parks: More than 260 in last 5 years Number of lakes: 122[90]	The extent of its built-up area rose from 36.1% (173.58 sq.km) in 2021 to 39.3% (189.03 sq.km) in 2023[54]. With such an urbanization rate, green areas need to be preserved to accommodate future population growth. Targeted additional green cover[83]: 2030: 35 sq. km 2050: 72 sq. km 2070: 90 sq. km	During extreme heat, the intensity of urban heat islands increases as built-up areas expand. Intense rainfall increases urban flooding and inundation by increasing the area of impermeable surfaces. Risk score: 9 (Medium)

Health and education, though often overlooked in L&D assessments, face significant risks from extreme heat and urban flooding in Ahmedabad. Despite a robust network of 2,080[83] hospitals and high healthcare accessibility, around 31.3%[83] of hospitals (651) are vulnerable to flooding, particularly where slum residents already face limited access to government facilities. Rising heatwaves and intense rainfall threaten to overwhelm healthcare systems, causing disease outbreaks, infrastructure damage, and access disruptions, especially for low-income populations. Similarly,

88 Information sourced from parks & garden department, AMC

89 As a part of preparation of 'Ahmedabad Climate Resilient City Action Plan', spatial analysis of parks and gardens has been carried out and accessibility analysed for neighbourhood parks, community parks, and city parks. Access is computed using road network grids and population coverage within 400 m of neighbourhood parks, 800 m of community parks, and 3 km distance from city parks as suggested in the Development Plan for Ahmedabad. Locations of parks and gardens in the city, 2021 was provided by parks and garden department, AMC; road network analysis using network analyst in GIS; pixel-based population analysis for recent built-up area

90 AMC proposed augmenting lakes with stormwater outlets and recharge wells under NPCA to mitigate floods and enhance groundwater recharge. Detailed project reports for 45 new lakes have been submitted to MoHUA and the state government.

91 Shastri, P. (2025, June 2). 33% of built environment in Ahmedabad on water recharge zones, says report. The Times of India. https://timesofindia.indiatimes.com/city/ahmedabad/33-of-built-environment-in-abad-on-water-recharge-zones-report/articleshow/121555077.cms

Environment Sector (Focus on Urban Greening and Biodiversity)		
Climate Impacts	**Possible ELD/NELD**	**Planned adaptation strategies[59]**
Urban flooding: Polluted runoff and debris degrade water quality in lakes and wetlands, harming aquatic life. Prolonged waterlogging stresses vegetation, increases mortality, and heightens pest vulnerability. Encroachment in wetlands and floodplains weakens natural buffers and accelerates biodiversity loss. Urban heat: High temperatures stress vegetation and native species, while warmer lake water lowers oxygen levels, reducing aquatic biodiversity.	Economic Losses & Damages (ELD): Increased maintenance costs for green infrastructure; loss of productivity due to heat-related stress. Non-Economic Losses & Damages (NELD): Loss of urban biodiversity and species, shrinkage[91] of lakes & waterbodies, extinction, decline in ecosystem services, reduced well-being.	Promote green city planning by expanding green cover (90 sq. km), integrating parks, urban forests, green roofs, and permeable landscapes in town planning to reduce runoff and urban flooding. Enhance biodiversity and ecosystem resilience through the restoration of degraded sites, the creation of microhabitats (pollinator gardens, grasslands, rain gardens), and the development of interconnected green–blue corridors. Implement Local Biodiversity Strategies and Action Plan (LBSAP) to guide sustainable urban greening and climate-resilient land use

municipal schools and colleges face structural damage, closures, and reduced learning outcomes during floods and heatwaves, affecting student well-being and continuity of education. Without resilient infrastructure and continuity planning, these impacts could erode gains in public health and education. Strengthening surveillance systems, upgrading facilities for climate resilience, and integrating digital and climate education are crucial to safeguard these essential services.

Table 21: Health Sector Climate Risk Projection for Ahmedabad

Health Sector			
Parameter	**Existing (2023–24)[85]**	**Future Demand**	**Climate Fragility Statement[58]**
Health Infrastructure (UPHCs, CHCs, hospitals)	Government hospitals: 4 super speciality hospitals, 2 medical colleges, 1 dental college and hospital, 1 Physiotherapy college, trauma center Existing urban primary health centers: 85 Existing community health centers: 12 Urban health and wellness centre: 130 Total hospitals: 2,080 hospitals with a capacity of 34,432 beds Accessibility[92] of health infrastructure: 99.7% of the total population can access health infrastructure, both public and private, within 3km Availability of number of beds per 1000 people: 5 beds (more than WHO guidelines of 3 beds per 1000 people)	Surcharge in demand for beds, intensive care facilities, surveillance systems, emergency care. Targets[93]: By March 2026, 100 urban primary health centers, 15 community health centers and 164 urban health and wellness centers	More frequent heatwaves can cause heatstroke, dehydration, and cardiovascular strain, particularly among the elderly, outdoor workers, and urban poor who lack cooling access, while heavy rainfall and flooding may trigger waterborne disease outbreaks (cholera, diarrhoea, leptospirosis, dengue), straining local health systems. Risk score: 16 (High)

Table 22: Education Sector Climate Risk Projection for Ahmedabad

Education Sector			
Parameter	**Existing (2023–24)**	**Future Demand (2050)**	**Climate Fragility Statement[58]**
Education Infrastructure	AMC manages 459 municipal schools, of which 53 have been upgraded to Smart Schools. The city achieved 100% enrolment with over 50,000 students; while more than 5,000 parents chose municipal schools over private ones. In 2022, the 'Signal School' program was initiated with the aim of promoting 'Bhiksha Nahi Shiksha'. Currently, 10 dedicated buses have been allocated under the program, benefiting 151 enrolled children.	Student enrolment and infrastructure demand are projected to rise significantly by 2050, driven by population growth, urban expansion.	Flooding and extreme rainfall can damage school infrastructure, cause closures and learning disruptions, while heatwaves and poor ventilation reduce attendance, learning outcomes, and pose health risks to children Extreme heat risk score: 9 (Medium) Urban flooding risk score: 12 (High)

92 As a part of preparation of 'Ahmedabad Climate Resilient City Action Plan', spatial analysis of hospitals has been carried out 94.1% of the total population (6.7 million people) can access health care facilities within 1 km, 4.7% (0.3 million people) within 2km, and 1% (75,000 people) within 3 km. 25% of all slum dwellers (0.2 million people) can access health care facilities within 1 km, 27% within 2km, and 27% within 3 km.

93 Information sourced from health department, AMC

94 During household surveys in Ahmedabad, 61% respondents highlighted increased expenses in health treatment.

Health Sector		
Climate Impacts	**Possible ELD/NELD**	**Planned adaptation strategies[59]**
Urban Flooding: Vector-borne & water-borne disease outbreaks. Flood events can hamper mobility and access to hospitals, affecting timely medical care and ambulance services Urban Heat: Risk of heatstroke, dehydration & other heat-related morbidities	Economic Losses & Damages (ELD): Damage to hospitals, equipment, and cold-chain systems; increased operational costs, increased health treatment costs[94] Non-Economic Losses & Damages (NELD): Loss of lives, health deterioration, and psychosocial distress among vulnerable groups.	Upgrade and expand healthcare infrastructure to handle climate-induced health impacts, ensuring adequate bed capacity and accessibility for vulnerable populations during emergencies. Strengthen disease surveillance and response systems for timely detection and management of heat- and flood-related outbreaks. Implement localized preventive and heatwave action measures to reduce public health risks from extreme climatic events.

Education Sector		
Climate Impacts	**Possible ELD/NELD**	**Planned adaptation strategies[59]**
Urban Flooding: School closures & infrastructure damage Urban Heat: Decline in attendance & learning outcomes. High temperatures and insufficient water/ sanitation in schools can cause dehydration, illness, and dropouts, particularly for marginalized students.	Economic Loss & Damage (ELD): Damage to buildings, classrooms, and learning equipment. Non-Economic Loss & Damage (NELD): Learning loss, reduced attendance, and psychosocial stress among students	Integrate climate change, disaster risk reduction, and sustainability into school curriculum and teacher training programs. Retrofit school infrastructure for improved ventilation, heat protection, and flood resilience. Strengthen digital learning infrastructure to ensure education continuity during climate emergencies.

4.3 Surat: Sector-wise assessment

The sector-wise assessment presented in Table 23 provides a comprehensive evaluation of potential climate-induced impacts on key urban systems in Surat,[95] including water supply, drainage and stormwater management, solid waste management, and urban transport. Building on historical trends and projected future climate scenarios, the table integrates observed vulnerabilities, expected stressors from heatwaves and urban flooding, and compound climate risks to identify areas of fragility within each sector. It further links these risks to prospective ELD and NELD, highlighting both infrastructure-related impacts and broader social and environmental consequences. The assessment also outlines proposed adaptation interventions aimed at enhancing system resilience, ensuring continuity of services, and mitigating potential losses under projected climate conditions through 2050.

The risk scoring for each sector is derived from the combination of two pivotal factors: likelihood, the probability of a hazard occurring, and consequence, the magnitude of its potential impact on urban systems and population groups. The likelihood depends on the possibility of the occurrence of a hazardous event in the future; the consequence depends on the vulnerability of the urban systems or population groups. The risk assessment exercise is explained in detail in Annexure.

The assessment indicates that urban flooding generally has more severe consequences than heat stress for most infrastructure sectors. Water-related facilities, such as water supply networks, treatment plants, and sewerage systems, are particularly vulnerable, as both heatwaves and floods can disrupt operations. Solid waste management is highly sensitive to flooding, while heat stress poses a moderate operational risk.

Limitations:

Surat has implemented a range of adaptation strategies across urban sectors, as reflected in city-level plans such as the City Resilient Strategies, Heat Action Plans, Master Plans, General Development Control Regulations (GDCR), and City Disaster Management Plans. These strategies cover thematic areas including water management, public health, green infrastructure, governance, disaster preparedness, and urban planning.

Despite this progress, gaps remain in addressing the complex and compounding nature of future climate risks, particularly those arising from heatwaves, urban flooding, and other extreme events. The following sector-wise analysis highlights these limitations and the implications for both ELD and NELD.

From a L&D perspective, most existing strategies remain primarily sectoral and infrastructure-focused, with limited attention to retrospective assessments of climate-induced damages, particularly non-economic losses such as displacement, psychological trauma, or ecosystem degradation. Disaster management plans typically focus on short-term response

95 The sector-wise assessment for Surat is mainly sourced from the Net-Zero Climate Resilient City Action Plan, developed based on inputs and suggestions from city officials and relevant sectoral departments. It has been further refined through Focus Group Discussions (FGDs), one-to-one consultations with officials from state and city departments, and workshops with NGOs and community-based organizations (CBOs).

mechanisms and often lack robust mechanisms for tracking cumulative losses, especially in low-income and high-risk communities.

Furthermore, the limited integration of climate risk data into planning tools reduces the effectiveness of current adaptation measures. There is an absence of formal reporting mechanisms to account for recurrent losses due to climate events such as urban flooding or prolonged heatwaves. These gaps highlight the need for dynamic, inclusive, and data-driven adaptation planning capable of minimizing both ELD and NELD while enhancing the adaptive capacity of vulnerable populations and urban systems.

Additional limitations of the sector-wise assessment include:

- **Socio-economic Projections:** Future population, urbanization, and sectoral demand projections are based on generalized Shared Socioeconomic Pathways (SSPs). Actual growth rates, migration patterns, or economic developments may differ, affecting demand and vulnerability.
- **Limited Intersectoral Analysis:** The assessment primarily evaluates individual sectors in isolation. Cascading or cross-sectoral impacts, for example, how drainage flooding may disrupt transport or water supply are not fully quantified.
- **Infrastructure Assumptions:** Existing infrastructure status (water supply networks, STPs, stormwater drains) is assumed from current surveys. Future upgrades, maintenance, or policy interventions may alter vulnerability profiles.
- **Adaptation Implementation:** While adaptation interventions are identified strategically, their feasibility, cost, efficiency, and operational challenges are not fully assessed.

Table 23: Water Supply Sector Climate risk projection for Surat

Water Supply Sector			
Parameter	**Existing (2023–24)**	**Future Demand (2050)**	**Climate Fragility Statement[96]**
Water Demand & Supply	1,555 MLD, 95.5% coverage, 156.5 LPCD (19% NRW)	2050: 4,680 MLD The city has prepared the Water Supply Master Plan 2041, forecasting demand based on population. But it does not take in to account future compounded climate risks.	Rising demand and climate shocks pose a serious risk to long-term supply sustainability Overall Risk score: 16 (High)
Treatment Capacity	1,954 MLD	Capacity expansion is needed to meet growing demand and address climate-induced stress on treatment systems.	Existing treatment infrastructure may become insufficient under rising demand, operational stress, and climate impacts. A widening treatment gap could expose the population to unsafe or inadequately treated water.
Groundwater Status[101]	118% exploited[102]	Demand expected to increase further due to population growth and climate-induced stress, intensifying pressure on aquifers.	Over-extraction during droughts and heatwaves increases risk of depletion, while saltwater intrusion and contamination threaten water quality.

While these adaptation interventions are crucial, they may not fully account for the combined impacts of heatwaves, droughts, and urban flooding on water availability and quality in the future. Moreover, projections of future water demand and source stress are based on SSP (sourced from Surat Net-zero CRCAP 2024); extreme or compound events could overwhelm infrastructure, leading to significant disruptions. Existing strategies, such as those outlined in

96 The climate resilience and fragility of urban systems were assessed by examining the service levels and baseline situation of urban infrastructure in the city, especially the direct and indirect impacts of the identified climate hazards (i.e., urban heat, urban flood). Risks associated with climate fragility were assessed by determining the likelihood of their occurrence and potential consequences. For example, an increase in heat conditions could affect water consumption patterns, while urban flooding could lead to water contamination in areas where the water supply network is already compromised. The risk assessment exercise involved in-person discussions with key officials of SMC through Climate Core Team meetings and focused group discussions with vulnerable populations.

97 Adaptation strategies and actions for the sector are aligned with the Surat Net-Zero Climate Resilient City Action Plan (CRCAP) 2024, which was developed with the suggestions and inputs of Surat city officials involving sectoral departments. These measures have been further refined based on insights from Focus Group Discussions (FGDs), one to one consultation, workshops involving parastatal bodies, district emergency operation center, fire department and NGOs/CBOs.

Water Supply Sector		
Climate Impacts	**Possible L&D (ELD/NELD)**	**Adaptation strategies and actions[97]**
Heatwaves increase peak water demand and intensify groundwater stress High-intensity rainfall can disrupt supply systems and cause contamination, affecting public health Combined climate hazards increase both chronic scarcity, seasonal supply deficits and contamination risks	Economic Losses (ELD): High operating cost (tanker/bottled water distribution,[98] extra chemicals for treatment, intensive groundwater pumping, increased potable water production) Economic Damages: Partial/total damage to water supply infrastructure – pipelines, treatment plants, pumping stations, mains, storage tanks, distribution networks, pumps Non-Economic Losses & Damages (NELD): Reduction in safe, reliable water-supply coverage[99] (fall in % of households with direct connections), disproportionate burden on vulnerable groups (women) for water access,[100] environmental contamination of water resources and disposal sites.	Strategy: Strengthen planning and policy mechanisms to improve long-term water resilience **Actions:** • Prepare an action plan for effective water management. Integrate climate projections into city water master plans and demand–supply forecasting • Establish cross-departmental coordination (water utility, disaster management, health, environment) for integrated action. • Diversify water sources: surface water, groundwater, recycled wastewater, and rainwater harvesting • Implement SCADA and smart-meter–based supply systems for real-time monitoring and adaptive management.
Concurrent heat and flood events can severely affect treatment performance and reliability.		Strategy: Design a holistic water management system to promote efficient distribution and equitable access to safe water **Actions:** • Expand storage capacity (service reservoirs, decentralized tanks) to buffer short-term deficits. • Integrate reuse of treated wastewater to reduce pressure on fresh water sources and groundwater extraction.
Combined drought and flood cycles can lead to both quantity and quality stress — over-extraction depletes reserves, while subsequent flooding introduces contaminants. These interactions reduce groundwater reliability and pose long-term risks to public health and urban water security.		Strategy: Safeguard and restore local water bodies through protection, rejuvenation, and revitalization efforts **Actions:** • Ecological restoration of the Riverine ecosystem (including natural streams) and lakes in the city • Promote rainwater harvesting and recharge structures to replenish aquifers.

the Water Supply Master Plan 2041 by SMC, primarily target physical infrastructure, with limited emphasis on demand-side measures, behavioural adaptation, or decentralized solutions and the impact of future climate risk. As a result, future ELD could include high operational costs for emergency water provisioning and repair of damaged infrastructure, while NELD could manifest as reduced safe water coverage, disproportionate burden on vulnerable populations, and environmental contamination.

98 During household surveys in Surat, 81% respondents highlighted increased expenses in food and water.

99 37% respondents in Surat reported worsening access due to contamination, irregular supply, or increased reliance on handpumps and water tankers. Furthermore, in response to extreme weather events, such as heatwaves or water shortages, 35% of households reported having to purchase drinking water.

100 As highlighted in FGDs, during floods in areas like Udhna and Katargam, drinking water becomes a major issue. Government-supplied water often turns muddy or contaminated with sewage. Though residents are informed in advance and clean water is later restored, delays force many to rely on stored or bottled water, increasing expenses.

