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MSc. Territorial, Urban, Environmental and Landscape Planning
[Planning for the Global Urban Agenda]

Master Thesis

" Strengthening Disaster Risk Reduction and Climate Resilience in Global South Coastal Cities"

'Lessons from Global North Approaches to Climate Change–Induced Urban Flooding, Coastal Erosion, Water Stress, and Heat Risks in Accra, Cape Town, and Chennai'

[Case of Accra, Cape Town and Chennai]

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Abstract

Climate change has aggravated these types of climate-induced hazards, including urban flooding, coastal erosion, water scarcity, and extreme heat — particularly risking rapidly urbanizing coastal cities in the Global South. With poor infrastructure, expansive informal settlements, and institutional capacity gaps, resilience becomes more imperative.

This thesis explores DRR and climate resiliency strategies in three case study cities: Accra (Ghana), Cape Town (South Africa), and Chennai (India), while also gleaning insights from northern star examples in the Global North such as Copenhagen, Amsterdam, Barcelona, and Chicago. Inspired by the Sendai Framework for Disaster Risk Reduction (2015–2030), the Paris Agreement, and international efforts like MCR2030, C40, and the Resilient Cities Network, the study uses a three-tiered approach. First, it makes a synthesis of global systems and resilience approaches. Second, it sets case-specific benchmarks through spatial and socio-economic assessments of climate hazards, vulnerabilities and adaptive capacity. Third, it evaluates project-level interventions, from Accra's GARID project, Cape Town's Green Infrastructure Framework, and the restoration of Chennai's Pallikaranai Marsh to Global North innovations like Copenhagen's Cloudburst Management Plan and Amsterdam's Rainproof Program.

Using an indicator-based approach, the paper combines hazard mapping, spatial overlays and resilience indices with a qualitative policy survey. Together, they underscore the value of ecosystem-based adaptation, community engagement, and blue–green infrastructure as flexible but context-sensitive approaches. Compared to cities in the Global North, where strong governance and financial capital exist, the contexts in the Global South necessitate adaptation that integrates informal settlements, local livelihoods, and inclusive governance systems.

This study argues that anticipatory, climate-informed spatial planning offers a potential path for shifting from reactive disaster response to resilience-minded development. By aligning global frameworks with local realities, the thesis identifies scalable practices and policy recommendations to strengthen DRR and increase climate resilience in vulnerable coastal cities of the Global South.

Keywords: *Climate Resilience; Disaster Risk Reduction (DRR); Climate Change Adaptation; Urban Flooding; Coastal Erosion; Ecosystem-based Adaptation (EbA); Geospatial Analysis; Global South Cities; Socio-economic Vulnerability.*

1. Introduction

Climate change is one of the most important current global challenges, which has increased the frequency and intensity of natural disasters worldwide. These environmental, economic, and social losses are enormous, with cities and urban areas particularly vulnerable to these impacts. In recent decades, the rising frequency of climate-related hazards has put increasing pressure on urban regions, complicating their efforts toward climate change mitigation and adaptation goals. Spatial planning thus must be developed in a resilient way to answer the challenge of climate change and prevent major losses. While both developed and developing countries are increasingly vulnerable to climate-induced hazards, their capacity to manage and recover from such events differs substantially. Developed nations generally possess more robust infrastructure, comprehensive institutional frameworks, and access to financial and technological resources that support disaster risk reduction (DRR) and climate adaptation (Hallegatte et al., 2016; IPCC, 2022). In contrast, developing countries often face a dual burden: they must expand and maintain basic infrastructure and services, while simultaneously responding to escalating climate-related risks. These recurring disruptions can divert limited resources away from long-term development priorities, including progress toward the Sustainable Development Goals (SDGs), thereby compounding existing socio-economic vulnerabilities (World Bank, 2021). Therefore, examining strategic spatial planning approaches from developed contexts can provide valuable insights for enhancing resilience in urban areas of the Global South, particularly when adapted to local governance, capacity, and socio-economic conditions.

Between 1970 and 2021, the world saw more than 11,700 climate-related disasters, claiming over 2 million lives and $4.3 trillion in economic losses (Economic Costs of Weather-related Disasters Soars but Early Warnings Save Lives, 2023). According to the World Bank in 2024, more than half of the population live in urban areas responsible for over 80 percent of the global GDP. Therefore, these are not only centers of economic growth but also hotspots of vulnerability in respect of climate-related risks. This again suggests that investment in spatial planning and mitigation and adaptation strategies targeting such urban areas is key for securing the future of such a metropolitan region.

Disaster risk reduction (DRR) is a core policy objective of disaster risk management, focused on preventing the creation of new risks, reducing existing risks, and managing residual risks. Through comprehensive strategies and plans, DRR aims to strengthen resilience, which is essential for achieving sustainable development (UNDRR, 2017). On the other hand, the IPCC (2012) provides clear definitions of key terms essential to understanding disaster risk management and climate adaptation. Exposure refers to the presence of people, infrastructure, and assets in areas vulnerable to adverse effects, while vulnerability highlights the propensity or predisposition of systems or communities to be harmed by such hazards.

A *disaster* occurs when a hazard, such as an extreme weather event or geophysical disturbance, interacts with exposed and vulnerable human systems, leading to significant disruptions that exceed local coping capacities and require immediate emergency response and recovery efforts (UNDRR, 2020). It is essential to distinguish between a *natural hazard* and a *disaster*—while the hazard itself (e.g., flood, drought, storm) may be a naturally occurring event, it only becomes a disaster when it impacts societies that are unable to adequately anticipate, mitigate, or respond to its effects (Wisner et al., 2012).

In the context of climate-induced disasters, risk is shaped by the combination of hazard intensity, exposure of assets and populations, and their socio-economic vulnerability (IPCC, 2022). These disasters can result in diverse and compounding losses—including physical damage to infrastructure, economic setbacks, displacement, loss of livelihoods, degradation of ecosystems, and increased public health risks. Understanding this interconnected risk framework is crucial for implementing effective disaster risk reduction (DRR) strategies and climate adaptation measures, particularly in vulnerable regions.

A clear relationship between the impacts of climate change, developments, vulnerabilities, and exposure of the human population can be understood in Figure. 1.1. Disaster risk management and climate change adaptation measures induce major policies in the development projects and initiatives and further reduce the impact of climate change thus creating a whole loop.

As stated by IPCC (2012), disaster risk management encompasses processes for designing, implementing, and evaluating strategies and policies aimed at enhancing disaster preparedness, response, and recovery. It focuses on improving the understanding of disaster risk, reducing and transferring it, and promoting resilience to protect human security and well-being. Adaptation, especially in human systems, refers to adjustments made to mitigate harm from actual or expected climate impacts, while in natural systems, it involves adjustments facilitated by human intervention. Resilience reflects a system's capacity to absorb, adapt to, and recover from hazardous events efficiently, preserving or improving essential structures and functions for sustainable development.

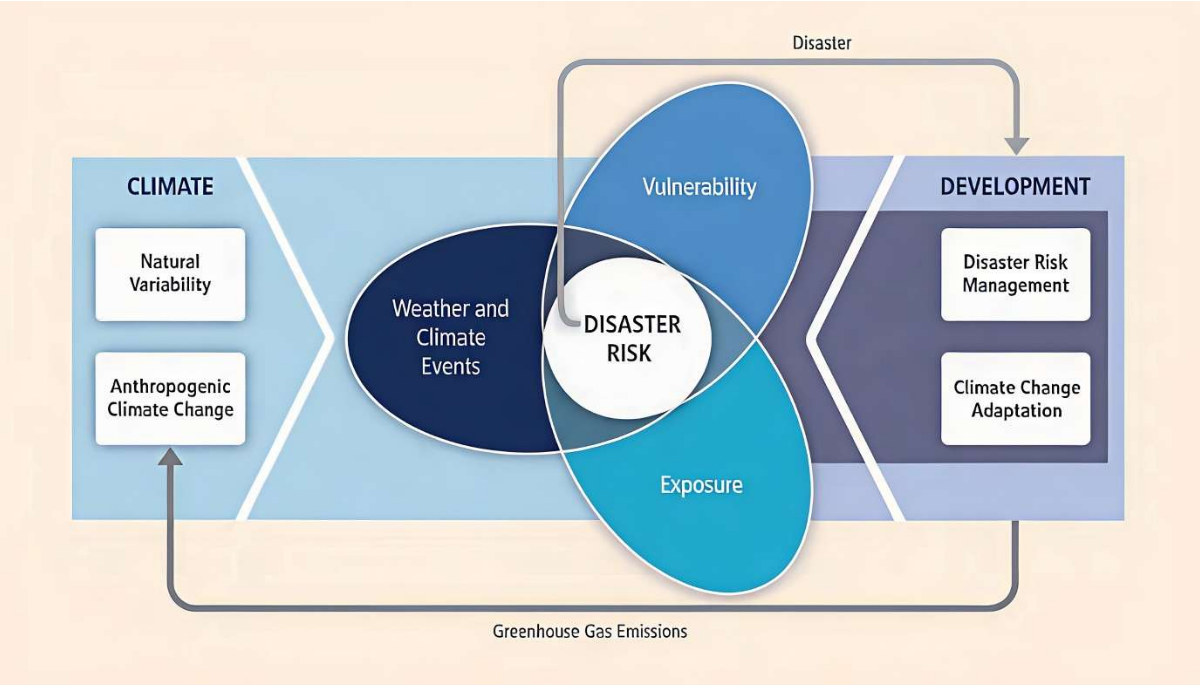


Figure 1.1: Relationship of core concepts on impacts of extreme climate events (source: IPCC 2012)

The thesis will elaborate mostly on the climate related factors and assessments on DRR, however the sub-factors responsible for increased risks and vulnerabilities will also be considered. The effective integration of DRR into national development programs and spatial planning would require a broad-based effort by all relevant government agencies to develop an overarching framework that links risk reduction for broader, long-term socio-economic goals and objectives. The Department for International Development by the UK federal government known as DFID (2006) states that DRR (disaster risk reduction) is a systematic process that aims at reducing the impact of disasters, comprising three core components: hazards, vulnerability, and exposure. According to Cash et al. (2003) and UNISDR (*Department of Economic and Social Affairs, 2009*), this approach thus helps governments to protect their goals on sustainable development from potential large-scale impacts of disasters. These are institutional development, financial planning, multi-hazard risk assessment, risk-informed urban planning, resilient infrastructure, enhanced ecosystem services, and improved emergency management systems, according to the World Bank (2024).

The Sendai Framework is a globally agreed policy framework that aims to achieve substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries within 15 years, since its adoption in 2015 (UNDRR, 2017).

Figure 1.2: Goals of DRR (source: UNDRR)

The Sendai framework outlines four priority areas: the first and initial process to understand the disaster risks involved or to be taken in account; secondly, strengthening the governance with specificity to estimated disaster risk; thirdly, a focus on investing in disaster risk reduction for resilience; and lastly, enhancing disaster preparedness for effective response and recovery. The discussion is based on the ongoing progress and developments realized so far based on the specific objectives, targets, in alignment with the Sendai Framework. The framework itself identifies a set of 4 priorities, 7 targets (indicated in the *figure 1.2*) and 38 indicators within a monitoring scope that helps in pre-defining an outline for this thesis.

Focusing specifically on the climate change induced hazards, risks and vulnerabilities the thesis will develop its key parameters to assess sustainable development programs and initiatives that fulfil DRR strategies identified under the framework.

The paper will also examine initiatives such as Making Cities Resilient 2030 launched by the UNDRR in 2020, a global effort to help cities become more resilient toward disasters and climate-related risks by 2030-develop specific cases and challenges across the globe, basically in the Global North. Building on the former Making Cities Resilient Campaign (2010-2020), it extends from an advocacy agenda into implementation, action, and monitoring, providing a structured road that cities can take, helping them progress from building awareness to implementing policies and strategies that foster resilience.

In 2013 Rockefeller Foundation brought up the 100 Resilient Cities Network initiative as a platform to share knowledge through a common platform with tools for implementing strategies, financial support, multi-stakeholder engagement on building urban resilience. The 100 Resilient Cities Network, in its document discusses that urban resilience extends beyond traditional risk management but rather focusing on sustaining and enhancing adaptive capacities in the uncertainty. It also sheds lights on the vitality of managing resilience as a measure for supporting sustainable development by adopting complex systems perspective. It describes that the urban resilience not only protects vulnerable populations but also integrates strategies to recover and thrive with features like smart grids and strong social networks.

The 100 RC network concluded its operations as a centralized platform in 2019 that allowed the ongoing Resilient Cities Network to emerge as slightly decentralized approach for cities with more autonomous roles and partnerships with government bodies, NGOs, businesses, and international agencies. The Resilient Cities Network adopted a more regional approach allowing tailored solutions based on locally identified regional risks and conditions while facilitating the global exchange of ideas and practices. In another terms it is seen as more bottom-up approach that advocates for resilience by expanded its efforts to influence global policy and inclusive participation in international forums for global development agendas. This in line with the Sendai Framework for Disaster Risk Reduction and SDGs, particularly Goal 11, which intends to make cities and human settlements inclusive, safe, resilient, and sustainable. UNDRR (2020). The thesis will gather necessary insights from these campaigns, initiatives and programs as they directly form a baseline standard for the goals that identifies the city resiliency measures specifically on the grounds of urban landscape developments and transformations, stakeholder management, and social inclusivity.

The thesis will also draw learnings from the C40 initiative (founded in 2005) with an initial focus was on climate leadership from large cities in developed countries from metropolitan areas in North America, Europe, and Australia. As per the joint report with ARUP (2011), the C40 climate leadership represented a total of 58 cities 8 percent of the global population, 12 percent of global greenhouse gas emissions and 21 percent of global GDP. Today, the C40 climate leadership is a network of 98 cities with cities from both Global North and Global South, representing over 582 million people and accounting for one-fifth of global economy. Some of the megacities listed were Accra, Addis Ababa, Barcelona, Cape Town, Chennai, Chicago, Guadalajara, Milan, Mumbai, Jakarta, Lagos, Hanoi, Paris, Madrid, Sao Paulo, Rome, Seoul, Rio de Janeiro, etc. while cities like Copenhagen, Amsterdam, Portland, Stockholm, Heidelberg, Vancouver, etc. were seen as the Innovators in the C40 cities memberships.

Furthermore, this study will also discuss a few discourses concerning disaster risk reduction and climate resilience by examining a few critical reviews of these programs and initiatives across the global south cities that seek more discussion and actions through some research articles. These journals and articles can also serve as valuable inputs in terms of data integration for analysis. Upon initial review the research found that IPCC Report 2021 stated, "Our urban areas are hotspots of risks but also key sources of solutions to mitigate climate change and foster adaptation resilience." The World Bank's Global Assessment Report 2021 resilient urban development must become the cornerstone of future climate action, with cities playing a dual role of risk absorbers and catalysts for sustainable transformation.

The Guidance Note on Using Climate and Disaster Risk Management to Help Build Resilient Societies titled "Integrating Disaster Risk Reduction and Climate Change Adaptation in the UN Sustainable Development Cooperation Framework" by UNDRR (2020) provides a set of prevention agenda, roadmaps for cooperation framework while defining major impacts of the four set of hazards on each of our sustainable development goals. The document cites the UNDRR 2019 Global Assessment Report on Disaster Risk Reduction to mention the non-existence of natural disasters but only natural hazards, while defining risk, vulnerability and exposure.

Figure 1.3 is an illustration from the UNDRR 2020 document discussed above provides the categorized set of hazards that are directly or indirectly related to our SDGs and their relevant targets, and this research will only explore a select set of hazards that are under the natural and the slow-onset climate-related hazards. Specifically, the primary hazards that will be considered such as coastal floodings, drought, floods, sea level rise and rising temperature or urban heat island effects so that we can address or justify a larger share and role of strategic spatial planning while developing close relationship & integration between climate change adaptation and disaster risk reduction.

IPCC (2012) simply quotes that Disaster Risks are associated with differing levels and types of adverse effects that can either be limited to financial costs or large-scale human lives, or biodiversity and natural resources, or all. And these effects can correspond to catastrophic levels or levels commensurate with small disasters over time. The research will develop an understanding of different factors and dimensions of disaster risks and vulnerability, and breakdown simple associative definitions in the context of different cities and hazard typologies.

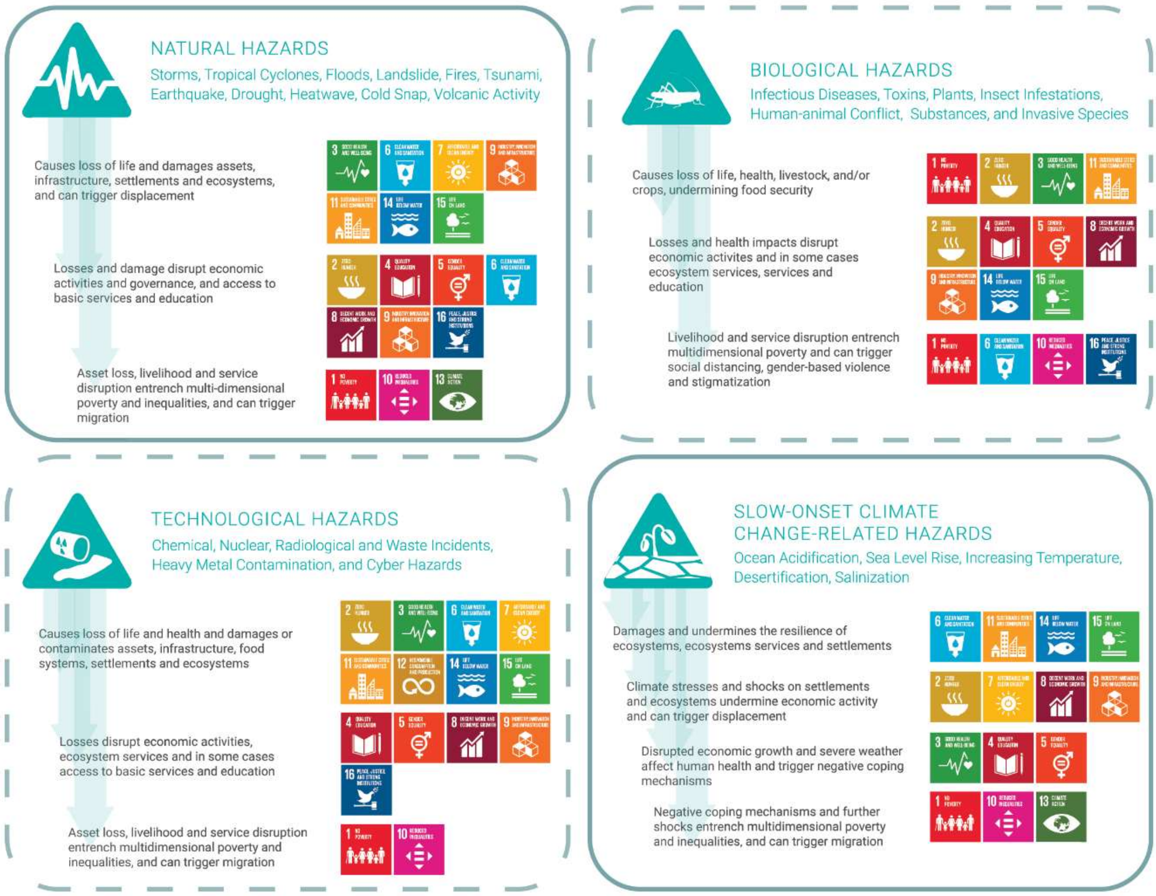


Figure 1.3: Hazard Typologies (source: UNDRR, 2020)

DRR is indeed a large scope of research field, stretched across almost all quarters of our discussions and arguments with Sustainable development and resiliency. However, in this thesis the focus is on identifying the set of risks and vulnerabilities, its factors and drivers, the major key issues when it comes to the set of frequently occurring climate-induced hazard events in the select cities from global south.

Urban areas in the Global South, especially coastal metropolises, face mounting climate-related risks driven by sea-level rise, coastal storms, and urban sprawl into low-lying zones. These cities frequently experience high-impact monsoon rainfall, storm surges, and flooding, all compounded by weak infrastructure, informal settlements, and governance deficits (Hallegatte et al., 2016; IPCC, 2022). Such conditions create compound and cascading risks, where one extreme event triggers socioeconomic disruption, displacement, ecological degradation and entrenched inequality. Rapid urban growth in Africa and Asia is expected to account for over 90% of global urban expansion by 2050, adding to the existing pressure on city populations, especially those in flood-prone or coastal zones (UN-Habitat, 2020).

Coastal cities such as Cape Town, Accra, and Chennai are hereby considered as case cities in this thesis, that exemplify rapidly urbanizing centers among the Global South facing a growing convergence of climate-induced hazards, including droughts, urban heatwaves, floods, and coastal storms. These risks are exacerbated by high population densities, the presence of extensive informal settlements, and aging or inadequate infrastructure, all of which hinder effective adaptation and intensify social and economic vulnerabilities. Notable events, such as Cape Town's "Day Zero" drought crisis between 2015 – 2018, Accra's frequent annual urban flooding, and Chennai's recurrent floods and extreme heat events—demonstrate the severity and complexity of climate risks increasingly confronting these cities.

In response to these mounting challenges, these cities are actively engaged with international urban resilience frameworks such as the C40 Cities Climate Leadership Group, the Resilient Cities Network, and the Making Cities Resilient 2030 (MCR2030) initiative. These platforms provide critical tools, technical support, and opportunities for knowledge-sharing aimed at promoting inclusive, proactive, and integrated disaster risk reduction (DRR) and climate change adaptation (CCA).

For Global South cities—where poverty, spatial inequality, and environmental risks converge—the insights and strategies offered through such initiatives are particularly valuable. As urban centers increasingly shape regional and global resilience outcomes, Accra, Cape Town, and Chennai offer strong prospects for analyzing development pathways that bridge local action with international goals. Enhancing resilience in these contexts is not only essential for reducing disaster-related losses but also for achieving sustainable development objectives and protecting the future of vulnerable coastal populations. Accra, Cape Town, and Chennai exemplify fast-growing coastal cities in the Global South facing shared climate risks—like flooding, sea-level rise, and socio-economic vulnerability. This study emphasizes the need for proactive climate-informed urban planning over reactive disaster responses. By learning from advanced resilience strategies in cities such as Amsterdam, Copenhagen, and Chicago, this study aims to identify adaptable approaches for building inclusive, climate-resilient futures in vulnerable urban regions.

Ultimately, studying Accra, Cape Town, and Chennai enables a deeper understanding of how urban resilience can be operationalized in high-risk, low-capacity environments. It also allows for the identification of scalable tools and frameworks that respond to the compound and systemic nature of climate risks faced by some of the world's most vulnerable urban populations.

1.1 Research Areas, Aims and Objectives

1.1.a Climate Change-Induced Hazards and anthropogenic conditions

Human activities significantly contribute to the worsening of climate change induced hazards in cities. Rapid urban expansion often leads to the loss of natural landscapes such as wetlands and green spaces. This increases surface runoff during heavy rainfall and weakens natural defenses against flooding, making such events more frequent and damaging (UN-Habitat, 2020). The concentration of concrete and other heat absorbing materials in dense urban areas raises local temperatures, intensifying the urban heat island effect and increasing the likelihood of extreme weather events (IPCC, 2022). Along coastlines, infrastructure development and land reclamation disrupt natural sediment flows, which accelerates coastal erosion and increases flood risks for low lying areas (United Nations Environment Programme [UNEP], 2019). These human driven changes to natural systems often magnify the impacts of storms, floods, heatwaves and shoreline retreat, placing vulnerable communities at even greater risk.

Cases of climate change impacts and their associated hazards are evident in cities worldwide. In Chicago, the combination of intense rainfall and an outdated combined sewer system led to significant urban flooding in 2021. The city's infrastructure struggled to manage the increased water volume, resulting in widespread basement backups and street flooding. Similarly, Amsterdam faced urban flooding challenges in 2020 due to heavy rainfall overwhelming its drainage systems. The city's low-lying geography and dense urban development make it particularly susceptible to such events. Coastal cities like Copenhagen and Rotterdam are also experiencing the effects of climate change. In 2017, Copenhagen experienced significant coastal flooding due to a combination of high tides and strong winds, leading to property damage and disruptions. This event underscored the need for robust coastal protection measures in urban planning. Rotterdam, with its extensive port infrastructure, faces similar risks. The urban heat island effect is another pressing issue. In Chicago, the dense concentration of buildings and limited green spaces exacerbate the urban heat island effect, leading to higher temperatures in the city compared to surrounding areas. This intensifies the likelihood of extreme weather events and increases energy consumption. Amsterdam has also observed the urban heat island effect, particularly in areas with limited vegetation [The Copenhagen Post, (2017, 2024); Climate Central, (2023); Euronews, (2024); Inside Climate News, (2023)].

Urban flooding occurs when excessive rainfall or poor drainage systems overwhelm urban infrastructure, leading to water accumulation in streets and basements, causing property damage and health risks due to waterborne diseases (UN-Habitat, 2020).

Storm Surge: A rise in seawater levels caused by strong winds during storms, leading to coastal flooding and damage. The loss of land and infrastructure caused by waves, currents, or human activities, worsened by rising sea levels and storm surges, is further understood as Coastal Erosion (UNEP, 2019).

Water Stress & Drought: Water Stress occurs when water demand exceeds supply, leading to shortages affecting drinking water, agriculture, and sanitation. A prolonged period of low rainfall causing water shortages that impact agriculture and water supplies defined as Drought (WHO, 2017), is a major concern in the urban conditions that enhances the probabilities of Water Stress.

On the other hand, Urban heat risks arise from higher temperatures in cities compared to rural areas, are caused by heat-absorbing buildings and roads, leading higher energy use, pollution, and health risks (Li et al., 2023) particularly for old age, kids and women, among urban population with limited green spaces.

Coastal cities in the Global South are increasingly vulnerable to climate change, facing compounded risks due to rapid urbanization, inadequate infrastructure, and limited financial resources. By 2050, over 800 million urban residents are projected to be at risk of coastal flooding and storm surges, with many cities lacking necessary resilience measures. Population growth, rising sea levels, and the intensified urban heat island effect due to limited green spaces make these cities highly vulnerable to flooding, erosion, and extreme heat, leading to increased energy consumption and health risks. Addressing these challenges requires comprehensive urban planning, resilient infrastructure, and international cooperation to enhance adaptive capacity.

Taking references from Water-Sensitive Urban Design (WSUD) and Nature-Based Solutions (NBS) projects in Copenhagen, Denmark, such as the Enghaveparken Climate Park and Cloudburst Management Plan, this thesis will address key issues like flood risk, soil permeability, and wastewater management. Similarly, Chicago's Climate Action Plan, including initiatives like the Green Alley Program and Green Stormwater Infrastructure Strategy, will provide insights into managing risks and vulnerabilities in Global North cities. Amsterdam's Rainproof Program, Circular Economy Strategy, and Room for the River Program will also be analyzed to draw insights into smart urban planning and climate resilience.

1.1.b Research Aim

The thesis aims to identify, examine, and evaluate the effectiveness of urban climate mitigation and adaptation practices in addressing climate change induced hazards such as urban flooding, water stress from drought, urban heat, coastal erosion, and storm surge as part of Disaster Risk Reduction (DRR) strategies in Global South coastal cities. Lessons will be drawn from climate resilient initiatives in the Global North to inform the analysis. This includes examining practices such as green infrastructure, water sensitive design, nature-based solutions, and sustainable urban agriculture. The study will identify innovative urban design and planning approaches that enhance climate resilience through DRR strategies. It will also assess the role of community engagement and policy frameworks in implementing these approaches, providing a critical review of existing practices and exploring refinements that can strengthen DRR measures, with particular emphasis on Global South coastal contexts such as Accra, Cape Town, and Chennai.

The thesis identifies key objectives aimed at fulfilling its purpose of critically examining the challenges faced by Global South coastal cities and the pressing issues of growing concern. These objectives are structured to develop a comprehensive understanding of how cities respond to climate change–induced hazards, while also pinpointing strategies that can be tailored and adapted to different urban contexts.

Research Objectives:

- Assess climate change mitigation and adaptation measures in Global South coastal cities in relation to corresponding climate change–induced hazards, identifying key vulnerabilities and risks.
- Highlight context-specific lessons from Global North coastal cities that can be adapted to Global South contexts for effectively addressing climate change–induced hazards.
- Determine the extent of DRR integration in developing climate resilience and explore the potential application of spatial planning tools such as the ecosystem-based approach, community-based approach, low-impact development, sustainable construction practices, and blue–green infrastructure.
- Evaluate the inclusivity and effectiveness of policy frameworks and action plans in supporting DRR-focused adaptation and mitigation measures, with particular attention to priority areas for improvement and the use of AI-based tools for advancing climate resilience

Research Questions

With the above determined set of objectives, the research intends to respond to a set of questions key to addressing how cities can strengthen their resilience to climate change–induced hazards through Disaster Risk Reduction (DRR) measures.

- How effective are current urban climate mitigation and adaptation practices in addressing climate change–induced hazards and contributing to DRR in selected Global North and Global South coastal cities?
- What innovative practices, such as Blue-Green Infrastructure, Nature-Based Solutions, Urban Farming, and water-sensitive design, that have proven successful, and what factors determine their effectiveness?
- What is the scope of effective policy frameworks, governance structures, projects and initiatives to strengthen DRR strategies, particularly in data-scarce regions?
- The geospatial analytics can be used for determining sustainable cost-effective practices or areas of focus, so in what state the mitigating risk impacts were discovered and what are the hurdles towards adaptation among these regions?

These questions are grounded in the need to evaluate the performance of existing measures, identify enabling conditions for their success, and explore pathways for transferring lessons across contexts. Community engagement emerges as a crucial factor in sustaining and scaling DRR efforts. By comparing the experiences of Global North and Global South coastal cities, the study will highlight both transferable strategies and the context-specific adaptations needed to address hazards such as flooding, erosion, water stress, and urban heat.

The study will employ spatial and geospatial analysis to map climate change–induced hazards, assess vulnerability patterns, and simulate resilience scenarios for urban flooding, coastal erosion, water stress, and heat risks. GIS-based hazard mapping and remote sensing will evaluate the floodwater retention and multifunctional role of Copenhagen's Enghaveparken, the stormwater capture efficiency of Amsterdam's Rainproof Program, and the heat and flood mitigation capacity of Rotterdam's water plazas. In the Global South, these techniques will measure drainage improvements from Accra's Greater Accra Resilient and Integrated Development (GARID) Project, track green cover changes in Cape Town's Philippi Horticultural Area, and monitor ecological restoration progress in Chennai's Pallikaranai Marsh. AI-driven spatial modelling will enhance these assessments, enabling scenario-based analysis of hazard exposure and resilience potential.