101 Report on Dynamic Ground Water Resources of Gujarat State as on March 2023

102 Surat Urban Area (including Surat City) is classified as "over-exploited", with extraction levels reaching 115.32%.

Table 24: Drainage Sector Climate risk projection for Surat

Drainage Sector (wastewater and stormwater management)			
Parameter	**Existing (2023–24)**	**Future Demand (2050)**	**Climate Fragility Statement[103]**
Wastewater Reuse and recycling	As of 203-24, wastewater generation is approx. 1076 MLD treated through 11 STPs with a cumulative treatment capacity of 1,726 MLD in 2024-25 (1812.5 MLD as of 2025). • 330 MLD (27.47% treated sewage reused in irrigation, gardening, other non-potable usages, and industrial sector)[105]	Wastewater generation (2050): 3744 MLD[106] Treatment capacity required (2050): 5198 MLD[107] The city has planned 100% treated wastewater reuse by 2035	Mixed discharge of stormwater and sewage during high-intensity rainfall events may lead to surcharging of sewer lines and backflow into households. This may reduce the effectiveness of sewage treatment systems, leading to untreated or partially treated sewage entering natural drains, creeks, and water bodies, and posing potential public health and environmental risks. Overall Risk score: 16 – High
Stormwater network coverage	The city has a 1119.32 km-long stormwater network that extends across approximately 74.5% of the city's road network. The city also has a network of creeks (Varachha, Koyali, Mithi, Kankara, Bhedvad, and Chhaprabhatha creeks), which form part of a larger hydrological system.	By 2050, the network may need to be reconfigured into a climate-resilient system integrating natural drainage corridors, retention basins, and real-time flow management to cope with increased peak rainfall, sea-level rise, and urban densification.	Increased waterlogging due to the lack of maintenance of the stormwater network during heavy rainfall events may lead to public health hazards, including water-borne and vector-borne diseases.

While infrastructure upgrades such as stormwater drains and sewage treatment plants—form the cornerstone of current adaptation strategies, they may not fully address cascading impacts across sectors. For example, drainage failure during heavy rainfall can disrupt transport networks, compromise water supply, and increase health risks, revealing interdependencies that are not fully captured in planning. The operational efficiency of drainage networks is uncertain, with blockages, poor maintenance, or inadequate capacity

103 The climate resilience and fragility of urban systems were assessed by examining the service levels and baseline situation of urban infrastructure in the city, especially the direct and indirect impacts of the identified climate hazards (i.e., urban heat, urban flood). Risks associated with climate fragility were assessed by determining the likelihood of their occurrence and potential consequences. For example, an increase in heat conditions could affect water consumption patterns, while urban flooding could lead to water contamination in areas where the water supply network is already compromised. The risk assessment exercise involved in-person discussions with key officials of SMC through Climate Core Team meetings and focused group discussions with vulnerable populations.

104 Adaptation strategies and actions for the sector are aligned with the Surat Net-Zero Climate Resilient City Action Plan (CRCAP) 2024, which was developed with the suggestions and inputs of Surat city officials involving sectoral departments. These measures have been further refined based on insights from Focus Group Discussions (FGDs), one to one consultation, workshops involving parastatal bodies, district emergency operation center, fire department and NGOs/CBOs.

105 Currently, over 27.47% of the total sewage generated, amounting to 330 MLD of secondary-treated wastewater, is being effectively reused for various purposes, including industrial, horticultural, and agricultural applications. Of this, a significant portion is utilized by textile clusters (115 MLD) and industries (112 MLD). This is followed by wastewater reused for treatment processes at STPs (49 MLD), agriculture (28 MLD), construction purposes (20 MLD), gardening (17MLD), conversion to ecological park (5 MLD), lake rejuvenation (2 MLD) and 0.5 MLD each in the bio-diversity park and the Dream city project.

Drainage Sector (wastewater and stormwater management)		
Climate Impacts	**L&D (ELD/NELD)**	**Adaptation strategies and actions[104]**
Increased frequency and intensity of rainfall may cause stormwater and sewer overload, leading to urban flooding, sewage backflow, and waterlogging. These conditions may contribute to water quality degradation, spread of water-borne diseases, and damage to drainage and treatment infrastructure.	Economic losses: Unexpected expenses- Septic tank clean-up Economic Damages: Partial/total damage to Sewerage infrastructure[108]: collection systems, lift-stations, treatment plants, drainage systems, outfalls. Non-Economic Losses and Damages (NELD): Increase in vector-borne, air-borne, and water-borne diseases[109]	Strategy: 100% efficient sewage collection and treatment **Actions:** • Holistic action plan and strategies for collection, treatment, reuse and recycling of wastewater • Upgrade and climate-proof stormwater drainage systems to manage increased runoff. • Integrate nature-based solutions (NBS)—bioswales, retention ponds, green corridors, and permeable pavements to manage surface runoff.
Heavy rainfall events may lead to prolonged waterlogging and local flooding, particularly in low-lying areas. Stagnant water may become a breeding ground for disease vectors, contributing to outbreaks of water-borne and vector-borne diseases. Repeated inundation may also damage roads, underground utilities, and built infrastructure.		Strategy: Foster innovative and sustainable urban planning to enhance flood resilience and water resource conservation **Actions:** • Develop a water conservation and augmentation plan through detailed watershed analysis and aquifer mapping, with a focus on enhancing groundwater recharge • Expand and enhance the stormwater drainage network, focusing on areas highly susceptible to flooding • Adopt predictive flood modelling and early warning systems

potentially limiting effectiveness during extreme rainfall. Non-economic impacts, including waterborne and vector-borne diseases, remain underrepresented in current plans. Furthermore, stormwater and sewage management strategies tend to be reactive, with limited integration into proactive urban planning, land-use policy, or risk-informed development, increasing future vulnerability.

106 While the existing infrastructure is nearly sufficient to meet the demand until 2030, SMC is planning new STPs to ensure capacity to manage and treat wastewater effectively beyond that period.
107 Information taken from Surat Net-zero Climate Resilient City Action Plan (Net-zero CRCAP), 2024.
108 8% households reported damage to sanitation infrastructure during flooding event
109 During household surveys conducted in Surat, respondents reported that rising temperatures, irregular rainfall, and frequent extreme weather events have led to a marked increase in heat-related illnesses (reported by 71% of households), as well as outbreaks of water-borne (59%) and vector-borne diseases (40%) such as diarrhoea, dengue, and malaria. Specific symptoms such as fever and dizziness were reported by 60% of households during heat events and 25% during floods.

Table 25: Solid waste Sector Climate risk projection for Surat

Solid waste Management Sector			
Parameter	**Existing (2023–24)**	**Future Demand (2050)**	**Climate Fragility Statement[110]**
Solid waste (Collection, Treatment & Disposal)	The city collects 2,443 MT/day of waste and treats 100% of it through MRFs, composting (1,500 TPD), RDF (1,000 TPD), bio-methanation (50 TPD), and specialized plants for C&D (300 TPD), plastics (200 TPD), e-waste (1 TPD), and biomedical/hazardous waste (6 TPD). Only inert and non-recyclable residues are sent to the Khajod landfill..	2050: 10202 MT. It will increase significantly due to population growth, urbanization, and changing consumption patterns, requiring expansion and climate-resilient upgrading of collection and treatment systems.	Increasing temperatures accelerate decomposition rates and create hazardous conditions for workers Increased rainfall can cause uncollected solid waste to block sewerage and drainage networks, leading to waterlogging or urban flooding, posing public health risks. Overall Risk score: (12-16) Medium – High

Solid waste systems are inherently sensitive to climate stressors. Rising temperatures accelerate decomposition, creating hazardous conditions for workers, while heavy rainfall can disrupt collection and processing, leading to blockages in drainage networks and increased urban flooding. Current strategies may not fully account for operational risks posed

110 The climate resilience and fragility of urban systems were assessed by examining the service levels and baseline situation of urban infrastructure in the city, especially the direct and indirect impacts of the identified climate hazards (i.e., urban heat, urban flood). Risks associated with climate fragility were assessed by determining the likelihood of their occurrence and potential consequences. For example, an increase in heat conditions could affect water consumption patterns, while urban flooding could lead to water contamination in areas where the water supply network is already compromised. The risk assessment exercise involved in-person discussions with key officials of SMC through Climate Core Team meetings and focused group discussions with vulnerable populations.

111 Adaptation strategies and actions for the sector are aligned with the Surat Net-Zero Climate Resilient City Action Plan (CRCAP) 2024, which was developed with the suggestions and inputs of Surat city officials involving sectoral departments. These measures have been further refined based on insights from Focus Group Discussions (FGDs), one to one consultation, workshops involving parastatal bodies, district emergency operation center, fire department and NGOs/CBOs

Solid waste Management Sector		
Climate Impacts	**L&D (ELD/NELD)**	**Adaptation strategies and actions[111]**
Extreme rainfall and heat may disrupt waste collection, transportation, and treatment operations, damage infrastructure, and increase disease and pollution risks.	Economic Damages: Partial/total damage to Solid waste infrastructure: transfer stations, trucks, disposal/ composting sites Non-Economic Loss & Damage (NELD): Health impacts and occupational hazards for sanitation workers; loss of environmental quality and urban liveability due to improper waste management.	Strategy: Promote a circular economy by minimizing waste through integrated 3R (reduce, reuse, recycle) practices **Actions:** • Strengthen Extended Producer Responsibility (EPR) and enforce circular supply chains for plastics, e-waste, and packaging • Promote circular and decentralized waste systems (3R practices, local composting/biogas units) to minimize waste volume, improve recovery, and strengthen community resilience

by extreme or compound climate events, leaving infrastructure and services vulnerable. Additionally, non-economic impacts—such as worker health hazards, proliferation of vector-borne diseases, and community-level exposure may amplify NELD in future climate scenarios.

Table 26: Transport Sector Climate risk projection for Surat

Transport Sector			
Parameter	**Existing (2023–24)**	**Future Demand (2050)**	**Climate Fragility Statement[112]**
Urban Transport System	4,200 km road network with 327 km arterial and 445 km sub-arterial roads. 86% roads have sidewalks; 85 km cycle lanes, 120 PBS stations, and 1,267 bicycles. Public transport: 875 buses (466 city + 409 BRTS) with daily ridership of 2.75 lakh	The number of vehicles in Surat has been increasing at an average annual growth rate of 13.12%[114] , driven by ease of vehicle procurement, financial incentives, and rising income levels. Without targeted interventions, this growth is expected to continue, increasing traffic congestion, air pollution.	Increasing temperatures and rainfall may lead to reduced use of public transport, greater dependence on personal vehicles and higher emissions. Higher temperatures may adversely impact on the health of commuters, two-wheeler riders, pedestrians and cyclists, especially the elderly, and young children.
			Extreme rainfall events are likely to worsen road infrastructure, especially the already damaged sections. Waterlogged roads during intense rainfall exacerbate congestion, disrupt connectivity, and contribute to higher air and noise pollution.

Surat's transport infrastructure, including road networks, public transport, and non-motorized transport facilities, faces high flood vulnerability, with waterlogging and intense rainfall threatening connectivity and mobility. While current strategies focus on infrastructure strengthening, they may not fully capture cascading disruptions to emergency services, freight movement, or commuter flows. Heat stress further affects system performance, yet its impacts are not comprehensively quantified in planning. Additionally, rapid growth in

112 The climate resilience and fragility of urban systems were assessed by examining the service levels and baseline situation of urban infrastructure in the city, especially the direct and indirect impacts of the identified climate hazards (i.e., urban heat, urban flood). Risks associated with climate fragility were assessed by determining the likelihood of their occurrence and potential consequences. For example, an increase in heat conditions could affect water consumption patterns, while urban flooding could lead to water contamination in areas where the water supply network is already compromised. The risk assessment exercise involved in-person discussions with key officials of SMC through Climate Core Team meetings and focused group discussions with vulnerable populations.

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114 The percentage increase in vehicle registration was calculated using data from the VAHAN National Register, an integrated online database maintained by the Ministry of Road Transport and Highways (MoRTH), Government of India. The VAHAN portal records on registered vehicles across India, providing updated information on vehicle types, ownership, and growth trends

Transport Sector		
Climate Impacts	**L&D (ELD/NELD)**	**Adaptation strategies and actions[113]**
Flooding leads to infra-structure damage, traffic congestion, and disruption of emergency services	Economic Losses (ELD): Damage to road surfaces, bridges, and bus depots; disrup-tion of freight and passenger services. Non-Economic (NELD): Reduced mobility, loss of access to essential services, and increased commuter stress.	Strategy: Strengthen climate-resilient, low-carbon transport infrastructure Actions: • Integrate flood-resilient design and permeable surfaces in road construction • Expand green, electric, and non-motorized transport systems to reduce emissions and enhance adaptive capacity

private vehicles could exacerbate congestion, emissions, and exposure to climate hazards, potentially reducing the effectiveness of current adaptation measures. ELD may include repair costs, operational delays, and economic losses from transport disruptions, while NELD could manifest as reduced accessibility, health impacts, and increased social vulnerability.

Table 27: Environment Sector Climate risk projection for Surat

Environment Sector (focus on Urban Greening and Biodiversity)			
Parameter	**Existing (2023–24)**	**Future Demand (2050)**	**Climate Fragility Statement[115]**
Urban Greening and Biodiversity	• Green cover: ~38% of total city area (as per SMC) • Tree cover: ~18% of city area (based on 326 sq. km area, 2020) • Water bodies: 193 within city limits • Green space per person: 15.8 m^2 (higher than WHO guideline of 9 m^2/person)	• Rapid urbanization is expected to reduce per capita green space due to expansion of built-up areas. • Built-up area increased by 23% between 2016–2024 (~3% annual growth). Without green buffers, this trend may continue.	Expansion of impermeable surfaces and insufficient integration of green infrastructure in planning processes increase vulnerability to heat stress and surface runoff.

Table 28: Health Sector Climate risk projection for Surat

Health Sector			
Parameter	**Existing (2023–24)**	**Future Demand (2050)**	**Climate Fragility Statement[117]**
Health Infrastructure	Surat has a strong healthcare network comprising ~ 1,015 hospitals with a bed capacity of 22,593 as per DMP 2025 (List of Hospitals). SMC operates 8 CHCs, 80 UPHCs and 97 UHWCs across the city for primary healthcare. The city has 2.8 beds per 1000 population, instead of the WHO benchmark of 3 beds per 1000 population.	By 2050, healthcare demand is expected to increase substantially due to population growth, urbanisation, and rising climate-induced illnesses. Strengthening healthcare infrastructure, surveillance systems, and emergency response will be essential.	Increased frequency of heatwaves may lead to heatstroke, dehydration, and cardiovascular strain, disproportionately affecting elderly, outdoor workers, and urban poor without cooling access. Heavy rainfall and flooding events may cause outbreaks of water-borne diseases (cholera, diarrhea, leptospirosis, dengue), aoverwhelming local health systems.

115 The climate resilience and fragility of urban systems were assessed by examining the service levels and baseline situation of urban infrastructure in the city, especially the direct and indirect impacts of the identified climate hazards (i.e., urban heat, urban flood). Risks associated with climate fragility were assessed by determining the likelihood of their occurrence and potential consequences. For example, an increase in heat conditions could affect water consumption patterns, while urban flooding could lead to water contamination in areas where the water supply network is already compromised. The risk assessment exercise involved in-person discussions with key officials of SMC through Climate Core Team meetings and focused group discussions with vulnerable populations.

116 Adaptation strategies and actions for the sector are aligned with the Surat Net-Zero Climate Resilient City Action Plan (CRCAP) 2024, which was developed with the suggestions and inputs of Surat city officials involving sectoral departments. These measures have been further refined based on insights from Focus Group Discussions (FGDs), one to one consultation, workshops involving parastatal bodies, district emergency operation center, fire department and NGOs/CBOs.

Environment Sector (focus on Urban Greening and Biodiversity)		
Climate Impacts	**L&D (ELD/NELD)**	**Adaptation strategies and actions[116]**
• Reduced groundwater recharge and stormwater infiltration. • Intensified Urban Heat Island (UHI) effects. • Increased risk of vector-borne diseases, especially among vulnerable groups (children, elderly).	ELD: Increased maintenance costs for green infrastructure; loss of productivity due to heat-related stress. NELD: Loss of urban biodiversity, decline in ecosystem services, reduced wellbeing.	Strategy: Increase urban green cover using native plantation **Actions:** • Integrate green-blue infrastructure in urban planning. • Develop biodiversity parks and ecological corridors.

Health Sector		
Climate Impacts	**L&D (ELD/NELD)**	**Adaptation strategies and actions[118]**
Increase in heat-related and vector/water-borne diseases; stress on emergency care.	Economic (ELD): Damage to hospitals, equipment, and cold-chain systems; increased operational costs. Non-Economic (NELD): Loss of lives, health deterioration, and psychosocial distress among vulnerable groups.	Strategy: Enhance urban health systems to tackle climate-induced health impacts through upgrades, improved accessibility, effective monitoring, and prevention. **Actions:** • Upgrade and climate-proof healthcare infrastructure (e.g., improved cooling, drainage, and backup power in hospitals and UPHCs). • Expand surveillance and early-warning systems for heat-related, water-borne, and vector-borne diseases. • Enhance public health outreach and community-based awareness, focusing on vulnerable populations (elderly, informal workers, slum dwellers). • Integrate climate-health indicators into city-level emergency and health planning (HAP, CDMP).

117 The climate resilience and fragility of urban systems were assessed by examining the service levels and baseline situation of urban infrastructure in the city, especially the direct and indirect impacts of the identified climate hazards (i.e., urban heat, urban flood). Risks associated with climate fragility were assessed by determining the likelihood of their occurrence and potential consequences. For example, an increase in heat conditions could affect water consumption patterns, while urban flooding could lead to water contamination in areas where the water supply network is already compromised. The risk assessment exercise involved in-person discussions with key officials of SMC through Climate Core Team meetings and focused group discussions with vulnerable populations.