A comparative policy and planning review will evaluate the extent to which climate action plans, DRR frameworks, and spatial planning instruments in the case study cities integrate adaptation and mitigation measures. This will examine Copenhagen's policy support for multifunctional parks and urban agriculture, Amsterdam's decentralized stormwater governance under the Rainproof Program, and Rotterdam's climate-adaptive infrastructure strategies. In parallel, it will assess Accra's GARID urban development strategy, Cape Town's Green Infrastructure Framework and protections for the Philippi Horticultural Area, and Chennai's policies for wetland restoration and urban agriculture. The analysis will identify strengths, gaps, and opportunities for enhancing resilience through improved policy alignment and integration.

Impact evaluation will measure the environmental and socio-economic outcomes of the selected resilience projects. Quantitative assessments will include before-and-after comparisons of flood incidence, stormwater retention capacity, green cover area, temperature regulation, and water quality. For example, it will assess urban heat island changes near Enghaveparken, flooding reductions in Amsterdam under the Rainproof Program, and water storage gains from Rotterdam's water plazas. In the Global South, similar metrics will evaluate the GARID Project's flood mitigation in Accra, ecosystem services in Cape Town's Philippi Horticultural Area, and hydrological restoration in Chennai's Pallikaranai Marsh. Qualitative indicators, such as community satisfaction and governance efficiency, will complement the quantitative data.

The research will be supported by a synthesis of peer-reviewed literature, technical reports, and case evaluations from credible international bodies and multi-governmental organizations. Sources will include scientific assessments from the Intergovernmental Panel on Climate Change (IPCC), adaptation guidance from UN-Habitat, environmental policy insights from UNEP, and implementation reports from the World Bank. Additional evidence will come from municipal documentation, academic research, and evaluations for Enghaveparken, the Rainproof Program, water plazas, the GARID Project, Cape Town's Green Infrastructure Framework, and Chennai's Pallikaranai Marsh Restoration. This evidence base will ground the comparative analysis in both global best practices and localized experiences.

The thesis follows the methodology that is briefly explained in the Figure 1.4 below and further detailed methodology adopted has been discussed in the Chapter 3.

Methodological Framework Diagram

Preliminary Studies and Research

Theoretical and Conceptual Frameworks
DRR and Climate change adaptation - Concepts, Global and Regional Frameworks

Global South statistics, Challenges

Answers sought

- Explore global frameworks like the Sendai Framework, Paris Agreement, and Sustainable Development Goals (SDGs).
- International Cooperations and Partnerships - Making Cities Resilient 2030, C40, 100 Resilient cities Network, Making Cities Resilient
  UNFCCC; UNDRR or UNISDR; IPCC; OECD; GFDRR; UNEP; World Econonomic Forum,etc.
- Conduct a comprehensive review of existing literature on DRR measures, BGI, NBS, and Urban Farming, focusing on their role in mitigation and adaptation strategies, further establish their relevance to urban climate resilience.
- Spatial planning policies and governances in integrating these strategies into DRR measures.
- Highlight the unique challenges faced by Global South cities, such as rapid urbanization, informal settlements, and economic constraints.
- Case Study Selection: Defining case cities and projects based on their relevance to DRR, BGI, NBS, and Urban Farming.

Data Collection, Interpretation and Analysis

Data accumulation and review
Use qualitative and quantitative data from government reports, academic publications, and international organizations (e.g., UNFCCC, UNDRR, IPCC, World Bank).
Collect data on frequent climate hazards (e.g., floods, heatwaves), urban vulnerabilities, and resilience metrics.

Case Projects from Global south cities
GARID (Accra, Ghana); Green Infrastructure Framework (Cape Town) ; Pallikaranai Marsh Restoration (Chennai).

Geospatial data on land-use changes, urban heat islands, and flood risk maps.

Analytical Framework
Developing criterias for assessing the urban resiliency and DRR measures. Adding weights to each aspect and conversion of qualitative to quantitative data.

Vulnerability Assessment and Analysis
Assess vulnerabilities specific to Global South cities, considering factors like rapid urbanization and economic constraints.

Data sought and Analyzed

- Overview of geographic, meteorological and climatic disaster events - floods, urban heat, drought, sea-level: frequency over the years and impacts on the population.
- Qualitative data, publishings and reports and reviews of major policies, action plans, redevelopment revitalization programs and strategies for climate change. (Examples of circular economy, SUDS, NBS, Water Sensitive Urban Designs, public private participation development models in urban initiatives, etc.)
- Reports and articles on prevailing risks - water scarcity, soil erosions, energy demands and cuts, loss in agriculture yields, health and sanitations risks (recorded history of diseases), excessive infrastructure & economic losses, food security and inflated rate of commodities and services, loss of natural streams.
- Statistics and reports on current urban challenges: Waste disposal and management, pollutions and contaminations, low ground water, soil sealing Urban Population, urbanisation rate, %loss in agriculture lands (extension of city boundaries), poor infrastructure in the disaster affected regions, etc.
- References of community engagement and participation, local voluntary organizations on notable development projects of mitigations and adaptations.

Breaking down Case Projects of Accra, Capetown, and Chennai.

Urban landscape mapping - % change of soil sealing and land taking phenomenons., % change or encroachment of river basins, natural catchment areas, % green building initiatives, % solar panel roofing, % change of soil sealing and land taking phenomenons.
Land-use planning study, buffer and proximity to critical services and disaster prone areas, green infrastructure areas.

Setting up major evaluation criteria

References from Global North, Findings and Outcomes, Opportunities.

Discussing and analyze major/ notable projects from Global North cities - **Copenhagen, Portland, Chicago, Amsterdam**

Comparative Insights
Innovations, challenges, limitations, etc. with respect to DRR measures in case cities.
Identify gaps in the implementation of BGI, NBS, and Urban Farming in Global South cities.

Opportunities for Global South for adopting and adapting successful strategies from the Global North.

Address potential barriers and areas of interventions
Funding, governance, technical capacity, possible solutions

Conclusions

Summary of Findings
Summarize key findings from the comparative analysis, highlighting significant differences and similarities in BGI, NBS, and Urban Farming strategies. The areas of key

Implications for Policy and Practice
Discuss the implications of your findings for urban planning and policy-making in Global South cities.

Future Research Directions
Suggest areas for future research, particularly in understanding the long-term impacts of BGI, NBS, and Urban Farming on DRR measures.

Enhancing urban climate resilience through key effective DRR measures what major considerations for cities in Global South would require?`

Figure 1.4: Methodological framework

2 Background and Theoretical Framework

Over the past three to four decades, urban regions have undergone rapid and complex transformations. Cities have expanded spatially and socially, with shifting demographic structures, intensified migration, growing cultural diversity, deeper economic interdependence, and rising resource consumption. These dynamics, together with changing built–unbuilt land ratios, make it increasingly difficult to grasp the full scale of contemporary urban risks, damages, and vulnerabilities. Planners and decision-makers are repeatedly challenged by three intertwined pressures: growing populations, limited land suitable for safe development, and the rising frequency and intensity of natural disasters (Sutanta et al., 2010).

Disasters unfold both in time and space. Twigg (2015) distinguishes sudden-onset events such as storms, earthquakes, conflicts, and disease outbreaks from slow-onset stresses, including prolonged droughts, environmental degradation, unregulated urbanization, climate change, political instability, and economic decline. Disasters can be interpreted through the interaction of three core dimensions: the type and magnitude of the hazard, the vulnerability of exposed populations, and their degree of exposure. While hazards are often physical in origin, vulnerability is fundamentally a human construct, rooted in social, economic, and political conditions that shape the capacity or incapacity of communities to anticipate, cope with, and recover from impacts (Twigg, 2015).

Urban vulnerability may be physically linked to settlement form, location, and infrastructure performance or socio-economic, shaped by demographic profiles, income, education, and social cohesion. Living in compact, hazard-prone environments, such as along unstable slopes, floodplains, or coastal fringes, tends to heighten exposure. Vulnerability can also be subjective, influenced by economic status, social hierarchies, health conditions, or gender. Poorly conceived development interventions may even generate new risks, for example, irrigation schemes that exacerbate waterborne diseases, or transport and housing projects that obstruct natural drainage and intensify flooding (Twigg, 2015). In this thesis, the primary concern is with natural hazards, including flooding, heatwaves, drought, storms, and coastal hazards, rather than with technological or industrial risks, such as accidents in power plants or major industrial facilities.

Given these complexities, understanding the interconnected nature of hazards, vulnerabilities, and exposure is essential for effective disaster risk reduction (DRR) and climate adaptation. Strategies must address not only physical risks but also the structural inequalities and governance shortcomings that amplify them. Building on this discussion, the next section examines the global policy frameworks and resilience approaches that guide how cities prepare for, respond to, and adapt to the escalating risks associated with climate change.

2.1 Disaster Risk Reduction, Resilience Frameworks and Climate Change

As per the UNISDR (2009), disaster risk reduction can be termed or understood as a systematic effort to reduce risks of disaster by reducing the exposure of elements at risk to hazards, vulnerability of people and property, efficient land management practices and improved preparedness. It is necessary to understand that the impact of disasters is directly proportional to the exposure of population, infrastructure facilities and biodiversity.

DCAF (2020) defined DRR as a concept and practice of reducing disaster risk through systematic efforts to analyze and manage the causes of disasters and referred it as the anticipation, reduction and implementation of necessary resilience arrangements. DRR and Disaster risks management (DRM), the two terms are often used in similar contexts, however, DRM is conceptually more narrow, narrower than

DRR; it specifically targets the operational and practical aspects and practices employed to meet the targets and goals set out during DRR initiatives- which could include reducing exposure to hazards, reducing vulnerability of people and property, sustainable management of land and the environment (ecosystems), and improving preparedness for adverse events. The UNDRR lists down four actions under disaster risk management: prevention, mitigation, transfer and preparedness but has emphasized heavily in the risk assessment starting with risk identification and simulation exercises. UNDRR (2024) highlighted the fact that generation of risks is getting much more into act than to see the reduction of risks, although much success has been seen in managing the disaster rather making crucial changes to reduce the risks. And in addition to that UNDRR specifically pushes for more inclusive practices with DRM encoded at different levels of public private investments, risk sharing, financial systems and social protection mechanisms.

Seven years prior to Sendai Framework for Disaster Risk Reduction and the Paris Agreement, and eight years post the Hyogo Framework, important insights into the relationship between climate change and disaster risk reduction (DRR) were emphasized. Urgent action was identified as crucial in preparing for and adapting to climate change to minimize global vulnerabilities and risks. Clear definitions provided by the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC) highlighted how, while natural climate fluctuations have occurred throughout history, recent changes, such as the rise in global temperatures, are largely human induced. Extensive urbanization, industrialization, deforestation, and greenhouse gas emissions have exacerbated these shifts, contributing directly or indirectly to changes in the Earth's atmospheric composition.

Climate change, in this understanding, is not merely a natural phenomenon but also the result of long-term shifts caused by human activity. Based on the evidence gathered by the IPCC up to 2007, it became clear that by the end of the 21st century, an increase in the frequency and intensity of extreme weather events – such as cyclones, typhoons, and rising sea levels, would be inevitable. UNDRR (2008) This would bring severe socio-economic consequences, especially for those residing in highly populated or industrialized areas, where vulnerabilities would multiply, and access to resources like water and food would become increasingly scarce. Health services, too, would face tremendous pressure, especially in the face of growing urbanization and increased demand for care during extreme weather events.

The following key scenarios were projected for 2050 based on these trends:

Table 2.1: Projected scenarios for 2050 (source: UNDRR)

Issues	Regions Affected	Description
Water scarcity and flood risks	Mid-latitude regions, dry tropics, mountainous areas	Reduced water availability, leading to greater water stress in some areas, while other areas experience severe flooding due to heavy rainfall, creating imbalances in water resources.
Disruptions in agriculture	Lower latitudes	Erratic precipitation destabilizes crop yields, complicating food security.
Urban health impacts	Urban centers	Increased heatwaves, floods, droughts, and storms, overburdening fragile health systems, rising waterborne diseases like malaria, and widespread malnutrition, especially in vulnerable populations.
Coastal and floodplain vulnerabilities	Coastal and river floodplain areas	Rising sea levels and frequent flooding threaten industries, settlements, and communities, leading to unsustainable socio-economic costs.

2.1.a Climate Change

According to **UNDRR, 2008**, climate change is expected to exacerbate disaster risks by increasing the frequency of extreme weather events and amplifying the vulnerabilities of communities exposed to these hazards. Disasters arise when natural hazards intersect with human vulnerabilities and poor preparedness. Between 1989 and 2007, 45% of fatalities and 79% of economic losses from natural hazards were caused by hydrological and meteorological events, highlighting the disproportionate impact on poorer countries with limited capacities for risk reduction.

A significant realization is that developing nations will bear the brunt of climate change impacts, intensifying existing inequalities. Limited resources, weak institutional capacity, and high exposure place these nations at a disproportionate disadvantage. The projected regional effects include:

- Africa: Agricultural productivity could decline by up to 50% by 2080, with expanding arid regions exacerbating food insecurity and water scarcity.
- Asia: Rapid coastal urbanization heightens flood risk and water shortages, while melting Himalayan glaciers cause irregular flooding and crop losses.
- Australia & New Zealand: More frequent droughts, wildfires, and storms, alongside shrinking glaciers, strain agriculture and water supplies.
- Europe: Increased heatwaves, reduced precipitation, and declining agricultural productivity challenge sustainable development.
- Latin America: Reduced water availability, rising seas, desertification, and lower energy production threaten livelihoods.
- North America: Declining snowpack, prolonged heatwaves, flooding, and wildfires disrupt ecosystems and settlements.
- Polar Regions: Melting Arctic ice transforms ecosystems, infrastructure, and traditional livelihoods.
- Small Island States: Rising seas reduce freshwater access, erode coasts, and increase flood risks.

While most consequences are adverse, some regions—particularly in the Global North—may see temporary benefits. Higher latitudes could experience longer growing seasons, improved crop yields, and reduced winter heating costs (IPCC, 2014). Melting Arctic ice may open shorter shipping routes between Europe and Asia (Smith & Stephenson, 2013). However, these benefits are unevenly distributed and often offset by severe environmental trade-offs. The same warming that lengthens seasons in the north can devastate agriculture in tropical regions, deepen water stress, and heighten disaster risks in the Global South, reinforcing global inequities (UNDRR, 2022).

These dynamics underscore the urgency of integrating climate adaptation with disaster risk reduction (DRR). Strategies include resilient infrastructure, early warning systems, food and water security measures, and health system strengthening. Ecosystem protection, risk-sensitive urban planning, and renewable energy investment further reduce future risks. Without urgent action, vulnerabilities will deepen, and adaptive capacity will erode.

Mitigation measures aim to reduce greenhouse gas emissions through energy efficiency, low-energy industrial and transport solutions, reduced reliance on energy-intensive products, and expanded renewable energy use. Adaptation efforts involve risk assessments, ecosystem restoration, improved water management, climate-smart agriculture, resilient construction, public awareness, and social safety nets.

UNDRR (2008), drawing on the Hyogo Framework for Action (HFA), emphasized five priorities:

- Make DRR a national and local priority with strong institutional foundations.
- Identify, assess, and monitor risks; enhance early warning systems.
- Use knowledge, innovation, and education to foster safety and resilience.
- Address underlying risk factors.
- Strengthen disaster preparedness for effective response.

Sector-specific recommendations include climate-resilient crop varieties, altered planting schedules, and improved land topography for water retention. Water-sensitive urban design is promoted in both Global North and South contexts to manage flood and drought risks.

In the health sector, UNDRR (2008) stressed early warning systems for heatwaves, floods, and storms; public awareness on water and food safety; and affordable healthcare access for vulnerable groups. Innovations in affordable medicines and local resilience initiatives remain critical, particularly for low-income urban populations.

Environmental management is central to mitigation and adaptation—protecting mangroves, coral reefs, and wetlands buffers communities from hazards while sustaining biodiversity and livelihoods. Transitioning away from environmentally degrading practices and enforcing sustainability regulations are necessary for long-term resilience.

Cost-effectiveness is also key. Examples include China's urban flood control projects, Rio de Janeiro's drainage upgrades, and Vietnam's mangrove restoration, all of which demonstrate that well-designed DRR measures deliver economic and social benefits.

The UNFCCC's Bali Action Plan advanced integrated risk management, insurance mechanisms, and vulnerability assessments, while encouraging capacity-building and integrating DRR into national and sectoral planning. For developing countries, these measures are vital for reducing exposure and strengthening adaptive capacity.

UNDRR (2008) outlined three complementary action plans:

- National coordination mechanisms to link DRR and adaptation across governance levels, fostering collaboration between climate change, DRR, and development agencies.
- Baseline assessments of DRR and adaptation performance through data-sharing, institutional reviews, and socio-economic analysis.
- Adaptation plans aligned with the HFA's five priorities, ensuring comprehensive integration of risk reduction into national development.

Eight years after the HFA's launch, the UNDRR's assessment highlighted gaps in political commitment, resource allocation, and public awareness. Full DRR implementation, especially in vulnerable nations, was deemed critical for building resilience and reducing unacceptable levels of disaster risk.

Climate change and Conflicts

Climate change is increasingly recognised as a *threat multiplier* for conflict and insecurity, exacerbating existing political, social, and economic tensions (Mach et al., 2019). Rising temperatures, water scarcity, and the degradation of critical resources intensify competition over food, land, and energy, especially in fragile states where governance systems are already under strain.

Conflicts and wars across the globe have further entrenched vulnerabilities, pushing already at-risk communities into deeper poverty and humanitarian crisis. In regions dependent on climate-sensitive sectors such as agriculture and fisheries, the combination of conflict and environmental change results in lower yields, disrupted supply chains, and rising food prices (FAO, 2021). Prolonged instability diverts government attention and resources away from climate resilience strategies, weakening administrative capacity to implement disaster risk reduction (DRR) and climate adaptation plans.

The war in Syria, for example, was preceded by the 2006–2010 drought—linked to climate change—which forced rural migration into urban centres already struggling with resource scarcity and unemployment, contributing to heightened socio-political tensions (Kelley et al., 2015). In the Sahel region, recurrent droughts have intensified clashes between pastoralist and farming communities over shrinking water and grazing resources, often escalating into violence (Benjaminsen et al., 2012).

Conflicts also cause irreversible damage to ecosystems and biodiversity. Warfare can destroy forests, pollute water sources, and degrade arable land, further reducing a region's ecological resilience. The loss of critical habitats and the collapse of ecosystem services hinder recovery and prolong the pathway toward sustainable development. Post-conflict reconstruction in such environments is far more resource-intensive, requiring the restoration of both human systems and the natural environment.

These interlinkages highlight the urgent need for integrated approaches where peacebuilding, humanitarian relief, and climate resilience are pursued in tandem. Strengthening governance, restoring ecosystems, and building adaptive capacity in conflict-affected regions are essential to breaking the cycle of environmental degradation, poverty, and instability.

2.1.b Understanding Sendai Framework 2015-2030

The Sendai Framework for Disaster Risk Reduction (2015–2030) builds on the Hyogo Framework for Action (2005–2015) and marks a shift from reacting to disasters toward managing disaster risks proactively. Its goal is to significantly reduce loss of lives, livelihoods, health, infrastructure, and economic assets by embedding resilience into all aspects of development.

A key lesson from the HFA was the need to address the root causes of risk and strengthen long-term resilience. The Sendai Framework connects DRR with global priorities such as climate change adaptation and sustainable development, promoting a multi-hazard, cross-sectoral approach. By safeguarding infrastructure, investments, and supply chains, risk reduction is positioned not only as a humanitarian priority but also as a driver of economic stability.

The framework also promotes "building back better" after disasters, creating opportunities in resilient construction, infrastructure protection, and community-based preparedness. Implementation challenges—such as resource constraints, limited coordination, and data gaps—are acknowledged, with solutions centred on international cooperation, capacity building, and adaptive national strategies.

DRR is presented as a shared responsibility among governments, civil society, the private sector, and communities. The Sendai Framework urges national and local DRR strategies, stronger international cooperation for developing countries, expanded access to multi-hazard early warning systems, and targeted support for vulnerable nations.

Following is the figure are the targets set by UNDRR under the framework:

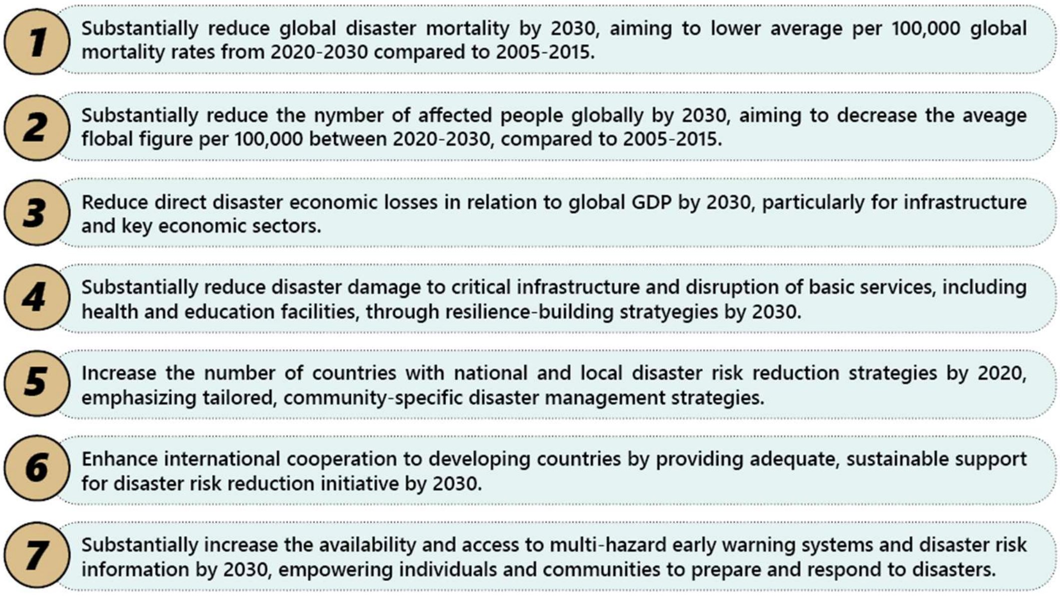


Figure 2.1: Targets under Sendai Framework (source: Adapted from UNDRR)

Its **seven global targets** aim to:

Reduce disaster mortality, affected populations, economic loss, and damage to critical infrastructure.

- Increase the number of countries with DRR strategies.
- Improve international cooperation and access to early warning systems.
- Strengthen resilience through integrated economic, social, environmental, and institutional measures.

These targets by UNDRR (2015) focus on reducing the human, economic, and infrastructural impacts of disasters while strengthening global cooperation and resilience-building measures.

Major Goals Cited for the Year 2030

UNDRR (2015) outlines several critical goals aimed at enhancing disaster risk reduction and resilience by 2030, addressing the increasing challenges posed by disasters and ensuring a more sustainable future. These major goals are as follows:

- **Increase National and Local Strategies:** A key goal is to significantly raise the number of countries with national and local disaster risk reduction strategies by 2020. This emphasizes the need for localized approaches, ensuring strategies meet the specific needs and vulnerabilities of communities.
- **Enhance International Cooperation:** UNDRR (2015) highlights the importance of increasing international cooperation to provide developing countries with sustainable support. This goal is essential for complementing national actions and ensuring effective disaster risk reduction implementation by 2030.
- **Access to Early Warning Systems:** Another critical objective is to enhance access to multi-hazard early warning systems and disaster risk information. By doing so, communities are better equipped to prepare for and respond to disasters, thus reducing their impact.
- **Strengthening Resilience:** The overarching aim is to prevent new disaster risks and reduce existing ones through inclusive and integrated measures across sectors, including economic, structural, social, health, environmental, and institutional. This goal focuses on enhancing preparedness and resilience at all levels.

- **Support for Vulnerable Countries:** Special attention is given to developing nations, particularly least developed countries, small island developing states, and landlocked developing nations. This support is crucial for strengthening their capacities and enabling the implementation of disaster risk reduction strategies in line with national priorities.

UNDRR (2015) sets out to improve national strategies, foster international cooperation, expand access to early warning systems, strengthen resilience, and provide targeted support to vulnerable nations, fostering a more resilient global community.

2.1.c Paris Agreement

Adopted at COP21 in Paris (2015) and entering into force in 2016, the Paris Agreement is a legally binding treaty under the UNFCCC with the primary aim of limiting global temperature rise to **well below 2°C**, and preferably to 1.5°C, above pre-industrial levels.

Its main mechanisms include:

Nationally Determined Contributions (NDCs): Countries submit, and update climate action plans every five years, showing increased ambition over time.

Global Stocktake: A collective progress review occurs every five years, with the first completed in 2023.

Adaptation and Resilience: Enhancing adaptive capacity, reducing vulnerability, and integrating climate adaptation into all sectors is treated as a shared global responsibility.

Climate Finance: Developed nations committed to mobilizing USD 100 billion annually by 2020, with scaling beyond 2025, to support developing countries.

Relevance to DRR:
Urban areas, as both major emitters and highly vulnerable systems, are central to the Agreement's goals. Partnerships between governments, local authorities, private actors, and civil society are encouraged to promote low-carbon, climate-resilient urban development. DRR measures—such as early warning systems, risk-sensitive land-use planning, and resilient infrastructure—are integral to NDCs, especially in the Global South where adaptive capacity is often limited.

The Paris Agreement therefore creates a unifying framework where climate change adaptation, DRR, and sustainable urban development converge, encouraging cities to take proactive roles in climate governance.

2.2 Global Initiatives in DRR and Climate Resilience - MCR2030 | 100 Resilient Cities | C40 Cities

Climate change as discussed previously has been one of the most pressing challenges that the world faces today, with its impacts felt across all regions, ecosystems, and economies. Since the mid-20th century, global temperatures have risen significantly, largely due to human activities such as the burning of fossil fuels, deforestation, and industrial activities. This has led to an increased frequency and intensity of natural disasters such as floods, storms, droughts, and heatwaves. Simultaneously, the world is witnessing unprecedented urbanization. Over 55% of the global population now lives in urban areas, and this number is expected to rise to nearly 70% by 2050 (World Bank, 2019).

Cities, particularly in the Global South, are growing rapidly, often in an unplanned or poorly managed manner, leading to significant increases in urban vulnerabilities. The rapid expansion of urban populations frequently outpaces infrastructure development, resulting in poor housing conditions, inadequate access to essential services, and exposure to environmental hazards.

Many of the world's largest and fastest-growing cities, including Mumbai, Lagos, Dhaka, and Jakarta, are in regions highly vulnerable to the effects of climate change. These cities are often situated in coastal or riverine areas, exposing them to rising sea levels, storm surges, and flooding. Coastal megacities, such as Manila and Lagos, face the dual threat of increased extreme weather events and subsidence, making them more prone to disasters.

100 Resilient Cities | Resilient Cities Network

The Rockefeller Foundation (May 2013) pledged a $100 million commitment to build urban resilience through an initiative to bring 100 cities together and form a network of resilient cities with an aim to build resilience to physical, social and economic challenges of the 21st century known as 100 Resilient Cities network. This initiative aimed to encourage investments, funding, tools and expertise for long-term development strategies for global resilience in the face or increasing climate change, urbanization and globalization giving rise to multiple socio-economic challenges. The member cities can be visualized across the globe from the figure 2.2 below with the founding member cities in blue and the later in yellow.

Under this initiative, cities would require a Chief Resilience Officer (CRO) appointed within the local government responsible for spearheading relevant strategies across all sectors. The best practices and innovations for disaster risk management, public health crisis that will be shared across the network of cities. Also, a customized resilience strategy must be adopted by each city that will be provided with logistics and financial support for global expertise from private-sector firms, international organizations, etc. This initiative encouraged cities for long-term sustainability, improving aging infrastructure, prepare for and respond to shocks and stresses like unemployment, migration, shelter, social segregation and regional migration.

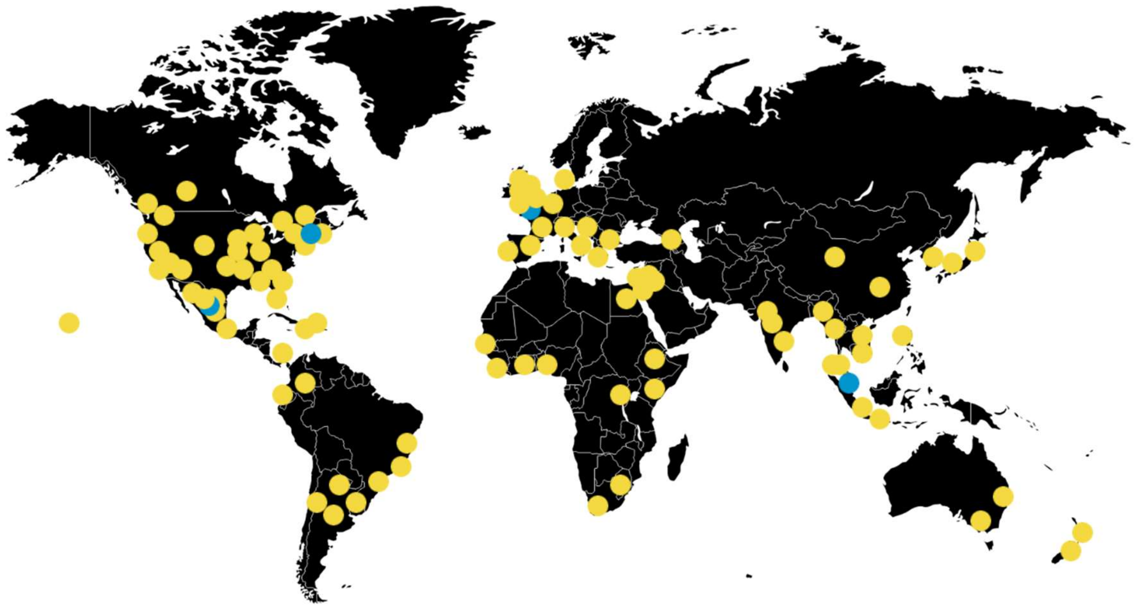


Figure 2.2: Member cities - Resilient Cities Network (source: Resilient Cities Network, Rockefeller Foundation) Blue Dot indicate the primary founding member cities and the yellow dots indicate the cities that partnered in later years.

According to the Urban Resilience: Executive Summary (McTarnaghan, et.al. 2022) the effectivity and influence across the 21 sample cities, the initiative in almost all cities advanced on at least a few outcomes, but very few advanced across all domains. Cities such as Norfolk (US) and Wellington (New Zealand) that had stronger capacity a baseline were able to accelerate and institutionalize their resilience practices by sharing usual business policies of the city government. But cities with low capacities, demonstrated incremental growths and needed more support in capacity building, such as the Addis Ababa (Ethiopia) along with other cities with uneven progress.

Cities with different socio-economic backgrounds, infrastructure and geographic conditions were able to share, experience and communicate among each other the different ways to address the challenges of climate change and build for urban resilience. In 2020, building on the foundations of the 100 resilient cities, Resilient cities network came as an evolved platform with its existence in 40 countries, as an independent non-profit organization advancing urban resilience solutions to protect vulnerable communities (Global Cities Hub, 2023). With more emphasis on providing tools and resources to empower cities for effectively executing the strategies for urban resilience. The mission of Resilient cities network has been to reduce vulnerability and improve the well-being, draw global knowledge, practice, partnerships, and funding to empower among the member cities. (Resilient Cities Network, 2023)

MCR2030

The Making Cities Resilient 2030 (MCR2030) initiative, launched by the United Nations Office for Disaster Risk Reduction (UNDRR) in 2020, is a global effort to support cities in becoming more resilient to disasters and climate-related risks by 2030. It builds on the previous Making Cities Resilient (2010-2020) campaign, expanding the focus from advocacy to implementation, action, and monitoring. MCR2030 provides a structured pathway for cities to follow, helping them progress from building awareness to implementing policies and strategies that foster resilience. MCR2030 promotes city resilience through multi-stakeholder partnerships, including collaboration with governments, private sectors, academia, and civil society organizations. Key principles of MCR 2030 can be understood from Figure 2.3 on the right and their inter-relationships among each other. The initiative emphasizes integrating disaster risk reduction (DRR) into urban planning, enhancing governance frameworks, and developing local capacities to manage risk. It also aligns with the Sendai Framework for Disaster Risk Reduction and the Sustainable Development Goals (SDGs), particularly Goal 11, which focuses on making cities inclusive, safe, resilient, and sustainable (UNDRR, 2020).

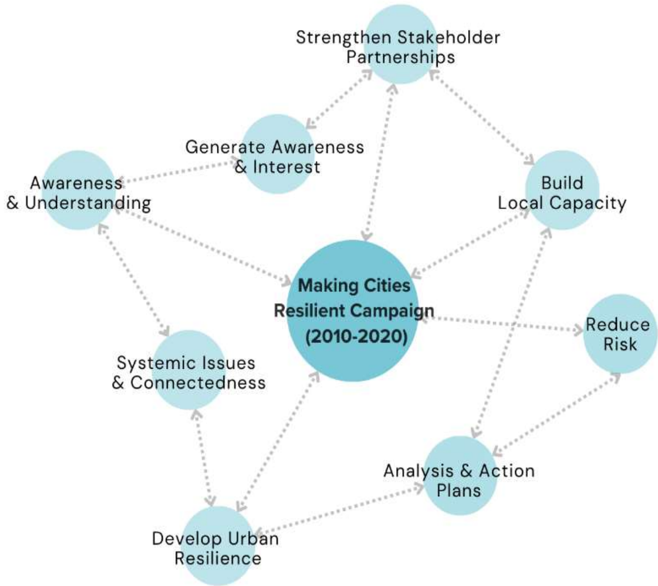


Figure 2.3: Making Cities Resilient Campaign foundational ideas and relationship

One notable example of a city participating in MCR2030 is Jakarta, Indonesia. As a coastal megacity prone to flooding, Jakarta has developed a comprehensive flood management strategy as part of its resilience efforts. Through the MCR2030 framework, the city has worked to enhance its early warning systems, improve drainage infrastructure, and integrate green infrastructure, such as urban parks and flood retention ponds, to reduce flood risks. Additionally, Jakarta's participation in the initiative has fostered stronger collaboration between local government, the private sector, and communities in mitigating disaster risks (UNDRR, 2021).

Another example is Barcelona, Spain, which has embraced the MCR2030 initiative to strengthen its urban resilience against climate change impacts like heatwaves and water scarcity. Barcelona's resilience strategy focuses on integrating disaster risk reduction into its spatial planning and infrastructure development. The city has implemented green roofs, urban forests, and water-efficient systems to reduce the urban heat island effect and manage drought risks. The MCR2030 initiative has also encouraged Barcelona to enhance its public awareness campaigns on climate resilience and engage local communities in participatory urban governance (UNDRR, 2021).

Cape Town, South Africa is another city participating in MCR2030, focusing on water security and climate adaptation after the severe drought it experienced between 2015 and 2018. Cape Town's water management strategies include diversifying water sources, improving water efficiency, and implementing early warning systems for drought. The city has also incorporated risk-sensitive land-use planning, restricting development in areas vulnerable to flooding and drought (UNDRR, 2021).

Through MCR2030, cities like Jakarta, Barcelona, and Cape Town demonstrate the importance of integrating resilience-building strategies into urban planning and governance. This initiative provides a collaborative framework for cities to enhance their capacity to manage disaster risks and create safer, more sustainable urban environments.

C40 Cities

C40 Cities is a network of cities around the world committed to addressing climate change through reducing greenhouse gas emissions and enhancing urban resilience. But founded in 2005, under the mayor of London and supported by many international organizations both private and public, non-governmental and corporate bodies, C40 sets its primary focus on climate action, particularly through climate mitigation and adaptation strategies in large cities. Today it is a global network of 100 leaders (city mayors) representing each of the world's leading cities that are united in action to confront climate crisis. The leaders (mayors) are committed to an inclusive, science-based and collaborative approach to cut their fair share of emissions in half by 2030 and help the world limit global heating to 1.5°C and build healthy, equitable and resilient communities. The organization's goal is to cut climate change-related emissions by 50% in its member cities within a decade to prevent global warming past 1.5° Celsius (www.c40.org/about-c40/).

Climate Justice and Equity are the primary emphasis of the organization, it started as C20 and 18 cities before it merged with the Climate initiative of Clinton Foundation along with the joining of then Mayor Michale Bloomberg in 2007 to host its second annual conference. Since then, the C40 organization has been developing annual reports with major key focus strategies and cities in discussions. Since 2015, the C40 Cities Climate Leadership Group has developed several guidelines and frameworks aimed at enhancing climate change mitigation and adaptation strategies, particularly for cities in the Global South and majorly the delta cities in focus. As per the C40cities (2016) some of the key initiatives include:

1. Good Practice Guides: Published in 2016, these guides provide urban policymakers with practical solutions to tackle climate breakdown, reduce climate risk, and encourage sustainable urban development.
2. Climate Action Impacts Framework: This framework assists cities in understanding how climate actions can yield multiple benefits, facilitating the integration of mitigation and adaptation strategies.

3. Adaptation Planning Resources: C40 emphasizes the importance of comprehensive, city-wide, and multi-hazard adaptation strategies based on thorough climate risk assessments to enhance urban resilience. (C40 Knowledge Hub, 2022).

Following is a brief comparison and anomaly,

Table 2.2: Understanding approach of the international cooperations, partnerships, initiatives and frameworks.

Aspect	C40 Cities	100 Resilient Cities	MCR 2030	Sendai Framework
Lead Organization	Independent, supported by member cities and partners	Rockefeller Foundation	United Nations (UNDRR)	United Nations (Global Framework)
Focus	Climate change (mitigation and adaptation)	Broad urban resilience (social, economic, disaster)	Disaster risk reduction and urban resilience	Disaster risk management on a global scale
Primary Goals	Reducing GHG emissions, climate adaptation	Building holistic urban resilience	Disaster resilience, DRR strategies	Reducing disaster risks globally
Key Approach	Climate Action Plans, city leadership	Chief Resilience Officer model, city resilience strategies	Step-by-step resilience roadmap for DRR	Global policy for DRR
Target Participants	Cities with over 3 million people, megacities	100 global cities	Cities (open participation)	All countries and cities (via programs)
Global Collaboration	Climate-focused city network	City-specific strategies	DRR-focused technical support, city network	Global disaster risk reduction targets
Main Outcome	Climate Action Plans (Paris Agreement-aligned)	Urban Resilience Strategies	DRR strategies for cities by 2030	Global DRR strategies for all countries

2.3 Hazards, Risks, Vulnerabilities and Exposure

Hazard

A hazard is defined as a process, phenomenon, or human activity that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, or environmental resources (UNDRR, 2020). Climate change–induced hazards include both extreme weather events (e.g., tropical cyclones, floods, heatwaves) and slow-onset processes (e.g., drought, desertification, sea-level rise) that are intensified by anthropogenic climate change (IPCC, 2022).

Figure 2.4: Relationship diagram of Risk (source: Author based on UNDRR, 2020)

Risk

Risk is "the potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems" (IPCC, 2023, p. 5). Disaster risk emerges from the interaction between a hazard, the exposure of people and assets, and their vulnerability. This relationship is often expressed as:

Risk = Hazard x Exposure x Vulnerability

The relationship between Hazard, Risk and Vulnerability is shown in the figure 2.4. In the climate change context, risks are influenced not only by hazard probability and severity but also by societal responses, adaptive capacity, and governance frameworks (Reisinger et al., 2020).

Vulnerability

Vulnerability refers to the conditions determined by physical, social, economic, and environmental factors or processes that increase the susceptibility of a community or system to the impacts of hazards (UNDRR, 2020). Vulnerability is not an inherent characteristic but a result of systemic inequalities, marginalization, and inadequate capacity to anticipate, cope with, or recover from hazard impacts (Birkmann et al., 2013).

There is a dynamic relationship between climate-related hazards with the exposure and vulnerabilities of affected humans and ecological systems that could be further amplified with the associated uncertainty of the magnitude, frequencies, spatial-temporal changes in socio-economic conditions and human decision-making. While the other notion or set of factors in case of climate change impacts, the risks are associated or results from potential trade-offs, related side effects, societal objectives, such as SDGs that can arise from policy differences, systematic transitions, climate-related investments, etc. (Reisinger et al., 2020). Overall, risks when discussing the climate change, it applies to both "impacts" and "responses" to climate change, "humans and ecological systems" and recognition of diverse values and objectives".

Climate-related hazards (or climate change–induced hazards) refer to the physical events or processes whose frequency, intensity, or duration are influenced by climate variability and long-term climate change (IPCC, 2022). These hazards include both extreme weather events, such as heatwaves, heavy precipitation, droughts, cyclones, and storm surges: and slow-onset processes such as sea-level rise, ocean acidification, glacier retreat, and desertification. Climate change increases the likelihood and magnitude of these hazards through anthropogenic drivers like greenhouse gas emissions, deforestation, and urban heat amplification (UNDRR, 2020; IPCC, 2022).

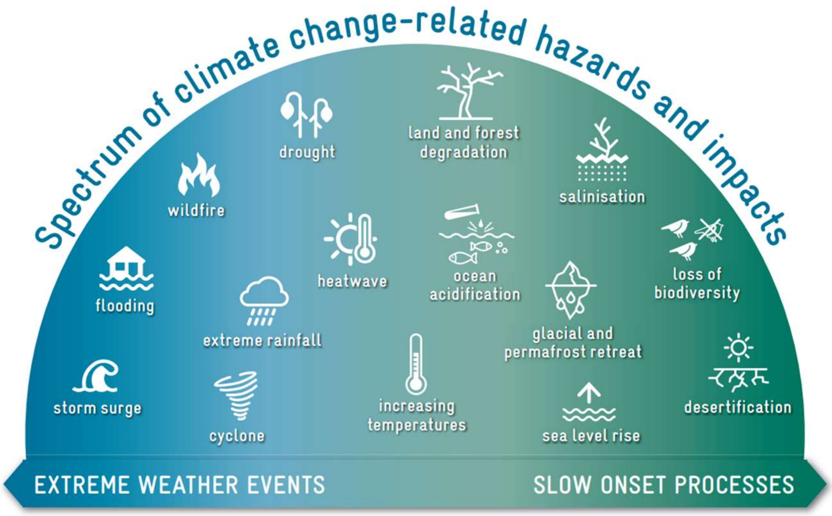


Figure 2.5: Spectrum of Climate Change-related Hazards and Impacts. (Source: GIZ, 2021)

In the context of urban planning and disaster risk reduction (DRR), climate change–induced hazards are significant because they often intersect with existing vulnerabilities—such as inadequate infrastructure, high population density, and socio-economic marginalization—resulting in compounded risks and cascading impacts.

Some key aspects of climate change-related risks involve the understanding or identification of risks, communications, assessments and management, and its distribution can be widely seen ranging from the extreme weather events and slow onset processes while assessing the climate risk management strategies. The Climate Risk Management (CRM) framework developed by the GIZ's Global Programme on Risk Assessment and Management for Adaptation to Climate Change (Loss and Damage) is a collective response towards the Article 8 of Paris Agreement on the collective consensus towards contributing to avert, minimize, and address losses and damages (GIZ, 2021). This framework provides a 6-step methodology towards the climate risk assessment (CRA) starting with the identification of the risk, assessing the magnitude of impacts on people, assets, value chains, critical infrastructures, settlements, and ecosystems establishing a close relationship and interaction with socio-economic factors that determines the overall risk and ways to respond (see figure 2.6).

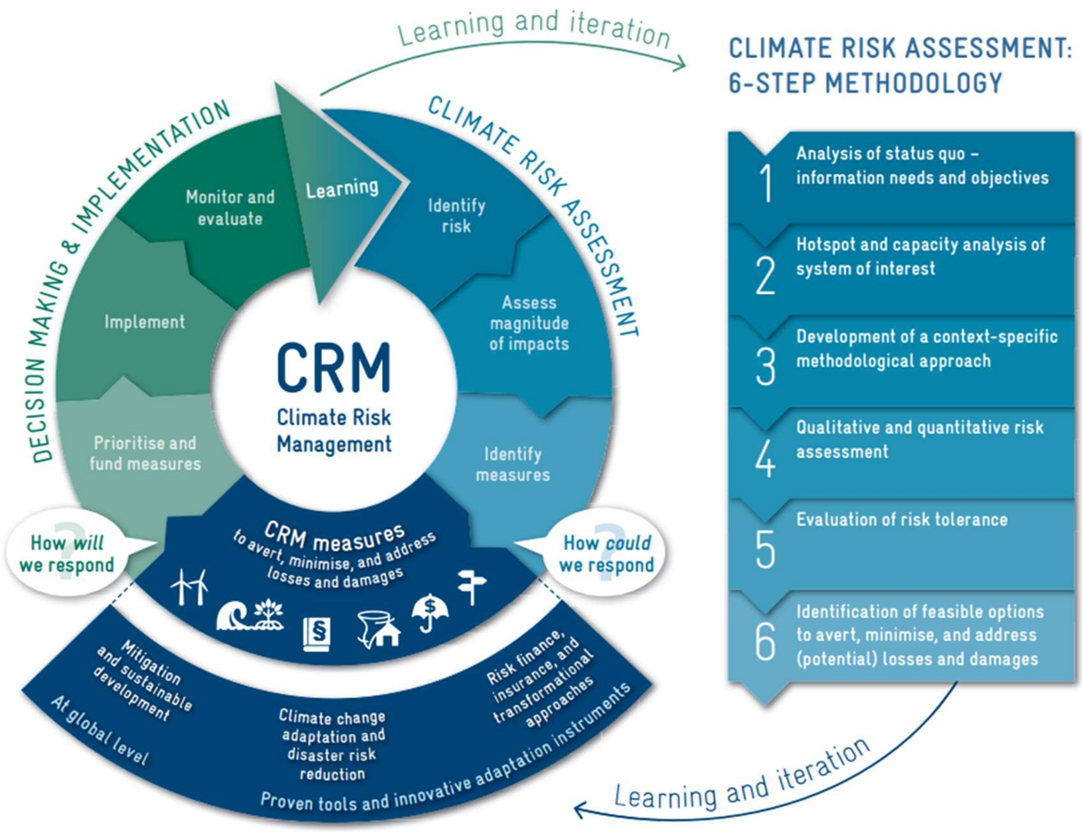


Figure 2.6: 6-Step Methodology to assess climate-related risks (source: GIZ, 2021).

Without the exposure to any Hazard, there is no vulnerability but technically the assessments will associate only with the probabilities. IPCC (Field et al., 2012) in its report for 'Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation' highlighted that risk and vulnerability assessments that intend to inform these adaptation strategies require also a multi-dimensional perspective.

These frameworks (as illustrated in Figure. 2.5 and Figure 2.6) emphasize that understanding climate change–related risks require assessing both hazard characteristics (magnitude, frequency, duration, and spatial extent) and societal factors (exposure, vulnerability, adaptive capacity). The GIZ (2021) six-step methodology for Climate Risk Assessment (CRA) begins with hazard identification and moves through impact assessment, risk evaluation, and the development of adaptation and risk transfer measures.

- *Step 1* identifies the type and scale of hazards likely to occur under various climate scenarios, including both extreme and slow-onset events.

- *Step 2* assesses exposure by mapping populations, assets, and ecosystems within hazard-prone zones.
  Step 3 evaluates vulnerabilities, considering socio-economic conditions, governance structures, and institutional readiness.
- *Step 4* quantifies potential impacts on critical systems—such as water supply, health services, energy grids, and transport networks—highlighting direct and indirect losses.
- *Step 5* involves developing adaptation strategies and risk management measures, prioritizing cost-effective, inclusive, and ecosystem-based solutions.
- *Step 6* monitors and revises strategies as conditions evolve, integrating new data and lessons learned into planning frameworks.

This iterative process ensures that DRR and climate adaptation strategies are evidence-based, forward-looking, and adaptable to uncertainty. By linking scientific risk assessment with participatory planning, cities can design interventions that address the root causes of vulnerability, reduce hazard exposure, and strengthen resilience to climate change impacts over time (GIZ, 2021; IPCC, 2022).

2.4 Climate Induced disasters and losses in Urban Areas: Frequently Prevailing Hazards and Typologies | Determining Criteria

Urban areas are already bearing the brunt of climate-induced disasters, which generate profound social, economic, and environmental losses. Flooding is the most common climate-related disaster and has increased sharply in cities due to inadequate drainage, expanding impervious surfaces, and sea-level rise. Events such as the 2017 flooding in Houston, the 2019 floods in Jakarta, and the 2020 floods in Mumbai illustrate the devastating human and economic costs, including billions of dollars in damages, loss of livelihoods, and large-scale displacement. At the same time, the urban heat island (UHI) effect intensifies heatwaves, as dense built-up areas and human activities trap heat. Cities such as Phoenix and Delhi have recorded extreme heat events that triggered serious public health crises, disproportionately affecting the elderly, low-income households, and other vulnerable groups.

According to the United Nations Department of Economic and Social Affairs (UN DESA, 2019), using data from the Centre for Research on the Epidemiology of Disasters (CRED) and UNISDR, around 1.3 million people lost their lives and 4.4 billion were injured or otherwise affected by disasters between 1998 and 2015, with millions displaced or left in need of emergency assistance. Approximately 69 million people worldwide were affected by severe extreme events in 2018 alone, and economic losses between 1998 and 2017 are estimated at around USD 2.9 trillion. More frequent and intense climate and weather extremes are now being documented in many urban areas (Gencer et al., 2018), underscoring the urgency of understanding linkages between climate change impacts and disaster risk, and of integrating disaster risk reduction (DRR), climate change adaptation (CCA), and resilience building.

Rapidly growing urban populations often outpace the capacity of governments in developing countries to provide basic infrastructure and essential services (IPCC, 2012; UN-Habitat, 2009). Unplanned and agglomerated urban expansion leads to the loss of green and permeable spaces, which in turn heightens exposure to extreme climate conditions by reducing stormwater infiltration, amplifying UHI effects, degrading air quality, and undermining biodiversity (IPCC, 2012; Wilby & Perry, 2006). Key drivers of urban vulnerability include: (i) high population densities and concentration of assets, (ii) uneven economic conditions, social inequality, and weak or unstable governance, and (iii) cumulative exposure to recurrent and overlapping hazards. In many cities, both frequently occurring events (e.g., flash floods, heatwaves, storms) and slow-onset processes (e.g., land subsidence, loss of topsoil, groundwater depletion, and chronic water scarcity) interact to deepen risk.

Coastal cities are particularly exposed to compound climate risks. Coastal zones host many of the world's largest urban populations and economic hubs, yet face escalating threats from sea-level rise, storm surges, tidal flooding, and saline intrusion. Nicholls et al. (2019) estimate that nearly 570 coastal cities, representing over 800 million people, could be exposed to sea-level rise and related hazards by 2050 if current trends persist. Since around 2015, the frequency, intensity, and unpredictability of climate-induced hazards have risen markedly (IPCC, 2022). Extreme heat events, catastrophic floods, intensified storm surges, and prolonged droughts are affecting millions, often with limited lead time. These evolving risks, driven by global warming, rapid urbanization, and ecosystem degradation, are testing existing preparedness systems and compelling cities—especially in the Global South—to rethink and strengthen their resilience frameworks.

The risks stem from a combination of *physical exposure* (location on low-lying coasts or river deltas), *socio-economic vulnerability* (informal settlements, poverty), and *governance capacity* (planning, enforcement, and funding constraints). Figure 2.8 and 2.9 provides an illustration of the effects of frequent cases of rising temperatures across global cities worldwide. The following hazard typologies illustrate the multi-dimensional threats to coastal urban resilience:

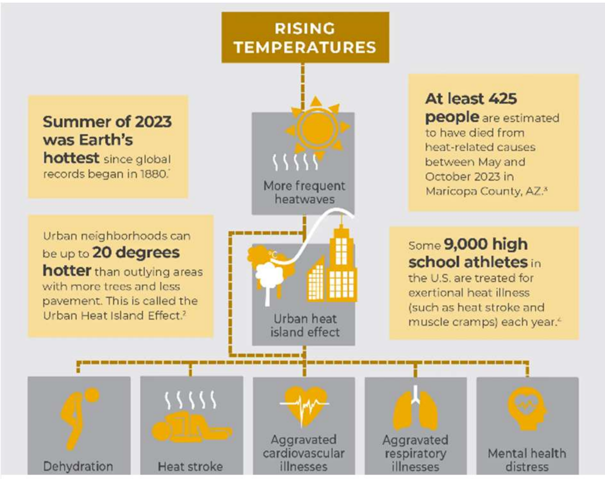


Figure 2.7: Climate change and affected health risks (source: National league of cities)

Urban Heat Risks

Urban Heat Risks stem from the Urban Heat Island (UHI) effect, where built-up areas absorb and retain heat, raising temperatures by 2–7°C above surrounding rural zones (Rodríguez et al., 2020). Prolonged exposure to high temperatures can cause heat stress, exacerbate cardiovascular and respiratory illnesses, and increase mortality among vulnerable populations. In 2019, Europe recorded its hottest June, with Paris reaching 42.6°C, leading to thousands of heat-related hospitalizations (WHO, 2020). In India, the 2015 heatwave killed over 2,500 people, with cities like Hyderabad and Delhi reporting record-breaking temperatures exceeding 47°C (IMD, 2015). One of the major reasons Urban Heat Risks are becoming a priority across global cities is the fact that it worsens the air quality, increasing the vulnerability among the young and old age groups having low adaptability to changing climate. The workforce population is also seen facing major climate change challenges across the urban regions worldwide as per UN-Habitat.

Figure 2.8: Urban Workforce and Urban Heat effects. (source: UN-Habitat)

Drought and Water Stress

Drought is a prolonged period of deficient rainfall, while water stress occurs when demand for water exceeds the available supply. In urban settings, these hazards can disrupt municipal water provision, agriculture, and industry, and exacerbate social tensions. Cape Town's 2018 "Day Zero" crisis brought the city within weeks of shutting off municipal water taps due to prolonged drought, affecting nearly 4 million residents (Enqvist & Ziervogel, 2019). In Chennai, India, the 2019 drought caused major reservoirs to dry up, leading to severe water rationing and economic losses (UNICEF, 2020) (Enqvist & Ziervogel, 2019). An example of droughts in 2018 can be seen in figure 2.9.

Urban Flooding

Figure 2.9: Residents queue to fill water bottles at a natural water spring in Cape Town, South Africa (source: National Geographic, 2018)

Urban flooding results from intense rainfall events, overwhelming drainage systems, often compounded by high impervious surface covers. In coastal contexts, it can be worsened by tidal surges and sea-level rise (IPCC, 2022). Flooding disrupts transport, damages infrastructure, contaminates water supplies, and can trigger secondary health crises. In 2022, Lagos, Nigeria experienced severe flooding after heavy rains, displacing over 100,000 residents and damaging critical road and drainage networks (UNDRR, 2023). Similarly, the 2020 floods in Jakarta inundated large parts of the city, killing 66 people and displacing nearly 400,000 (BNPB, 2020).

Coastal Erosion and Storm Surge

Coastal erosion is the loss of land along shorelines due to wave action, currents, tides, and human activities, while storm surges are abnormal rises in sea level generated by storms, often causing devastating coastal flooding. Typhoon Haiyan (2013) produced storm surges over 6 meters high in Tacloban, Philippines, killing over 6,000 people and displacing 4 million (IFRC, 2014). In West Africa, coastal erosion has caused the retreat of Ghana’s shoreline by up to 2 meters per year, threatening communities and infrastructure (World Bank, 2019).

Figure 2.10: A road washed by the coastal waters (source: marinetimeindia.org)

2.4.a Vulnerability of Coastal Cities

Coastal cities are among the most vulnerable urban systems to climate change impacts due to their geographic exposure, socio-economic dependencies, and population growth. According to the *World Urbanization Prospects 2018*, more than 680 million people currently live in low-lying coastal zones—a figure projected to exceed 1 billion by 2050 (United Nations, 2019). Many of these cities are economic powerhouses, hosting critical ports, industries, and tourism infrastructure, making climate disruptions disproportionately costly. Figure 2.10 can be taken as example to understand the impacts of coastal erosion and the conflict of nature and anthropological changes across the coastline.

In the Global South, vulnerability is compounded by rapid, often unplanned urban growth, inadequate drainage infrastructure, and limited adaptive capacity (Nicholls et al., 2019). Informal settlements in coastal areas are particularly at risk, as residents often lack secure tenure, resilient housing, and access to early warning systems. Furthermore, saltwater intrusion into freshwater aquifers threatens drinking water supplies and agricultural productivity.

The high exposure of coastal cities to hazards such as sea-level rise, storm surges, and tidal flooding means that without urgent investment in nature-based solutions, resilient infrastructure, and adaptive governance, these urban areas face escalating risks to both livelihoods and long-term sustainability (IPCC, 2022).

Several Global North cities have implemented advanced adaptation measures to address these hazards:

- **Rotterdam, Netherlands** integrates multifunctional flood defenses (parks doubling as retention basins) and floating urban districts.

- **Copenhagen, Denmark** has pioneered cloudburst management through permeable streets and underground storage.

While these strategies offer valuable models, direct transplantation into the Global South requires careful contextual adaptation, considering differences in governance, financing, and socio-economic conditions. Nevertheless, the core principles: nature-based infrastructure, integrated water management, and risk-sensitive land use, are transferable and essential for future coastal resilience planning.

2.4.b Global South Cities

The significance of the global south cities lies in the extent to which cities can develop strategies to invest in strengthening urban resilience, develop tools to invent and perform research and development. Also, the need for stable governance, increased human growth index and quality of life provides a magnitude of factors to consider how cities across the world are responding to strengthen urban resilience. Globally, the pressure for urban areas to expand onto flood plains and coastal strips has resulted in an increase in exposure of populations to riverine and coastal flood risk (IPCC, 2012; McGranahan et al., 2007; Nicholls et al., 2011).

For example, intensive and unplanned human settlements in flood-prone areas appear to have played a major role in increasing flood risk in Africa over the last few decades (IPCC, 2012; Di Baldassarre et al., 2010).

“In India, the risks from drought, extreme heat, and water stress (Slow Onset Processes) and floods, landslides, and cyclones (Extreme Weather Events) in coastal and mountain hotspot areas have been assessed with a focus on rural livelihoods and critical infrastructure to inform state-level CRM practitioners about CCA and DRR measures” (GIZ, 2021).

Global South cities face a distinct set of structural, socio-economic, and governance challenges that exacerbate their vulnerability to climate-induced hazards. Rapid urbanization, often in the absence of adequate spatial planning, has resulted in informal settlements expanding into high-risk zones such as floodplains, unstable slopes, and coastal strips (UN-Habitat, 2022). These areas frequently lack essential infrastructure for drainage, waste management, and public health, making them particularly susceptible to floods, heatwaves, and disease outbreaks (IPCC, 2022).

Institutional capacity constraints compound these vulnerabilities. Many local governments operate with limited technical expertise, financial resources, and enforcement mechanisms, restricting their ability to integrate disaster risk reduction (DRR) into development planning (UNDRR, 2022). Furthermore, fragmented governance—often marked by weak inter-agency coordination—delays emergency response and inhibits proactive adaptation measures.

Socio-economic inequality plays a pivotal role in amplifying risk. Marginalized communities often reside in hazard-prone areas due to limited housing options, while lacking access to early warning systems, insurance, and post-disaster recovery resources (Dodman et al., 2019). This inequality is further deepened by gender and age dimensions, with women, children, and the elderly disproportionately affected during and after disasters.

International bodies such as the United Nations Office for Disaster Risk Reduction (UNDRR), UN-Habitat, and the World Bank have consistently stressed the urgency of embedding climate resilience into urban governance frameworks. Key recommendations include:

Strengthening multi-level governance to ensure local DRR strategies align with national frameworks and global agreements like the Sendai Framework and Paris Agreement.

Along the Gulf of Guinea (see figure 2.11) the coastal erosions are forcing the fishing communities to disappear along with the coastal infrastructures.

Figure 2.11: Coastal damages recorded across the Volta region in the Gulf of Guinea, Ghana (source: Dialogue Earth)

Enhancing access to climate finance mechanisms for urban infrastructure projects, particularly those that integrate nature-based solutions.