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Table 29: Education Sector Climate risk projection for Surat

Education Sector			
Parameter	**Existing (2023–24)**	**Future Demand (2050)**	**Climate Fragility Statemen[119]**
Education Infrastructure	The city has a well-established educational network, including 382 municipal schools, several private institutions, and multiple higher education establishments.	Student enrolment and infrastructure demand are projected to rise significantly by 2050, driven by population growth, urban expansion.	Rising temperatures and extreme weather events may disrupt school operations, damage infrastructure, and affect learning continuity, particularly in flood-prone areas.

The health and education sectors show clear vulnerability. Health systems face dual pressures from extreme heat and flooding, with high risks of mortality and morbidity among vulnerable groups. Similarly, education infrastructure and continuity are at risk from school closures, poor classroom conditions, and disaster-induced displacements, leading to both high and medium risk scores.

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Education Sector		
Climate Impacts	**L&D (ELD/NELD)**	**Adaptation strategies and actions[120]**
Disruption of schooling during floods or heatwaves; infrastructure damage; increased health risks for students and staff during extreme heat.	Economic (ELD): Damage to buildings, classrooms, and learning equipment. Non-Economic (NELD): Learning loss, reduced attendance, and psychosocial stress among students	Strategy: Strengthen climate resilience of educational infrastructure and ensure continuity of learning during climate-induced disruptions. **Actions:** • Retrofit and climate-proof existing school infrastructure, especially in flood- and heat-prone zones (e.g., improved ventilation, reflective roofs, raised plinths). • Integrate school-level heat action and disaster preparedness plans with the city's HAP and CDMP.

5.

Limits to Adaptation

While a wide range of adaptation strategies have been identified to address the risks of heat stress and flooding, their successful implementation is often constrained by technical, political, and financial limits. The IPCC AR6 (2022)[121] emphasizes that while adaptation can reduce climate risks, it cannot prevent all losses and damages. Understanding these barriers is crucial for prioritizing actions that are both feasible and impactful, while also highlighting where systemic reforms or capacity building are needed. Additionally, assessing both hard and soft limits will help to evaluate sector-wise city-level losses and damages.

'Hard limits' and 'soft limits' are defined as per IPCC AR6:

- **Hard limits** are the point where adaptation options are no longer technically, physically, or ecologically feasible. For example, the effectiveness of vertical and rooftop gardening is inherently constrained by structural limitations of existing buildings, and by water availability for irrigation. Similarly, cool roof programs in dense informal settlements face challenges due to poor building quality and limited space for large-scale retrofits.
- **Soft limits** arise when adaptation is possible in theory, but progress is prevented by governance, finance, capacity, or social acceptance barriers. For instance, incentivizing sustainable vernacular architecture and integrating green building principles into building codes (GDCR) face soft political and financial limits; these can be addressed through stronger regulations, subsidies, and public awareness. Likewise, street-vending zone cooling strategies face soft political and financial challenges, which could be reduced by mainstreaming them into city-level development schemes.
- Recognizing these limits helps cities set realistic expectations, prioritize near-term feasible interventions, and plan long-term systemic changes for more transformative resilience.

City-specific Hard and Soft Limits to Adaptation

The city-specific limits to adaptation in Ahmedabad and Surat arise from a combination of hard (technical and physical) constraints and soft (institutional, governance, financial,

121 Intergovernmental Panel on Climate Change. (2023). Sixth assessment report (AR6). https://www.ipcc.ch/assessment-report/ar6/

and behavioral) barriers that influence the effectiveness of climate adaptation strategies across urban sectors.

Hard Limits reflect the physical thresholds beyond which adaptation measures become unviable, such as inadequate drainage capacity, limited land availability for infrastructure expansion, overexploited water sources, and irreversible ecological degradation.

Soft limits stem from institutional fragmentation, limited financing, knowledge gaps, and socio-behavioral factors that constrain implementation despite available technologies or plans. These limits have been systematically tabulated sector-wise, covering health, education, built environment and energy, water supply, wastewater, stormwater, solid waste, environment, and transport to identify where residual L&D persists even after adaptation measures. The sectoral tables distinguish between technical barriers, adaptation strategies, and their corresponding residual ELD and NELD, providing a comprehensive evidence base to guide future institutional and governance frameworks for L&D assessment. The hard and soft limits to adaptation strategies across various sectors have been evaluated in line with the CRCAPs for both Ahmedabad and Surat, with feasibility assessed within these limits.

5.1 Definitions and Operationalization of Adaptation Limits

Following IPCC AR6, adaptation limits are classified as:

Hard Limits (Physical/Technological):

- Occur when physical constraints make it impossible to adapt further, regardless of resources or technology. Examples:
  - Heat mortality despite HAP: If ambient temperature exceeds human physiological tolerance (e.g., >50°C wet-bulb temperature), even with full cooling provision, heat stroke becomes inevitable. Current Ahmedabad temperatures approach this threshold on rare days; projected 2050 scenarios could exceed it on 5–10 days/year.
  - Groundwater depletion: Aquifer recharge is limited; if extraction exceeds recharge rate persistently, supply becomes zero. Ahmedabad's groundwater is currently over-exploited at 152%; extraction cannot increase further without crossing hard limit.
  - Coastal inundation in Surat: Sea-level rise combined with extreme tides eventually inundates low-lying areas regardless of embankments; the hard limit is reached when adaptation measures (embankment height, elevation) can no longer be feasibly engineered or economically justified.

Operationalized criteria for hard limits: A hard limit is reached when:

1. One or more essential needs (water, cooling, food) cannot be met despite full deployment of available technology and resources.
2. The cost of further adaptation becomes infinite or exceeds societal willingness to pay.
3. Fundamental planetary or physiological constraint is reached (e.g., temperature exceeding human tolerance, water availability = zero).

Soft Limits (Institutional/Behavioural/ Financial):

- Occur when adaptation is technically feasible but constrained by governance, finance, social behaviour, or equity concerns. Examples:
  - Maladaptive air-conditioning lock-in: Air conditioning reduces individual heat exposure but increases urban heat island, raises temperatures for the entire city and increasing electricity demand (energy burden on the poor). Full universal air-conditioning is technically possible but economically and socially unsustainable (energy demand exceeds grid capacity; the cost is unaffordable for low-income households).
  - Planned relocation constraints: Relocating vulnerable populations away from flood zones is technically feasible but politically

difficult (land disputes, social networks, livelihood ties to current location prevent willing migration).

- Informal settlement formalization: Many flood-prone areas are occupied by informal settlements; formalizing land tenure and upgrading infrastructure requires political will, and resources are often unavailable. Without this, residents cannot access formal adaptation finance.
- Coordination failures: The water, electricity, and health sectors operate under different governance structures; integrated planning (nexus approach) is technically feasible but institutionally difficult, so residual risks persist from uncoordinated sectoral adaptation.

Operationalized criteria for soft limits: A soft limit is reached when:

1. The adaptation option is technically feasible but financially unaffordable for the target population or the city budget.
2. The required governance coordination or institutional reform is politically infeasible (resistance from incumbent interests, lack of political will).
3. The adaptation option conflicts with other societal values (equity, livelihood, cultural identity); proceeding with it incurs unacceptable social cost.
4. Timing mismatch: Adaptation measures require years to implement, but hazards accelerate faster than the implementation timeline.

In Ahmedabad and Surat assessments, both hard and soft limits are identified for each sector. Hard limits tend to emerge in water supply and heat extremes; soft limits dominate in housing, livelihoods, and multi-sectoral coordination. This distinction is critical because responses differ: hard limits require transformative change (e.g., migration, fundamental lifestyle change); soft limits are addressable through policy, financing, and governance reform.

5.2 Hard Limits to Adaptation

The Hard Limits contextually specific to Ahmedabad and Surat have been detailed in Table 24 below. The table establishes a cause-and-effect relationship between structural limitations and their climate consequences. The adaptation focus area outlines the key system or function under stress (e.g., infrastructure accessibility, material design, or ecosystem restoration). The Technical Barriers describe non-negotiable physical constraints, such as land scarcity, morphological limits, energy dependence, or irreversible ecological degradation, that limit adaptation potential. The Residual Risks and L&D column captures the residual L&D that will persist despite adaptation, economic and non-economic L&D (health risks, well-being loss, ecosystem degradation, and social disruption).

The sectors analysed include Health, Education, Built Environment and Energy, Water Supply, Wastewater, Stormwater, Solid Waste, and Environment, representing the critical urban systems most affected by climate extremes such as heatwaves, flooding, and droughts.[122] The comparative understanding of cross-sectoral thresholds indicates the adaptive capacity plateaus and residual L&D becomes unavoidable.

122 Prepared by gathering Information through field visits, stakeholder consultations (Government & Non- Government), Workshops, One to one consultations and Inferences from CRCAPs (Ahmedabad & Surat)

Table 30: Hard Limits to Adaptation

Focus Area	Adaptation Strategy	Technical Barriers (Hard Limits)	Residual Risks and L&D
Health			
Infrastructure & Accessibility	Expand decentralized healthcare delivery systems through mobile medical units, local health posts, and community-based emergency care to reduce facility pressure during crises.	Limited land availability and high population density restrict the expansion of healthcare facilities and emergency facilities	Persistent overcrowding and delays in care during extreme heat or flood events, Higher mortality and morbidity, particularly among vulnerable groups (elderly, children, slum populations). Continued vector-borne disease outbreaks, delayed outbreak detection, and loss of public trust in health systems.
	Establish resilient supply-chain systems for medicines, vaccines, and essential supplies to ensure continuity of care during climate-related disruptions.	Spatial constraints impede rapid emergency response.	
	Upgrade and climate-proof existing healthcare infrastructure by improving ventilation, flood-proof design, and installing reliable backup power and water during heatwaves and floods.	Climate-proofing health infrastructure is restricted by building design and technical capacity.	
Education			
Spatial constraints	Integrate climate risk zoning in school site planning to avoid floodplains and high-heat zones	Schools sited on floodplains, near drains, or industrial areas face inherent exposure that cannot be eliminated.	Reduced safety zones, limited scope for emergency shelters, and higher exposure during floods or heatwaves. Injury or loss of life risk during disasters, learning loss due to prolonged closures.
Retrofitting aging infrastructure	Retrofit schools with flood and heat-resilient infrastructure, including ventilation improvements, reflective roofing, elevated plinths, and natural shading. Develop modular classrooms and safe learning shelters adaptable for use during extreme climate events.	Many older or informal school structures cannot be safely retrofitted for heat insulation, flood resilience, or seismic safety without full reconstruction. Even with efficiency upgrades, power grid and building design limitations limit cooling or ventilation effectiveness during extreme heat.	Economic L&D: recurring repair costs. Non-economic L&D: Persistent thermal discomfort, reduced attendance, increased illness, prolonged school disruption, psychosocial effects, and gendered impacts on attendance.
Digital infrastructure divide	Provide mobile learning units to maintain continuity of education during school closures.	Inadequate connectivity or bandwidth in peripheral areas limits effective e-learning continuity during extreme events.	Persistent learning loss and exclusion, particularly for low-income students.

Focus Area	Adaptation Strategy	Technical Barriers (Hard Limits)	Residual Risks and L&D
Built Environment and Energy Sector			
Extreme Temperature and Cooling Dependence	Develop citywide heat mitigation strategies, including reflective and cool/green roofing programs, urban green corridors, and passive cooling designs. Expand access to energy-efficient and affordable cooling technologies for vulnerable populations.	Daytime temperatures often exceed 46–47 °C, surpassing the performance limits of passive cooling measures. Physiological heat limits for occupants are regularly exceeded during the summer months, especially in dense low-income settlements.	Persistent heat stress–related health impacts among vulnerable populations. Increased household energy demand for cooling, causing economic L&D through higher utility costs. Residual mortality and morbidity despite heat-action measures.
Land and Morphological Constraints	Integrate green infrastructure into redevelopment zones to reduce heat-island intensity and urban flooding. Revise development control regulations to mandate open spaces, permeable surfaces, and setback areas. Promote adaptive reuse and vertical greening in dense cores	High land-use intensity in city cores limits open surfaces and tree-cover enhancement. Lack of designated urban cooling features or permeable areas. Urban morphology traps heat and pollution, with limited scope for redesign	Sustained urban heat-island amplification and deterioration of air quality. Cumulative non-economic losses such as wellbeing decline
Material and Design Limitations	Promote the use of low-emission and reflective building materials, integrating thermal insulation and cool-roof technologies. Encourage retrofitting of informal and affordable housing with cost-effective heat-resilient materials.	Traditional low-cost construction materials (asbestos sheets, concrete roofs, uninsulated walls) have low reflectivity and high heat retention, with limited scope for redesign Lack of locally available, affordable alternatives for large-scale substitution.	Continued thermal discomfort and indoor heat exposure for low-income households. Increased incidence of heat-related illness and reduced energy efficiency.
Water Supply			
Stressed and Overexploited Water Sources	Diversify water sources through integrated surface, groundwater management and treated wastewater reuse	Source diversification options face land and energy constraints. High dependency on single or limited surface water sources (Tapi, Sabarmati) that are overdrawn and vulnerable to seasonal variability. Groundwater extraction already exceeds recharge capacity (e.g., 118% in Surat), making further abstraction unsustainable.	Unavoidable summer shortages even with improved efficiency. Higher energy and tanker costs. Inequitable access, health burden from low-quality water, and social stress in underserved areas.

Focus Area	Adaptation Strategy	Technical Barriers (Hard Limits)	Residual Risks and L&D
Ageing and Weak Infrastructure	Upgrade pipelines with pressure-regulated networks and smart metering systems to minimize Non-Revenue Water (NRW)	Physical deterioration and limited space for new trunk lines or service reservoirs restrict full rehabilitation. Old, undersized, and corroded pipeline networks cause chronic leakage losses (19% NRW in Surat).	Service interruptions during peak demand periods, increasing household coping costs and health risks.
Unequal Access and Informal Distribution	Expand piped connections in informal and peri-urban settlements through flexible service delivery models (e.g., community taps or shared meters).	Network expansion is limited by a lack of legal tenure, narrow rights-of-way, and unmetered supply. Socio-spatial disparities in water supply persist even after system upgrades. Informal settlements and peri-urban areas rely on unregulated borewells or private tankers.	Chronic water insecurity in low-income communities. Reduced wellbeing, increased time (especially for women), and increased exposure to contaminated sources.
Quality Degradation and Source Pollution	Protect and restore recharge zones, wetlands, and riverine buffers to maintain natural filtration capacity. Regulate industrial effluents and adopt decentralized pollution monitoring systems.	Natural recharge areas are encroached, reducing dilution and filtration potential. Salinity ingress in coastal aquifers is irreversible. Intense rainfall events cause flooding of pumping stations, electrical panels, and mains, leading to contamination and service downtime.	Risk of contamination and disease outbreaks during monsoon periods. Permanent loss of potable water sources (irreversible L&D). Escalating treatment costs and dependence on external sources. Ecosystem degradation and public health decline.
Wastewater			
Rehabilitating Old Sewerage Networks	Implement phased replacement of old sewer lines with high-capacity, corrosion-resistant materials Introduce smart monitoring systems to detect blockages, infiltration, and leaks in real time.	Dense built-up urban fabric and congested underground utilities (water, gas, telecom) restrict large-scale replacement or realignment of existing sewer lines and exceed hydraulic capacity during intense rainfall. Ground subsidence risk and traffic disruptions further limit intervention feasibility. Limited accessibility makes trenchless methods technically not feasible.	Recurrent contamination of urban areas leads to water-borne disease outbreaks and public health emergencies. Persistent leakage and infiltration losses reduce network efficiency and contaminate groundwater. Recurrent repair and maintenance costs represent chronic economic L&D. Health burden from unsafe sanitation and degraded living environments.

Focus Area	Adaptation Strategy	Technical Barriers (Hard Limits)	Residual Risks and L&D
Construction of New or Expanded Treatment Plants (STPs / TTPs)	Promote decentralized wastewater treatment systems (DEWATS) and modular STPs.	Land scarcity in high-density zones limits space for constructing new or expanded sewage treatment or tertiary treatment plants.	Residual untreated sewage discharge into rivers, drains, and coastal waters results in in ecological degradation and loss of aquatic biodiversity. Higher downstream treatment costs. Loss of environmental services and community wellbeing.
Sludge and Septage Management Limits	Develop citywide sludge management plans, including co-treatment at existing STPs; identify and designate land for regional sludge drying and reuse facilities. Adopt energy-efficient sludge processing technologies (e.g., solar drying, anaerobic digestion for biogas recovery).	Limited land availability for sludge drying beds and disposal sites. Transporting sludge from peripheral or low-access areas is logistically and financially challenging. Energy-intensive sludge treatment technologies (e.g., dual membrane, mechanized dewatering) are difficult to retrofit into existing STPs.	Residual pollution and odor issues are lowering the quality of life near treatment zones. Repeated operational expenses and reduced land value. Environmental degradation and community dissatisfaction.
Stormwater			
Protection and Restoration of Natural Drains	Restore and conserve natural drainage channels and floodplains through integrated urban river management and buffer zoning. Implement catchment-based stormwater management to manage runoff.	Natural drainage channels are encroached upon, concretized, or permanently altered due to urban expansion and land-use change. Catchment hydrology is irreversibly modified, and restoring natural gradients or floodplains is no longer feasible.	Persistent urban flooding during intense rainfall events. Property damage, infrastructure repair costs, and business interruption. Loss of ecological function, habitat degradation, and declining urban livability.
Nature-based and Infiltration Measures	Introduce green infrastructure retrofits, such as bio-swales, infiltration trenches, and permeable pavements along major corridors and public spaces. Integrate rain gardens, treebox filters, and vegetated buffer zones into redevelopment projects.	Space constraints along roads and footpaths, compounded by congested underground utilities, limit installation of swales, infiltration trenches, or permeable pavements. Low soil permeability, shallow groundwater, and contamination risks restrict the effectiveness of percolation wells or recharge structures.	Residual runoff and flash flooding continue even after partial implementation of nature-based measures. High maintenance and rehabilitation costs for infiltration systems. Reduced co-benefits such as heat mitigation, green cover loss, and diminished environmental quality.