Promoting inclusive planning processes that engage vulnerable groups in decision-making.

Without targeted interventions, the urban systems of the Global South risk entering a cycle of "resilience deficit," where each disaster further undermines adaptive capacity, pushing cities into deeper socio-economic fragility (World Bank, 2021).

2.5 Strategies and practices of mitigation and adaptation aimed towards DRR and climate resiliency.

As we concur DRR measures share indefinite relationship with the scenarios of climate resiliency, we can further improvise our strategies and actions as key anchors. Current modern-day scenarios include measures that widely consider mitigations and adaptation strategies across all major cities but what the impacts need to be discussed in a dynamic way as we set our climate goals. The degree of mitigation and adaptation and the extent can be analysed with different conditions across multiple cities. The diversity of actors is a major determinant of the increased legitimacy and sustainability of adaptation processes (Bernauer & Gampfer, 2016; Finan & Nelson, 2009; Paavola, 2008; as cited by Chu et al. 2015). The participatory bodies at the local levels and their integration of state and non-state actors addresses a large share of justified outcomes of the adaptation measures. Development policies, stakeholder engagements, awareness programmes towards uplifting the economic constraints adds up to the measures for climate change adaptation planning processes. As per Chu et al. (2015) addressing Vulnerability of the poor and the procedural representation with equity facilitates the justified outcomes.

Urban areas exposed to climate change–induced hazards need solutions that both limit future risks (mitigation) and help communities live with current and future changes (adaptation). Ecosystem-based Adaptation (EbA) uses natural systems—like wetlands, mangroves, urban forests, and green corridors—to protect against hazards such as floods, heatwaves, and storms. These measures provide multiple benefits, from improving biodiversity and cooling cities to enhancing public spaces (Colls et al., 2009; IPCC, 2022). Community-based Adaptation (CbA) focuses on involving residents directly, using their knowledge and priorities to design solutions that fit local needs and conditions (Reid et al., 2014).

Each strategy in the following sub-sections links to EbA or CbA—or both. Sustainable Urban Drainage Systems (SUDS), Blue-Green Infrastructure (BGI), and Water-Sensitive Urban Design (WSUD) are core EbA measures, integrating natural water cycles into urban planning to reduce flood risks and heat stress. Urban farming and carbon sequestration combine EbA's ecological restoration benefits with CbA's emphasis on food security and community livelihoods. Restoration projects for rivers, wetlands, and coasts follow EbA principles, while also benefiting from CbA-led stewardship and monitoring.

Wastewater recycling and reuse and low-cost sustainable housing directly involve communities in managing resources and building resilient infrastructure, aligning with CbA's participatory approach while incorporating EbA's environmental safeguards. Together, these methods address hazards and socio-economic vulnerabilities in an integrated way, supporting global goals such as the Sendai Framework and the Paris Agreement.

2.5.a Sustainable Urban Drainage Systems | Blue Green Infrastructure Initiatives | Water Sensitive Urban Design | Urban Green Networks and Corridors

Sustainable Urban Drainage Systems (SUDS) are a set of planning and engineering approaches aimed at managing stormwater in ways that mimic natural hydrological processes. Rather than rapidly channeling water away, SUDS slow, store, and filter runoff, reducing flood risk and improving water quality (Fletcher et al., 2015). In the context of climate change adaptation, these systems provide co-benefits such as biodiversity enhancement, recreational spaces, and mitigation of the Urban Heat Island (UHI) effect.

Blue-Green Infrastructure (BGI) refers to the interconnected network of natural and semi-natural water (blue) and vegetated (green) spaces designed to deliver a wide range of ecosystem services in urban areas (Everard & Moggridge, 2012). Examples include rain gardens, green roofs, restored wetlands, and permeable pavements. These features improve resilience to extreme weather events by increasing infiltration, delaying runoff, and creating cooler microclimates.

Water-Sensitive Urban Design (WSUD) integrates the urban water cycle—including potable water, wastewater, and stormwater—into spatial planning to create liveable, resilient, and sustainable cities (Brown et al., 2009). By incorporating decentralized water treatment, greywater reuse, and rainwater harvesting, WSUD reduces dependence on centralized systems, which are often vulnerable during disasters.

Urban Green Networks and Corridors link parks, forests, riparian zones, and street trees to create a continuous ecological network that supports biodiversity, enhances urban cooling, and improves air quality (Kabisch et al., 2016). These corridors also serve as flood pathways during extreme rainfall, reducing infrastructure damage.

Figure 2.12: Shenzhen Bay Talent Park, China (source: Urban Governance for Health and Well Being)

Copenhagen's Cloudburst Management Plan integrates SUDS and BGI, converting streets into temporary canals and parks into water retention zones during heavy rains, significantly reducing flood damages (City of Copenhagen, 2014). In Manila, the Pasig River Rehabilitation Project combines riverbank greening, floating wetlands, and improved drainage to reduce flooding while enhancing public space (Asian Development Bank, 2020). Figure 2.12 provides a sample example of Water Sensitive Urban Design aimed towards improving quality of life and sustainability measures across the Shenzen city in China.

Integrating SUDS, BGI, WSUD, and green networks into urban planning enhances climate resilience by addressing multiple hazards simultaneously. These systems also contribute to social resilience by improving public health, liveability, and community engagement. For cities in the Global South, phased implementation supported by international climate finance can overcome cost and governance barriers, ensuring long-term sustainability and scalability.

2.5.b Urban Farming and Carbon Sequestration

Urban farming refers to the cultivation, processing, and distribution of food within urban and peri-urban areas, contributing to food security, livelihoods, and environmental sustainability (Mok et al., 2013). In the context of climate change, urban farming offers both mitigation and adaptation benefits. By reducing "food miles" and promoting local food systems, it lowers greenhouse gas (GHG) emissions from transport and storage. Moreover, green roofs and vertical gardens associated with urban agriculture provide microclimate regulation, enhance biodiversity, and contribute to stormwater management.

Carbon sequestration in urban areas involves capturing and storing atmospheric CO_2 through biological and technological processes. Urban green spaces, trees, and agricultural soils act as carbon sinks, storing carbon in biomass and soils while providing co-benefits such as shading, cooling, and habitat provision (Pelfrêne et al., 2013).

Integrating urban farming with carbon sequestration initiatives can amplify resilience. For example, soil restoration through composting and regenerative agriculture not only increases carbon storage but also enhances water retention, reducing flood risk during extreme rainfall events.

Figure 2.13: Nairobi, Kenya Urban Farming project (source: Sacco Trend)

Toronto's *Green Roof Bylaw* mandates green roofs on new developments, enabling widespread rooftop agriculture and carbon capture, while reducing UHI effects (City of Toronto, 2019). In Nairobi, the *Urban Agriculture Promotion and Regulation Act (2015)* supports household-level farming, contributing to food security while integrating tree planting schemes to capture carbon and improve air quality (UN-Habitat, 2018). Urban opportunities and social resilience by empowering communities, providing income opportunities and fostering local stewardship of urban ecosystems. When combined with carbon sequestration strategies, it creates multifunctional urban landscapes that address climate mitigation, adaptation, and equity.

2.5.c Restoration Projects | Catchment areas of rivers, wetlands and landfill developments and coastal developments.

Restoration projects aim to rehabilitate degraded ecosystems to restore their ecological functions, enhance biodiversity, and build resilience to climate change (Aronson et al., 2016). Restoring catchment areas of rivers improves water quality, reduces sedimentation, and enhances flood regulation capacity. Wetland restoration, in particular, provides a natural buffer against storm surges and coastal flooding while serving as carbon sinks.

Rehabilitation of landfill sites through capping, revegetation, and conversion into public green spaces can reduce methane emissions, mitigate contamination risks, and increase carbon sequestration. Similarly, sustainable coastal development incorporates living shorelines, mangrove restoration, and coral reef rehabilitation to protect urban coastlines from erosion and storm impacts (Barbier et al., 2011).

The *Cheonggyecheon Restoration Project* in Seoul transformed a buried urban stream into a vibrant ecological corridor, reducing local temperatures, improving flood capacity, and enhancing biodiversity (Kang & Cervero, 2009). In Vietnam, large-scale mangrove restoration projects in the Mekong Delta have reduced storm damage, enhanced fishery productivity, and sequestered significant amounts of carbon (IFRC, 2011). These projects contribute to DRR by reducing exposure to hazards, strengthening ecosystem services, and providing livelihood opportunities. In urban planning, integrating restoration projects into masterplans ensures long-term resilience while aligning with global biodiversity and climate targets.

2.5.d Waste Water Recycling ReUse | Waste Management

Wastewater recycling involves treating and reusing wastewater for non-potable and, in some cases, potable purposes. This reduces demand on freshwater resources, enhances drought resilience, and minimizes environmental pollution (Angelakis et al., 2018). Technologies such as membrane filtration, constructed wetlands, and UV disinfection are increasingly adopted in both Global North and Global South contexts.

Waste management, including solid waste reduction, segregation, and resource recovery, plays a critical role in reducing GHG emissions from landfills, improving public health, and preventing flood-related blockages in drainage systems (Hoornweg & Bhada-Tata, 2012). Circular economy approaches—such as composting, recycling, and waste-to-energy—can generate economic value while reducing environmental impacts.

Figure 2.14: Wetlands at Coastal locations Illustrations for adaptive measures (source: Urban Design Lab, 2022)

Singapore's *NEWater* program treats wastewater to potable standards using microfiltration, reverse osmosis, and UV disinfection, supplying up to 40% of national water demand (PUB Singapore, 2020). In Windhoek, Namibia, direct potable reuse of treated wastewater has been practiced for over 50 years, ensuring water security in one of the driest regions of Africa (Lahnsteiner & Lempert, 2007). Integrated waste and wastewater management not only mitigates climate risks by reducing methane and pollution but also enhances urban resilience by diversifying resource supply and reducing vulnerability to droughts and extreme rainfall.

2.5.e Low-Cost Housing and Sustainable Construction practices.

Low-cost housing solutions are critical for reducing urban vulnerability by providing safe, affordable, and resilient shelter for low-income populations. Sustainable construction practices integrate energy efficiency, resource conservation, and climate-adaptive design features, ensuring long-term habitability under changing climate conditions (Dabaieh, 2015).

Techniques such as passive cooling, locally sourced materials, modular design, and renewable energy integration reduce construction costs and environmental impact. Incorporating hazard-resistant features—such as elevated structures in flood-prone areas or seismic-resistant frames—directly reduces disaster risk (UN-Habitat, 2020).The *BedZED* eco-village in the UK combines affordable housing with high energy efficiency, renewable energy use, and community-based resource sharing (BioRegional, 2016). In post-earthquake Nepal, the *Owner-Driven Reconstruction* model facilitated rebuilding using locally available materials and hazard-resistant techniques, guided by community training programs (World Bank, 2017). Low-cost housing must be planned alongside urban infrastructure, ensuring access to services and integration into city resilience strategies. Public-private partnerships and international finance mechanisms can scale these solutions in the Global South, aligning with SDG 11 on sustainable cities and communities.

The chapter has explored the interplay between climate change–induced hazards, vulnerabilities, exposure, and risk, particularly in urban areas of the Global South. It examined global frameworks such as the Sendai Framework for Disaster Risk Reduction and the Paris Agreement, along with key urban resilience initiatives, while introducing concepts like Ecosystem-based Adaptation (EbA) and

Community-based Adaptation (CbA). Together, these discussions form the conceptual foundation for understanding how integrated strategies can address both immediate disaster risks and long-term climate adaptation needs.

Going forward, some of the key takeaways and highlights from this chapter would be:

- Climate change acts as both a driver of hazards and a multiplier of vulnerabilities, especially in coastal and rapidly urbanizing cities.
- Effective responses require multi-benefit strategies that combine ecological restoration, infrastructure resilience, and community participation.
- EbA and CbA approaches link environmental protection with socio-economic empowerment, offering scalable pathways for risk reduction.

A few indicators that provide a baseline for the methodology adopted in this research include:

- **Exposure Indicators:** Population in hazard-prone zones, critical infrastructure in floodplains, urban growth in coastal strips.
- **Vulnerability Indicators:** Poverty rates, proportion of informal housing, governance capacity, and service access.
- **Resilience Indicators:** Early warning system coverage, share of renewable energy, green space ratio, and DRR investment levels.

The relationships and multiplying risk factors that studies in this chapter of the research could be understood as:

- *Hazard × Exposure × Vulnerability = Risk*, with socio-economic fragility and governance gaps amplifying hazard impacts.
- Adaptive capacity improves with strong governance, coordinated institutions, and community engagement.
- Poorly planned density can multiply risks, while well-managed density can improve service efficiency and resilience.

Methodological insights from literature suggest that urban risk can be effectively assessed using multi-criteria approaches combining hazard mapping, vulnerability scoring, and resilience indicators (Revi et al., 2014; Tyler & Moench, 2012). Spatial analysis tools like GIS allow these layers to be integrated into a visual and analytical framework for targeted intervention planning. The analytical framework that could be developed based on the topics discussed in this chapter would be incorporated:

- Spatial overlay of hazard, exposure, and vulnerability data.
- Composite index development for risk and resilience using weighted indicators.
- Comparative analysis between cities to identify common challenges and unique risks.
- Integration of qualitative governance and policy capacity assessments.

This framework will guide the analysis of the three case cities: Accra, Cape Town, and Chennai, linking theoretical insights to measurable, city-specific indicators. The resulting methodology will combine quantitative spatial datasets with qualitative governance assessments to identify resilience gaps and adaptation opportunities in each urban context. Some common datasets for these cities would include identifying hazard zones, high density settlement mapping, informal settlements, groundwater tables, low-income population, policy reviews on water management, rainfall data trends, heat wave index, etc.

3 Methodology

This chapter explains how the research was designed, how data were collected, and how the different strands of analysis were brought together to answer the research questions. It follows the logic already introduced in Chapter 1, moving from global frameworks to city-level realities and finally to project-level interventions, using an indicator-based approach to compare findings across all case cities.

The methodology is structured into four main parts:

Research design and case selection *– the overall three-tier design, the choice of hazards and cities.*
Data collection *– sources and types of data for each tier.*
Data analysis and evaluation *– indicator framework, scoring, and comparative assessment, including how Global North and Global South analyses are linked.*
Study scope and limitations *– key constraints that shape how results should be interpreted.*

Together, these steps create a practical pathway from literature and global frameworks to concrete takeaways for Accra, Cape Town and Chennai, and to answers for the research questions stated in Chapter 1.

3.1 Research design and case selection

3.1.a Three-tier mixed-methods design

The study adopts a **three-tier, mixed-methods design** to evaluate how coastal cities address climate-change-induced hazards—urban flooding, coastal flooding and erosion, drought and water stress, and urban heat—through mitigation, adaptation and Disaster Risk Reduction (DRR).

Tier 1 – Global / Mainframe synthesis

This tier reviews global DRR and climate resilience frameworks and initiatives, including the Sendai Framework for Disaster Risk Reduction, the Paris Agreement, MCR2030, 100 Resilient Cities / Resilient Cities Network, C40 Cities, and guidance from UNDRR, UNFCCC, UN-Habitat and the World Bank. The objective is to distil shared goals, targets, hazard focus and typical strategies (e.g. Ecosystem-based Adaptation, Community-based Adaptation, blue–green infrastructure, water-sensitive urban design, urban farming, improved waste management). These serve as a normative benchmark for later assessment of the cities.

Tier 2 – Case-city baselines (Accra, Cape Town, Chennai)

This tier builds **diagnostic profiles** for the three Global South coastal cities. It compiles baseline information on:

- demographic trends and urbanization.
- land-use / land-cover change, green cover and imperviousness.
- coastal and hydrological characteristics.
- recorded climate-related hazards, losses and vulnerabilities.

Existing climate and DRR strategies and governance arrangements. The purpose is to situate each city's **risk context** and identify which hazards and vulnerable groups are most critical for DRR priorities.

Tier 3 – Project-level interventions and initiatives

The third tier evaluates specific interventions and initiatives that respond to these hazards, both in Global North and Global South contexts. In the Global North chapter, this includes, for example, Copenhagen's Cloudburst Management Plan, Amsterdam's Rainproof Programme, Barcelona's Climate Plan and Green Infrastructure Plan, and Chicago's Climate Action Plan and Riverwalk / Green Alley initiatives.

In the Global South chapter, it examines interventions such as Accra's Greater Accra Resilient and Integrated Development (GARID) project, Cape Town's Green Infrastructure Framework and drought response, and Chennai's programmes including Pallikaranai Marsh restoration and Water as Leverage / City of 1000 Tanks concepts.

Across all three tiers, the research combines qualitative policy and project review with indicator-based scoring and simple spatial analysis. This allows both narrative depth and structured comparison between cities.

Hazard focus and city selection

The hazard focus is restricted to **four climate-induced urban hazards** identified in Chapter 1 as most relevant for rapidly urbanizing coastal cities:

- Urban flooding (pluvial and fluvial),
- Coastal flooding and erosion / storm surge,
- Water stress and drought,
- Urban heat and heat-related health risks.

Accra, Cape Town and Chennai were selected as **Global South case cities** because they:

- are fast-growing coastal metropolis regions with high exposure to these hazards.
- have significant informal settlements and socio-economic vulnerabilities.
- are already engaged with global resilience initiatives such as C40, Resilient Cities Network, or MCR2030.
- offer accessible documentation on recent climate events, risk assessments and adaptation / DRR strategies.

Global North cities such as Copenhagen, Amsterdam, Barcelona and Chicago were chosen as "northern star" examples because they have relatively advanced climate and DRR strategies, especially in blue–green infrastructure, water-sensitive urban design and multi-hazard climate action planning.

3.2 Data collection

Data collection follows the three-tier design and uses only **secondary data**, with careful logging of sources to ensure transparency and reproducibility.

3.2.a 3.2.1 Tier 1 – Global / Mainframe

For Tier 1, the study compiles and reviews:

International frameworks and agreements

Sendai Framework for DRR (2015–2030) and its targets / indicators.

Paris Agreement, NDCs, and climate adaptation chapters.

Global urban resilience initiatives

Making Cities Resilient 2030 (MCR2030), 100 Resilient Cities / Resilient Cities Network, C40 Cities, and related guidance on urban climate resilience and DRR.

Technical guidance and assessment reports

UNDRR, IPCC, UN-Habitat, UNEP, and World Bank publications on hazard typologies, urban risk, and risk-sensitive planning.

Outputs from Tier 1 include a consolidated list of objectives, priorities, hazard types, and recommended strategies for coastal urban contexts, which form the benchmark used later when evaluating both Global North and Global South cities.

3.2.b Tier 2 – Case-city baselines (Accra, Cape Town, Chennai)

For each case city, the study collects three main types of data:

Demographic and socio-economic data

- Population size, density and growth (national statistics, census data, UN urbanization datasets).
- Informal settlement distribution, poverty, and access to basic services were available.

Geospatial and environmental data

- **Land-use / land-cover (LULC) and green cover**: changes over recent decades derived from remote-sensing products (e.g. Copernicus land-cover maps, national or city land-cover datasets) and case-specific studies on urban expansion, wetland loss and imperviousness.
- **Coastal metrics**: shoreline change and erosion hotspots, low-elevation coastal zones, sea-level rise exposure.
- **Hydrometeorological records / hazard maps**: flood extent maps for different return periods, drought indices, land surface temperature / urban heat island proxies, and water-stress indicators, mostly drawn from municipal climate adaptation plans and scientific literature.

Planning, policy and governance documents

- City climate change strategies and action plans (e.g. Accra Climate Action Plan, Cape Town Climate Change Strategy, Chennai Climate Change Adaptation Plan).
- DRR and resilience strategies, coastal management plans, green infrastructure frameworks, sectoral plans (water, drainage, housing).
- Baseline profiles in Chapter 5 draw directly on these datasets and documents to describe how each city's **hazard exposure, vulnerabilities and institutional responses** have evolved over the last decade.

3.2.c Tier 3 – Project-level studies

For Tier 3, the study collects more detailed evidence on **selected flagship interventions**, both in Global North and Global South cities. Data sources include:

Project documentation – strategy documents, concept notes, feasibility studies, EIAs/SEAs, monitoring reports, and budget / implementation summaries.

Spatial / visual evidence – project maps and diagrams (e.g. cloudburst catchment maps, heat mitigation parks, wetland buffers, shoreline protection schemes), before–after satellite imagery from published sources where available.

Supplementary material – municipal reports, press releases, local media articles, and community reports, used cautiously and triangulated against more formal sources.

Examples include Copenhagen's cloudburst catchment projects, Barcelona's green corridors and Superblocks, Accra's GARID detention basins and drainage upgrades, Cape Town's green infrastructure actions and drought measures, and Chennai's Pallikaranai Marsh and Water as Leverage pilots.

3.3 Data analysis and evaluation

The study applies a **stepwise, indicator-based and spatially informed** analytical framework, consistent with the conceptual discussion at the end of Chapter 2 and the framework diagram in Figure 1.4

3.3.a Indicator framework and themes

Indicators are organised into **five themes**, kept intentionally compact so that they can be populated consistently across the three Global South cities using available data:

Social Vulnerability (SV)

- SV1: Population in hazard-prone zones (e.g. floodplains, low-lying coastal zones).
- SV2: At-risk groups and informal settlements in hazard-exposed areas.

Urban Physical–Environmental Risk (PE)

- PE1: Extent of impervious surfaces and exposure of critical services (e.g. roads, power, water, transport).
- PE2: Resilience of critical infrastructure (protection standards, redundancy, siting away from high-risk zones).

Economic and Governance Capacity (EG)

- EG1: Evidence of economic loss from recent climate hazards (relative to city size).
- EG2: Presence of DRR / adaptation budgets, dedicated units, and planning instruments (used as proxy where exact financial data are not available).

Mitigation Strategies (MT)

MT1: Existence and implementation of low-carbon development actions that have DRR co-benefits (e.g. transit-oriented development, energy efficiency, low-emission waste systems).

Adaptation and DRR Strategies (AD)

- AD1: Coverage and quality of Ecosystem-based Adaptation / Nature-Based Solutions and blue–green infrastructure in hazard-prone zones (wetlands, parks, green corridors, coastal buffers).
- AD2: Community adaptive capacity, including early-warning reach, risk communication, resilient housing schemes, and inclusion of informal settlements in DRR measures.

For each indicator, a **simple ordinal scale (1–5)** is used:

1 = absent or very weak;

2 = emerging / pilot;

3 = partial / moderate coverage;

4 = substantial though not yet citywide;

5 = strong and well-embedded / citywide.

Scoring is based on **documented evidence** from climate plans, DRR strategies, project reports and scientific literature rather than subjective impressions alone.

3.3.b Compilation, scoring and simple spatial analysis

Analysis proceeds in several steps, adapted from the generic risk-indicator methods highlighted in Chapter 2 but simplified to match data availability:

Indicator definition and city-specific operationalisation

For each case city, indicators are translated into concrete variables using available data (e.g. "% of slums exposed to 25-year flood depth >1 m" for SV1/PE1 in Chennai; "share of green and blue areas within flood-prone zones" for AD1).

Data compilation and harmonisation

Hazard, exposure and vulnerability information from maps, tables and narrative reports is extracted into **city-specific indicator tables**.

Where possible, values are expressed as percentages of area, population or infrastructure (e.g. "46% of GCC area at inundation risk for 25-year events; 60% of slums affected").

Qualitative + numerical scoring

Each indicator is assigned a score between 1 and 5 based on the compiled evidence.

Where only qualitative descriptions exist (e.g. "pilot NBS projects"), these are translated to scores using clear thresholds (e.g. pilot = 2; multiple districts = 3–4; citywide = 5).

Simple spatial reasoning

Rather than building full new models, the study uses **existing hazard and exposure maps** from municipal plans and key studies—such as risk maps for Chennai's floods and sea-level rise, Accra's flood-prone basins, and Cape Town's flood and drought hazard zones—to identify **spatial hotspots** where high exposure and high vulnerability coincide.

Where new GIS work is undertaken (e.g. basic land-cover change maps, schematic overlays for GAMA or Chennai), it follows standard procedures for re-projection, overlay, and area calculation, but remains at a **diagnostic** rather than predictive level.

Scores are then **aggregated by theme** (SV, PE, EG, MT, AD) to produce a basic resilience profile for each city. The intention is not to produce a highly technical index, but to **visualise strengths and gaps** that support the more detailed narrative analysis in Chapters 4 and 5.

3.3.c Methods for Global North Exemplary analysis

The Global North chapter uses a **comparative case-study approach** based on structured reading of each city's climate and resilience documentation. For each city–hazard pair (e.g. Copenhagen–pluvial flooding, Barcelona–drought and heat, Amsterdam–urban flooding and WSUD, Chicago–combined flooding and heat), the analysis:

- outlines local hazard context and recent events.
- summarizes the main DRR and climate strategies and plans.
- identifies key measures and tools (e.g. cloudburst streets, multifunctional parks, green corridors, water plazas);
- records implementation and performance evidence, such as design standards, reported damage reductions, or observed co-benefits.
- classifies actions against the five indicator themes (SV, PE, EG, MT, AD) and notes scores were broadly comparable (e.g. strong AD1 / AD2 for Copenhagen's cloudburst interventions, strong MT1 for Chicago's mitigation measures).

The aim is not to rank Global North cities but to **extract transferable principles and practices** that later inform the discussion on how Global South cities could strengthen their DRR and climate resilience strategies.

Methods for Global South case-city analysis

The Case Cities chapter applies the indicator framework and spatial reasoning to Accra, Cape Town and Chennai. For each city, the analysis proceeds in three layers:

Hazard and vulnerability profiling

Narrative synthesis of climate conditions, recent extreme events, and known patterns of exposure and vulnerability (e.g. recurrent flooding and erosion in Accra; drought-flood duality in Cape Town; flood, heat and SLR risks in Chennai).

Extraction of quantitative figures from official plans and scientific studies (e.g. % of area and slums in flood risk zones, share of infrastructure affected, population in SLR areas, dependence on external water sources, prevalence of heat-prone roofs).

Assessment of DRR, mitigation and adaptation responses

Systematic reading of each city's climate action plans, DRR strategies and major projects to identify:

- structural measures (drains, detention ponds, seawalls);
- ecosystem-based measures (wetland restoration, green corridors, floodplains);
- governance tools (early warning, zoning, risk-informed resettlement);
- social and community-based approaches.
- Coding of these measures against the five indicator themes and scoring 1–5.

Project-level effectiveness review

For selected flagship interventions in each city (e.g. GARID components in Accra, Cape Town's green infrastructure actions, Pallikaranai Marsh restoration and Water as Leverage pilots in Chennai), qualitative performance is assessed along five dimensions proposed in the draft methodology: hazard reduction, environmental outcomes, social equity, governance and partnerships, and implementation / scalability.

Where before–after or comparative maps exist (e.g. changes in water retention, redistribution of flood risk, increase in green space), they are used as visual evidence to support the narrative.

3.3.5 Cross-city comparison, takeaways and response to research questions

Finally, the city-level results are brought together through **comparative tables and synthesis narratives** that directly address the research questions set out in Section 1.2:

For RQ1 (effectiveness of current practices)

Indicator scores and project reviews for each city are compared with Tier 1 benchmarks, highlighting where DRR and climate strategies are relatively strong or weak for each hazard.

This step underpins the **"Summary of Findings"** in the Conclusions chapter, showing, for example, how Accra performs on flood mitigation and waste management, how Cape Town balances drought and flood, and how Chennai is tackling compound heat–flood–SLR risks.

For RQ2 (innovative practices and success factors)

Measures such as blue–green infrastructure, wetland restoration, water-sensitive design, urban agriculture, and community-based programs are compared across Global North and Global South examples.

The analysis focuses on **conditions for success**: governance, finance, technical design, and social inclusion, as they emerge from the case material.

For RQ3 (policy, governance and data / tool use in data-scarce contexts)

The study reflects on how much cities rely on global frameworks, external partnerships, and basic geospatial tools to build DRR strategies with limited data.

Lessons are drawn on the practical role of simple GIS, open datasets and indicator-based assessments as **"good-enough" tools** for guiding DRR in Global South cities.

These comparative steps are the bridge between the descriptive case chapters, and the **takeaways and recommendations** presented in the final conclusions chapter.

3.4 Study area

Global cities are undergoing significant economic changes accompanied by rapid infrastructure development, redevelopment, and eco-sensitive urban measures. The juxtaposition of rising urban populations, land-use changes, economic reliability, biodiversity conservation, and ecosystem preservation in the context of the Sustainable Global City competition is a key area of this research. The comparison between Global North and Global South cities is not merely a branding exercise but a critical analysis of how DRR measures can be tailored to address the unique challenges of each region. This research primarily examines ongoing and past initiatives since the initiation of the Sendai

Framework and the Paris Agreement in 2015, focusing on global projects, collaborations, and multi-stakeholder participation in climate change adaptation, urban resilience, and DRR measures. The research gap lies in the critical appreciation and analysis of cities' efforts to integrate mitigation and adaptation strategies into their climate action plans, particularly in the context of Global South cities. Local challenges, issues, opportunities, and growth potential for smart and resilient cities in the Global South differ significantly from those in the Global North because of varying economic, geographic, and environmental conditions. This research focuses on frequently occurring hazard events in Global South cities and analyzes corresponding measures to identify effective DRR strategies.

3.4.a Accra, Ghana (Greater Accra Metropolitan Area)

Accra, located along the Gulf of Guinea, regularly suffers flash floods and coastal erosion. A large proportion of residents live in informal settlements exposed to stormwater and flooding risks, with limited drainage and inadequate housing systems (World Bank, 2021). The Metropolitan region of Greater Accra features a Tropical Savanna climate designated as "Aw" Koppen climate typology, this means that the region is generally warm year-round, with pronounced rainfall seasonality and a dry interval, fitting the pattern of southern coastal Ghana and much of West Africa bordering the Gulf of Guinea (Bessah et al., 2022). The coastal edge of the Greater Accra region stretches to 225 km in length with low elevation plains, lagoons and beaches that consistently face coastal erosion along with the frequent urban flooding, hotter temperatures and increased drought frequency that are altogether projected to intensify in coming years as per the present climate change scenarios {Siabi et al., (2024); Ansah et al., (2020); Addi et al., (2021), Addo and Addo (2016)}.