Focus Area	Adaptation Strategy	Technical Barriers (Hard Limits)	Residual Risks and L&D
Solid Waste			
Land and Infrastructure Constraints	Promote regional solid waste clusters for segregation, treatment, and disposal. Retrofit existing waste processing facilities for flood resilience and fire safety, integrating biogas recovery and leachate management systems. Implement waste-to-energy or Biomethanation plants where feasible, using emission-controlled technology and strict environmental monitoring.	Severe space scarcity for new landfills, transfer stations, and treatment plants within city limits. Retrofitting old facilities for waste-to-energy or Biomethanation is limited by site geometry and emission control requirements.	Residual waste accumulation despite processing improvements. Rising operational costs and long-term environmental remediation expenses. Local pollution, odor nuisance, and community resistance.
Legacy Waste and Contaminated Sites	Implement phased biomining of legacy dumpsites to minimize leachate generation. Promote circular economy approaches to divert recyclables, reducing pressure on legacy waste volumes.	Existing dumpsites have limited scope for full biomining or reclamation due to volume, contamination depth, and lack of alternative disposal capacity. Limited land availability for interim processing or capping makes full remediation technically prohibitive.	Irreversible environmental degradation from leachate and methane emissions. High long-term mitigation and remediation costs. Ecological loss, reduced land usability, and intergenerational environmental burden.
Transport			
Vulnerability of Transport Infrastructure	Upgrade roads and transit infrastructure using heat-resistant materials and improving subsurface drainage	Low-lying and poorly drained corridors are chronically exposed to waterlogging during intense rainfall. Existing drainage systems along arterial roads cannot handle high runoff volumes. Asphalt deformation and buckling occur during prolonged high surface temperatures (often >47°C).	Recurrent damage to roads, bridges, depots, and underpasses; increased maintenance costs. Infrastructure deterioration requires frequent resurfacing. Reduced commuter mobility, delays in emergency services, reduced public transport ridership and diminished urban productivity.
Limited Land for Network Expansion and Green Corridors	Expand green, electric, and non-motorized transport (NMT) systems through new right-of-way allocations and mobility hubs.	Urban morphology restricts land available for additional bus depots, non-motorized transport (NMT) lanes, or cooling corridors.	Congestion-induced delays and higher operational costs. Increased exposure to air pollution, road safety risks, and inequitable access for low-income users.

Focus Area	Adaptation Strategy	Technical Barriers (Hard Limits)	Residual Risks and L&D
Environment			
Increase in urban greening and restoration of degraded natural sites	Integrate urban biodiversity and green infrastructure into land-use plans to protect open spaces and natural habitats. Promote native species plantations on available public lands, roadside buffers, and degraded urban commons to restore ecological connectivity.	Severe land scarcity and competing urban land-use priorities limit space for new green zones. Irreversible land-use change and encroachments in ecologically sensitive areas constrain reforestation and natural restoration. Soil compaction and contamination reduce regeneration potential. High maintenance demand for green areas in arid and heat-prone zones.	Permanent ecological degradation and biodiversity loss. Decline in ecosystem services (cooling, air purification, carbon sequestration), reduced well-being, and loss of natural identity. increased cooling energy demand and health expenditure. Increased urban heat mitigation costs and flood control expenditure.
Wetland and waterbody restoration	Undertake ecological restoration of wetlands and retention ponds through dredging, desilting, and the establishment of native vegetation buffers. Implement stormwater harvesting and wastewater pretreatment to minimize inflow of pollutants.	Many wetlands and natural retention ponds have been permanently reclaimed or polluted, making ecological restoration technically unviable. Hydrological connections are disrupted by built-up development and road infrastructure. Treated wastewater inflows alter the ecological balance and salinity.	Irreversible loss of urban ecosystem functions, such as flood buffering and groundwater recharge. Higher drainage and flood protection costs. Loss of biodiversity, recreation value, and cultural association with waterbodies.
Air Quality and Microclimate Regulation	Integrate urban forest corridors and pollution sinks (green belts, tree-lined avenues) along traffic-heavy zones.	Urban heat and pollution levels exceed capacity of natural dispersion; greening alone cannot offset emissions from traffic and industry.	Deteriorating air quality despite partial greening. Loss of thermal comfort, reduced public space quality, and urban liveability. Persistent air pollution and heat stress lead to health deterioration and rising healthcare costs.

5.3 Soft Limits to Adaptation

The Soft Limits to Adaptation identifies institutional, financial, governance, and behavioral constraints that impede the realization of climate adaptation measures, even when technical solutions exist. Unlike hard limits, which are defined by biophysical or structural thresholds, soft limits are context-dependent and potentially reversible through enhanced policy coherence, capacity-building, financing mechanisms, and social awareness. The table is structured to capture the systemic barriers to adaptive capacity. The residual risks and L&D demonstrate how these limitations translate into persistent or emergent losses despite ongoing adaptation measures.

The assessment covers eight key urban sectors: Health, Education, Built Environment and Energy, Water Supply, Wastewater, Stormwater, Solid Waste, and Environment, reflecting the impact of heatwaves, flooding, and other climate hazards on urban systems.

Built Environment and Energy Sector

Table 31: Soft Limits to Adaptation

Soft Limits	Limits of Adaptation Strategy	Residual Risks and L&D Implications
Institutional and Knowledge Capacity	Limited integration of vernacular architecture and passive design principles into urban development controls (GDCRs) and building codes. Inadequate enforcement mechanisms to ensure compliance with green building standards. Lack of climate-sensitive zoning and adaptive infrastructure planning within city Master Plans. Delayed finalization and operationalization of Urban Cooling Action Plans and city heat resilience frameworks.	Continued use of heat-absorbing materials and designs that intensify urban heat islands. Economic L&D: increased energy demand, rising cooling costs, and infrastructure maintenance expenses. Non-economic L&D: persistent indoor heat exposure, reduced labor productivity, health impacts, and well-being loss, especially for vulnerable communities.
Political, Administrative and Governance	Fragmented institutional mandates between urban planning, building regulation, and energy efficiency agencies limit coordination. Weak integration of energy resilience in urban policy frameworks and project approval processes. Inconsistent enforcement of building performance standards; most green certifications remain voluntary. Absence of a unified policy framework linking land use, heat mitigation, and energy planning across sectors.	Policy silos and poor coordination result in limited scaling of adaptation measures. Economic L&D: inefficient energy use and higher public expenditure on cooling infrastructure. Non-economic L&D: inequitable exposure to extreme heat, reduced urban liveability, and declining public confidence in governance systems.
Financial and Economic Feasibility	Short-term project financing and a lack of lifecycle cost accounting for energy-efficient buildings. Limited access to concessional finance or green credit lines for households, SMEs, and RWAs. Energy affordability and inequitable tariff structures are limiting access to cooling and renewables for low-income users. High upfront costs for retrofits and renewable installations with long payback periods.	Slow or uneven uptake of energy-efficient design, technology adoption, and renewable solutions across the housing and commercial sectors. Economic L&D: locked-in high energy costs and inefficient infrastructure investments. Non-economic L&D: energy poverty, increased vulnerability to heat stress, and widening inequality in adaptive capacity.

Soft Limits	Limits of Adaptation Strategy	Residual Risks and L&D Implications
Social and Behavioral Aspects	Low public awareness of heat-related risks and the co-benefits of energy-efficient, climate-responsive design. Persistent cultural preference for glass façades, sealed environments, and air-conditioning as status symbols. Limited citizen engagement and participation in community-based adaptation and decentralized renewable initiatives. Resistance to adopting traditional or nature-based design elements due to perceived aesthetic or maintenance concerns.	Consumer choices reinforce energy-intensive urban lifestyles, reducing overall adaptation effectiveness. Economic L&D: elevated household energy costs and peak-load strain on city power grids. Non-economic L&D: reduced wellbeing, environmental degradation, and erosion of local architectural identity and cultural resilience.

Health Sector

Soft Limits	Limits of Adaptation Strategy	Residual Risks and L&D Implications
Institutional and Knowledge Capacity	Existing healthcare infrastructure is not designed or climate-proofed to withstand prolonged heatwaves or flooding, leading to frequent service disruptions. Inconsistent disease surveillance and reporting impede the timely detection of heatstroke clusters and flood-related outbreaks. Absence of integrated heat-health and flood-health response protocols between hospitals, urban local bodies, disaster management, and emergency services. Limited workforce training in climate-sensitive health management and disaster triage. Absence of integrated climate-health information systems that combine meteorological, epidemiological, and environmental datasets for early warning.	Health systems remain reactive rather than preventive, leading to repeated strain during heatwaves, floods, and vector-borne outbreaks. Health facilities experience operational breakdowns during extreme weather events, affecting critical and preventive care delivery. Economic L&D: higher expenditure on emergency response, overtime staffing, supply chain disruptions, and hospital maintenance. Non-economic L&D: increased morbidity, mortality, illness, psychosocial distress, loss of life, and erosion of public trust in urban health services.
Political, Administrative and Governance	Weak horizontal coordination across health, environment, and disaster management departments delays emergency response and recovery. Lack of precise accountability mechanisms for implementing urban components of the NAPCCHH/SAPCCHH and city-level heat/flood action plans. Limited municipal authority to allocate climate-health budgets independently.	Fragmented governance delays mobilization during compound events (e.g., heatwave followed by flooding). Economic L&D: duplication of emergency expenditures, inefficient resource allocation. Non-economic L&D: increased morbidity and mortality, mental health deterioration, loss of public confidence in governance.

Soft Limits	Limits of Adaptation Strategy	Residual Risks and L&D Implications
Financial and Economic Feasibility	Chronic underinvestment in preventive and primary healthcare, with disproportionate spending on post-disaster curative measures. Absence of dedicated municipal funding streams for heatwave/flood preparedness, surveillance, or climate-health data systems. Dependence on external or donor-funded programs results in project discontinuity upon completion. Lack of financial protection (insurance or compensation) for climate-related illnesses and lost livelihoods, particularly for informal and migrant workers.	Financial fragility prevents sustained preparedness or rapid recovery after climate shocks. Economic L&D: repeated emergency spending, infrastructure degradation, and loss of workforce productivity. Non-economic L&D: widening inequities in access to care, food insecurity, and psychosocial strain in vulnerable groups.
Social and Behavioral Aspects	Low risk perception and awareness of climate-related health hazards (heat stress, vector-borne diseases, post-flood contamination). Cultural stigma around heat illness, mental health, and infectious diseases delays early care-seeking. Limited community participation in heat action plans, sanitation drives, and vector-control programs. Gender and social inequities restrict access to cooling centers, clean water, and healthcare facilities during emergencies. Lack of trust in government institutions due to inconsistent service delivery during disasters.	Vulnerable communities remain chronically exposed and underprepared for climate-induced health risks. Economic L&D: higher household medical expenses, income loss due to absenteeism. Non-economic L&D: long-term psychosocial distress, malnutrition, gendered vulnerability, and reduced quality of life.

Education Sector

Soft Limits	Limits of Adaptation Strategy	Residual Risks and L&D Implications
Institutional and Knowledge Capacity	Inadequate climate-proofing of school infrastructure; classrooms remain vulnerable to heat stress, roof damage, and flood inundation. Limited technical capacity for designing and maintaining flood-resilient or well-ventilated classrooms, particularly in older or informal school buildings. Lack of education-sector vulnerability assessments or mapping of flood/heat exposure of schools. - Absence of data on school closures, attendance loss, and learning outcomes linked to climate events. Absence of standardized continuity-of-learning protocols (online, modular, or temporary facilities) during prolonged school closures due to floods or extreme heat. Lack of uniform implementation of national/state frameworks such as NDMA's School Safety Guidelines[123] and Samagra Shiksha Disaster Modules[124].	Learning disruptions during climate events, especially in vulnerable and low-income wards. Decision-making remains reactive and under-informed. Economic L&D: infrastructure repair costs, loss of educational materials, and rising operational expenses (e.g., cooling, sanitation). Non-economic L&D: loss of education continuity, cognitive development setbacks, malnutrition and psychosocial stress among students and teachers. Under-recognition of climate impacts on child development, mental health, and learning quality.

123 National Disaster Management Authority. (2016, February). National Disaster Management Guidelines – School Safety Policy. Government of India. https://www.education.gov.in/sites/upload_files/mhrd/files/upload_document/Guidelines_feb.pdf

124 Gujarat Institute of Disaster Management. (2024). Training of teachers (ToT) on building disaster and climate resilience in schools. Government of Gujarat. https://gidm.gujarat.gov.in/sites/default/files/concept_note/ConceptNote_29.pdf

Soft Limits	Limits of Adaptation Strategy	Residual Risks and L&D Implications
Political, Administrative and Governance	Weak enforcement of school safety audits and climate-resilience retrofitting at the municipal level. Lack of inter-departmental coordination between education, disaster management, and public works departments for pre- and post-event response. Limited ownership at local levels to integrate climate adaptation into schools. Absence of dedicated municipal education resilience budgets or climate contingency planning for learning continuity.	Fragmented policy execution leads to unequal recovery across public and private schools. Economic L&D: delays in reconstruction and reopening, higher post-disaster costs. Non-economic L&D: widening education inequity, loss of trust in public systems, and psychosocial harm from repeated disruptions.
Financial and Economic Feasibility	Inadequate allocation of funds for school retrofitting, heat mitigation (cooling fans, insulation), and flood preparedness. Budget dependence on governments limits local flexibility to prioritize adaptation at the local level. The digital divide constrains continuity of learning during extreme weather (e.g., lack of devices, power outages, or connectivity in flood-hit areas). Limited access to climate finance or CSR funding for school infrastructure upgrades. Public schools face poor insurance coverage against climate-induced losses.	Inability to sustain or scale adaptation efforts leads to repeated economic strain after every climate shock. Economic L&D: damage to buildings and learning materials, lost school days, translating into lost human capital. Non-economic L&D: educational stagnation and diminished social mobility over time.
Social/ Behavioral Aspects and Community Engagement	Low awareness among teachers, parents, and students on climate-related health and safety practices (hydration, safe shelter, vector control, post-flood hygiene). Cultural reluctance to discuss climate change and disaster preparedness within school communities. Inadequate teacher training and curriculum integration of climate, environment, and sustainability education. Gender and equity barriers restrict access to schooling for girls and children with disabilities during emergencies. Psychosocial stress among children and educators after recurring exposure to disasters. Minimal collaboration with NGOs and CSR partners for temporary learning centers, digital learning support, or psychosocial recovery post-event.	Learning losses become chronic for children repeatedly displaced or unable to attend school. Missed opportunities for localized and rapid recovery interventions. Economic L&D: dropouts and increased education replacement costs. Non-economic L&D: trauma, reduced social cohesion, early marriage, or child labor among affected populations. Inequitable access to quality education recovery for marginalized groups.

Water Sector

Soft Limits	Limits of Adaptation Strategy	Residual Risks and L&D Implications
Institutional and Knowledge Capacity	Aging and undersized pipelines frequently fail during intense rainfall or flooding, leading to contamination and service interruptions. Weak real-time data integration between hydrological, meteorological, and distribution networks limits predictive action during floods or droughts. Insufficient storage and treatment capacity to meet increased water demand during heatwaves. Encroachment and siltation of urban lakes, wetlands, and recharge zones reduce flood buffering and natural storage capacity. Poor integration of green and grey infrastructure, resulting in lost opportunities for stormwater reuse and aquifer recharge.	Delayed detection of system failures and inefficiencies during climate extremes. Water shortages and contamination risk during and after extreme events. Economic L&D: infrastructure maintenance and restoration costs, increased treatment expenses. Non-economic L&D: public health risks, unequal access, inequitable service delivery, environmental degradation, and water scarcity.
Political, Administrative and Governance	Weak enforcement of groundwater extraction regulation and pollution control due to overlapping mandates between state and municipal bodies. Limited institutional mechanisms for catchment management and pollution control of rivers and reservoirs. Fragmented institutional coordination among urban local bodies, industrial authorities, and water utilities leads to delays in heat/flood response.	Inconsistent management of water supply during extreme heat and flooding events. Diminished capacity of urban ecosystems to moderate floods or retain water in dry seasons. Economic L&D: high costs from emergency water trucking and infrastructure repairs. Non-economic L&D: service disruption in vulnerable communities, health impacts from contaminated or inadequate water supply, and social distress.
Financial and Economic Feasibility	Limited access to climate-resilient financing instruments for utilities and city corporations. Lack of financial protection or insurance mechanisms for critical infrastructure affected by floods or prolonged droughts.	Prolonged recovery time after climate events. Economic L&D: Loss of industrial output due to water supply disruption, additional cost incurred for potable water Non-economic L&D: reduced quality of life and unequal access to safe water for low-income groups.
Social/ Behavioral Aspects and Community Engagement	Low public awareness about water conservation during heatwaves and safe storage during floods. Inequitable access to water services in informal settlements worsens during droughts or network breakdowns. Limited citizen participation in groundwater recharge, rainwater harvesting, or community-based water management initiatives. Dependence on ad-hoc private tankers during heat crises increases inequity and service unreliability.	Unequal exposure to water scarcity and contamination. Economic L&D: increased household expenditure on bottled or tanker water. Non-economic L&D: reduced wellbeing, gendered burden of water collection, and inter-community conflicts over scarce resources.

Wastewater Sector

Soft Limits	Limits of Adaptation Strategy	Residual Risks and L&D Implications
Institutional and Knowledge Capacity	Low network coverage in peripheral and informal areas increases untreated discharge during floods. Insufficient capacity of sewage treatment plants (STPs) to manage rising inflows from expanding urban areas and industrial effluents during high rainfall events. Lack of GIS mapping of sewer lines and manholes hampers rapid response to blockages and damage. Limited adoption of decentralized wastewater treatment systems (DEWATS) and dual plumbing due to space constraints, maintenance issues, and a lack of technical expertise.	Service breakdown and contamination of surface and groundwater during floods and power outages. Economic L&D: increased costs for emergency pumping, desludging, and water quality restoration. Non-economic L&D: waterborne disease outbreaks, reduced sanitation safety, and ecosystem contamination.
Political, Administrative and Governance	Weak enforcement of effluent standards and lack of accountability among multiple responsible entities (municipal bodies, industrial boards, SPCBs). Inadequate inter-departmental coordination between urban planning, industry, and water resource agencies leads to fragmented project implementation. Absence of a cohesive wastewater policy integrating reuse, recycling, and flood resilience across agencies.	Fragmented responsibility delays restoration of sanitation services during climate crises. Economic L&D: duplication of expenditure, infrastructure inefficiency, and lost investment in underutilized STPs. Non-economic L&D: heightened health vulnerability and loss of public trust in municipal management.
Financial and Economic Feasibility	Capital-intensive nature of wastewater infrastructure limits the scope for rapid scaling in developing urban areas. High energy costs for pumping and treatment make systems vulnerable during heatwaves (power shortages) and floods (equipment failure). Limited fiscal incentives or business models for treated wastewater reuse and private sector participation.	Post-disaster repairs outweigh preventive investments, perpetuating fiscal vulnerability. Economic L&D: recurrent repair and maintenance costs, productivity loss in affected industries and households. Non-economic L&D: long-term sanitation inequities and environmental degradation in low-income communities.
Social/ Behavioral Aspects and Community Engagement	Public perception barriers around the reuse of treated wastewater for non-potable purposes (gardening, flushing, industrial cooling). Lack of community awareness regarding safe sanitation practices during floods, leading to open defecation or disposal in drains. Limited participation of resident welfare associations (RWAs) and communities in decentralized treatment management or operation. Gender and occupational vulnerabilities: sanitation workers face heightened exposure risks during floods and heat events, with inadequate protection and social security.	Poor public engagement results in low acceptance of wastewater reuse initiatives and weak adoption of climate-safe sanitation behaviors. Economic L&D: higher costs of medical treatment, service restoration, and social welfare support. Non-economic L&D: loss of dignity, occupational health hazards for sanitation workers, and psychosocial stress in vulnerable communities.

Stormwater Sector

Soft Limits	Limits of Adaptation Strategy	Residual Risks and L&D Implications
Institutional and Knowledge Capacity	Outdated stormwater networks are not designed for current rainfall intensities; limited capacity causes frequent surcharging and backflow during heavy rainfall. Lack of city-wide hydrological and watershed modelling for climate-adjusted drainage planning. Absence of integrated flood dashboards linking meteorological, hydrological, and drainage data at the ward level. Encroachment and concretization of natural drains and recharge zones reduce permeability and increase runoff. Limited institutional capacity for real-time monitoring, flood forecasting, and GIS-based flood mapping. Insufficient inclusion of blue-green infrastructure (bio-swales, rain gardens, infiltration trenches) in new urban developments. Absence of urban design incentives for permeable surfaces or vegetated buffer zones in redevelopment projects.	Drainage networks repeatedly fail during extreme events, causing damage to roads, homes, and public spaces. Loss of natural flood buffering capacity and recharge potential. Economic L&D: repair and pumping costs, asset losses in flood-prone zones. Non-economic L&D: mobility disruption, contamination of water sources, and public health hazards.
Political, Administrative and Governance	Absence of urban stormwater policies or byelaws mandating on-site runoff management. Weak enforcement of land-use controls against encroachment on natural drains, wetlands, and floodplains.	Institutional inefficiency prolongs urban flooding and public inconvenience after heavy rainfall. Economic L&D: duplication of expenditure on emergency dewatering and infrastructure rehabilitation. Non-economic L&D: community displacement, public frustration, and erosion of confidence in governance.
Financial and Economic Feasibility	High costs of retrofitting old networks constrain adaptation in dense urban areas. Drainage projects often lack lifecycle cost accounting, leading to poor upkeep and early deterioration. Underinvestment in preventive drainage maintenance; funding allocated primarily for post-event recovery.	Delayed upgrades and maintenance increase vulnerability to recurring flooding. Economic L&D: recurring repair expenses, property damage, traffic losses. Non-economic L&D: disruption to education and livelihoods, inequitable recovery in low-income wards.
Social/ Behavioral Aspects and Community Engagement	Public negligence in solid waste disposal exacerbates drain clogging during rainfall. Resistance to temporary mobility restrictions or floodplain clearance due to short-term inconvenience or economic loss. Limited inclusion of informal settlements in flood early-warning communication and preparedness programs. Minimal public participation in the maintenance of nature-based drainage infrastructure.	Clogged or damaged drains increase localized waterlogging and disease exposure. Economic L&D: increased household repair costs, loss of working days, damage to small businesses. Non-economic L&D: health hazards, stress, and recurring social disruption for low-income and informal communities.

Solid waste Sector

Soft Limits	Limits of Adaptation Strategy	Residual Risks and L&D Implications
Institutional and Knowledge Capacity	Inadequate segregation at source and weak enforcement of rules cause mixed waste dumping, aggravating methane emissions and vector breeding during floods. Legacy dumpsites continue to emit greenhouse gases and leachate, especially under high heat or rainfall, exacerbating pollution and fire risks. Lack of real-time data on waste generation, composition, and logistics hampers adaptive operations during climate events. No digital monitoring systems for landfill temperature, leachate, or fire risks under heatwave conditions.	Disruption in waste logistics and rising vector-borne disease outbreaks during floods or heat spells. Economic L&D: increased expenditure on cleanup, landfill restoration, and emergency sanitation drives. Non-economic L&D: health impacts on nearby communities, reduced urban liveability, and long-term ecological degradation.
Political, Administrative and Governance	Weak enforcement of SWM Rules (2016)[125] and local bylaws on segregation, extended producer responsibility (EPR), and scientific landfill management. Ad-hoc decision-making during flood or heat emergencies often leads to temporary dumping or open burning.	Reactive operations and a lack of accountability lead to prolonged service breakdowns. Economic L&D: duplicated resource deployment, post-flood restoration costs. Non-economic L&D: heightened health vulnerability, especially in low-income wards, and loss of citizen confidence in governance.
Financial and Economic Feasibility	High O&M costs for mechanized collection and waste-to-energy systems during heatwaves (fuel costs, power outages). Decentralized waste processing is less financially viable due to low land availability and economies of scale. Weak financial mechanisms for private sector participation or PPP models in circular waste-economy initiatives.	Chronic underinvestment perpetuates the vulnerability of waste systems during heat and flood crises. Economic L&D: equipment damage, waste collection delays, and resource diversion from other essential services. Non-economic L&D: diminished environmental quality, reduced workforce safety, and inequitable recovery outcomes across city zones.
Social/ Behavioral Aspects and Community Engagement	Low citizen compliance with source segregation and waste reduction initiatives exacerbates volume overload during floods. Occupational vulnerability of sanitation and waste workers — high exposure to infectious and chemical hazards during heatwaves and post-flood cleanup. Social stigma and exclusion prevent formal recognition and safety coverage for informal recyclers and ragpickers.	Poor participation leads to ineffective adaptation measures and residual vulnerability. Economic L&D: health treatment costs for waste workers, rising household expenditure due to service disruptions. Non-economic L&D: loss of dignity, psychosocial trauma among sanitation workers, and intergenerational inequality in environmental exposure.

125 Central Pollution Control Board. (2021, January 27). Municipal Solid Waste Management Rules, 2016. https://cpcb.nic.in/rules-2/

Transport Sector

Soft Limits	Limits of Adaptation Strategy	Residual Risks and L&D Implications
Institutional and Knowledge Capacity	Limited technical capacity for integrating design with modelling of flood or heat impacts on transport infrastructure. Prioritization of road widening and vehicular mobility over non-motorized transport.	Economic L&D: Inefficient project prioritization leading to misallocation of adaptation investments. Non-Economic L&D: Weak institutional learning reduces preparedness and prolongs disruption recovery time after extreme events.
Political, Administrative and Governance	Fragmented jurisdiction between transport, traffic, road, and stormwater departments impedes integrated planning. Lack of cross-sector data systems prevents real-time coordination during flood or heat emergencies.	Economic L&D: Repeated damage to critical corridors due to delayed action, higher cost of post-event rehabilitation. Non-Economic L&D: Decline in commuter trust and service reliability; inequitable access for low-income users.
Financial and Economic Feasibility	Most municipal budgets are allocated to routine maintenance rather than resilience upgrades.	Economic L&D: Rising maintenance and energy costs and underfunded infrastructure renewal. Non-Economic L&D: Increased vulnerability of public commuters to service failure during heat and flood events.
Social/ Behavioral Aspects and Community Engagement	Preference for private vehicles and air-conditioned mobility options undermines modal shift in public and non-motorized transport. Lack of awareness of climate risks in mobility choices, and low citizen participation in sustainable transport initiatives.	Economic L&D: Declining public transport revenue and higher emissions-related costs. Non-Economic L&D: Increased heat exposure, congestion stress, and social exclusion for low-income and non-motorized commuters.

Environment Sector

Soft Limits	Limits of Adaptation Strategy	Residual Risks and L&D Implications
Institutional and Knowledge Capacity	Limited spatial data on vegetation cover, tree health, and heat-mitigation potential impede evidence-based planning. Poor urban microclimate management, fragmented green spaces, and loss of ecological connectivity weaken cooling effects during heatwaves. Insufficient city-level biodiversity inventories and climate vulnerability assessments of ecosystems, and a Lack of quantitative evidence linking urban greening to reduced heat stress and improved flood resilience. Weak institutional capacity for monitoring and maintaining restored wetlands and green-blue corridors under changing rainfall patterns.	Reduced ecological buffering capacity during extreme heat and heavy rainfall. Economic L&D: high maintenance costs, loss of property value, and infrastructure degradation due to poor natural shading or drainage. Non-economic L&D: biodiversity decline, ecosystem fragmentation, reduced thermal comfort, and deterioration of the environment
Political, Administrative and Governance	Limited cross-departmental coordination between the forest, environment, town planning, and urban development authorities. Encroachment and land-use change in ecologically sensitive zones (wetlands, floodplains) persist due to weak enforcement. Overlapping mandates between municipal and state-level agencies hinder continuity of restoration projects.	Uncoordinated governance weakens long-term ecosystem stability and flood mitigation capacity. Economic L&D: duplication of green initiatives and inefficient resource use. Non-economic L&D: erosion of community trust, loss of heritage landscapes, and reduced adaptive governance credibility.
Financial and Economic Feasibility	The high opportunity cost of land in urban cores discourages allocation of funds for parks, wetlands, and green buffers. Lack of dedicated biodiversity financing mechanisms within city budgets. Short-term project cycles restrict long-term ecological recovery; maintenance budgets are often overlooked after projects.	Loss of long-term benefits from green assets due to short-term financial planning. Economic L&D: recurrent restoration expenses, reduced tourism potential, and higher heat mitigation costs. Non-economic L&D: declining ecosystem services, wellbeing loss, and weakened natural heritage conservation.
Social/ Behavioral Aspects and Community Engagement	Resistance to land-use restrictions in ecologically sensitive zones due to competing housing and commercial priorities. Inadequate citizen participation in biodiversity action plans or urban greening programs. Absence of community ownership models for sustaining restored natural areas.	Poor public stewardship reduces sustainability of restoration and green cover projects. Economic L&D: increased cooling energy costs and loss of productivity from heat stress. Non-economic L&D: reduced aesthetic, recreational, and psychological benefits; community detachment from natural systems.

Beyond Residual Impacts:

While sectoral limitations in terms of physical constraints represent hard limits of infrastructure as presented in the table above, the thresholds described can be further extended through a combination of adaptation measures rather than individual sectoral initiatives realizing their residual impacts.

Nature-Based Solution: For instance, choked natural drainage resulting in persistent flooding due to illegal dumping of solid waste could be countered by community-owned clean-up drives and ownership of these commons for the implementation of nature-based solutions along with right-sized grey infrastructure. The Rajokri waterbody restoration is another example of the Government of NCT of Delhi using nature-based solutions along with community ownership and environmental stewardship.

From climate calamity to opportunity with impact (long-term changes to which an intervention contributes): Further, flooding along the Yamuna Riverbank in Delhi has been utilized for groundwater recharge by holding the floodwaters in reservoirs created along the banks of the Yamuna River. This was done acknowledging that there are policy implementation bottlenecks and that with a growing population with limited access to water, groundwater extraction is an urban reality.

Social protection enabling climate resilience: While city governments have a limited role in social protection measures, they are often the conduits for the implementation of central and state government programs.

Across sectors such as water supply, wastewater, stormwater, health, and the built environment, most adaptation measures remain technically viable but are impeded by policy, funding, or implementation barriers. This understanding of limits of adaptation directly informs the subsequent chapter on Loss and Damage Adaptive Pathways, which builds upon these findings to project residual losses and damages that persist even after feasible adaptation. This will support evidence-based prioritization for climate-resilient infrastructure, governance reforms, and risk-transfer mechanisms in the next phase of the City-Level Loss and Damage Framework.

By identifying both actionable opportunities and inherent constraints, the next chapter provides a crucial bridge between climate risk assessment and the development of long-term city-level L&D management frameworks, guiding local governments to prioritize adaptation strategies that are technically plausible, institutionally supported, and financially feasible.

6.

Loss & Damage Adaptive Pathways: Future Projections of L&D

This study examines L&D through the specific lens of adaptation limits, treating them as practical boundaries beyond which well-intentioned and technically sound interventions stop delivering benefits for specific populations or locations.

The analysis begins with two contrasting futures. In the first future, adaptation does not scale beyond current practice. A business-as-usual baseline is established by combining exposure patterns with standardized loss and damage indicators, and current annual losses are projected forward under plausible climate trajectories to estimate cumulative impacts. In the second future, the actual adaptation measures that cities have committed to or begun to implement are tracked. The analysis measures how these measures reduce harm and asks the critical question: at what point, and for whom, do these measures cease to be effective? Answering this question requires integrating technical thresholds, governance and finance barriers, and social acceptance into a single analytical frame.

Residual impacts are expressed in monetary terms and complemented with narrative descriptions of non-economic harm. This dual presentation enables planners and decision-makers to understand both the arithmetic of costs and the lived consequences that numbers alone cannot capture.

Building on the risk assessment and identified limits to adaptation, and using the methodology outlined for valuing losses and damages in Section 2.4, this chapter lays out the detailed approach for generating estimates of future L&D for Ahmedabad and Surat under Business-As-Usual (BAU) and projected climate scenarios. This approach provides quantified projections that support evidence-based policy and planning, and is illustrated through two case studies.

6.1 Approach to Future Projections of Loss and Damage – Adaptive Pathways Framework

This chapter operationalizes the concept of 'adaptive pathways'—sequences of management choices over time that respond to evolving climate conditions and feedback on adaptation effectiveness. Rather than assuming a single future, we explore divergent pathways reflecting different adaptation and non-adaptation scenarios, showing how L&D trajectories change across pathways.

Methodological Steps:

Step 1: Define adaptation tipping point (where current measures are no longer sufficient).

- Identify the climate threshold at which planned adaptation measures begin to fail. Example: The current Heat Action Plan is designed for heatwaves up to 48°C; beyond that, the plan's effectiveness declines (e.g., cooling centers become overwhelmed).
- Use climate scenarios to project when this threshold is likely to be exceeded. Example: RCP 8.5 projects 50+ days/year with T>48°C by 2050.

Step 2: Define L&D under current adaptation (no new interventions).

- Project health, economic, and non-economic losses if only current adaptation measures remain in place, using impact functions from Chapter 2 and climate scenarios from Chapter 3.
- Example: If temperatures exceed the current HAP design capacity, heat-related mortality could increase from the current 68 deaths per year to 200–300 deaths per year by 2050 under RCP 8.5.

Step 3: Design alternative adaptation pathways.

- Pathway A (Incremental): Enhance current measures (HAP upgraded to handle 50°C; additional cooling centers; targeted support for vulnerable groups).
- Pathway B (Transformative): Fundamental system changes (distributed cooling networks, heat-resilient affordable housing, occupational shifts away from outdoor work).
- Pathway C (Maladaptive or Non-adaptive): Status quo or poorly designed measures (e.g., universal AC without addressing grid capacity; embankments that increase downstream flood risk).

Step 4: Quantify L&D under each pathway.

- Using impact functions, project health, economic, and social losses under each pathway + climate scenario + time horizon.
- Illustrate graphically: L&D trajectory curves showing how losses change over time under each pathway.
- Identify pathways that successfully keep losses below critical thresholds (e.g., mortality <100/year) vs. those that do not.

Step 5: Identify decision points and switching points.

- Decision point: Moment when the current pathway is deemed insufficient (e.g., HAP effectiveness <50%).
- Switching cost: Cost to transition from current pathway to new pathway (e.g., infrastructure investment, policy change, institutional reform).
- No-regret measures: Adaptation measures that are effective across all pathways and climate scenarios (e.g., water efficiency, public health surveillance).

Step 6: Accommodate uncertainty and flexibility.

- The adaptive pathway framework accounts for uncertainty by exploring multiple scenarios.
- It emphasizes flexibility: early measures can be adjusted if conditions change faster or slower than expected.
- Compare costs of committed vs. wait-and-see vs. proactive approaches.

Illustrative case studies (6.2.1 and 6.2.2) demonstrate this framework being applied to two specific impacts: heat-related health and flood infrastructure damage.)