Figure 3.1 Floods across settlements, Accra Ghana (source: AfricaNews, 2024)

Among the most discussed issues, the improper waste management practices, poor sanitation, inefficient drainage systems, irregular urban expansion, and encroachment of wetlands are the primary reasons for urban flooding making serious damage to the infrastructure, human health and economy (Kyeremanteng P., 2025). According to Amoako and Inkoom (2017), over 60% of Accra's population resides in informal settlements, many of which are in flood-prone areas, making them highly vulnerable to climate change hazards. This vulnerability is further compounded by the lack of effective waste management and sanitation systems, which often lead to clogged drains and increased flood risks (Amoako & Inkoom, 2017). Almost 3 million people live in Accra, which has seen tens of thousands of residents forced to move to high-risk flood zones due to overcrowding. This issue has been magnified by the increasing frequency and intensity of rainstorms driven by climate change (AfricaNews, 2024).

The Greater Accra Metropolitan Area as per the World Urbanization Prospectus (2018), is expected to acquire an annual average urban agglomeration growth by 2.61% between 2030-2035 and the share of urban population will jump to 73.2% by 2050. With the current urban population 5,455,692 as per the Ghana Statistical services in its recent 2021 census, there is a looming risk of losing the existing biodiversity, natural catchment areas, degradation and loss of agricultural lands. Climatic events and most importantly human-induced changes could change their course of sustainable development and Accra Climate Action Plan 2020-2025 developed within the C40 initiative has adopted major decisions and steps toward low emission climate resilient development by 2050. Also on the other hand, the Greater Accra Resilient and Integrated Development (GARID) aimed towards flood risk management, solid waste management, and flood prone informal settlements, impacting over 2.5 million residents was launched in 2019 by Government of Ghana in collaboration with international partners such as the World Bank, Dutch government, AFD (French Development Agency) and SECO (Swiss government economic cooperation agency).
The research will provide an overview of Greater Accra's resilient city strategy as a fast-growing economy in a Global South city among African nations by analyzing Accra's Climate Action Plan 2020–2025 and the Greater Accra Resilient and Integrated Development (GARID) project, highlighting their integrated approach to urban flood risk reduction, infrastructure improvement, and climate adaptation for inclusive and sustainable growth. Furthermore, with the growing trends of extreme drought events and prolonged dry spells exacerbated by climate variability, the study will also explore the gaps in current strategies and assess the adaptive measures necessary to strengthen future climate action policies and regional collaborations, particularly in integrating water security, nature-based solutions, and urban heat resilience.

3.4.b Cape Town, South Africa

Cape Town, South Africa, sits within the distinct topography of the Table Mountain, the Cape Peninsula, rolling sandy soils, and the Cape Flats, most of which are flood-prone and low-lying with a coastline of 307km bordered by both the Atlantic Ocean and Table Bay. The climate is characterized by cool, wet winters (May–September) and warm, dry summers (November–March), classified as Mediterranean (Csb) climate (Jury, 2020). While the mean annual rainfall recorded is approximately 515mm, concentrated in winter months, while summer high temperatures typically range from 26–29°C and winter lows average 7–9°C (Jury, 2020), a steady increase in maximum and minimum temperature reflecting the effects of regional and global warming patterns (Ndebele et al., 2022)

As per the Rebelo et al. (2023) highlighted in the 'The Conversation' newsletter of Cape Town being the latest African city to redraft its climate change strategy addressing key challenges that includes a significant increase in temperatures, long-term decrease in rainfall, changes in rainfall seasonality, more extreme heat days and heat waves, and coastal erosion based on its 2018 risk and vulnerability assessment. During the years 2022 and 2023, severe wind and rainstorms shook the city of Cape Town frequently followed by widespread, deadly and destructive flooding in June and September 2023 floods alone recorded 8 fatalities and $75million (Omar & Conradie, 2024).

Ziervogel et al., (2019) cites the city's rapid urban expansion, coupled with its semi-arid climate, informal settlements, lack of adequate drainage systems, socio-economic inequalities, marginalized populations, inadequate infrastructure and limited access to services makes it more challenging in addition to the disproportionate impacts from climate hazards for local communities particularly susceptible to flooding during heavy rainfall events.

Figure 3.2: Flooding in Nyanga, Cape Town due to record breaking rainfall (Daily Maverick, 2023)

South Africa's coastal cities such as Cape Town experience eroding shorelines, frequent flooding, and the loss of critical infrastructure and natural habitats and a major issue is unresolved integrating climate and ocean concerns at the policy level were important to effectively address the rising sea level threat (Willima; Saad, 2025). During the severe drought run from to 2015-2018, the city’s water supply system crumbled as the taps were predicted to run dry, but eventually Cape Town escaped a severe crisis that could have been a “Day Zero” in its history (Enqvist & Ziervogel, 2019). According to *The Daily Mavericks (2022)*, a statement from the Western Cape Department of Local Government, Environmental Affairs, and Development Planning describes the province’s weather and climate regime as highly variable. It identifies the Western Cape as South Africa’s most disaster-prone province, particularly vulnerable to climate-related hazards. Its coastal location and rising sea temperatures are contributing factors, influencing regional weather patterns and amplifying the province’s exposure to climate risks.

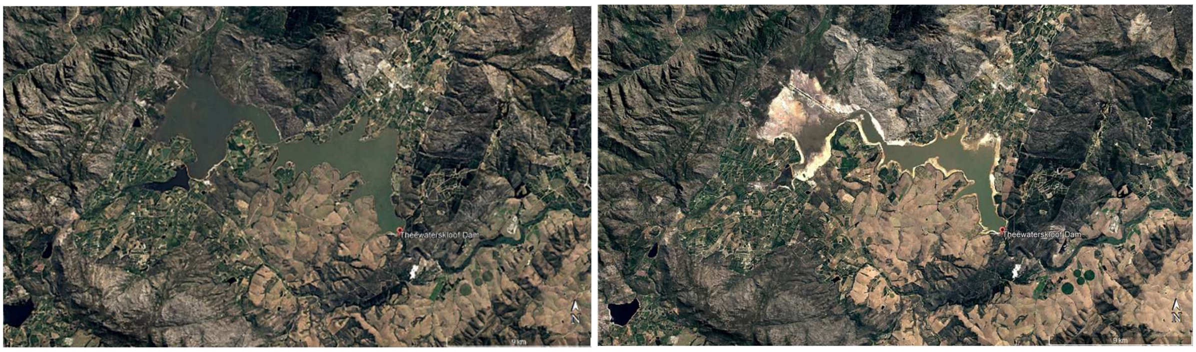


Figure 3.3: Theewaterskloof reservoir in Western Cape (Source: Daily Mavericks, NASA Earth Observatory)
These images show Theewaterskloof, the province’s largest reservoir, in Decemberr 2014 and in December 2017. Exposed sediment around the edge of the basin in the later image shows where the water level has declined.

The IPCC (2021) Working Group 1 in its report notes of West Southern Africa highlights that with global warming of at least 2ºC, there will be an “observed decrease in mean precipitation; observed and projected increase in aridity, agricultural and ecological droughts” and a “projected increase in dryness from 1.5°C, higher confidence with increasing global warming” by the mid-21st century. Cape Town is a striking example of how climate change can manifest in opposing extremes. While recent years have brought severe droughts that raised concern over declining water supplies, the city continues to face heavy rainfall and flooding. This seeming contradiction reflects the growing unpredictability and dual nature of climate impacts (Diemen, 2022). However, the risk flooding with rainstorms are discussed as the result of extreme vulnerabilities in the city of Cape Town and not necessarily the extreme climate change events and weather hazards, requiring less rainfall to develop a situation of flooded city (Davison; Diemen, 2022). Cape Town faces significant physical and geographical vulnerabilities, with many areas located in low-lying zones, surrounded by numerous water bodies and near the coastline. Social vulnerabilities are also prevalent, particularly among residents living in social housing within poorly planned and outdated neighbourhoodss, as well as informal settlements lacking adequate drainage infrastructure. These conditions, coupled with the limited adaptive capacity of local governance, exacerbate the city's risk in responding effectively to flood events.

The current Resilient City Strategy has been shaped largely in response to the severe drought experienced between 2015 and 2018, which now forms the foundation for water-related actions in the city's Climate Action Plan. This plan takes a holistic approach to achieve water sensitivity by 2040. The Climate Change Strategy and Action Plan identify two key strategic focus areas: first, promoting water sensitivity, flood readiness, and storm management through the restoration and rehabilitation of rivers and wetlands, development of livable urban waterways, improved flood risk mapping, and implementation of early warning systems; and second, enhancing water security and drought readiness by increasing water supply and reducing demand. The research here will identify effective measures and initiatives within the Climate change strategy and Climate Change Action Plan of Cape Town towards urban resiliency, along with the other academic resources.

3.4.c Chennai, India

Chennai's coastline extends roughly 25 km, characterized by sandy beaches and low-lying coastal plains that are increasingly impacted by urban growth and recurrent flooding (Robin et al., 2021). Situated on India's southeastern shore along the Bay of Bengal, the city experiences a tropical wet-and-dry (savanna) climate, marked by hot, humid summers and mild winters. Annual rainfall averages between 1,200 mm and 1,300 mm, with the majority occurring during the Northeast Monsoon (October–December) and the remainder during the Southwest Monsoon (June–September) (Robin et al., 2021; Rangarajan et al., 2018). Throughout the year, average monthly temperatures typically range from 25 °C to 33 °C (Robin et al., 2021; ISPRS Archives, 2023).

Looking at the 2015 winter monsoon floods, many experts considered it to be a man-made calamity rather than the result of one of the major climatic events for one of the largest economies in South Asia. "The Hindu" quoted the 2015 floods as "Decades of faulty planning, concretization of vast tracts of land, the colonization of water bodies, and encroachment" (The Hindu, 2022), while the CAG (Comptroller and Auditor General of India) mentioned in its hearing that it was a man-made disaster (The Hindu, 2018). On another article by The Hindu (2021) quoted 'Lack of a database on disasters, risk reduction and mitigation policies are major limitations' for the disastrous event that affected more than 1.5 million people while 400 lives were lost.

Apart from these events the "Water as Leverage for Resilient Cities Asia" programme supported by the Netherlands government in its publication "The City Report" (2018), highlighted some of the key issues the city of Chennai has been facing such as the loss of wetlands due to improper waste management and disposal. Coastal communities in Chennai, particularly fishing populations, are acutely affected by shoreline erosion, which damages homes, infrastructure, and fishing areas. This erosion not only leads to the loss of coastal land and displacement, undermining social and economic resilience, but also destabilizes roadways, buildings, and other critical infrastructure near the shore. As a result, repair and protection costs escalate, while urban mobility and safety are increasingly compromised (Periasamy, 2023).

While urbanization in Chennai increased from 1.46% to 18.55% in the period between 1991 and 2012, vegetation cover fell by 22%, and, if this trend continues, the loss might increase to 36% by 2026 (Aithal & Ramachandra, 2016; Tajuddin & Dąbrowski, 2021). As a result of rapid urbanization over the last two decades, the natural green areas and water bodies that provide buffers and enable the city's water management by absorbing and directing water away from built areas across the city have been threatened (Tajuddin & Dąbrowski, 2021). The expansion of urban infrastructure into wetlands, marshes, and coastal zones has reduced natural buffers against storms and floods, increasing exposure to hazards and intensifying impacts from climate events (Robin et al., 2021; ISPRS Archives, 2023).

By 2025, Chennai, with a population exceeding 12.3 million and ranking as the fourth largest city in India and the thirty first largest in the world (World Population Review), faces mounting pressures from rapid urbanization. Declining green cover, increasing flooding and coastal erosion, inadequate waste management, rising urban heat, and water scarcity are among the city's most pressing challenges, placing both its large population and diverse industries at significant risk. Addressing these issues within climate change strategies and adaptation plans will be examined in this research, with a focus on the potential integration of key Disaster Risk Reduction (DRR) measures through spatial planning tools to ultimately help reduce losses.

Figure 3.4: A view of CTO Colony in West Tambaram near Chennai is flooded with rainwater. (Source: The Hindu, G Krishnaswamy)

To summarize, the methodology adopted in this research follows a stepwise design that moves from global frameworks to local realities and project-level interventions. This structure ensures that the study is anchored in international commitments while remaining grounded in the lived experience of coastal cities facing climate-related hazards such as urban heat waves, drought and water stress, flooding, storm surge, and coastal erosion.

The first stage establishes a global mainframe for DRR and climate resilience. It draws on the Sendai Framework for Disaster Risk Reduction, the Paris Agreement, C40 Cities, the Resilient Cities Network, and Making Cities Resilient 2030, complemented by guidance from UNDRR, UNFCCC, UN-Habitat, the

World Bank, and the IPCC. Together, these frameworks clarify common goals, targets, and approaches, including ecosystem-based adaptation (EbA), community-based adaptation (CbA), water-sensitive urban design (WSUD), blue–green infrastructure, urban farming, and improved waste management. This stage serves as a benchmark against which city-level practices are interpreted, highlighting how international cooperation, financing, and partnerships frame pathways toward resilience in coastal contexts.

The second stage turns to the Global South case cities: Accra, Cape Town, and Chennai, to build a shared baseline of vulnerabilities, exposures, and resilience capacities. Using demographic and urbanization data, the analysis traces settlement expansion along coastlines and the concentration of informal settlements in hazard-prone zones. Geospatial methods are applied to track land-use change, loss of green cover, increasing impervious surfaces, and selected coastal indicators such as shoreline change and groundwater stress. These inputs help identify dominant hazards in each city and show how risk patterns have evolved over the past decade, ensuring that the study is rooted in context-specific realities rather than abstract generalizations.

The third stage focuses on project-level interventions that address priority climate risks, such as wetland and lagoon restoration, groundwater recharge schemes, urban greening and cooling projects, and coastal defense or flood retention systems. Each project is assessed in terms of environmental outcomes (e.g. green cover gain, cooling, water storage), social outcomes (populations protected or benefiting, especially vulnerable groups), and governance arrangements (roles of municipalities, national agencies, communities, and international partners). Where detailed monitoring data are limited, proxies derived from remote sensing, secondary statistics, or established coefficients are used to maintain an evidence-based assessment. Selected Global North examples are briefly reviewed to extract transferable lessons without assuming direct replication.

Across these stages, an indicator-based framework structures evaluation. Indicators are grouped into five themes: (1) social vulnerability, (2) urban physical–environmental risk, (3) economic and governance capacity, (4) mitigation strategies, and (5) adaptation strategies. Each indicator is scored on a 1–5 scale, and an equal-weight model is used as the baseline, with flexibility to adjust weights where specific hazards are clearly dominant. Composite indices are then calculated to generate a resilience profile for each city and to enable cross-city comparison.

In this way, the methodology directly addresses the research questions. It evaluates how current practices manage climate-related hazards (RQ1), identifies innovative approaches such as blue–green infrastructure, nature-based solutions, and WSUD (RQ2), and examines how policy frameworks, governance structures, and geospatial or AI-based tools can strengthen DRR in data-scarce contexts (RQ3). The result is an integrated framework that links global ambition to local implementation and project performance, offering insights into how coastal cities in the Global South can navigate climate risks and build more resilient futures.

3.5 Study scope and limitations

The methodology is designed to be robust yet realistic for the research relying on **secondary data and limited original spatial analysis**. Several limitations need to be acknowledged:

Dependence on existing data and reports

The analysis is constrained by the quality, resolution and currency of available city plans, hazard maps and scientific studies. Some indicators could only be populated qualitatively, and data are not always directly comparable between cities.

No primary surveys or interviews

Due to time and resource constraints, the study does not include fieldwork, community surveys or key-informant interviews. Governance and social equity aspects are therefore interpreted from documents rather than lived experience.

Simplified spatial analysis

The thesis uses basic overlays and reading of existing hazard and exposure maps rather than performing new hydrological or climate modelling. Results are diagnostic and comparative, not predictive.

Subjectivity in scoring

Although scoring is grounded in documented evidence and consistent rubrics, it still involves interpretive judgement. Scores should therefore be read as relative assessments that support narrative insight, not as precise measurements.

Limited number of case cities

Focusing on three Global South coastal cities and a selected set of Global North exemplars allows depth but limits generalizability. The intention is to provide illustrative lessons, not universal rankings.

Despite these limitations, the combination of global framework synthesis, city-level diagnostics, project-level reviews, and indicator-based comparison provides a coherent basis for answering the research questions. It also offers a practical and reproducible method that other researchers and practitioners could adapt to assess DRR and climate resilience in similar coastal urban contexts.

Following table is considered as the guidelines and indicator matrix for a comparative assessment of the Projects and further Cities.

Table 3.1: Table for the Indicators considered in assessing case cities

Theme	Indicator code	Indicator name	Operational definition	Preferred metric / proxy	Primary data sources	Scoring rule (1–5)
Social Vulnerability (SV)	**SV1**	Population in hazard-prone zones	Share of total population living in mapped flood, coastal, drought- or heat-risk zones (combined or per hazard).	% of city population in hazard areas; or qualitative classes from official risk assessments.	City climate action plans & DRR strategies; national census; UN or WB risk studies.	1 = negligible exposure; 2 = limited pockets; 3 = moderate, spatially concentrated; 4 = high; 5 = very high, widespread exposure.
	SV2	At-risk groups & informal settlements in hazard areas	Extent to which informal settlements, low-income or other vulnerable groups are in hazard-prone areas.	% of informal settlements / social housing in hazard zones; or narrative classification.	Slum / informal settlement maps; social vulnerability studies; DRR plans.	1 = almost none; 2 = few clusters; 3 = moderate exposure; 4 = extensive; 5 = very extensive, majority of vulnerable groups exposed.

Urban Physical–Environmental Risk (PE)	**PE1**	Impervious surface & exposure of critical services	Degree of impervious cover and concentration of critical infrastructure (roads, transport, utilities, hospitals, schools) in hazard zones.	% impervious area in hazard zones; length of critical roads / # facilities in flood / coastal risk areas.	LULC maps; infrastructure maps; hazard maps; published case studies (e.g. Kaaviya & Devadas 2021 for Chennai).	1 = low imperviousness & low service exposure; 5 = very high imperviousness & many critical services in high-risk areas.
	PE2	Critical infrastructure resilience	Quality of protection, redundancy and siting of key systems (water, power, transport, drainage) vis-à-vis hazards.	Design standards; backup systems; relocation away from high-risk zones; documented performance in recent events.	Climate / resilience strategies; sector plans; post-event assessments.	1 = largely unprotected, frequent failures; 3 = partial protection / redundancy; 5 = robust, risk-sensitive design and operation.
Economic & Governance Capacity (EG)	**EG1**	Economic loss from climate hazards	Scale and recurrence of economic damages and disruption from recent climate events relative to city size.	Damage estimates, loss of GDP / service downtime; where missing, qualitative severity from reports.	World Bank / UN reports; national disaster reports; peer-reviewed studies (e.g. GARID, Day Zero analyses).	1 = very low or rare; 3 = moderate recurring losses; 5 = very high, frequent, systemic losses. *(Higher values = more risk, i.e. lower resilience.)*
	EG2	DRR / adaptation governance & financing	Existence and strength of dedicated DRR / climate units, strategies, and indicative budgets or external support.	Presence of climate/DRR strategy; dedicated office; budget lines; international programmes (C40, MCR2030, R-Cities, etc.).	1 = ad hoc, no clear strategy; 2 = strategy on paper only; 3 = active but limited; 4 = strong with growing budgets; 5 = very strong, mainstreamed across departments.	
Mitigation Strategies (MT)	**MT1**	Low-carbon development with DRR co-benefits	Extent to which mitigation actions (energy, mobility, buildings, waste) also reduce hazard risks (heat, flooding, air quality).	Existence and implementation of climate mitigation plans; share of renewables; modal shift; building retrofits; waste reforms with DRR links.	City climate/energy plans; sector strategies; e.g. Copenhagen Carbon Neutral Plan, Chicago CAP, Accra CAP.	1 = no or minimal linkage; 2 = isolated pilots; 3 = several measures; 4 = broad programme; 5 = citywide, integrated into planning.
Adaptation & DRR Strategies (AD)	**AD1**	Ecosystem-based / nature-based and blue–green measures	Coverage and integration of EbA/NBS (wetlands, parks, green corridors, green roofs, floodplains, coastal buffers) in high-risk areas.	% of hazard-prone area under functional BGI; number / scale of EbA projects; qualitative coverage.	Green infrastructure plans; wetland / coastal / river restoration projects (e.g. Pallikaranai Marsh, GARID detention areas, Cape Town GI Framework, WaL).	1 = absent; 2 = pilots; 3 = moderate coverage; 4 = substantial though not citywide; 5 = well-embedded and citywide network.
	AD2	Community adaptive capacity & inclusion	Strength of early warning, risk communication, community participation, and inclusion of informal settlements in DRR.	Existence / coverage of EWS; community-based DRR; co-designed projects; relocation / upgrading schemes; social protection.	Resilience strategies; participation frameworks; project reports; CbA documentation.	1 = minimal awareness / participation; 2 = limited projects; 3 = moderate but uneven; 4 = strong in many areas; 5 = very strong, institutionalised and inclusive.

4 Lessons from Global North Cities and Analysis

4.1 Copenhagen Cloudburst plan

Figure 4.1: Submerged streets in Copenhage (source: City of Copenhagen; State of Green, 2023)

The 2011 cloudburst served as a critical turning point in the city's climate adaptation policy. On 2 July 2011, Copenhagen received nearly 135 mm of rainfall in a single day, with localized peaks of up to 150 mm within two hours. This event resulted in damages approximately €0.8–1.0 billion in insured losses and caused widespread disruption to infrastructure (UNDRR Prevention-Web, 2022; The American-Scandinavian Foundation, 2013).

Copenhagen is a low-lying coastal city that experiences a temperate climate. The local meteorological conditions are compounded by risks of sea-level rise and higher groundwater tables (World Bank; City of Copenhagen, 2011). The European Environment Agency (EEA) and the Danish Meteorological Institute (DMI) project that winter precipitation could increase by 25–55% by 2100, while heavy-rain intensity may rise by 20–50%. Without efficient and adequate adaptation strategies in place, such extremes are likely to overwhelm Copenhagen's legacy combined sewer systems and with the rising sea level the Danish coastal cities including Copenhagen are under a long-term risk (Colgan et al., 2022; European Environment Agency, 2016).

The Copenhagen Cloudburst Management Plan (2012) sets out a structured approach to risk dimensioning in response to extreme rainfall. The City of Copenhagen acknowledges that it is neither technically feasible nor economically justifiable to protect the city against all possible rainfall scenarios. Instead, an acceptable standard of protection is defined. Analyses undertaken for the plan show that when floodwater levels are kept at approximately 10 centimeters on roadways, the risk of water entering basements is negligible, and basic urban mobility by car, bicycle, and foot can still be maintained. Consequently, 10 cm has been designated as the acceptable maximum flood depth for pluvial events.

Risk dimensioning is expressed through two key parameters: the frequency of acceptable flooding and the acceptable depth of floodwater. Socio-economic assessments demonstrate that the most beneficial balance occurs when Copenhagen is protected against 1-in-100-year flood events. Higher levels of protection yield disproportionately high costs with limited additional benefit, while lower levels reduce construction costs but expose the city to much higher damages. The plan therefore recommends a revised standard: sewer discharge may continue to reach the ground level once every 10 years, but water levels exceeding 10 cm above ground should only occur during events of a 1-in-100-year intensity. Exceptions are made for designated storage areas intended to manage excess floodwater.

Under the Cloudburst Management Plan, each water catchment area in Copenhagen is evaluated on four criteria: flood risk, ease of implementation, alignment with urban development projects, and potential for synergies. Areas with higher risk and stronger connections to urban development are prioritized for action.

Given that full implementation of the Cloudburst Management Plan is expected to extend over a 20-year horizon, the city has adopted a prioritization framework to phase interventions effectively. This framework ranks catchment areas and projects on the basis of four elements:

- Flood risk – areas identified on risk maps as most vulnerable to damage receive the highest priority.
- Ease of implementation – locations where water can be redirected with relatively simple measures, such as near the harbour, are advanced in the sequence.
- Alignment with ongoing urban development – flood projects are coordinated with activities such as road renovations or neighbourhood renewal to maximize efficiency and reduce costs.
- Synergistic effects – measures that contribute to broader urban goals, such as blue–green corridors, recreational landscapes, or compliance with water directives, are prioritized.

To operationalize this system, Copenhagen has been divided into 26 local catchment areas, each assessed according to the four criteria. Adaptation activities are initiated simultaneously in several areas, coordinated with roadworks and redevelopment projects across the city. In some districts, natural watercourses such as Harrestrup Å are employed as main floodways, while in others, new engineered flood routes are designed. Wherever possible, these new infrastructures are conceived as green recreational spaces, reinforcing the city's wider strategy of expanding its blue–green infrastructure.

Figure 4.2:Copenhagen flow routes – The flow routes start at the point where the lines are thin and become thicker proportional to the quantities of water flowing into them. You will notice that all flow routes end in the sea despite the long distance travelled in some cases. (source: City of Copenhagen – Cloudburst Management Plan, 2012).

The plan's 20-year timeframe, projects will be initiated in multiple catchment areas simultaneously rather than sequentially. Adaptation measures are coordinated with ongoing city works, such as road renovations and urban development which may require adjustments to the original ranking order.

In some areas, such as the Harrestrup Å catchment, existing natural watercourses can serve as primary floodways. In most districts, however, new floodways must be constructed, ideally along natural flow paths. Wherever possible, these are designed as green recreational spaces, ensuring that climate adaptation investments also contribute to Copenhagen's blue-green infrastructure and broader urban livability.

4.1.a Enghaveparken Counteracts flooding

Designed by Arne Jacobsen in 1927, the Enghaveparken is now the largest climate project in Copenhagen. With a 22.600 m3 water reservoir, the park has been positively transformed into a large retention basin and as well as for recreational opportunities for everyday use. Normal rainfall from rooftops in Enghaveparken's catchment area is led onwards to the park via a closed piping system. In the park's Rosegarden, five underground pipes, each measuring 100 metres, make up a 2,000-cubic-metre circular retention basin (*Klimatilpasning*, 2020).

Enghaveparken exemplifies the "sponge park" concept with adaptive, resilient urban infrastructure integrating urban design with water management to address extreme rainfall while enhancing public space. The park serves recreation, social gathering, and water management, ideal for maximizing urban land use. The project has been backed with strong governance, financing mechanisms, and commitment for climate change adaption. It also incorporates water recycling measures, enabling rainwater collected on site to be reused for irrigation, cleaning, and fountains. This reduces demand on potable water supplies, while enhancing biodiversity and ecological value within the park. Such integration of resource efficiency with adaptation demonstrates how climate resilience can be combined with environmental stewardship.

Figure 4.3: Enghaveparken Climate Park (source: State of Green)

One of the defining strengths of Enghaveparken is its multifunctionality. On ordinary days, it operates as a recreational and social space where residents gather, children play, and communities interact. Yet during extreme rainfall events, the park transforms into a functional stormwater reservoir, capable of holding more than 22,600 cubic metres of water. This dual-purpose design ensures that valuable urban land is used efficiently, serving both everyday social needs and critical climate adaptation functions.

Another vital dimension is the role of *community involvement*. The City of Copenhagen, in partnership with Områdefornyelsen Vesterbro and the utility HOFOR (Hovedstadsområdets Forsyningsselskab – Greater Copenhagen Utility), actively engaged residents in the design process. This participatory approach fostered a sense of ownership and awareness among citizens, strengthening social resilience and ensuring the park reflects the needs of its local users. In this way, the project became not only an infrastructure investment but also a civic collaboration. (klimatilpasning, 2020).

The following table provides an idea on the functional approach and functional aspects of the Cloudburst Management Plan with the example of Enghavenparken's transformation in accordance with its alignment with some common DRR and MCR 2030 goals and targets.

Table 4.1: Enghaveparken's Approach alignment with DRR Strategies of Sendai Framework

DRR / MCR2030 Strategic Target	Enghaveparken's Approach & Contribution
Sendai Priority 1 – Understanding disaster risk	Community engagement in design raised awareness of pluvial flooding; the park itself demonstrates risk visually, turning abstract hazards into everyday experience.
Sendai Priority 2 – Strengthening disaster risk governance	Multi-stakeholder collaboration between City of Copenhagen, HOFOR, local residents, and foundations created shared ownership and integrated governance.
Sendai Priority 3 – Investing in disaster risk reduction for resilience	Park retrofitted to retain 22,600 m^3 of stormwater, reducing direct flood damages and protecting dense Vesterbro district.
Sendai Priority 4 – Enhancing disaster preparedness & "Build Back Better"	Flexible surface-based solutions (sports courts, rose garden, plazas) double as water basins during cloudbursts, embodying resilient urban design that adapts to extremes.
Sendai Target C – Reduce direct economic loss	Avoided flood damages, property value protection, and enhanced recreational/amenity value.
MCR2030 Stage A – Awareness	Public consultation and visibility of adaptation raised local understanding of cloudburst risks.
MCR2030 Stage B – Planning	Integration into Copenhagen's Cloudburst Management Plan and catchment-based urban strategy.
MCR2030 Stage C – Implementation	Fully delivered multifunctional climate-park that combines resilience, recreation, and ecology as a flagship adaptation project.

The redevelopment of Enghaveparken illustrates how climate adaptation can be harmonized with cultural preservation and innovative design. The project demonstrates that it is possible to integrate robust stormwater management systems without compromising the historic and aesthetic qualities of a city park.

4.1.b An overview of Copenhagen's strategies for Climate Resiliency

The **Climate Adaptation Plan** of Copenhagen 2011 has been the mainframe guiding principle at the core for developing city's strategies towards reduced risks from climate change extreme events. The city despite being a coastal city, has less exposure than other Danish coasts but the plan still discusses risks and strategies:

- Copenhagen's coastline is mostly artificial (harbours, filled land, beaches), so direct coastal erosion is limited compared to natural coasts.

- However, sea-level rise and storm surges increase risk of erosion, flooding, and infrastructure damage

The City of Copenhagen's focuses majorly on reducing the impact of extreme events and prevent major losses, and towards coastal protection the city lays out limitations for new developments along the coastal edge with strict provisions to withstand waves and higher water levels quay walls, stone armoring, and robust design in waterfront development. It has primarily made the landowners who benefit under the coastal protection act towards financing their facilities for barriers such as dikes, and breakwaters.

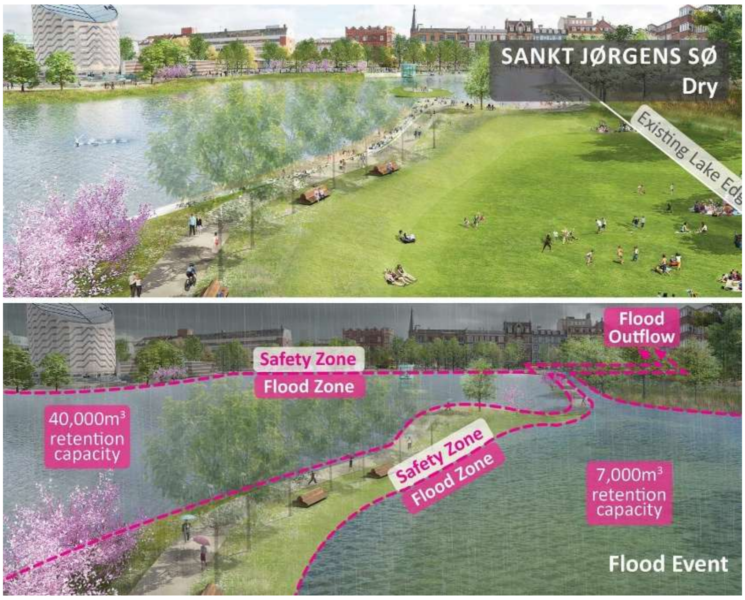


Figure 4.4: A before and after illustration of one of the parks in Copenhagen for Rainwater restoration and active response to extreme rainfall events. (source: Urban Governance Atlas, 2023)

The Climate Adaptation Plan of Copenhagen is a majorly risk-based, adaptation-focused, preparing the urban environment against climate risks (floods, storms, heat, drought) with strong emphasis on resilience, green-blue infrastructure, and flexible planning. The Cloudburst Management Plan 2012 became one of its primary implementation strategy of the climate adaptation plan and as of mid-2025, Copenhagen is evolving toward a "sponge city" concept integrating nature-based and engineered infrastructure to soak up, store, and redistribute floodwaters, enhancing resilience against extreme precipitation events(*'Sponge City': Copenhagen Adapts to a Wetter Future*, 2025).

In the 2011 Climate Adaptation Plan, rising temperatures and more frequent heatwaves are identified as significant urban risks for Copenhagen. The plan emphasizes the Urban Heat Island (UHI) effect, whereby dense clusters of buildings, paved surfaces, and infrastructure retain heat. Unlike rural surroundings, urban areas remain warmer both day and night, and prolonged heatwaves intensify this effect, limiting night-time cooling and straining both public health and ecosystems (City of Copenhagen, 2011). To address these risks, the plan outlines considerations and actions. At the municipal level, strategies promote green and blue spaces—parks, canals, and waterfronts—to lower temperatures and improve ventilation. Open courtyards, promenades, and shaded recreational areas are also encouraged.

At the local level, requirements include planting trees, ensuring shaded areas, and integrating cooling systems into new developments. Shading must be balanced with daylight, and space is recommended for district cooling systems based on groundwater or seawater. Through building regulations, the plan highlights indoor comfort through shading, orientation, and ventilation. Beyond regulation, the city commits to monitoring and research, including surface temperature studies and assessments of optimal levels of green and blue infrastructure. Special emphasis is placed on greening dense areas with little open space (City of Copenhagen, 2011).

Finally, the plan identifies Vesterbro, Sydhavnen, Amagerbro, Nørrebro/Bispebjerg, and the Inner City as priority areas where compact forms and limited vegetation intensify UHI impacts. These districts are targeted for interventions to enhance resilience during future heatwaves (City of Copenhagen, 2011).

Copenhagen's push for carbon neutrality by 2025 is framed as both a global climate responsibility and a response to local health hazards tied to air pollution and heatwaves. The city notes that carbon emissions and air quality are interconnected: fossil fuel combustion not only drives global warming but also contributes to smog and particulate pollution, worsening heat stress during extreme events (City of Copenhagen, 2016). By reducing emissions through renewable energy, efficient transport, and green mobility, Copenhagen aims to lower local air pollutants, thereby improving public health and reducing the vulnerability of residents during heatwaves. This framing elevates carbon neutrality as a mainstream urban priority, linking climate mitigation with direct quality-of-life improvements.

The **Copenhagen Carbon Neutral Climate Plan (2025 Plan)** represents one of the most ambitious city-level mitigation strategies in Europe. Adopted in 2012 and reinforced through roadmaps in subsequent years, with a strong emphasis on reducing greenhouse gas emissions while aligning with sustainable urban development it envisions to position Copenhagen as the world's first carbon-neutral capital (City of Copenhagen, 2016).

One of the central pillars of the plan is energy efficiency retrofits in buildings. The city highlights that inefficient heating and ventilation in housing stock waste energy and increase emissions. Through the Energy Leap partnership, major building owners, housing associations, and the municipality committed to optimizing heating installations and retrofitting outdated building envelopes, including roofs and facades, with a target of 20–30% reductions in energy use (City of Copenhagen, 2016). Such interventions simultaneously cut CO_2 emissions, lower energy costs, and improve indoor comfort during both heatwaves and cold spells, reinforcing resilience while advancing the neutrality goal.

Copenhagen's 2016 carbon neutral climate plan is mitigation-focused, cutting emissions through *renewables, mobility transition, and efficiency*. It frames carbon neutrality as both climate action and economic opportunity and shows that energy efficiency retrofits are central to its carbon neutrality strategy. The city targets a 20% cut in heat use, 20% in commercial electricity, 10% in households, and 40% in municipal buildings by 2025, contributing about 7% of total CO_2 reductions.

Through the Energy Leap partnership, building owners and housing associations committed to improving efficiency across 17% of the city's building stock, projected to reduce 6,000 tonnes of CO_2 by 2025. Priority is given to retrofitting E–G labelled buildings, which consume 23% of residential and 32% of commercial energy.

The city allocated DKK 161 million (2017–2020), rising to DKK 188 million by 2025, for retrofits. Beyond emissions cuts, these investments improve indoor climate and noise conditions, linking mitigation to resilience during hazards such as heatwaves.

4.2 Drought Hit Barcelona: 2008

After a previous drought struck Barcelona in 2008, the city invested in recycling wastewater, desalinating seawater and persuading citizens to save more drinking water. Its efforts have increased supply and brought the city's demand for water down to some of the lowest levels in Europe. (The Guardian, 2024).

According to Martin-Ortega & Markandya (2009), based on their findings on drought struck Barcelona (so-called Ter-Llobregat system) in 2008, the Catalonian city recorded a loss of 1,661 million Euros (1% of the Catalonian GDP) over an year period through significant direct, indirect, and non-market welfare losses, alongside public communication campaigns that drove demand reduction and fostered public participation. The chronological order of the episode of drought in Catalonia states the city region went at 52% of its water reserves at the beginning of 2007, which enforced a Drought Management Plan and a Permanent Committee. It took a year for the water reserves to become 21% in Mar 2008, until the shipping of water and the precipitation levels revived the city in the following months. Finally in Jan. 2009 the city sees through intense precipitation with the reserves getting back to 77%, with all the river basins resuming to their normal levels.

Figure 4.5: Posters in a subway station in Barcelona declaring a drought emergency. (Source: [The Guardian])

In the span of over 24 months the city saw a comprehensive water management plan that included recycling of wastewater, improvement and enlargement of desalination plants, reducing potable water uses for public utilities, 15% decrease of irrigation resources, a water shipping plan, aggressive public communication campaign with reduced per capita water consumption at 105L/ day.

The city of Barcelona has suffered recent floods due to the drought and new norms are in place to mitigate water scarcity and floods, but only on the sites of new buildings. Barcelona has been supplying water from the aquifer to irrigate green areas. Phreatic water currently covers 20 % of urban gardens requirements but there is enough water to cover 100 % of green areas' requirements ((Del Mar Pérez Cambra et al., 2025).

A project completed three years ago along the 'Salzereda promenade in Santa Coloma de Gramenet', introduced a 500-meter-long walkway designed to allow rainwater infiltration without the use of impermeable barriers. Prior to the intervention, the area experienced frequent water accumulation caused by the absence of slope and the presence of elevated planters.

The new infrastructure channels approximately 90% of the walkway's runoff into rain gardens connected to drainage trenches and infiltration wells. The trenches, measuring 40 by 60 centimetres, direct water into wells that are 4 meters deep and 2 meters in diameter. These wells also function as overflow systems, thereby preventing flooding. The accumulation of water due to poor drainage was remodeled to have increase the rainwater infiltration by 90%.

Figure 4.6: Before and after of the Salzereda Promenade (source: European Commission)

Barcelona has prioritized WSUD's as a measure to mitigate the rising climate change risks that included greywater recycling, increased capacity for desalination plants, and managing the stormwater with rainwater reuse. The RESilience to cope with Climate Change in Urban arEas shortly known as **RESCCUE** developed the Resilience Action Plan for Barcelona in 2020 identifies the climate change risks will evolve and projected a 11% reduction in surface water by 2100, 12-16% increase in rainfall intensity and 30–40% more high-hazard flood zones for pedestrians and vehicles. RESCCUE listed 4 strategies and multiple measures that target: Water security, flood resilience, institutional governance, and cross-sector integration.

Barcelona also has a Climate Plan in effect, developed by Ajuntament de Barcelona that has laid out plans for 2018-2030. It has several lines of action, out of which one is the coastal improvement addressed as the seafront conservation that outlines ensuring the functional integrity of the coastline. Key short-term plans included Redefining the existing coastal use, inclusivity with the Green Corridor Network, and Beach regeneration by sediment conservation but the Mid and Long-term goals and plans mainly emphasized in increasing coastal resiliency, reduced discharge during heavy rainfall events and ensuring sufficient quality of discharged water.

Flood impacts reduction in a context of Climate Change

Measures to reduce the impacts of flooding events identified for Barcelona in the framework of RESCCUE project. It includes structural measures, non-structural measures and nature-based solutions.

Environmental improvement of receiving water bodies

Measures to decrease the impacts of combined sewer overflows (CSOs) by: limiting the entrance of stormwater into the sewer system, increasing the retention capacity of the urban drainage/sanitation system during storm events or anticipating preventive actions through early warning.

Not a single drop wasted. Alternative water resources

Use of alternative water resources such as regenerated water, groundwater, greywater, rainwater or desalinated water to increase water availability and guarantee water supply during critical situations such as drought or turbidity episodes in water treatment and supply processes.

Guarantee security of services provision

Measures intended to increase the resilience of urban services to critical events such as the ones caused by climate change. It includes a city resilience diagnosis) development of the resilience action plan (with its corresponding strategies to the city and its urban services resilience) and resilience management centre to rapidly respond during critical situations.

Figure 4.8: RESCCUE strategies based on Barcelona Resilience Action Plan by Barcelona City Council (source: Author)

Figure 4.7: Barcelona Green Network Corridor (source: Ajuntament de Barcelona, 2020)

Barcelona also has Green Infrastructure and Biodiversity Plan induced in 2020 alongside its Resilience Action Plan which strategically focuses on increasing the green network and corridors within the city. According to ISGLOBAL (2019), the total recorded green spaces were at 7.3% and plans to increase it to 11% by 2030 under its Green Corridor plan. The GIBP provides a framework to build on strengthening the ecological infrastructure with nature-based solutions that promote the environmental and sociocultural values with multiple functional qualities and services to offer. The GIBP is a larger long-term plan within the frameworks of both the Resiliency Action Plan and the Climate Plan that are making a major impact towards risk reduction and climate resilience.

Looking at Barcelona City's response towards climate change risks, the active policies and initiatives have brought significant positive changes, the city has reshaped its WSUD's from its learnings of 2008 drought scenarios into major sociocultural, economic and environmental opportunities. The Climate Plan (2018–2030) establishes the overarching climate policy framework and targets for mitigation, adaptation, and climate justice. The Resilience Action Plan (2020–2030) operationalizes hazard-specific resilience across urban systems, particularly focusing on water management, flooding, and heat stress. Complementing these, the Green Infrastructure and Biodiversity Plan (2020) prioritizes nature-based solutions that enhance ecological connectivity and urban permeability, thereby supporting both mitigation and adaptation objectives (Ajuntament de Barcelona, 2018; Ajuntament de Barcelona, 2020a; RESCCUE, 2020).

Barcelona has strategically increased its green cover and improved city permeability. The addition of over 44 hectares of parks (2017-2019) and planned 165 hectares by 2030 underscores this commitment. Green accessibility now reaches over 90% of residents. Green Corridors expect a 3.64% increase in green surface area, delivering public health benefits via lowered mortality. Superblocks mitigate urban heat by reducing temperatures by around 1.2 °C through enhanced public greenery. Meanwhile, permeable, nature-based enhancements in plazas capture and infiltrate nearly half the rainwater, supporting urban aquifer recharge and stormwater resilience. (Ajuntament de Barcelona, 2018; Ajuntament de Barcelona, 2020a; RESCCUE, 2020).

Framework	Timeframe	Inclusive Features	Services Addressed	Impact Areas
Climate Plan (2018–2030)	2018–2030	242 actions structured around mitigation, adaptation, climate justice, and citizen engagement	Energy efficiency, low-carbon mobility, circular economy, water efficiency	Carbon reduction, energy transition, improved air quality, social equity in adaptation
Resilience Action Plan (2020–2030)	2020–2030	4 strategies & 27 measures, developed under RESCCUE; integrates risk-based, cross-sector analysis	Water cycle (supply, wastewater, stormwater), mobility, energy, urban services	Water availability, flood risk reduction, multi-sector governance, systemic resilience
Green Infrastructure & Biodiversity Plan (2020)	2020–2030	Expands green space (160 ha new greens by 2030), ecological connectivity, renaturalization	Urban greening, biodiversity corridors, ecosystem services, nature-based solutions	Urban cooling, biodiversity restoration, improved permeability, public health benefits

Barcelona's Climate Plan (2018–2030), Resilience Action Plan (2020–2030), and Green Infrastructure and Biodiversity Plan (2020) operate as interlinked frameworks that reinforce one another. The Green Infrastructure Plan, through green corridors and improved urban permeability, underpins the Resilience Plan's goals of flood reduction and urban cooling, while also advancing the Climate Plan's emission-reduction targets. In turn, the Resilience Plan's emphasis on water security and stormwater management directly aligns with the adaptation priorities of the Climate Plan, ensuring that measures addressing drought, heat, and extreme rainfall are integrated. Collectively, these frameworks create a coherent strategy where nature-based solutions and water-sensitive design enhance both climate resilience and long-term sustainability.

4.3 Chicago Climate Action Plan | Riverwalk redevelopment

Chicago, situated along the confluence of the Chicago River's main branches within a humid continental climate, faces distinct urban resilience challenges. Its historic industrial legacy, river channelization, and extensive impervious surface coverage, especially through its vast alley network (~1,900 miles); have exacerbated flood risk, combined sewer overflows, and urban heat island effects (City of Chicago, n.d.; Newell et al., 2013). The city's resilience trajectory has evolved from monumental civic planning (e.g., Burnham's vision) to tactical green infrastructure interventions. Two major initiatives illustrate this blend:

the Green Alley Program addressing localized stormwater and heat, and the Riverwalk Redevelopment (Phases 2 & 3) reshaping the riverfront into a flood-resilient, social-ecological public realm.

Chicago has had recurring issues with urban flooding and extreme heat as identified in the Chicago Climate Action Plan (City of Chicago, 2008). More frequent and intense rainfall events have been recorded, which have overwhelmed the combined sewer system and resulted in basement flooding, street ponding, and combined sewer overflows into the Chicago River and Lake Michigan. These impacts have been disproportionately experienced in low-income neighbourhoods, where adaptation capacity is limited (Nitkin, 2024). The city's extensive impervious alley network has further contributed to localized runoff and flooding pressures. The city's 1995 heatwave was recognized as a major benchmark, with over 700 fatalities recorded in a single week, and has since been viewed as a turning point that induced strategic changes in infrastructure planning. Measures such as reflective surfaces, expanded tree canopy, and green infrastructure retrofits have been advanced as part of the city's mitigation and adaptation response to climate change.

Chicago's resilience strategy blends micro-scale green infrastructure for stormwater and equity (alleys, bioswales, permeable pavements) with macro-scale civic and economic regeneration projects (Riverwalk). Together, they demonstrate how the city uses both distributed, community-focused GI and centralized, high-visibility urban redevelopment to tackle flooding, enhance quality of life, and strengthen its identity as a sustainable, resilient city.

Since their inception, Chicago's Green Alley Program and Riverwalk redevelopment have redefined how the city integrates climate resilience into urban design. Launched in 2006, the alley initiative has converted more than 400 alleys into permeable, reflective, and energy-efficient corridors, reducing localized flooding, mitigating urban heat, and serving as a national model for green infrastructure (City of Chicago, n.d.; Newell et al., 2013; Nitkin, 2024). Meanwhile, the Chicago Riverwalk, completed in phases through 2016, has transformed a hardened industrial riverfront into a flood-tolerant civic space with ecological habitats, cultural amenities, and economic vitality (Sasaki, 2019; Landscape Performance Institute, 2019). Together, these projects illustrate Chicago's progress in aligning localized green infrastructure with large-scale adaptation strategies.

4.3.a Green Alley Program

The Chicago Green Alley Program was initiated in 2006 as an innovative response to recurrent flooding, urban heat stress, and waste concerns within the city's extensive 1,900-mile alley network (City of Chicago, n.d.). Traditionally built with impermeable concrete or asphalt, alleys contributed to stormwater runoff that overwhelmed combined sewers and caused basement flooding, particularly in vulnerable neighbourhoodss. By reimagining these underutilized corridors as sites of ecological intervention, the program positioned alleys as decentralized green infrastructure that could simultaneously address hydrological, thermal, and social challenges.

The design strategies integrated permeable pavements, including porous asphalt, concrete, and pavers, which facilitated infiltration and groundwater recharge. Reflective, high-albedo materials were used to mitigate the urban heat island effect, while recycled construction content such as slag, reclaimed asphalt, and tire rubber reduced waste streams (Newell et al., 2013). Energy-efficient, dark-sky compliant lighting was also introduced to reduce light pollution and improve safety, signaling how technical interventions could produce layered co-benefits (City of Chicago, 2010).

From its early pilot projects, the program expanded steadily, with more than 100 alleys completed by 2009 and over 400 installations citywide by 2024 (Nitkin, 2024). These interventions demonstrated measurable reductions in runoff and localized flooding, while also cooling adjacent built environments and enhancing walkability (Coseo & Larsen, 2015). The program became a national model, informing similar green infrastructure retrofits in Los Angeles, Detroit, and other U.S. cities (Newell et al., 2013).

Figure 4.9: Before After Green Alleys (source: The Laneway Project)

Yet challenges remain. Maintenance of permeable pavements—particularly sweeping to prevent clogging—proved critical for long-term performance (City of Chicago, 2010). Equity concerns also emerged, as most installations were concentrated in North and Northwest wards, leaving flood-prone South and West Side communities underserved (Nitkin, 2024). Despite these issues, the Green Alley Program illustrates how small-scale, distributed interventions can significantly advance climate mitigation and adaptation, aligning with Chicago's Climate Action Plan priorities for stormwater management, urban cooling, and sustainable materials.

4.3.b Chicago Riverwalk Redevelopment

The Chicago Riverwalk redevelopment emerged as a bold reimagining of the city's industrial waterfront. Historically defined by hardened riverbanks, service docks, and fragmented pedestrian access, the river corridor was restructured into a continuous walkway that reconnected downtown to its waterway. The expansion provided universally accessible ramps and underbridge connections, ensuring uninterrupted pedestrian movement while opening views and physical access to the riverfront.

A defining feature of the project was its spatial organization into six distinct "rooms"—the Marina Plaza, Cove, River Theater, Water Plaza, Jetty, and Confluence. Each segment was programmed with specific functions, from recreation and dining to ecological education, creating a layered public realm that blended civic, cultural, and leisure uses. Flood-tolerant terraces and durable materials were employed to ensure that these spaces could withstand fluctuating river levels, embedding resilience into the urban design.

Figure 4.10: (source: Chicago Architecture Center)

Ecological integration was advanced through floating wetlands, riparian planting, and fish habitats that addressed decades of biodiversity loss and poor water quality. These measures created microhabitats along the river's edge and introduced visible ecological education into the heart of the city. The presence of native vegetation and aquatic structures was paired with landscape strategies to reduce stormwater runoff and improve air quality.

The redevelopment also positioned the Riverwalk as an economic and cultural catalyst. Revenue from restaurants, cafes, and seasonal programming was designed to offset public investment, while public art and community events activated the riverfront year-round. Governance and funding were underpinned by a mix of federal grants and local revenue payback mechanisms, balancing the project's civic ambition with financial sustainability.

Despite these successes, challenges remain in maintaining the ecological features, managing stormwater inflows, and ensuring that commercial pressures do not outweigh environmental goals. Nevertheless, the Riverwalk has become an emblem of Chicago's capacity to transform post-industrial infrastructure into a resilient and multifunctional civic landscape that strengthens the city's identity in the era of climate change.

4.4 City of Amsterdam

Amsterdam is a low-lying delta city shaped by canals, polder systems and engineered defenses. Climate change is recognized not as a distant threat but as a direct risk to everyday life, the urban economy and long-term territorial continuity. Municipal analyses highlight four main hazards: extreme rainfall, heat waves, drought-induced subsidence, and sea-level rise. These processes interact with dense, highly paved neighbourhoods and ageing building stock, especially homes on wooden pile foundations, to create multi-hazard risk.

Importantly, Amsterdam frames climate impacts as socially uneven: households in poorly insulated dwellings, residents with lower incomes, the elderly, and people in districts such as Nieuw-West, Noord and Zuidoost are described as more exposed and less able to adapt. Climate risk is therefore treated as both an environmental and an equity problem, linking adaptation directly to the city's broader agenda of "equal opportunities".

On the spatial side, Amsterdam increasingly treats public space, parks and water bodies as adaptation infrastructure. Design guidelines and standards include, for example:

- Rainfall design standards: new or heavily renovated developments must be able to manage around 60 mm of rainfall in one hour and drain it within a specified time window, while vital or vulnerable functions (e.g. hospitals, key networks) are designed for more extreme conditions (≈90 mm in one hour).
- Green–blue networks: new neighbourhoods and major redevelopments are expected to include a continuous ecological structure and a green–blue network that connects parks, canals, water squares and green streets.

- Grey-to-green retrofits: existing streets, canal edges and squares are gradually converted from hard surfaces to green, nature-inclusive designs, with examples such as park upgrades that deepen watercourses, install nature-friendly banks and increase on-site water storage.

Programmes like Amsterdam Rainproof promote measures at building and plot scale (green roofs, rain gardens, de-paving private gardens) while municipal investments focus on larger-scale storage, infiltration and shading in public space. Together, these interventions target pluvial flooding, urban heat and biodiversity loss simultaneously.

4.4.a City of Tomorrow - Rainproof Programme, Floating neighbourhoods

Amsterdam's "city of tomorrow" agenda couples long-term climate resilience with everyday liveability. Municipal climate-adaptation policies frame heavier rainfall, more frequent heatwaves, drought and subsidence as key risks, and call for a climate-proof city that can cope with pluvial flooding, heat stress and high groundwater without major damage or disruption (City of Amsterdam). In this vision, streets, canals and neighborhoods are reconceived as adaptive infrastructure: places that store, slow and evaporate water, and provide cooling through vegetation and open water rather than purely hard surfaces.

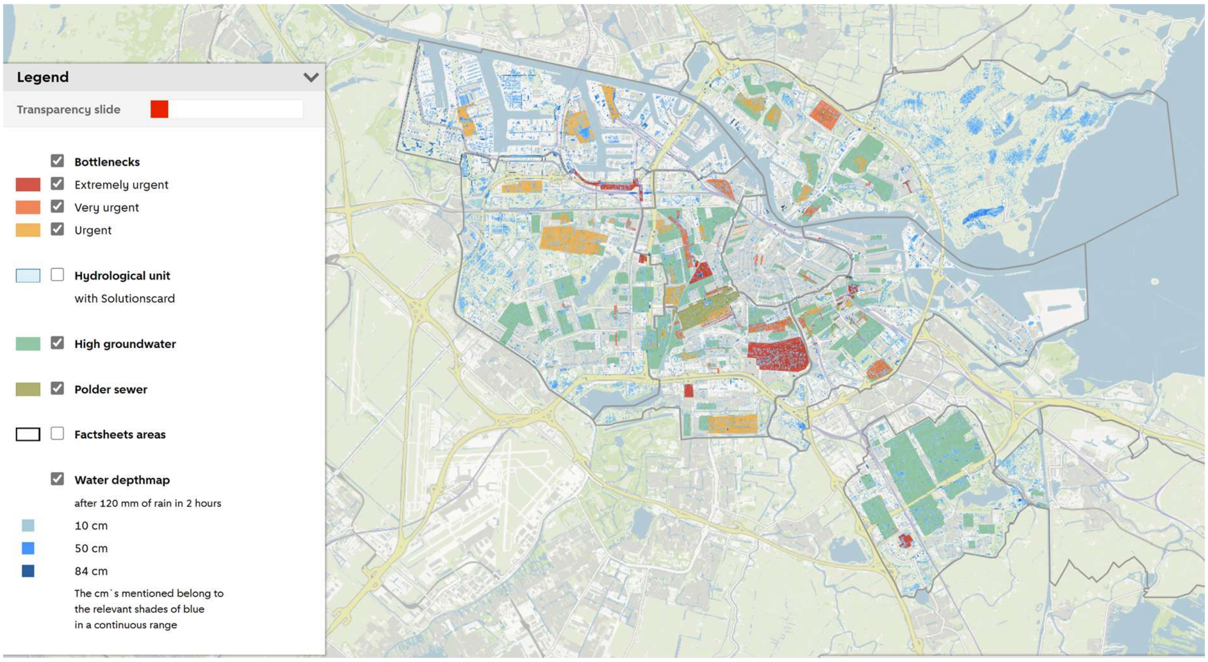


Figure 4.11: Amsterdam Rainproof program interactive map (source: Commune Amsterdam) not for scale.

A central instrument is **Amsterdam Rainproof** (see figure 4.11), which treats the whole city as a "sponge" and targets pluvial flooding through green–blue infrastructure (GBI). Stress maps of "rainwater bottlenecks" identify locations where intense downpours overwhelm drainage; these maps guide investments in water squares, infiltration strips, tree pits and de-paving (City of Amsterdam). Recent quantitative work shows how municipal and household-level nature-based measures—extra green areas, water-storage squares, allocated flow-paths for water, garden de-paving and green roofs—have been implemented in specific neighborhoods such as Rivierenbuurt to reduce insured pluvial damage (Ooms et al., 2025). These interventions exemplify *ecosystem-based adaptation* (EbA): they use soil, vegetation and surface water to increase storage, infiltration and shading, while providing co-benefits for biodiversity and public space quality (see schematic GBI visualizations in Figure 4.12).

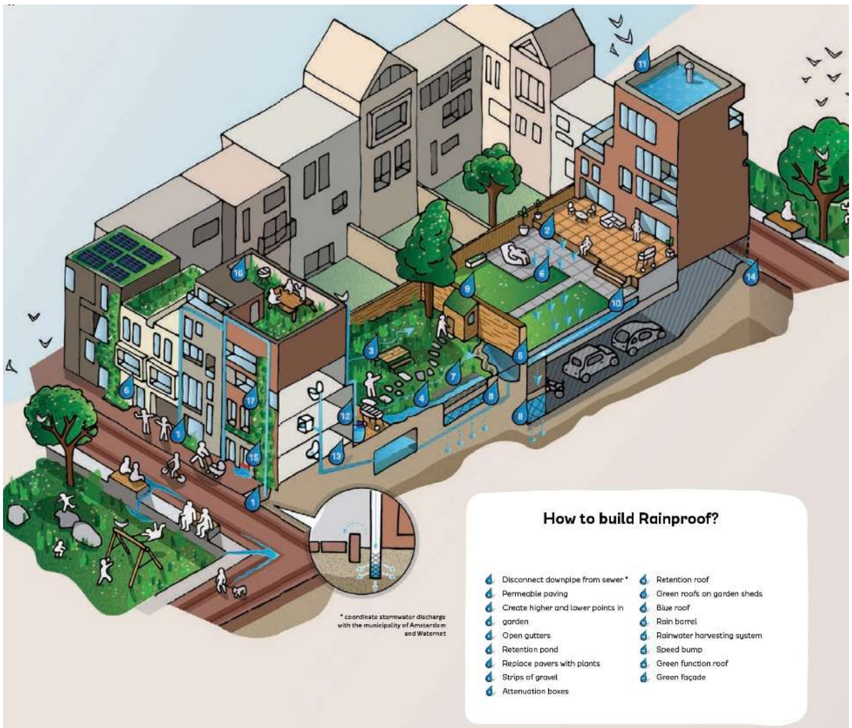


Figure 4.12: Rainproof Programme Amsterdam schematic visualization (source: Rainproof Magazine, 2023)

At the same time, Amsterdam's climate-resilience strategy has a strong *governance and justice* dimension. Sharma (2023) shows how Amsterdam Rainproof is framed as an urban climate-resilience initiative that must address pluvial flooding while also negotiating uneven socio-ecological conditions across neighborhoods. In practice, this means prioritizing districts with high exposure and social vulnerability, and engaging residents, housing corporations and local organizations in co-producing small-scale measures: rain gardens, courtyard greening, shared green roofs and community squares redesigned for water storage and cooling (Sharma, 2023). This aligns closely with *community-based adaptation* (CbA) principles: local knowledge and collective organization are treated as part of the adaptation infrastructure, not an afterthought. Amsterdam's Rainproof approach is embedded in four mutually reinforcing principles.

- *Regenerative water services* treat the whole urban water cycle as a resource loop: water, energy and nutrients are saved, reused and recovered, with Rainproof ensuring that roofs, streets and gardens help store and infiltrate rain rather than simply drain it away.
- *Basin connected cities* recognises Amsterdam's position in the Rhine–Meuse delta; city-scale pluvial measures are coordinated with regional freshwater strategies, national flood standards and cross-border water quality agreements so that local downpours, river floods and droughts are managed as one system.
- *Water sensitive urban design* translates this into concrete spatial rules: street profiles, materials, green strips, polder roofs and visible water features are designed to attenuate runoff, reduce flood risk and enhance liveability and ecology.
- Finally, *water-wise communities* focus on people and governance: citizens are encouraged to depave and green private plots, water professionals sit in multidisciplinary planning teams, and policies and funding (e.g. the sustainability agenda and green funds) reward Rainproof design, making "every drop counts" a shared urban culture.