Phase 1: Project Scoping and Setup

A comprehensive review of municipal adaptation documents, including CRCAPs, sectoral policies, and development strategies, was undertaken to catalog adaptation strategies, associated stressors, timelines, and implementing agencies. This process generated a baseline adaptation inventory, which serves as the foundation for subsequent analysis.

Phase 2: Literature Review and Limits Research

Each documented strategy was classified, and a thematic literature review was conducted to identify "hard" thresholds for adaptation measures. Global case studies and syntheses provided empirical benchmarks for these limits.

Clear use of IPCC-aligned definitions ensures a shared understanding among researchers and alignment with international standards.

Phase 3: Soft Limits Validation through Stakeholder Engagement

Future work will focus on systematically identifying "soft" limits arising from governance, finance, equity, and capacity barriers through stakeholder engagement. Structured interviews and workshops are proposed with municipal officials, NGOs, resident representatives from vulnerable neighborhoods, and financial institutions. These engagements would validate assumptions, refine scoring criteria from Phases 1–2, and ground findings in local realities.

Phase 4: Climate Projections and Future Scenarios

City-scale climate projections under RCPs 4.5 and 8.5 were combined with exposure and vulnerability datasets (heat, flood, drought, and sea-level rise) to model stressors. Projections incorporated expected population growth based on current forecasts.

Phase 5: Residual Loss and Damage Estimation

Residual losses and damages are quantified once adaptation measures reach their hard or soft limits. The analysis combines quantitative estimates (e.g., economic losses using Cost of Illness methods) with qualitative narratives that capture non-economic dimensions such as mental health impacts, loss of cultural spaces, displacement, and ecosystem degradation.

Results can then be presented for each affected ward and socio-economic group, showing how vulnerability and losses differ across the city and population over time and under various scenarios.

6.2 Illustrative Cases

This approach is operationalized through two Illustrative examples and a detailed explanation of economic estimation:

Case Study 1: Evaluation of the health and economic impacts of extreme heat in Ahmedabad and Surat.

Case Study 2: Assessment of flood-related damages to public infrastructure in Surat.

Methods Box 6.2.1: Heat-Related Health Impacts - Ahmedabad 2050 Projection

Objective: Project future heat-related mortality and morbidity under different climate scenarios and adaptation pathways, showing residual L&D.

Data & Methods:

1. Baseline mortality (2023): 68 official heat deaths in 2015; assume 50/year baseline in recent years (AMC records, HAP monitoring).
2. Climate scenarios: Temperature projections for 2050 from Chapter 3 (RCP 4.5 and 8.5); assume 1.5–2.5°C warming above 2023 baseline, translating to 50–80 additional heat days/year (T>40°C) and higher intensity on extreme days.
3. Temperature–mortality function: Exposure-response relationships from Indian studies (Kinney et al., 2020; Hajat & Kosatsky, 2010) indicate ~2–4% increase in mortality per 1°C above threshold (~35–40°C); use mid-range 3% for Ahmedabad.
4. Adaptation scenarios:
   - No new adaptation (Baseline): Only current HAP measures; assume effectiveness plateaus as temperatures exceed design capacity. Projected mortality at 2050 under RCP 8.5 ≈ 200–250 deaths/year.
   - Enhanced Incremental Adaptation (Pathway A): Upgraded HAP (larger coverage, additional cooling centers, public awareness), early warning systems, healthcare capacity increase. Assumption: Reduces mortality by ~30–40% relative to the no-adaptation scenario. Projected mortality ≈ 130–170 deaths/year.
   - Transformative Adaptation (Pathway B): Cooling centers in every ward, heat-resilient housing retrofits for low-income areas, occupational shift to safer hours/indoor work, health system expansion. Assumption: Reduces mortality by ~60–70%. Projected mortality ≈ 60–90 deaths/year.

5. Residual L&D calculation:
   - Health L&D = Projected deaths × VSL (INR 3 crore per death) + Projected morbidity × COI (INR 4,460 per case, from section 2.6.3).
   - Projected morbidity at 2050 (RCP 8.5, no new adaptation) ≈ 5,000–8,000 outpatient cases/year (vs. current 2,000–3,000).
   - Total health L&D (2050, no adaptation, RCP 8.5): ~250 deaths × INR 3 crore + 7,000 morbidity cases × INR 4,460 ≈ INR 75 crore/year + INR 3.1 crore/year = ~INR 78 crore/year (~USD 9.4 million/year).
   - With Pathway A (enhanced incremental): ~INR 50 crore/year.
   - With Pathway B (transformative): ~INR 24 crore/year.
6. Uncertainty quantification:
   - Baseline uncertainty from climate model spread: ±30% (RCP 4.5 vs. RCP 8.5 span).
   - Temperature–mortality function uncertainty: ±50% (literature range 2–4%).
   - Adaptation effectiveness assumption: ±25%.
   - Combined uncertainty range: Central estimate × 0.4 to × 2.4.

Limitations:

- Does not account for adaptation fatigue (if heatwaves become normalized, behavioral adaptation may wear off).
- Assumes linear scaling of mortality with temperature; actual relationship may be nonlinear (threshold effects).
- Does not include cascading health impacts (e.g., heat→malnutrition → infection; heat → mental health → suicide).
- Distributional impacts: Projected mortality assumes current vulnerable-group composition; if demographic shift occurs (e.g., younger population average, better nutrition), future mortality may differ.
- Data Quality & Confidence: MODERATE. Driven by imperfect temperature–mortality relationships and uncertain adaptation effectiveness estimates. Best interpreted as an illustrative scenario set, not a precise forecast.

6.2.1 Evaluating the Health and Economic Impacts of Extreme Heat in Ahmedabad and Surat

Ahmedabad and Surat are vulnerable to these heatwaves, and the health impacts are disproportionately borne by vulnerable populations, including children. The rise in pediatric emergencies during periods of extreme heat not only represents a serious health crisis but also translates into a substantial economic burden on families and the healthcare system. Understanding the scale of this future challenge is critical for effective public health planning and climate adaptation.

This analysis aims to quantify the projected future health and economic burden of heat-related pediatric emergencies in Ahmedabad for the period 2025–2050, by computing the excess number of pediatric cases owing to heatwaves. Furthermore, it seeks to evaluate the potential effectiveness of the cool roofing measure in adapting to these impacts. By modeling future climate scenarios and their health consequences under the "Business-as-Usual" and "Proposed Adaptation" scenarios for RCP 4.5 and RCP 8.5, this study provides a data-driven case for investing in climate-resilient infrastructure to protect public health and reduce future economic losses.

The analysis is divided into three main parts:

1. The generation of daily climate projections from 2025 to 2050;
2. The modeling of health impacts under "Business-as-Usual" and "Proposed Adaptation" scenarios;
3. The economic valuation of the adaptation's benefits.

Stage 1: Generation of Daily Climate Projections (2025–2050)

This phase focuses on creating a synthetic daily climate dataset for March to June from 2025 to 2050.

1. **Baseline Data:** The daily weather patterns (maximum temperature, minimum

temperature, and rainfall) from March to June 2010[126],[127] serve as the foundational baseline for all future projections.

2. **Future Climate Projections:** Long-term trends for temperature, rainfall, and heatwave frequency were established, using the Future Climatic Scenario as per Gujarat's SAPCC[128],[129]:
   - **Maximum and Minimum Temperatures:** A two-phase, non-linear increase was projected. From a 2010 baseline, temperatures are projected to increase by 1.0–1.5°C under RCP 4.5 and RCP 8.5 by 2040, followed by an accelerated increase of 1.5–2.0°C and 2.0–3.0°C under RCP 4.5 and RCP 8.5, respectively, by 2070.
   - **Rainfall:** A gradual linear increase in total seasonal rainfall was projected, rising by 20 mm under RCP 4.5 and 40mm under RCP 8.5 by 2040, and a total of 40 mm and 60mm under RCP 4.5 and RCP 8.5, respectively, by 2070.
   - **Heatwave Days:** The number of heatwave days (defined as **maximum temperature > 40°C**) was projected to increase cumulatively, rising by 10 days by 2040 under RCPs 4.5 and 8.5, and by an additional 25 days under RCP 4.5 and 30 days under RCP 8.5 by 2070.
3. **Generating Daily Data:** For each year from 2025 to 2050, the following steps were taken:
   - The 2010 baseline daily data was cloned for all years from 2025 to 2050.
   - The projected gradual increase in daily maximum and minimum temperatures was applied to every day.
   - The total rainfall was scaled to match the annual target for that year.
   - Finally, the temperatures were adjusted to strictly enforce the exact target number of heatwave days for that year. This was done by identifying the N hottest days (where N is the target) and ensuring their temperatures were above 40°C, while also ensuring all other days remained below 40°C.

Key Assumptions for Climate Projections:

- Baseline Representativeness: The daily weather variability of March–June 2010 is assumed to be a suitable template for future years, as March to June are the hottest months in Ahmedabad.
- Linear Rainfall Increase: The model assumes a steady, linear increase in total rainfall over time.
- Two-Phase Temperature and Heatwave Increase: The projections for temperature and heatwave days follow a defined, non-linear trend with an acceleration point around 2040, as per the climate projections under RCP 4.5 and RCP 8.5.
- Seasonality: All significant heatwave impacts are assumed to occur within the March–June period.

Stage 2: Health Impact Modeling of Pediatric Cases (GAM)

This phase uses the projected climate data to model pediatric emergency cases and evaluates the impact of the adaptation strategy, under both climate scenarios - RCP 4.5 and RCP 8.5.

Overall, the following approach allows for a direct assessment of the health burden during extreme heat events and provides a focused measure of the cool roofing adaptation strategy's effectiveness in mitigating these impacts in the context of pediatric emergency cases.

126 The historical daily data for Ahmedabad has been sourced from Indian Meteorological Data (IMD) through the OpenCity: Urban Data Portal.

127 The historical daily data for Surat has been sourced from the India Meteorological Department (IMD) data.

128 The Future Climate Scenarios for Ahmedabad have been sourced from the Ahmedabad Climate Resilient City Action Plan: Towards a Net Zero Future (Government of Gujarat, 2023).

129 The Future Climate Scenarios for Surat have been sourced from the draft of Surat Climate Resilient City Action Plan: Towards a Net Zero Future (Government of Gujarat, 2026).

Process:

1. **Historical Baseline Calculation:** A stable historical climate baseline was calculated by averaging daily maximum temperature, minimum temperature, and rainfall for each month from March to June using historical data from 1951–2024[130],[131]. This data-driven baseline serves as the benchmark against which future "excess cases" are measured.
2. **Scenario Definition:** Two scenarios were created:
   - "Business-as-Usual": Uses the projected climate data directly.
   - "Proposed Adaptation": This scenario simulates the phased implementation of a cooling strategy. The impact is modeled keeping the following limits of the adaptation strategy:
     i. Hard Limit in Temperature Reduction: A potential 5.0°C reduction in felt temperature (as this is the hard limit of this strategy in the context of Ahmedabad[132]) is applied on all days with a maximum temperature of 40°C or higher.
     ii. Efficacy Rate: The strategy is assumed to operate at a 70% efficacy rate[133], resulting in a 3.5°C decrease on qualifying hot days. We intend to validate this through stakeholder engagement.
     iii. Phased Coverage: The strategy's implementation coverage is gradually (linearly) increased over the years: 35% until 2030, 40% until 2035, 80% until 2047[134], keeping it consistent with the city's targets. For 2048-2050, the coverage is assumed to remain at 80%.
3. **Statistical Model Fitting:** A Generalized Additive Model (GAM) with a quasi-Poisson family was fitted to the 2024 data[135], in order to train the model. This model was chosen for its ability to capture complex, non-linear relationships between the climate variables and health outcomes. The model formula was:

$$log(E(Y_t))=\alpha+s1(Temp_t)+s2(Rainfall_t)+\gamma \cdot DOW_t$$

Where:

- **Yt:** number of pediatric emergencies on day t
- **Tempt:** maximum temperature on day t
- **s1, s2:** smooth functions (natural splines) capturing non-linear effects of temperature and rainfall
- **DOWt:** categorical variable for day of the week
- **α:** model intercept

4. **Calculating "Excess Cases":**
   - The GAM was used to predict the number of cases that would occur under the stable, historical climate baseline (i.e., Yt,baseline) for each day during March to June, from 2025 to 2050.
   - The GAM was also used to predict the number of cases that would occur under the projected maximum temperature (i.e., Yt,actual) for each day during March to June, from 2025 to 2050.
   - For both, "Business-as-Usual" and "Proposed Adaptation" scenarios, the model predicted the number of cases for each day, using the following formula:

130 The historical data has been sourced from the Indian Meteorological Department through the OpenCity: Urban Data Portal.

131 The historical daily data for Surat has been sourced from Indian Meteorological Department (IMD).

132 The source for Identifying the hard limit of the Cool Roofing strategy in Ahmedabad is a research study titled "Hot Take: Cool Roofs: The impact of rising temperatures on women workers living in Bapalaal Kadiyani Chaali – an urban slum in Ahmedabad, India" (Mahila Housing Trust, 2024). https://www.mahilahousingtrust.org/wp-content/uploads/2024/04/Hot-Take-Cool-Roof-Research-Study-Report-2024.pdf

133 This is an assumption at the moment, but will be revised after stakeholder engagement.

134 The information on the soft limits of coverage of the cool roofing strategy for both cities, has been sourced from the draft of Surat Climate Resilient City Action Plan: Towards a Net Zero Future (Government of Gujarat, 2026).

135 The daily pediatric cases for the year 2024 were sourced from "Heat-Health Preparedness & Response Activities" (National Programme on Climate Change & Human Health, 2024), wherein the case-count for India was taken as proxy for Ahmedabad, owing to lack of data availability. Additionally, the daily data for temperature and rainfall was sourced from IMD.

$Excess\ Cases_t = Y_{t,baseline} \times ((Y_{t,actual}/Y_{t,baseline})-1)$

5. **Health Impact Quantification on Heatwave Days:** The analysis focuses specifically on the health burden attributable to extreme heat.
    - The annual counts, including total predicted cases for actual values of maximum temperature, total cases for the baseline values of maximum temperature, and excess cases, were calculated by summing the respective values only from this subset of heatwave days during each year in the study time period.
6. **Population Growth Adjustment:** To account for a growing population, the final annual case estimates were scaled using a cumulative population growth factor. This factor was derived from projected annual growth rates for Ahmedabad[136] (2.80% until 2030, 1.90% until 2040, and 1.80% until 2050).

Key Assumptions for Health Modeling:

- **Relationship between Health-Risk and Temperature:** The model's projections are based on the temperature-health relationship learned exclusively from the observed data of a single year (2024). This assumes that the health response patterns observed through 2024 are representative and will remain constant for the entire 2025-2050 projection period.
- **Constant Vulnerability:** The model assumes the relationship between temperature and health risk remains constant over time and does not account for changes in population vulnerability, such as demographic shifts (e.g., an aging population), improvements in healthcare access, or increased public awareness of heat risks, which could alter the health response to heat over time.
- **Defined Adaptation Parameters:** The "Proposed Adaptation" scenario currently assumes that the cool roofing strategy's efficacy rate is 70% during the entire time period of 2025 to 2050, but this will be revised after the consideration of inputs from stakeholder engagement. Additionally, the phased coverage targets are also assumed to be met as scheduled, and for the remaining years of 2048-2050, the coverage is assumed to be 80%. Secondly, the coverage for 2025 is assumed to be 20%[137]. Lastly, the coverage rate is assumed to grow linearly in line with the coverage targets specified earlier.

Stage 3: Economic Analysis

The final step monetizes the health benefits of the adaptation strategy.

1. **Cost of Illness (COI):** The number of excess cases for each year, under both the scenarios, is multiplied by the average cost per pediatric emergency case (i.e., cost per visit in 2024 is Rs. 195).[138] This cost is based on direct costs at public hospitals.
    - The cost per pediatric emergency case has been adjusted using an annual inflation rate of 5% until 2050.[139] According to the World Bank, India's inflation rate in 2024 was 5%, and based on previous years' trends, the inflation rate is expected to average 5% annually, assuming no major shocks or events from 2025 until 2050.
2. **Discounting to Present Value:** To account for the time value of money, the future economic benefits calculated for each year are converted to their Present Value (PV) using a standard discount rate of 3%.[140] This allows for the total benefit of the adaptation strategy over the 2025–2050 period to be expressed in today's monetary terms.

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136 The future projections for annual average growth rates have been sourced from the Ahmedabad Climate Resilient City Action Plan: Towards a Net Zero Future (Government of Gujarat, 2023). https://ahmedabadcity.gov.in/ViewFile/ViewFile?TYPE=FileRepository,2098

137 This is an assumption at the moment, but will be revised after stakeholder engagement.

138 Data from the Surat Municipal Institute of Medical Education & Research has been used to estimate the cost of pediatric cases, referred to in Table 9.7 of the Annexure. Surat's costing has been used as proxy for Ahmedabad's costing.

139 The annual inflation rate for India has been sourced from the World Bank's open data portal.

140 The standard discounting rate in health cost-effectiveness analysis context has been sourced from "Recommendations for Conduct, Methodological Practices, and Reporting of Cost-effectiveness Analyses: Second Panel on Cost-Effectiveness in Health and Medicine." (Sanders, Gillian D et al, 2016). https://jamanetwork.com/journals/jama/fullarticle/2552214

- ***Formula Used:***

Where:

PV = Present value

FV = Future value

r = Rate of interest (percentage ÷ 100) [Discounting Rate, in our context]

n = Number of times the amount is compounding [Years from the starting point (i.e., 2025)]

***Note:** The R code used for stages 1 and 2 of the Ahmedabad case study can be found in Table 9.5 of the Annexure.

Findings

Based on the analysis employed, we have arrived at the following estimations of the cost of loss of health in Ahmedabad over the next 25 years until 2050:

	Business-as-Usual Scenario	Proposed Adaptation Scenario
RCP 4.5	112,27,24,033 Approximately ₹112.27 crore	56,23,46,255.4 Approximately ₹56.23 crore
RCP 8.5	116,82,02,188 Approximately ₹116.82 crore	59,34,09,625.2 Approximately ₹59.34 crore

Under RCP 4.5, this adaptation strategy mitigates approximately ₹56.04 crore. Similarly, under RCP 8.5, this strategy mitigates approximately ₹57.48 crore of health-related loss.