Within this broader "city of tomorrow" framework, Amsterdam's **Floating Neighborhoods**: notably Waterbuurt in IJburg and the cooperative neighborhood Schoonschip—provide a spatially radical way to "live with water" rather than fight it. Built on concrete pontoons moored to steel piles, these dwellings rise and fall with water levels, reducing direct exposure to fluvial and pluvial flooding and opening new urbanization space on water surfaces (Bol, 2014; Cutieru, 2021). Research on the floating community in IJburg finds that, for the physical and chemical parameters measured, the project does not significantly worsen local water quality compared with open water, alleviating concerns that large floating districts might degrade aquatic conditions (Bol, 2014). The same study recommends ecological design addons—floating wetlands, artificial reefs, geotextile tubes—to enhance habitat and water purification, directly linking floating architecture to EbA functions (Bol, 2014). Images of Schoonschip (Figure 4.13) show how these floating plots are embedded within canal basins, with generous roof surfaces for solar panels and vegetation.

Figure 4.13: Floating Houses of IJburg, Amsterdam [source: Cutieru (2021)]

Figure 4.14: Image of the neighborhood on Johan van Hasselt Canal in Amsterdam, now home to more than 100 residents, was initiated in 2010 by a group of enthusiasts set to create an energy-neutral community. [source: Cutieru (2021)]

Floating neighborhoods also act as *social laboratories for circular and climate-resilient living*. Analyses of Schoonschip highlight design strategies that respond simultaneously to sea-level rise, pluvial flooding and the housing crisis: compact floating plots, high energy performance, extensive rooftop photovoltaics, heat pumps using canal water, rainwater harvesting for non-potable uses, and shared gardens that mitigate heat and support local food production (Cutieru, 2021). These communities are typically organized as cooperatives, with residents co-financing and co-managing adaptation investments, which reinforces CbA: risk reduction is embedded in everyday practices, governance arrangements and shared infrastructure, rather than limited to top-down engineering (Sharma, 2023).

Together, the “city of tomorrow” vision, the Rainproof programme and floating neighborhoods constitute a multi-scalar DRR strategy. At the city-wide scale, hazard maps, policy norms and investment programmes steer Amsterdam towards a greener, more porous and cooler urban fabric (City of Amsterdam, n.d.). At the neighborhood scale, EbA measures—trees, permeable pavements, water squares, green roofs—are combined with social processes of co-design and co-ownership (Ooms et al., 2025; Sharma, 2023).

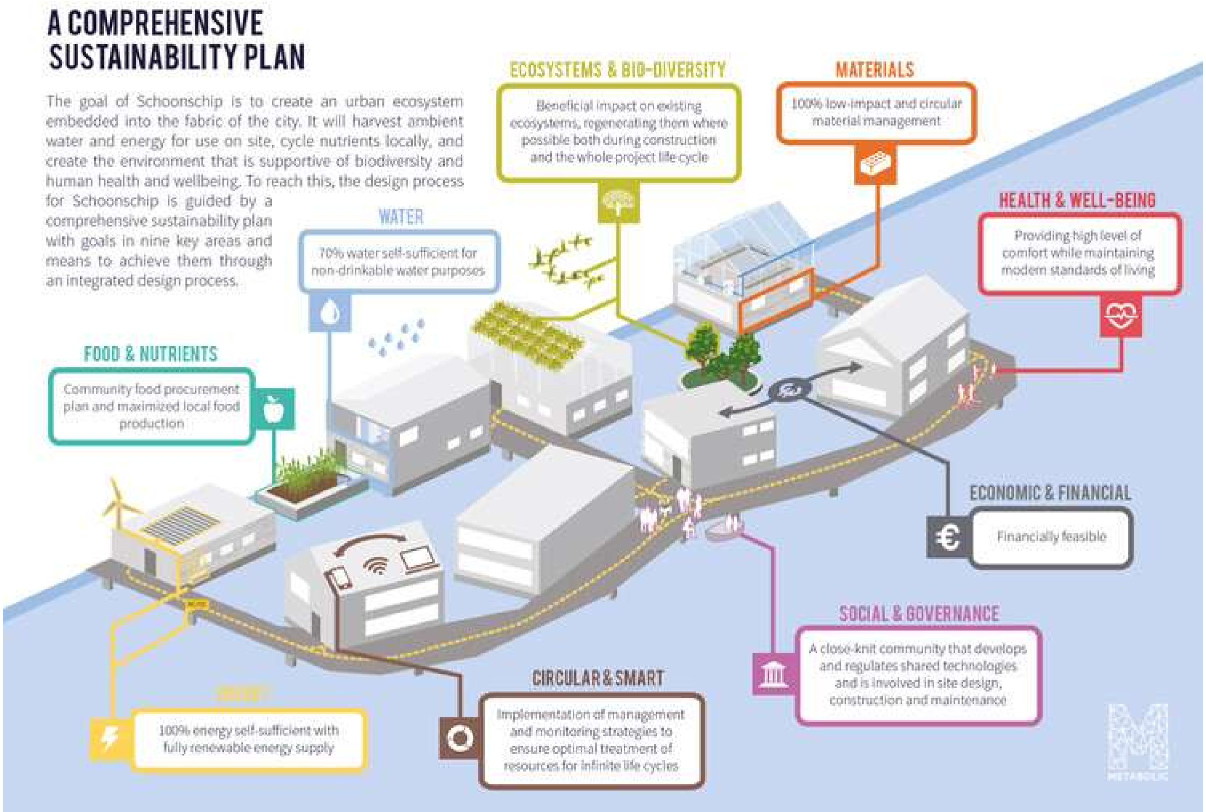


Figure 4.15: The Floating neighborhood sustainability plan developed by Space&Matter, Amsterdam. [source: Cutieru (2021)]

At the water–city interface, floating districts embody the shift from resisting water to accommodating it, turning canals and lakes into potential safe living spaces as sea level rises (Bol, 2014; Cutieru, 2021). Emerging evidence from Amsterdam shows that when these measures are bundled and targeted in vulnerable districts, they can measurably reduce pluvial damage while advancing broader agendas of environmental quality and social equity (Ooms et al., 2025; Sharma, 2023).

Table 4.2: A tabular assessment of the Amsterdam climate resilience strategies from above discussions.

Climate challenge / risk	City-wide & neighbourhood measures (Rainproof / "city of tomorrow")	Floating neighbourhood contribution	EbA / CbA dimension
Intense pluvial flooding	Rainwater bottleneck mapping; water-storage squares; sewer renewal; extra green areas along streets; enlarged tree pits and infiltration zones; household depaving subsidies and green roofs (City of Amsterdam; Ooms et al., 2025).	Floating dwellings rise with water level; use of basins and canals as controlled storage; potential integration of floating wetlands and ecological buffers (Bol, 2014).	EbA via increased storage, infiltration and vegetated surfaces; CbA through resident participation, Rainproof Garden coaching and housing cooperatives (Ooms et al., 2025; Sharma, 2023).
Urban heat and low climate comfort	Street trees, pocket parks, green courtyards, green roofs and façades; redesign of paved squares into shaded, vegetated community spaces (City of Amsterdam; Ooms et al., 2025).	Rooftop gardens, water surfaces and high-albedo materials provide evaporative cooling and reduce building heat loads (Bol, 2014; Cutieru, 2021).	EbA by enhancing green cover and evaporation; CbA where residents co-design courtyards and manage shared green spaces (Sharma, 2023).
Land scarcity, subsidence & sea-level rise	Strategic densification combined with green–blue networks; shift from purely land-based expansion to "room for water" in urban design (City of Amsterdam).	New housing capacity on water surfaces (IJburg, Schoonschip); experimental "floating city" concept as long-term adaptation to sea-level rise and ground subsidence (Bol, 2014; Cutieru, 2021).	EbA where floating projects integrate aquatic ecology measures; CbA through cooperative governance, shared smart-grid systems and community-driven sustainability goals (Sharma, 2023).

5 DRR as a Response in Spatial Planning: Mitigations and Adaptation in Global South Cities

5.1 Case Study 1: City of Accra, Ghana

5.1.a General Background – Climate, Urban Density and Geography

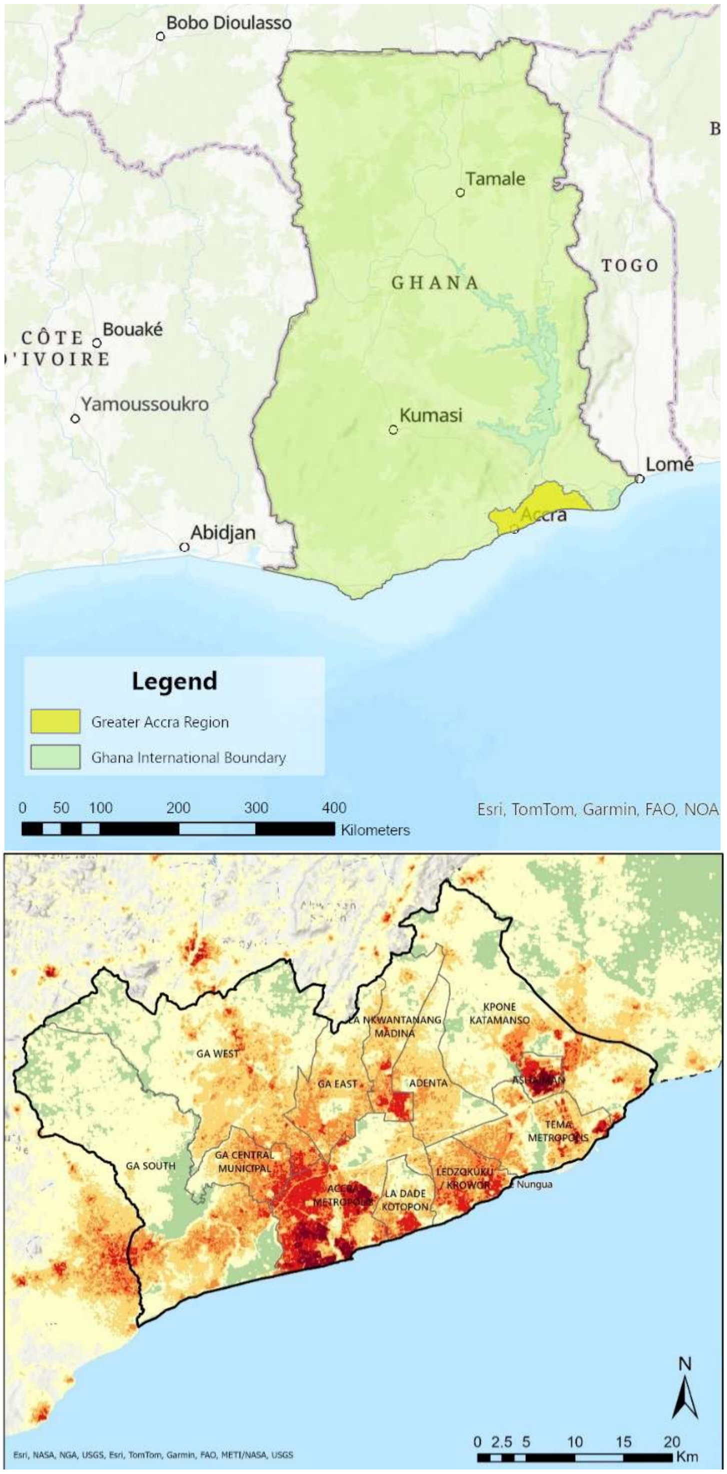


Figure 5.1: The Location map of Cape Town, and Population Density map of Accra per hectare (source: Author adopted based on the Open Street map repository, Africa Geoportal by ESRI, and Human Development Index by World Bank)

GAMA is Ghana's largest urban agglomeration centred on Accra, spanning roughly 1,585 km² along the Gulf of Guinea (≈5°05′–5°28′N; 0°05′E–0°37′W). The World Urbanization prospects, 2018(UN, DESA, Population Division, 2018) states the projected annual growth rate of change of urban agglomerations for 2035 since 1950, and prior to 2015 the growth rate has been stable at 2.11% which is not decent but neither it was worse, with the recorded urban population in the capital city was approximately 2, 4 million. As per the Ghana statistical services, the 2021 census recorded the overall population that is the 5, 455, 492 for Greater Accra Metropolitan Area (GAMA) itself contributes to 17.7% of its national population with a land area of 3706.72 Km^2, and the urban population within GAMA is spread across 91.7% of its land area that has doubled since 2010. The population density (person per km^2) by 2021 census of GAMA is 1681 (a 1/3rd rise). GAMA has its two major municipalities AMA (Accra metropolitan area) and Tema Metropolitan Area being the most densely populated, and rapidly radially expanding (see figure 5.1) having high population density at the urban centre and medium in the peri-urban areas.

Studies of informality post 2015 by researchers further indicated that informal settlements span from compact inner-city clusters and more dispersed peri-urban forms with different densities and service gaps. These studies depict an urban structure in which high-density core areas coexist with rapidly thickening peri-urban corridors, and in which formal and informal fabrics are interleaved rather than segregated—implications that matter for how density, service access and upgrading priorities are measured and targeted. Since 2000s, peripheral urbanization has been seen at the urban edge with limited early infrastructure allowing consolidated mixed formal and informal urban landscapes to take shape, resulting in a heterogenous mosaic that interleaves formal sub-divisions with self-built areas, often advancing along arterial corridors and around pre-existing villages and nodes such as Accra-Tema Axis. Spatial coupling of lower-density expansion with patchy service provisions has become prominent along the ecological sensitive zones, where encroachment reflects both housing pressure and uneven regulation. (Andreasen et al., 2022; Møller-Jensen et al., 2020; Owusu et al., 2021).

Climate, **Geology and Geomorphology**

GAMA experiences a tropical savanna climate (Köppen Aw), characterised by a major wet season from April to July and a minor wet season from September to November, separated by a brief midsummer dry interval. Annual temperatures remain consistently high, generally ranging between 24°C and 30°C, with the warmest conditions typically occurring between March and April. The metropolitan area receives 600–1000 mm of rainfall annually, most of it during the two rainy seasons. Recent climate analyses indicate that the intensity and variability of precipitation have increased, with more frequent high-intensity, short-duration rainfall events and longer drought periods. These shifts, documented by Balstrøm et al. (2024), Ansah et al. (2020), and Siabi, Adu-Poku et al. (2024), heighten exposure for GAMA’s growing population and critical infrastructure, amplifying risk to flood- and heat-sensitive urban systems.

Rainfall analyses further reveal a notable rise in extreme rainfall frequency and magnitude after 2000, based on rainfall gauge data from 1980–2019 (Padi, Ampofo, & Oteng, 2022). These shifts, combined with changes in the seasonal peak of rainfall, intensify strain on GAMA’s low-slope drainage networks and contribute to widespread flash flooding. In the urban core, impervious cover, encroached floodplains, undersized channels, and tide-affected outfalls exacerbate runoff accumulation and backwater effects, making drainage failures frequent and severe (Amoako & Frimpong Boamah, 2015; Gordon, 1999).

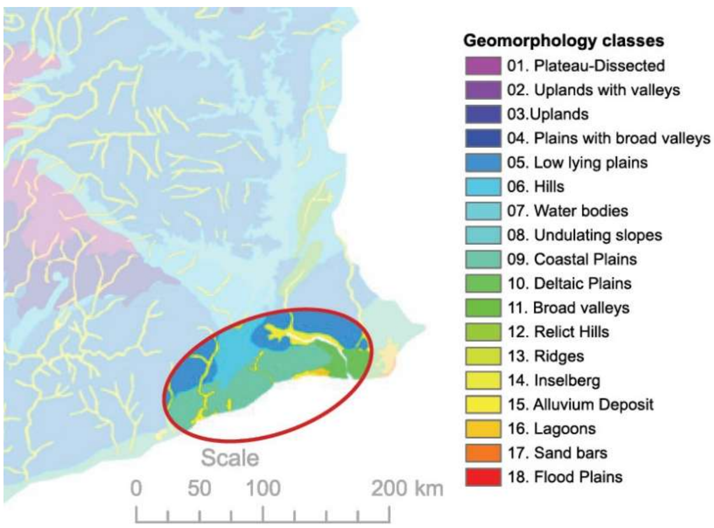


Figure 5.2: Geomorphology classes across Ghana with encircled region being the Greater Accra Region in focus. (source: Gumma and Pavelic, 2012)

GAMA is situated on the low-relief Accra Plains, a gently sloping coastal foreland that tilts towards the Gulf of Guinea and is bounded to the north by the Akwapim–Togo escarpment. Elevations across the metropolitan area are modest, commonly below ~75 m a.s.l., with extensive near–sea-level zones along lagoon-barrier systems such as Korle, Kpeshie, Chemu, and Sakumo, and along the Densu delta (Gordon, 1999). This low-gradient physiography produces a dense pattern of short, south-draining basins, the most prominent being the Odaw–Korle system, whose engineered channels meet tidal conditions at lagoon inlets. Where these flat grades coincide with lagoon backwater effects, tidal influence, and discontinuous drainage infrastructure, stormwater readily ponds, creating persistent flood hotspots.

Scientific evidence shows that the metropolitan terrain is shaped by thousands of micro-depressions, sink features, and shallow undulations, particularly concentrated along the Odaw basin. Hydro-conditioned terrain modelling by Balstrøm, Kaberry, & Opoku-Owusu (2024) demonstrates how these depressions form a fine-grained surface conducive to runoff concentration and temporary stormwater storage. Under intense, short-duration convective rainfall, such features significantly amplify pluvial flood risk, especially where wetlands have been infilled or where clayey soils reduce infiltration.

Geologically, the Accra Plains consist of coastal sands and regosols (*see image 4 of figure 5.3*) developed on beach ridges and dune complexes; ferrallitic and lateritic soils formed over Precambrian gneisses on slightly elevated terrain; and heavy clays and Vertisol-like soils occupying valley bottoms, backswamps, and lagoonal flats (Amoako & Boamah, 2014). These clay-rich units have low infiltration capacities, making them highly susceptible to saturation during intense rainfall, thus promoting rapid surface runoff and widespread ponding.

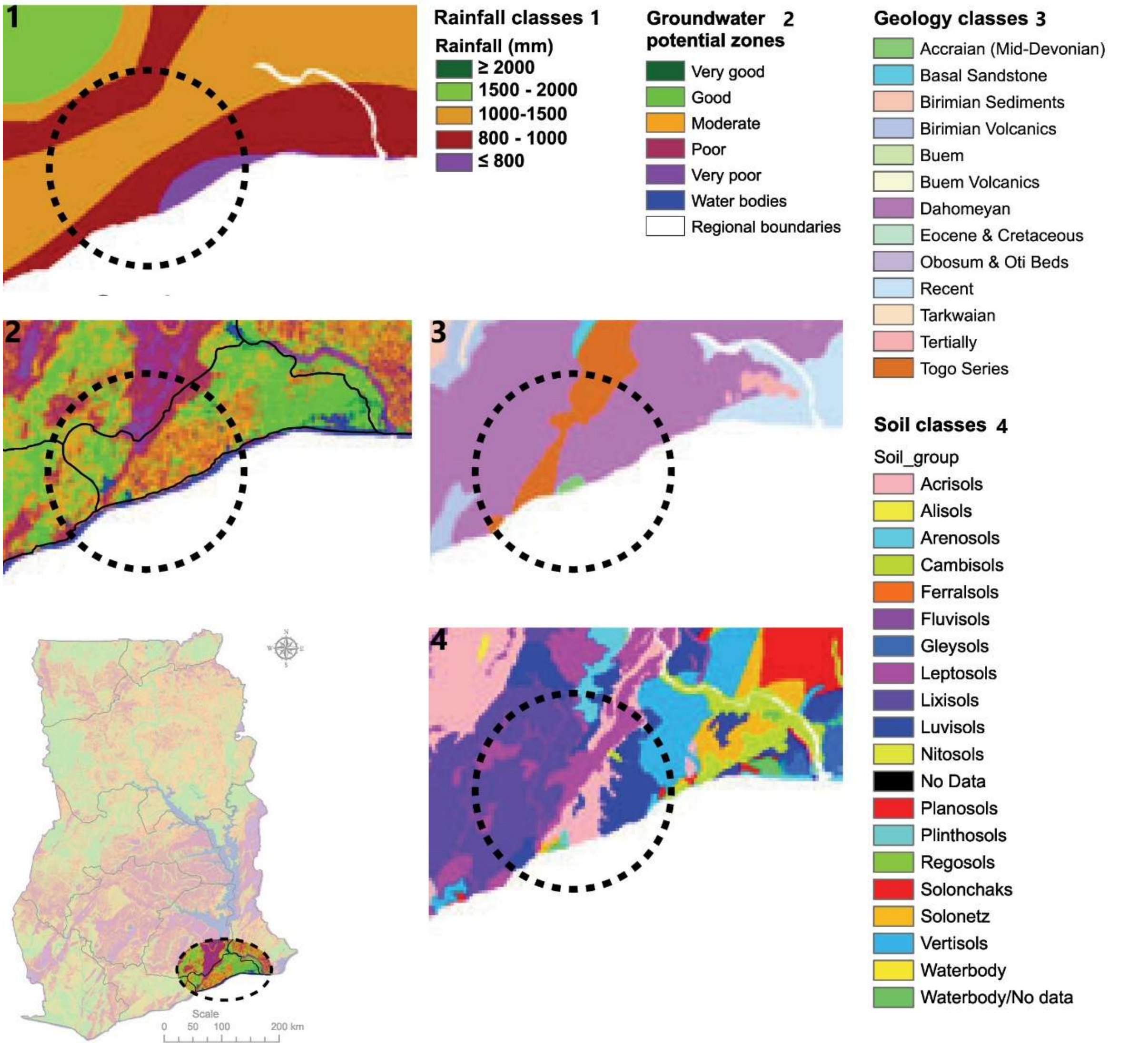


Figure 5.3: Geological Conditions, Soil Classes, Groundwaters, and Rainfall classification across Ghana with encircled focus area of Greater Accra Region (source: Gumma and Pavelic, 2012)

The Accra coastline is highly susceptible to erosion and marine flooding due to its low dune relief, narrow beach-ridge systems, and sediment-starved shores, which limit natural protection. Research along the Accra littoral, including Gleefe, shows that meter-scale dune crests and constricted barrier segments permit storm surges and elevated water levels to breach into backshore settlements and adjacent lagoons, intensifying multi-hazard exposure (Appeaning Addo, 2015). Inland, the Accra Plains contain a mosaic of coastal sands and regosols on ridge and dune complexes, ferrallitic and lateritic soils over Precambrian gneissic terrain, and clay-rich or Vertisol-like soils in valley bottoms and lagoonal flats (Amoako & Boamah, 2014). These heavy, low-permeability soils restrict infiltration and promote rapid surface runoff and ponding during storms, reinforcing flood susceptibility in low-lying and reclaimed areas. Combined with the fragile coastal geomorphology, these soil and shoreline conditions create a landscape where both pluvial and coastal flooding remain persistent risks.

Rainfall, Slope and Drainage Networks

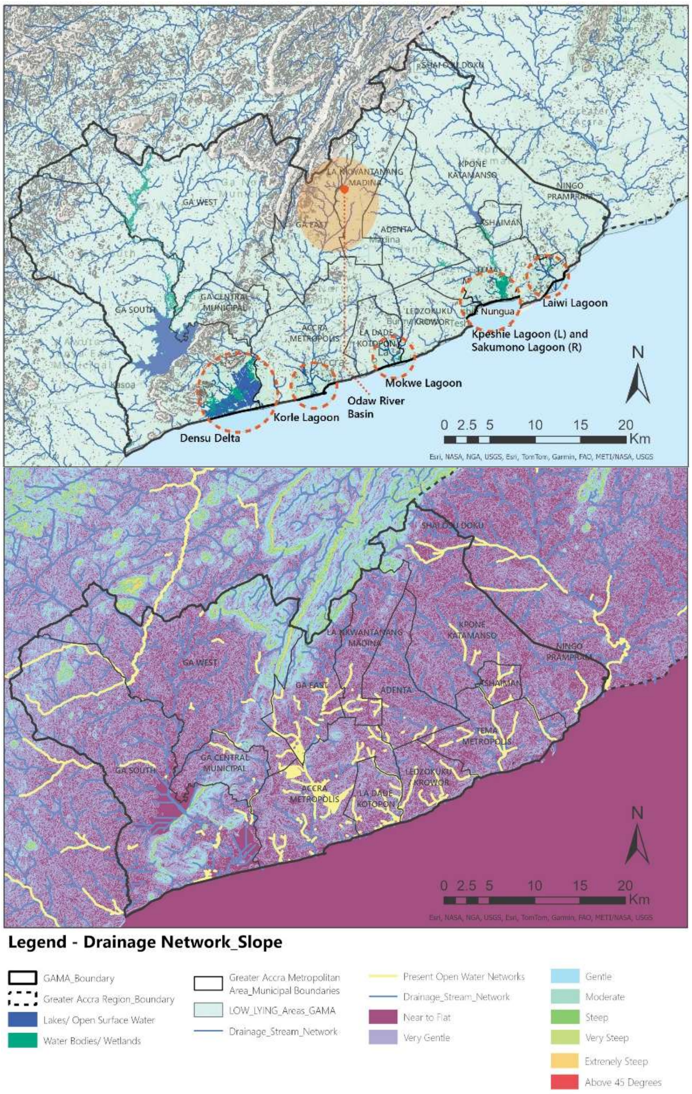


Figure 5.4: Drainage Networks and Slope across the GAMA. (source: Author, adopted from Copernicus 30M DEM)

Accra experiences a bimodal rainfall regime, which occurs from March to July (major rainy season) and from September to November (minor rainy season). Average annual rainfall is about 810 mm. Rainfall is usually intensive with short storms, giving rise to annual local flooding where drainage channels are missing or obstructed. (Ghana Meteorological Agency - GMET). These intensive rainfall events are seen as being the fundamental cause of flooding if the storm water or surface run-off that follows them are not properly managed or drained out of the various flood-prone communities. This coupled with a combination of low-lying topography, presence of rivers and their encroachments especially by slum populations, present flood vulnerability to slum and informal settlements in the affected areas. there is no evidence that unusual rainfall has been occurring recently that could explain the increased occurrences of flooding being experienced.

Looking at the Drainage networks (*see figure 5.4*) and slope, two things are primarily seen across the map of GAMA. Firstly, the slope across the most part of the GAMA and Greater Accra Region is majorly either flat or gentle not exceeding 6 degrees, providing major reasons for the stormwaters to remain stagnant for longer periods during extreme events. Secondly, if we see the current stream networks most of them across the Odaw river basin, and water networks around the Densu Delta are disconnected either due to extreme urbanization, or waste dumping creating additional pressure for stormwaters to be choked and raising high risk and vulnerability across the lower regions.

Odaw River–Korle Lagoon is heavily silted/polluted, receives large solid-waste loads, and traverses' dense built fabric, making it both the hardest to manage and the chief flood conduit. Past programs (KLERP, UESP drainage works) struggled due to finance, governance, and stakeholder conflict. (Amoako & Boamah, 2014b).

As per the Balstrøm, Kaberry, & Opoku-Owusu, 2024, recent hydro-conditioned terrain analysis using a 10 m DTM for the Odaw basin (≈ one-quarter of GAMA) mapped >5,000 depressional "sinks" capable of storing stormwater (≥ 0.1 m depth, ≥ 5 m^3), confirming a fine-grained template of flow accumulation and inundation pathways across Accra's built-up lowlands.

Land Use and Land Cover

The GAMA has undergone extensive changes and expansions in random manners and have accounted for an increase in the pressure across its ecological networks and natural water resources. GAMA recorded a huge loss in its cropland due to its expanding boundaries with a loss of 71Km^2 and an overall loss of 139 Km^2 of dense short vegetation and 23Km2 of its Tree covers (more than 3m foliage) *see figure 5.5*. We can see the increase in the built-up or urbanized area and loss wetlands/ water bodies as well in Table 5.1.

Based on the studies of Addae and Oppelt (2019), urban expansion is overwhelmingly at the expense of grasslands: between 1991–2000, about 88% of new built-up land came from grassland; between 2000–2015 this share rose to around 94%. Forest losses are largely to grassland (around 94% of forest lost in 2000–2015 becomes grassland), with a smaller share converting directly to urban land. The spatial patterns to demographic and economic drivers can be seen actively linked as well: high population growth (3–3.5% per year), concentrated economic opportunities in Accra–Tema, speculative real estate development, and the sale of customary lands by chiefs under weak planning control. They emphasize that market

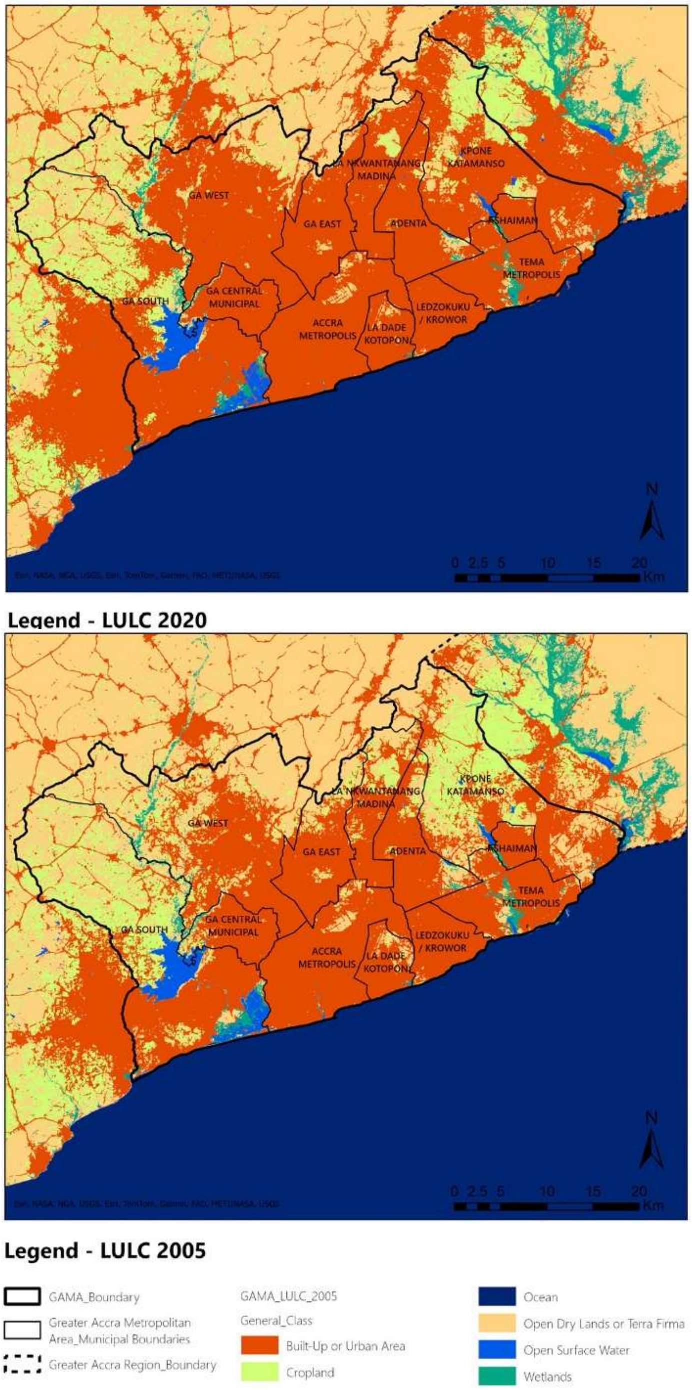


Figure 5.5: GAMA LULC comparison for 2005 and 2020 (source: Author, adopted from the GLULC data by Potapov et al., 2022b)

forces, rather than urban planning, are shaping GAMA's spatial development, leading to fragmented expansion at the fringes and pressure on ecological areas (Addae & Oppelt, 2019).