Although significant health-related losses persist under both climate scenarios, the adoption of the cool roofing strategy in Ahmedabad in the "Proposed Adaptation" scenario substantially reduces these impacts. However, residual health losses remain high, highlighting the need for further investment in assessing and managing climate-induced loss and damage in the city.

6.2.2 Evaluating Flood-Related Damages to Public Infrastructure in Surat

Flooding represents one of the most significant climate risks to urban centers, with the potential to cause widespread damage to public and private infrastructure. Surat, located along the Tapi River, is particularly vulnerable due to its exposure to dam releases, high tides, and variable monsoon rainfall. When extreme floods occur, apart from disruptions to income and education-related activities, significant damage is caused to essential infrastructure, such as schools, health centers, housing, and utilities, resulting in severe and long-term repair and reconstruction costs.

This analysis estimates the direct physical and monetary losses to public schools in Surat's Adajan ward, under a modeled 4-day flood scenario.[141] By simulating outflow releases from the Ukai Dam and mapping their impacts on critical assets, the study provides insights into the magnitude of damage under the "Business-as-Usual" and "Proposed Adaptation" scenarios (wherein the Pal-Adajan Flood Control Structure will be established in Adajan ward, Surat). Such quantification is crucial for planning resilient infrastructure investments and reducing long-term economic damages from climate change-induced floods.

The analysis proceeds in three main stages:

1. The generation of the highest 4-day sum of outflows from Ukai Dam from 2025 to 2050;
2. The modeling of flood impacts (i.e., damage) under BAU and Proposed Adaptation scenarios;
3. The economic valuation of the adaptation's benefits.

Stage 1: Generation of Future Outflow Values (2025–2050)

This phase focuses on creating a synthetic dataset containing the top 4-day sums of outflow values for the years 2025 to 2050, by replicating data scrapped from newspaper articles and government websites during the time period 2019-2025.

1. **Baseline Data:** The discharge (outflow) values from 2019 to 2025[142] serve as the foundational baseline for all future replications.
2. **Future Replications:** The historical dataset is replicated forward year-by-year up to 2050. For each target year, one baseline year is used as a template. Dates are shifted forward to ensure proper handling of leap years. Replicated data preserves the day-to-day sequence, variability, and seasonal patterns of the original baseline period.

- Annual highest 4-day sums of outflow values: After replication, annual aggregates (e.g., maximum cumulative outflow across 4 consecutive days) are computed to assess extreme event magnitudes.

Key Assumptions for Replication:

- **Baseline Representativeness:** The variability and sequence of the baseline dataset are assumed to reasonably approximate daily outflow behavior for future years. This has been done due to a lack of comprehensive, long-term data for outflows of the Ukai Dam.
- **No Trend Adjustment in Stage 1:** This stage replicates the historical structure only, and does not incorporate any long-term climate change signals (e.g., changes in the amount of rainfall under different climate scenarios) or assumes a relationship between rainfall and outflow. Moreover, assumptions about future rainfall projections can significantly affect model accuracy, especially given the complex relationship between rainfall and flooding, which depends on several factors such as dams, local geography, and drainage infrastructure. Owing to this, the city would be best served by conducting localized flood modeling to accurately estimate the impact of future rainfall scenarios on flood inundation.

Stage 2: Damage Assessment of Schools

This phase uses the projected climate data to model outflow values for the Ukai Dam and evaluate the impact of the adaptation strategy. The adaptation strategy is of a 'New flood control structure project to control waterlogging in low-lying areas (i.e., Pal-Adajan) when 2.5 lakh cusecs of water is released from Ukai Dam', as mentioned in the Surat CRCAP.

Overall, the following approach allows for a direct assessment of the economic burden during extreme rain events and flooding, and provides a focused measure of the Pal–Adajan Flood Control Structure adaptation strategy's effectiveness in mitigating these impacts in the context of economic costs of damage, through a direct comparison in the number of schools, classrooms, and toilets damaged, along with their present-day costs.

1. **Scenario Definition:** Two scenarios were created:
   - "Business-as-Usual": Uses the projected climate data directly.
   - "Proposed Adaptation": This scenario simulates a reduction in the forecasted amount of water outflow, which is modeled with the following limits of the adaptation strategy:
     i. Flood-water Reduction: A potential 250000 cusecs reduction in the amount of flood-water (as this is the hard limit of this strategy in the context of Surat[143]), subject to other soft limits, is applied on all the yearly highest outflows summed for 4 consecutive days.
     ii. Efficacy Rate and Temporal Limit: We assume that the strategy operates at a 60% efficacy rate,[144] from 2030 onwards.[145]
2. **Damage to Schools:** A threshold of 1-1.5 meters has been identified as the minimum threshold of water to cause damage, based on established disaster literature and post-disaster assessment experience, which suggests that buildings exposed to such depths typically incur significant structural and internal damage.[146]
   - Identification of schools: Based on the flood-mapping undertaken by Taru Leading Edge, Asian Cities Climate Change Resilience Network, Surat Climate Change Trust, and Surat Municipal Corporation in 2015, public schools in Adajan have been identified that meet the minimum water

143 The source for Identifying the hard limit of the proposed flood control structure has been the draft of Surat Climate Resilient City Action Plan: Towards a Net Zero Future (Government of Gujarat, 2026). Draft_Surat Net-Zero CRCAP.pdf

144 This is an assumption at the moment, but is open for revision after stakeholder engagement.

145 It has been assumed that the flood control structure will take 5 years to be established, and thus, will be operational from 2030 onwards.

146 The threshold for damage has been sourced from "Flood Depth-Damage functions for built environment" (Pistrika, et al; 2014) https://doi.org/10.1007/s40710-014-0038-2, and "Field survey assessment of flood loads and related building damage from the July 2021 event in the Ahr Valley (Germany)" (Wüthrich, et al.; 2024) https://doi.org/10.1111/jfr3.13024

threshold for damage under varying flood scenarios, ranging from 400000 cusecs to 1000000 cusecs of flood water. The mapping exercise also details the specifics of damaged schools, including the number of classrooms and toilets in each such school.

3. **Estimation of Cost of Damage:** The estimation of the cost of damage to physical infrastructure, in the context of public schools, using the following formula:

Total Loss $_{Govt\ Schools}$ ***= No. of Classrooms*Cost per Classroom + No. of Toilets*Cost per toilet***

Key Assumptions:

- **Definition of a flood-impacts:** For the purpose of the model and considering the availability of data, it has been assumed that in Surat, flood damages occur only beyond an outflow of 400000 cusecs of water from the Ukai Dam.

Stage 3: Economic Analysis

The final step monetizes the economic benefits of the adaptation strategy.

1. **Cost of Damage (COD):** The number of classrooms and toilets damaged in each year under both scenarios is multiplied by the cost of reconstruction of each classroom and toilet, respectively (i.e., the cost is ₹7.3 lakh per classroom and ₹23,000 per toilet in 2024).[147] These costs are based on standard government rates for repair and reconstruction.
    - The costs for reconstruction have been adjusted using an annual inflation rate of 5% until 2050.[148] According to the World Bank, India's inflation rate in 2024 was 5%, and based on previous years' trends, the inflation rate can be expected to average 5% annually through 2050, assuming no major shocks or events.
2. **Discounting to Present Value:** To account for the time value of money, the future economic benefits calculated for each year are converted to their Present Value (PV) using a standard discount rate of 3.5%[149]. This allows for the total benefit of the adaptation strategy over the 2025–2050 period to be expressed in today's monetary terms.
    - Formula Used:

      Where:

      PV = Present value

      FV = Future value

      r = Rate of interest (percentage ÷ 100) [Discounting Rate, in our context]

      n = Number of times the amount is compounding [Years from the starting point (i.e., 2025)]

****Note: The R code used for stages 1 and 2 for Surat city can be found in the Table 9.6 of the Annexure**

Findings

1. Surat

Based on the analysis employed, we have arrived at the following estimations of cost of the damage to physical infrastructure owing to floods in Surat, in the context of the Adajan ward over the next 25 years, until 2050:

Business-as-Usual Scenario	Proposed Adaptation Scenario
80,29,97,405.5 Approximately ₹80.30 crore	29,82,08,150 Approximately ₹29.82 crore

This adaptation strategy mitigates approximately ₹50.48 crore in Surat's Adajan ward.

Although considerable infrastructure-related losses persist under both climate scenarios, the establishment of the adaptation structure in Adajan in Surat in the "Proposed Adaptation" scenario substantially reduces these costs. However, residual health losses remain high, highlighting the need for further investment in assessing and managing climate-induced loss and damage in the city.

147 The source for estimating the cost of reconstruction of classrooms and toilets is "Post-Disaster Needs Assessment - Kerala" (UNDP; 2018). https://www.undp.org/publications/post-disaster-needs-assessment-kerala

148 The annual inflation rate for India has been sourced from the World Bank's open data portal. https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG?end=2024&locations=IN&start=1960&view=chart

149 The standard discounting rate in the context of construction has been sourced from "Discount rate in the construction industry" (2023). https://www.designingbuildings.co.uk/wiki/Discount_rate_in_the_construction_industry

7.

Conclusion and Way Forward

This study provides a foundation for assessing L&D arising from climate change in Ahmedabad and Surat. The study adapts global methodologies (PDNA, NDMA, GIDM) to the local context for city-level assessment. The framework expanded the NDMA and PDNA categories to include urban systems and cross-cutting social impacts while aligning with global meta-categories, creating a more inclusive approach to measuring both tangible and intangible losses and damages. The analysis emphasized that NELD often persists long after recovery from physical losses and damages, influencing social well-being, mental health, and intergenerational equity.

Historical climate-related events and climate trends for both cities were analyzed. Combined climate variability data and downscaled climate projections under RCPs 2.6, 4.5, and 8.5 scenarios revealed rising annual mean temperatures, intensifying heatwaves, and highly variable precipitation patterns. These findings indicate that existing adaptation measures will be insufficient and that a systemic climate risk assessment across sectors is necessary. Therefore, future sector-specific vulnerabilities across health, water, wastewater, stormwater, solid waste, built environment and energy, education, and environment sectors were analyzed based on projected demand and proposed adaptation strategies.

The hard and soft limits to adaptation were analyzed to study how they manifest differently across sectors. The hard limits reflected physical or biophysical thresholds, such as overexploited aquifers, limited land for infrastructure expansion, or irreversible loss of natural resources, beyond which adaptation options become infeasible. The identification of soft limits revealed barriers such as institutional fragmentation, inadequate financing, and behavioral inertia, which hinder adaptation despite available technologies.

7.1 Key Findings

- Urban heat impacts on vulnerable communities in Ahmedabad and Surat:
  - In Surat, migrant workers in the textile, zari, and fishing sectors face income loss and work disruption due to heat. The productivity of textile manufacturing units declines because high indoor temperatures shorten work duration and the incidence of heat-related illnesses. Informal housing

with poor ventilation, roofing material, and overcrowding intensifies indoor heat issues. Heat stress leads to fatigue, poor concentration, decline in school performance, and absenteeism amongst children. Reduced cultural and livelihood activities, including the decline of fishing activities, reduced fish species diversity due to extreme heat and water pollution. Outdoor vendors adopt coping mechanisms such as adjusting work hours, shifting their vending location, switching to casual labor, and seeking help from NGOs, temples, and mosques.

  - In Ahmedabad, tin and asbestos roofs and dense informal housing trap heat, causing extreme indoor temperatures in slums, due to which sleep/resting patterns are impacted
  - Prolonged exposure to heat among street vendors, construction workers, and informal laborers leads to productivity loss and heat illness. Absenteeism from work and shorter work duration due to heat stress and dehydration impact overall productivity amongst textile workers. Women experience income loss in the textile sector and in casual labor work. Increased heat exhaustion, dehydration, heatstroke, anemia, and rising medical costs amongst the families. There is limited access to knowledge about preventive measures for heat-induced illness, water, and cooling infrastructure. Outdoor play duration for children is compromised during the summer months. Dependence on tubewells and tank water supply increases due to irregular water supply, as identified in a few slum locations.

- Urban flood impacts on vulnerable communities
  - In Surat, informal settlements located along tidal creeks, riverbanks, and drainage channels are highly exposed to flooding. Creek flooding and monsoon waterlogging frequently inundate slum communities in low-lying areas, leading to loss of fishing equipment and disruption of livelihoods and income. Migrant communities often face difficulties in accessing government relief schemes. Households incur annual repair costs of about ~₹10,000–₹20,000 due to flood damage. Bottled water purchases/ dependency on water tankers increase due to a shortage of potable drinking water. Floodwaters increase the risk of waterborne diseases, skin rashes, and mosquito breeding. Informal settlements experience post-flood sanitation crises due to limited cleaning of drainage lines. Schools close for 1–3 weeks, disrupting children's education, and are sometimes used as emergency shelters during flooding.
  - In Ahmedabad, sewer overflow contaminates the water supply in informal settlements. Long queues at community tubewells during post-flood portable water shortages. Mosquito breeding, dengue and malaria outbreaks, skin infections, and diarrhea. Unsafe roads, open drains, and related road accidents during floods in dense slum areas. Schools are closed during periods of extreme flooding, impacting children's access to education. Inundation of houses leads to relocation of people to elevated areas and temporary makeshift arrangements. Flooding also damages raw materials stored in zari manufacturing units located on the ground floor and loss of work. Post-floods, low-income households face repair costs for their homes and income losses. The lack of insurance forces people to depend on informal borrowing. Women are unable to maintain proper menstrual hygiene during prolonged flooding.
  - Although the municipal corporation has a Heat Action Plan and other existing and planned adaptation measures, substantial L&D aftermath remains, including persistent health impacts, disruptions to education, psychosocial distress among vulnerable communities, and degradation of cultural and ecological assets. These impacts were shared during stakeholder engagements.
  - The hard and soft limits to adaptation are already emerging, especially in non-economic domains, due to extreme heat and flooding.

7.2 Implications for City Governance, Planning, and Policy

- Integrate L&D into core planning instruments: Embed ELD and NELD indicators, maps, and scenarios into Master Plans, Development Plans, CRCAP updates, Heat Action Plans, and sectoral strategies (water, transport, housing, health, education), ensuring that L&D becomes a routine lens in planning decisions.
- Strengthen municipal risk and L&D monitoring systems: Develop a city-level L&D monitoring framework that tracks both economic and non-economic indicators (e.g., infrastructure damage, livelihood loss, health outcomes, education disruptions, mental health signals, cultural and ecosystem changes) at the ward and neighborhood levels.
- Institutionalize inter-departmental coordination on L&D: Establish mechanisms (e.g., an L&D task force or working group) linking key departments (Water, Health, Transport, Housing, Education, Environment, Disaster Management) to jointly assess, report, and respond to ELD and NELD, and to align data systems and response protocols.
- Use L&D evidence for climate- and risk-informed budgeting: Apply L&D findings—including NELD insights—to prioritize investments in adaptation and risk reduction where recurrent and residual losses (especially among vulnerable groups) are highest, and to guide the design of social protection and public health interventions.

7.3 Priority Data and Methodological Gaps

- Health and NELD data: Establish robust, longitudinal datasets on climate-sensitive health outcomes (including mental health and psychosocial indicators), education disruption, and other key NELD dimensions to support more reliable quantification and trend analysis.
- Informal-sector livelihood and income tracking: Develop systems to capture climate-related income and employment disruptions among informal workers (street vendors, daily laborers, sanitation workers) that are otherwise missing in official statistics, including non-economic aspects such as loss of occupational identity.
- Ecosystem and ecosystem service monitoring: Strengthen monitoring of urban green spaces, wetlands, and biodiversity, including their regulating and cultural services, to better capture NELD related to ecosystem degradation and service loss.
- Community-level perception and social cohesion indicators: Systematically track community perceptions of risk, trust, social cohesion, displacement experiences, and cultural loss through periodic surveys or participatory assessments, to inform NELD-focused interventions.

7.4 Capacity-Building and Institutional Needs

- Technical skills for L&D and NELD assessment: Build capacity among municipal staff and local partners on L&D concepts, impact modeling, NELD assessment (including qualitative and participatory methods), and mixed-methods valuation techniques.
- Dedicated L&D function within city institutions: Consider establishing a small L&D monitoring and analysis unit (or designating a focal team) within the city disaster management authority or planning department to coordinate data collection, analysis, and reporting on both ELD and NELD.
- Vertical and horizontal integration: Strengthen linkages between city-level L&D assessment and state/national planning processes (e.g., SAPCC, NDC, NAP), and encourage knowledge exchange between cities on methodologies and use of L&D information in policy and planning.

7.5 Replication and Transferability

- Identify which elements of the framework (e.g., ELD/NELD typology, mixed-methods NELD approach, risk and pathways methodology) are transferable to other Indian and Global South cities, and which components require adaptation to local hazards, governance

structures, and socio-economic conditions.

- Highlight opportunities for peer learning and joint experimentation (North–South and South–South) on city-level L&D assessment, particularly in developing participatory NELD metrics, heat-health surveillance, and ecosystem-based risk reduction.

7.6 Research and Innovation Priorities for Phase II

- Advanced economic and systems modeling: Develop more detailed modeling of indirect and systemic economic effects of climate impacts, linked to both ELD and NELD (e.g., employment, health, social outcomes).
- Community-based NELD assessment and valuation: Pilot community-based, participatory methods and valuation approaches for key NELD domains (mental health, cultural heritage, social cohesion, ecosystem services) in selected high-risk neighborhoods, documenting replicable tools and lessons.
- Cost-effectiveness and distributional analysis of adaptation pathways: Assess the cost-effectiveness and distributional impacts (including on NELD) of different adaptation pathways, highlighting which measures provide the greatest reduction in ELD and NELD per unit of investment, and for which groups.
- Attribution and trend analysis: Strengthen attribution studies linking observed L&D—both economic and non-economic—to climate change signals and local vulnerability patterns, to refine projections, monitor effectiveness of adaptation, and inform iterative updates to the city L&D framework.

Building on these insights and the evidence base, the next stage of work will focus on developing the subsequent City-level L&D Assessment and Management Framework, which will embed institutional, financial, and operational mechanisms to address climate-related losses and damages. The following report will develop a methodology by defining clear institutional governance arrangements, financial strategies, and capacity-building pathways that align with both national/state mandates and international climate commitments. This will provide a comprehensive roadmap to strengthen governance and institutional capacity, enabling Indian cities to anticipate, assess, and manage L&D in a structured, transparent, and timely manner.

8.
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9.

Annexures

Annexures 9.1 Methodology for urban heat assessment for Ahmedabad & Surat

Indicator	Methodology for Ahmedabad & Surat
Air Temperature Trend and Future Scenario (section 3.1.2 for Ahmedabad & section 3.2.2 for Surat)	**Methodology Used:** Historic trend analysis of annual air temperature (including minimum, mean, and maximum temperature) **Data Used:** Daily and yearly air temperature data from 1970 to 2020 (for Ahmedabad) & 1972 to 2024 (for Surat) **Data Source:** IMD, Ahmedabad Airport Station & IMD, Surat Station
LST Analysis	**Methodology Used:** Temporal analysis (pixel-based statistical analysis) of satellite imagery for day and night times for years 2015, 2018, and 2021 (for Ahmedabad) & 2016, 2020, and 2024 (for Surat) was conducted to understand the trend of LST. LST hotspots were identified. Hotspot areas with consistently higher land surface temperatures as compared with median temperatures above 37°C (Ahmedabad) and 41°C (Surat) were considered. **Data Used for Ahmedabad:** Satellite imagery from May 2015, May 2018, and May 2021 (May 2021 – daytime analysis considered for hotspot identification) **Data Used for Surat:** Satellite imagery from May 2016, May 2020 and May 2024 (May 2024 – daytime analysis considered for hotspot identification) Data Source: 1. Day time Surface Temperature: 30X30m resolution LandSat8 image 2. Nighttime Surface Temperature: 500X500m (Ahmedabad) & 1kmX1km (Surat) resolution MODIS image
Heat Index Analysis (Feel Like Temperature for Ahmedabad)	**Methodology Used:** Heat index (feel like temperature) was analysed based on correlation between air temperature and humidity to establish and understand levels of thermal comfort in the city as per 'National Guidelines for Preparation of Action Plan – Prevention and Management of Heat Wave', prepared by NDMA. **Data Used:** Air temperature and humidity data for May 2021 **Data Source:** 1. Air temperature data: 50 environmental sensors (AMC) 2. Relative Humidity data: 10 Continuous Ambient Air Quality Monitoring Stations (AMC & CPCB)
Heat Wave Events[150] and Trend	**Methodology Used:** Analysed monthly heatwave warning days (including occurrences and frequency) for last five years and correlated with heat stroke cases and deaths for respective months. **Data Used:** Monthly data from 2015 to 2021 (summer months from April to July) **Data Source:** AMC

150 Heat wave events: Heat wave event is said to occur when maximum temperature of a station reaches at least 400°C or more for plains and at least 300°C or more for hilly regions (IMD)

Annexures 9.2 Methodology for urban flood assessment for Ahmedabad & Surat

Indicator	Methodology for Ahmedabad & Surat
Rainfall Trend and Extreme Rainfall Scenario (section 3.1.2 for Ahmedabad & section 3.2.2 for Surat)	**Methodology Used:** Analysis of annual rainfall and rainy days trends, intensity, and frequency of extreme rainfall events. **Data Used:** Daily and yearly rainfall data from 1970 to 2020 for Ahmedabad & 1972 to 2024 for Surat **Data Source:** IMD, Ahmedabad Airport Station & Surat Station
Analysing Waterlogging or Flooding Causes	**Methodology Used:** Analysis from satellite imagery using Digital Elevation Model. Natural contours and streamlines were overlaid with flood points, storm water network, road network, and built-up area (using Google Earth) layers, to identify most affected areas and causes of flooding or water logging. Areas located within a 250 m buffer of 166 flood points for Ahmedabad & 46 flood point for Surat have been identified as high-risk areas. Urban flood risk is examined by analysing and correlating spatial information with qualitative information and data received from AMC & SMC, through stakeholder consultations & and qualitative information from focused group discussions with vulnerable people in Surat. Based on data provided by AMC, 166 water-logged areas or flood points were mapped spatially and 46 waterlogged areas or flood points were mapped spatially for Surat **Data Used:** Water Logging Points (FY 2021-22, FY 2022-23 from AMC and FY 2024-2025, 2025-2026 from SMC) **Data Source:** 30X30m resolution LandSat8 image (May 2021 for Ahmedabad)
Analysis of Water and Vector Borne Diseases and Correlation with Urban Flooding	**Methodology Used:** Flood risk areas and spatial analysis of ward level water and vector borne disease cases are overlaid to build a correlation between flood prone areas and occurrence of water and vector borne diseases. **Data Used:** Water and vector borne disease data for 2021 (Ahmedabad) & 2024 (Surat) **Data Source:** Health Department, AMC & Information system Department, SMC

Annexures 9.3 Critical urban systems and climate fragility statements for Ahmedabad

Urban Systems	Climate Fragility Statements	Likelihood (a)	Consequence (b)	Risk Score (axb)	Risk Status
		Probability of occurrence of an event Almost certain- 5 Likely- 4 Possible- 3 Unlikely- 2 Rare- 1	Impact of an event Catastrophic- 5 Major- 4 Moderate- 3 Minor- 2 Insignificant- 1	Risk= Likelihood * Consequence	Extreme- >15 High- 11-15 Medium- 5-10 Low-<5
Built Environment	Informal settlements and slums are often built in low lying, waterlogged areas and lack resilient infrastructure, making them highly susceptible to floods, and may cause inundation of housing and property	5	4	20	Extreme
	During extreme heatwave, due to poor housing quality and roofing material the heatwaves can impact and cause heat related illness among vulnerable population (women & children)	5	4	20	Extreme
Water Supply	Increase in ambient temperatures, especially during extreme heat events, increases water demand. Limited availability of water during summer months increases ground water extraction impacting overall water resource availability. Wards with extreme heat conditions and drinking water supply related issues are more vulnerable.	4	4	16	High
	Increase in high intensity rainfall, leading to urban flooding, disrupts compromised stretches of the water distribution system, impacting public health.	4	4	16	High

Urban Systems	Climate Fragility Statements	Likelihood (a)	Consequence (b)	Risk Score (axb)	Risk Status
		Probability of occurrence of an event Almost certain- 5 Likely- 4 Possible- 3 Unlikely- 2 Rare- 1	Impact of an event Catastrophic- 5 Major- 4 Moderate- 3 Minor- 2 Insignificant- 1	Risk= Likelihood * Consequence	Extreme- >15 High- 11-15 Medium- 5-10 Low-<5
Wastewater	Increased urban flooding exacerbates the problems caused by compromised sewage networks, impacting health and ground water and surface water quality. Operation of sewage treatment systems is also impacted.	4	4	16	High
Stormwater	Extreme urban flooding can overburden the stormwater drainage network causing blockage and extended periods of waterlogging and additional manpower and expenditure to pump stormwater. Prolonged waterlogging may lead to public health hazards, including water-borne and vector-borne diseases.	5	3	15	High
Solid Waste	Increased temperature accelerates decomposition rates and also create potentially hazardous conditions in open dumpsites by increasing the probability of landfill fires. Workers are vulnerable to increasing heat stress, which also reduces their productivity.	4	4	16	High
	Drainage network blockages increase during periods of high rainfall. Land, surface water and ground water are contaminated due to increased leachate flows from the open dumpsite.	4	4	16	High

Urban Systems	Climate Fragility Statements	Likelihood (a)	Consequence (b)	Risk Score (axb)	Risk Status
		Probability of occurrence of an event Almost certain- 5 Likely- 4 Possible- 3 Unlikely- 2 Rare- 1	Impact of an event Catastrophic- 5 Major- 4 Moderate- 3 Minor- 2 Insignificant- 1	Risk= Likelihood * Consequence	Extreme- >15 High- 11-15 Medium- 5-10 Low-<5
Transport	Increase in extreme heat conditions will increase the demand for comfortable public transport and will impact pedestrians, cyclists, and commuters using two wheelers, particularly at major traffic junctions: leading to an increased dependence on personal vehicles.	4	4	16	High
	Extreme rainfall events are likely to worsen the road infrastructure, especially the already damaged sections. During periods of intense rainfall, waterlogged roads will further exacerbate road congestion and affect connectivity and mobility.	3	3	9	Medium
Emergency Services	Extreme heat conditions increase the number of heat stroke cases, heat stress, and heart disease related cases. Higher impact on populations with limited accessibility to healthcare and/or emergency services. Increased temperatures may also increase fire breakouts in the open dumpsites.	5	4	20	High
	Increase in extreme rainfall and water logging may lead to disease outbreak, especially in congested slum areas. Limited accessibility to health care facilities increases the vulnerability of urban poor. Accessibility to emergency services is also impacted during periods of heave rain and related flooding/inundation.	4	3	12	Medium

Urban Systems	Climate Fragility Statements	Likelihood (a)	Consequence (b)	Risk Score (axb)	Risk Status
		Probability of occurrence of an event Almost certain- 5 Likely- 4 Possible- 3 Unlikely- 2 Rare- 1	Impact of an event Catastrophic- 5 Major- 4 Moderate- 3 Minor- 2 Insignificant- 1	Risk= Likelihood * Consequence	Extreme- >15 High- 11-15 Medium- 5-10 Low-<5
Public Parks and Gardens	During extreme heat conditions, intensity of urban heat island increases, as a result of expanding built-up areas. Intense rainfall increases urban flooding and inundation, due to an increase in impermeable surfaces.	3	3	9	Medium
Health	Increase in temperature may increase number of heat stroke cases, heat stress, and heart disease related cases. Vulnerable people are at high risk with limited accessibility to healthcare services.	3	4	12	High
	Increase in extreme rainfall and water logging may lead to disease outbreak, especially in congested slum areas. Limited accessibility to health care facilities increases the vulnerability of urban poor. Accessibility to emergency services is also impacted during periods of heave rain and related flooding/inundation.	3	4	12	High
Education	Flooding and extreme rainfall events may damage school infrastructure, leading to closures and interruptions in learning	4	3	12	High
	Heatwaves and poor ventilation in schools may reduce attendance, learning outcomes, and pose health risks to children	3	3	9	Medium

Annexures 9.4 Critical urban systems and climate fragility statements for Surat

Urban Systems	Climate Fragility Statements	Likelihood (a)	Consequence (b)	Risk Score (a*b)	Risk Status
		Probability of the occurrence of an event Almost certain- 5 Likely- 4 Possible- 3 Unlikely- 2 Rare- 1	Impact of an event Catastrophic- 5 Major- 4 Moderate- 3 Minor- 2 Insignificant- 1	Risk= Likelihood * Consequence	Extreme: 17-25 High: 11-16 Medium: 5-10 Low:1-5
Built Environment	Poor quality housing in informal settlements is highly vulnerable to flooding and heatwaves, increasing risks of displacement, loss of assets, and health hazards.	4	5	20	Extreme
Water Supply	Rising temperatures may increase water demand and groundwater use, further depleting the already over-exploited groundwater table. Wards facing extreme heat and water supply issues are especially vulnerable.	4	4	16	High
	An increase in high-intensity rainfall increases urban flooding, may disrupt the compromised water distribution systems and impact public health.	4	4	16	High
Wastewater	Mixed discharge of rainwater and sewerage into sewer lines during high-intensity rainfall may lead to sewage backflow in households, reducing the effectiveness of sewage treatment systems, and in untreated sewage flowing into creeks and other water bodies, posing significant public health risks.	4	4	16	High
Stormwater	Increased waterlogging due to lack of maintenance of the stormwater network during heavy rainfall events may lead to public health hazards, including water-borne and vector-borne diseases.	3	4	12	High

Urban Systems	Climate Fragility Statements	Likelihood (a)	Consequence (b)	Risk Score (a*b)	Risk Status
		Probability of the occurrence of an event Almost certain- 5 Likely- 4 Possible- 3 Unlikely- 2 Rare- 1	Impact of an event Catastrophic- 5 Major- 4 Moderate- 3 Minor- 2 Insignificant- 1	Risk= Likelihood * Consequence	Extreme: 17-25 High: 11-16 Medium: 5-10 Low:1-5
Solid Waste	Increasing temperatures accelerate decomposition rates and create hazardous conditions for workers.	3	3	9	Medium
	Increased rainfall causes uncollected solid waste to block sewerage and drainage networks, leading to waterlogging or urban flooding, posing public health risks.	4	4	16	High
Transport	Increase in heat conditions and rainfall may reduce the use of public transport, leading to greater dependence on personal vehicles and higher emissions. Increased temperatures may adversely impact the health of commuters, two-wheeler riders, pedestrians and cyclists, especially the elderly, and young children.	4	4	16	High
	Extreme rainfall events are likely to worsen road infrastructure, especially the already damaged sections. Waterlogged roads during intense rainfall exacerbate congestion, disrupt connectivity, and contribute to higher air and noise pollution.	4	3	12	High

Urban Systems	Climate Fragility Statements	Likelihood (a)	Consequence (b)	Risk Score (a*b)	Risk Status
		Probability of the occurrence of an event Almost certain- 5 Likely- 4 Possible- 3 Unlikely- 2 Rare- 1	Impact of an event Catastrophic- 5 Major- 4 Moderate- 3 Minor- 2 Insignificant- 1	Risk= Likelihood * Consequence	Extreme: 17-25 High: 11-16 Medium: 5-10 Low:1-5
Emergency Services	Increased temperature and heatwave events may increase heatstroke and heat stress cases, particularly affecting the elderly, children, and those working outdoors. This impact may be further exacerbated by limited access to healthcare and emergency services.	4	4	16	High
	An increase in extreme rainfall events and waterlogging may trigger disease outbreaks, disproportionately affecting slum dwellers with limited access to healthcare and emergency services.	4	4	16	High
Public Parks and Gardens	Urban green spaces lacking soft scaping may increase urban heat islands and reduce the groundwater percolation rate of urban green spaces.	2	3	6	Medium
Health	Increased frequency of heatwaves may lead to heatstroke, dehydration, and cardiovascular strain, disproportionately affecting elderly, outdoor workers, and urban poor without cooling access.	4	4	16	High
	Heavy rainfall and flooding events may cause outbreaks of water-borne diseases (cholera, diarrhea, leptospirosis, dengue), overwhelming local health systems.	4	4	16	High

Urban Systems	Climate Fragility Statements	Likelihood (a)	Consequence (b)	Risk Score (a*b)	Risk Status
		Probability of the occurrence of an event Almost certain- 5 Likely- 4 Possible- 3 Unlikely- 2 Rare- 1	Impact of an event Catastrophic- 5 Major- 4 Moderate- 3 Minor- 2 Insignificant- 1	Risk= Likelihood * Consequence	Extreme: 17-25 High: 11-16 Medium: 5-10 Low:1-5
Education	Flooding and extreme rainfall events may damage school infrastructure, leading to closures and interruptions in learning	4	3	12	High
	Heatwaves and poor ventilation in schools may reduce attendance, learning outcomes, and pose health risks to children.	3	3	9	Medium

Annexures 9.5 Surat municipal institute of medical education & research

Hospital vharges

અનુ નં	કેટેગરી	નવા પ્રસ્તાવીત ચાર્જીસ
1. OPD Registration charges		Rs.
1	OPD CASE REGISTRATION	20
2	EMERGENCY CASE REGISTRATION	10
3	INJECTION FEE	10
4	DISPENSING Per Day	10
5	Tissue Culture Rabies Vaccines Per Dose	80
6	INJ. RABIES IMMUNOGLOBULIN Per Dose	230
7	MINOR DRESSING	10
8	MAJOR DRESSING	40

સ્પષ્ટીકરણઃ– (૧) ઓ.પી.ડી. કેસ પેપર ની વેલીડીટી છ મહીનાની રહેશે ત્યાર બાદ નવો કેસ પેપર લેવાનો રહેશે. લાલકેસના લાભાર્થીને લાલ રંગનો કેસ પેપર ફ્રી
ઓફ કોસ્ટ આપવામાં આવશે. ઈમરજન્સી કિસ્સામાં ચાર્જીસ રૂટીન ઓ.પી.ડી. રજીસ્ટ્રેશન મુજબ રાખેલ છે.
(૨)અપવાદ રૂપ ખાસ કિસ્સામાં અથવા દર્દીની આર્થિક સ્થિતિ ખુબ જ નબળી હોય તેવા સંજોગોમાં માફી આપવાની સત્તા ધરાવનાર અધિકારીઓ
ઉપરોકત ઓ.પી.ડી. ચાર્જમાં ૧૦૦% માફી (અનુક્રમ નં.૫ અને ૬ સિવાય) આપી શકશે. અનુક્રમ નં.૫ અને ૬ માં દર્શાવેલ ચાર્જમાં મહતમ
૫૦% માફી આપી શકાશે.

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