Urbanization takes the form of both edge expansion and leapfrog development, with infill within the existing urban core but very strong sprawl along major road corridors. "Distance to existing urban" and "distance to roads" are being the top drivers supporting the corridor-based, path-dependent growth pattern (Addae & Oppelt, 2019).

Table 5.1: Major findings and inferences from the studies of Addae & Oppelt, 2019 on the changing LULC across GAMA

Ecological and land-cover losses	Infrastructure and service deficits	Social and spatial disadvantages
Severe forest loss: from 34.2% of the area in 1991 to 6.5% in 2015, with around 43,900 ha of forest converted, mainly to grassland and then to urban land.	Rapid expansion has far outpaced infrastructure provision; large gaps exist between demand and supply of housing, sewage and waste management.	Inadequate formal housing has driven the proliferation of informal settlements, especially at the fringes where land is cheaper and planning control is weaker.
Progressive degradation of vegetative cover, including pressure on Achimota Forest Reserve and vegetated buffers along the Densu River and around Weija Lake.	Only around 15% of the metropolitan area is sewered, and existing sewers are in poor condition; only about 67.7% of solid waste is collected, with the rest disposed in open spaces and drains.	Land governance conflicts (customary land sales, weak regulation, limited compensation practices) have encouraged uncoordinated private land development, intensifying sprawl and exposing low-income groups to marginal, hazard-prone lands (Addae & Oppelt, 2019).
Ongoing and projected encroachment on wetlands and Ramsar sites (e.g., Weija and Sakumo), which function as natural flood storage and ecological habitats (Addae & Oppelt, 2019).	The city has "grown naturally," with limited capacity to monitor urbanization or enforce planning directives, resulting in scattered, low-density peripheral growth that is costly to service.	

5.1.b Urban Hazards, Risks and Vulnerabilities and Challenges

Flooding

Across GAMA, recurrent flooding leads to displacement, loss of livelihoods, damage to transport and utility networks, and serious public health risks such as cholera and other water-borne diseases. Informal settlements and poor and vulnerable populations, mapped at about 1.27 million people across key basins, face the highest exposure due to their location, housing quality and limited access to basic services, making flood risk a central constraint on safe urban development and resilience in the metropolitan region. (NADMO - Ghana, 2024). History of increased climate change activities and rising challenges. Some of the attributions of flooding in Accra cited across various research over the years has been to be overflow of Odaw River out of its natural valley and catchment; massive and uncontrolled growth of Accra (Afeku 2005; Karley 2009; Rain et al, 2011); prevention of natural infiltration by impervious surfaces; poor

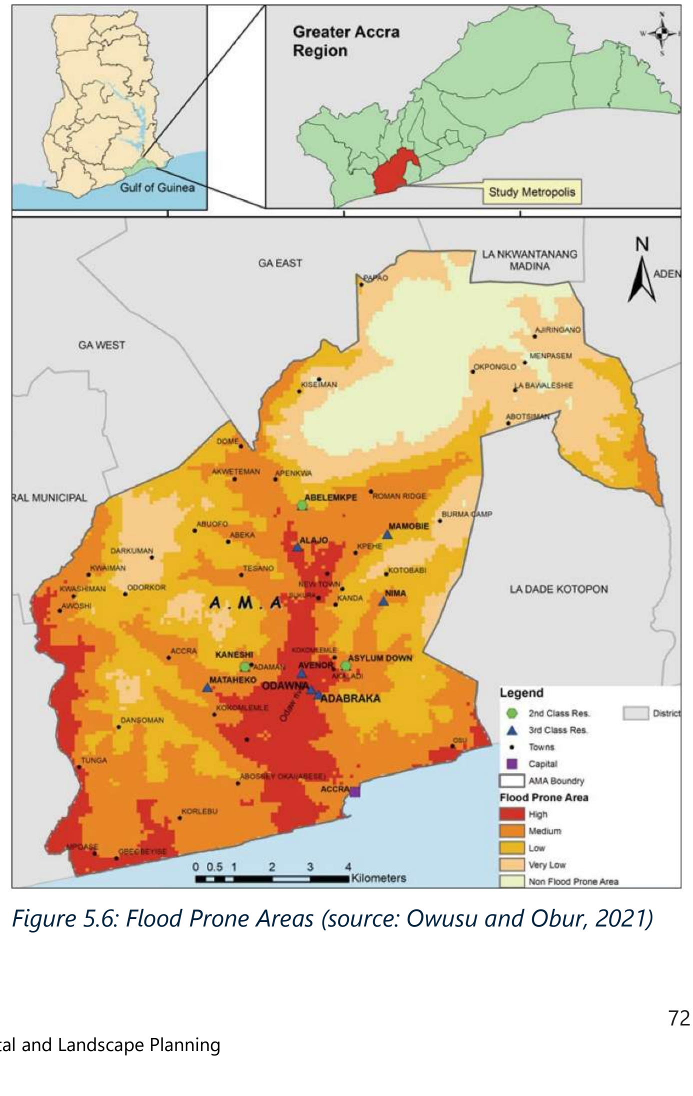


Figure 5.6: Flood Prone Areas (source: Owusu and Obur, 2021)

flows in drainage network such as undersized, unconnected and/or improperly channeled drains; poor development control practices; limited liquid and solid waste disposal channels; poor physical planning and flaws in the drainage network; and informal housing development practices (Amoako & Bomoah, 2014).

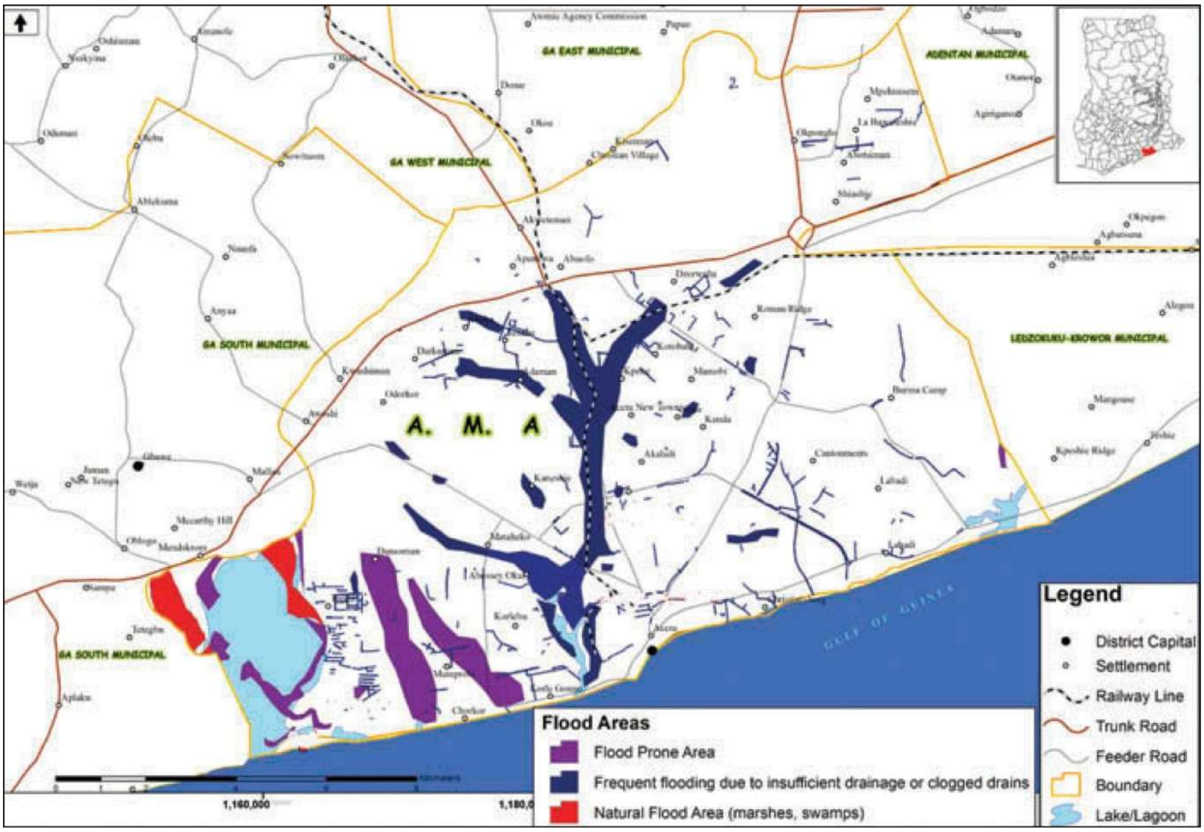


Figure 5.7: Flood prone areas (adopted from Amoako, 2014)

Flooding in Greater Accra is driven by a mix of rapid urbanization and weak drainage management. The brochure notes that paved surfaces and expansion of the drainage system have outpaced design capacity, especially in the lower reaches of the main drains. Siltation, solid-waste dumping, and lack of maintenance reduce the hydraulic capacity of channels, while informal settlements and valuable assets concentrate in low-lying flood-prone areas. Climate change–driven intense rainfall further amplifies these risks. Micro-level studies show that flood impacts cascade through everyday life. In heavily affected Odaw-side neighbourhoods such as Alajo, Avenor and Adabraka, around three-quarters of surveyed households reported flood-related losses in the previous decade; more than 65% had experienced temporary homelessness, and roughly 30% reported the death of a relative or acquaintance due to floods (Owusu & Obour, 2021).

Underlying these damages is a pattern of "built-in" flood risk. Rapid and largely unregulated urban expansion across GAMA has encroached onto wetlands, floodplains, riparian buffers and water-retention areas, while fragmented provision of drainage and road infrastructure blocks natural flow paths (Andreasen et al., 2023). These development practices are not confined to informal settlements; middle- and high-income estates in peri-urban basins such as Adenta and Pokuase also occupy low-lying riverine land, narrowing channels and amplifying runoff.

a. Flood marks in Adenta Housing Down

b. House built in a waterway, Ga South

Figure 5.8: Examples of Flood Damage from MMDAs in Greater Accra, Ghana (source: World Bank, 2020)

Combined with choked drains, solid-waste dumping and weak basin-scale coordination across more than 20 local authorities, this creates a city-region where even 10- or 25-year storms can generate widespread, recurrent damage—particularly in the Odaw, Densu delta, Sakumono and Kpeshie basins, which modelled risk maps identify as GAMA's highest-risk corridors (World Bank, 2020).

The June 3, 2015, disaster crystallized GAMA's vulnerability. A six-hour storm of ~130 mm over the Odaw Basin triggered flash floods that affected about 53,000 people and caused an estimated US$55 million in direct damages and losses to housing, transport, and water and sanitation infrastructure, with an additional US$105 million needed for reconstruction (World Bank, 2020; MESTI, 2016). World Bank damage modelling for the same event suggests roughly 176,000 people and 40,000 houses were exposed, underscoring the scale of built-up exposure in low-lying basins.

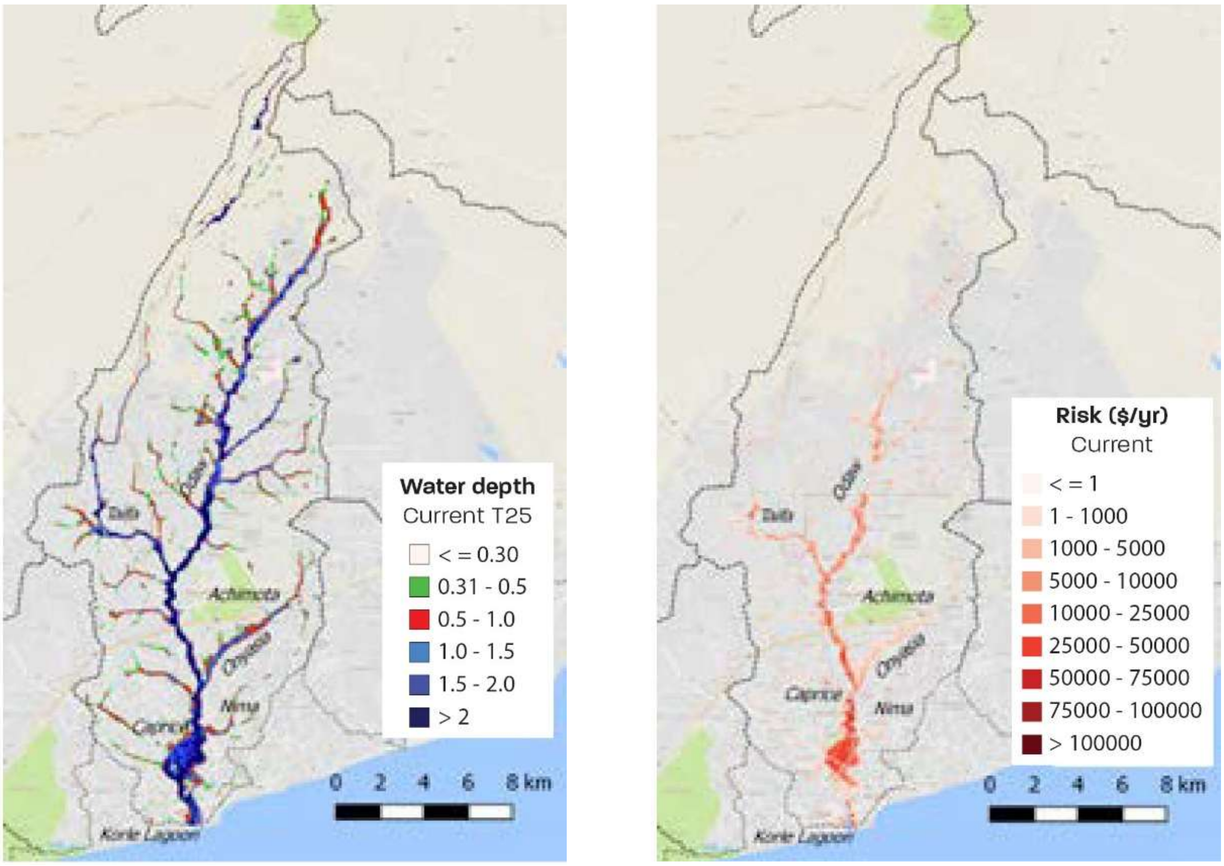


Figure 5.9: Flood Hazard in the Odaw Basin for a 25-Year Return Period, Assuming No Risk Mitigation Measures(source: World Bank, 2020) Left – Current Water Depth Risk ; Right – Current Damage Risk

Micro-level studies show that flood impacts cascade through everyday life. In heavily affected Odaw-side neighbourhoods such as Alajo, Avenor and Adabraka, around three-quarters of surveyed households reported flood-related losses in the previous decade; more than 65% had experienced temporary homelessness, and roughly 30% reported the death of a relative or acquaintance due to floods (Owusu & Obour, 2021). Beyond direct asset loss, residents face disrupted livelihoods, mobility, and heightened disease risks, particularly from cholera and other water-borne infections.

Climate change in Ghana manifests through increased storms, torrential and often unpredictable rainfall, and rising seas, all of which aggravate coastal hazards (Yankson et al., 2017). Projections indicate wetter wet seasons and drier dry seasons, implying more intense rainfall events interspersed with dry periods (Tachie-Obeng et al., 2014; World Bank, 2011). Intense storms and cloudbursts trigger severe pluvial flooding in low-lying coastal communities, especially where drains are inadequate or blocked, while storm surges and sea-level rise accelerate inland shoreline migration, submerging land and damaging coastal infrastructure and businesses (Appeaning & Adeyemi, 2013; Appeaning, 2014).

Although the direct attribution of recent floods solely to climate change is not yet conclusive (Karley, 2009), current rainfall patterns interacting with poor drainage already produce massive floods. In this context, climate-driven extremes amplify pre-existing vulnerabilities, transforming coastal erosion, land loss and settlement displacement into recurrent and potentially catastrophic risks for GAMA’s coastal population (Yankson et al., 2017; IPCC, 2014).

In response, the Greater Accra Flood Risk Mitigation Strategy proposes a “maintain–retain–store–drain” approach. “Maintain” focuses on regular dredging, sediment traps, rehabilitation of damaged drains, and works at Korle Lagoon. “Retain” and “store” emphasize redesigned tertiary drains that temporarily hold water in berms and micro-scale retention in yards, public low-lying spaces, and dedicated retention ponds to delay runoff. “Drain” involves widening riverbeds, upgrading bridges, lowering floodplains, constructing flood walls, and widening outlets to the sea, coupled with strict bans on building in flood zones. These are supported by early warning systems, flood zoning, and solid-waste management to keep drains clear.

Coastal Erosions

The coastal edge of GAMA is characterised by recurrent flooding, exposure to sea-level rise and storm surges, and ongoing inland migration of the shoreline, which threaten lives, housing, infrastructure and coastal businesses (Yankson et al., 2017; Appeaning & Adeyemi, 2013). Flood disasters have become almost annual since the early 1990s, culminating in events such as the 3 June 2015 Accra flood that caused over 150 deaths (Yankson et al., 2017). Chronic drainage problems, solid-waste dumping into channels and building on waterways magnify flood hazards. More broadly, the area forms part of Africa’s low-elevation coastal zones, where high concentrations of people and economic activity, combined with limited adaptive capacity, make coastal flooding and SLR-related hazards especially challenging (McGranahan et al., 2007; Bates et al., 2008).

Yankson et al. (2017) emphasise that GAMA’s coast lies in a low-elevation coastal zone with clayey soils, which naturally impedes infiltration and favours rapid surface runoff. This biophysical setting is compounded by inadequate and undersized drains, blockage of channels by refuse and encroachment on waterways, all of which intensify flood incidence (Twumasi & Asomani-Boateng, 2002). Regionally, vulnerability is heightened by dense economic and industrial development along the coast, rapid population growth in coastal zones, and weak planning and poverty that limit adaptive capacity (Woodroffe, 2003; McGranahan et al., 2007; Bates et al., 2008). A further structural factor is the lack of good historical and coastal-condition data, which constrains accurate assessment of sea-level rise and hinders effective, locality-specific adaptation planning (Aboagye, 2012; UN-Habitat, 2014). Together, these physical, socio-economic and institutional conditions create a highly exposed and sensitive coastal fringe (Yankson et al., 2017).

Figure 5.11: Fuveme-R.C.-Basic-School-detroyed-by-coastal-erosion-Image-by-Akorli-Simon

Figure 5.11: Damage-to-a-school-from-a-November-2021-storm-surge-Image-by-Akorli-Simon

Ghana's coast is expected to face sea-level rise and storm surges, driving inland shoreline migration and recurrent flooding (Yankson et al., 2017; Appeaning & Adeyemi, 2013; World Bank, 2011). Climate change in Ghana manifests through increased storms, torrential and often unpredictable rainfall, and rising seas, all of which aggravate coastal hazards (Yankson et al., 2017). Projections indicate wetter wet seasons and drier dry seasons, implying more intense rainfall events interspersed with dry periods (Tachie-Obeng et al., 2014; World Bank, 2011). Intense storms and cloudbursts trigger severe pluvial flooding in low-lying coastal communities, especially where drains are inadequate or blocked, while storm surges and sea-level rise accelerate inland shoreline migration, submerging land and damaging coastal infrastructure and businesses (Appeaning & Adeyemi, 2013; Appeaning, 2014).

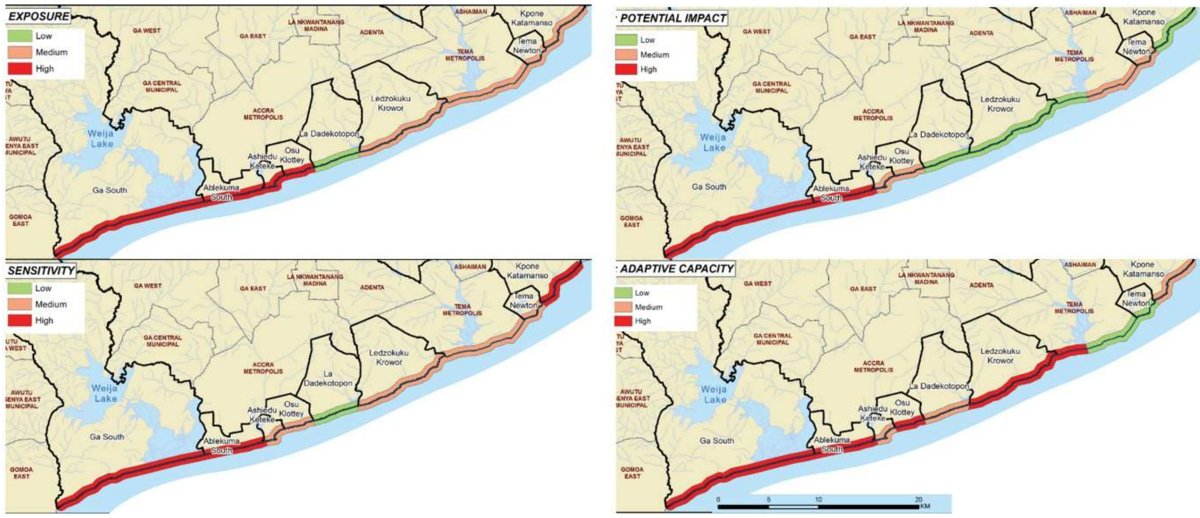


Figure 5.12: Exposure, Sensitivity, Adaptive Capacity, Potential Impacts, and weighted total Vulnerability identified from the studies of Yankson et al. (2017b) of coastal erosions.

Although the direct attribution of recent floods solely to climate change is not yet conclusive (Karley, 2009), current rainfall patterns interacting with poor drainage already produce massive floods. In this context, climate-driven extremes amplify pre-existing vulnerabilities, transforming coastal erosion, land loss and settlement displacement into recurrent and potentially catastrophic risks for GAMA's coastal population (Yankson et al., 2017; IPCC, 2014).

Based on the studies of Yankson et al. (2017) shown in the *figure 5.12*, the 'exposure' across the coast of

Ablekuma South, Ga South, Ashiedu Keteke and Osu Klottey record high exposure (≥0.30), reflecting frequent annual flooding and reported impacts from both rainfall and sea-level rise. La Dadekotopon has the lowest exposure (<0.18), while the remaining coastal communities fall in a medium band (0.18–0.29). While the 'sensitivity' ranges from 0.41 to 0.12. Ablekuma South, Ga South and Kpone Katamanso are highly sensitive (≥0.30), driven by high perceived risk to houses, fishing livelihoods and beaches, a large informal and tenant population, limited in-house water and toilets, and strong feelings of danger from flooding. La Dadekotopon alone shows low sensitivity (<0.18), with other communities in the medium range. And the 'adaptive capacity' scores are generally modest but relatively better than expected: Osu Klottey, Ga South, Ablekuma South and Ledzokuku Krowor have the highest adaptive capacity (0.15–0.16), while Ashiedu Keteke, La Dadekotopon and Kpone Katamanso are in a medium band (0.13) and Tema West scores lowest (≤0.12). Higher capacity is associated with more secure dwelling types and roofing, better access to electricity, and substantial assistance from non-governmental sources, although community-led mitigation and access to early warning remain weak across most sites.

Urban heat risks in Greater Accra

Across the Greater Accra Metropolitan Area (GAMA), urban heat has emerged as a major climate risk alongside flooding. Satellite and station analyses confirm a strong and expanding urban heat island (UHI): urban surfaces are several degrees warmer than surrounding non-urban areas, with night-time warming particularly pronounced (Wemegah et al., 2020).

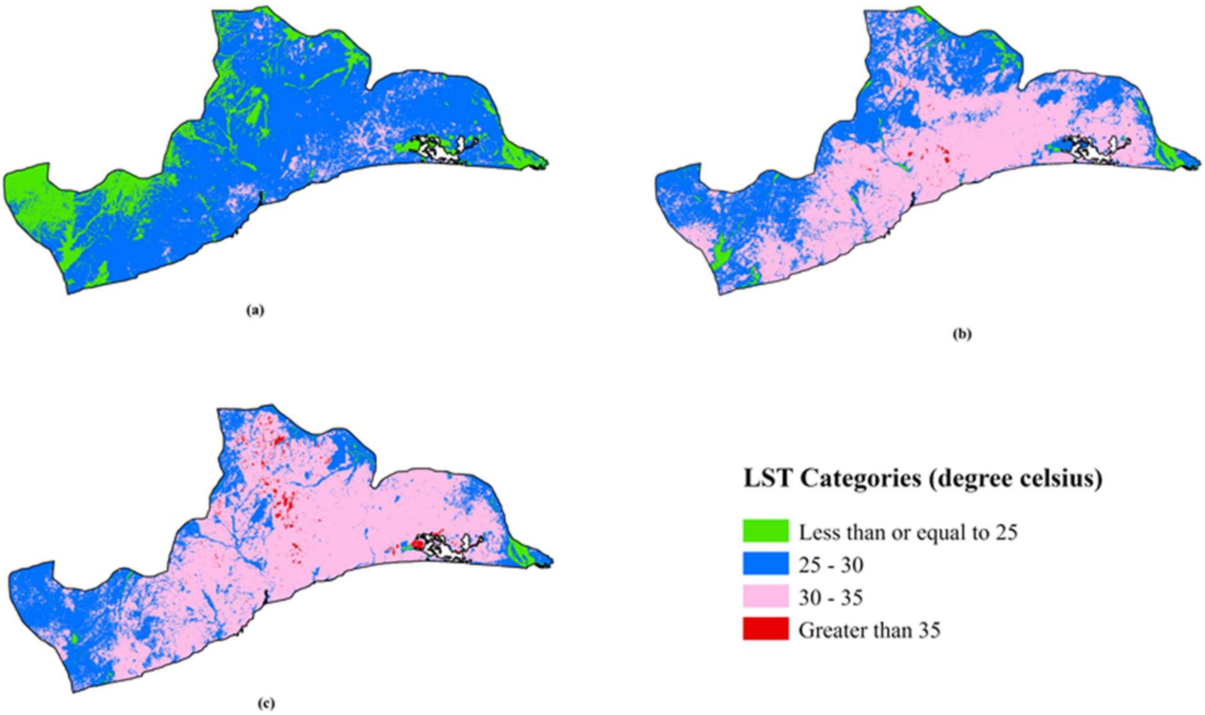


Figure 5.13: a-2000, b-2013, c-2020 Land Surface Temp maps estimated over the years across Greater Accra region (source: Identified from the studies of Devendran and Banon (2022).

Land-surface temperature (LST) mapping by Devendran and Banon (2022) shows that between 2002 and 2020 the share of the region in the 30–35 °C class rose sharply while areas below 25 °C almost disappeared, and hotspots above 35 °C began to appear. (Devendran and Banon, 2022). The LST maps in figure 5.13 (adapted from their study) clearly visualise this shift toward warmer surface conditions across GAMA. These patterns are closely linked to land-cover change. Athukorala and Murayama (2020) show that compact, highly built coastal and central districts form pronounced "hot belts," while vegetated peri-urban zones remain relatively cooler. (Athukorala & Murayama, 2020)

Accra's Climate Action Plan notes that mean temperatures have already risen and that very hot days above 35–40 °C are projected to become more frequent, framing UHI as a chronic risk for vulnerable groups (AMA & C40 Cities, 2020). Household surveys in GAMA report fatigue, sleep disruption and reduced work capacity during extreme heat, with impacts strongly shaped by income, housing quality and access to cooling (Boafo et al., 2025).

Together, rapid urbanisation onto former green and wetland areas, heat-retaining materials, limited ventilation and background climate warming are embedding chronic heat stress and deepening socio-spatial inequalities in GAMA. According to the literature, key drivers of heat risk in GAMA converge rapid, sprawling urbanization onto former agricultural lands, wetlands and open spaces; fragmentation and loss of urban green infrastructure; heat-retaining materials and urban forms that limit ventilation; and a background of regional climate warming. Together, these processes embed heat stress into the urban fabric, creating compound risk where high temperatures intersect with air pollution, inadequate housing and constrained adaptive capacity.

Climate change in Ghana manifests through increased storms, torrential and often unpredictable rainfall, and rising seas, all of which aggravate coastal hazards (Yankson et al., 2017). Projections indicate wetter wet seasons and drier dry seasons, implying more intense rainfall events interspersed with dry periods (Tachie-Obeng et al., 2014; World Bank, 2011). Intense storms and cloudbursts trigger severe pluvial flooding in low-lying coastal communities, especially where drains are inadequate or blocked, while storm surges and sea-level rise accelerate inland shoreline migration, submerging land and damaging coastal infrastructure and businesses (Appeaning & Adeyemi, 2013; Appeaning, 2014). Although the direct attribution of recent floods solely to climate change is not yet conclusive (Karley, 2009), current rainfall patterns interacting with poor drainage already produce massive floods. In this context, climate-driven extremes amplify pre-existing vulnerabilities, transforming coastal erosion, land loss and settlement displacement into recurrent and potentially catastrophic risks for GAMA's coastal population (Yankson et al., 2017; IPCC, 2014).

Risks and vulnerabilities identified

Flood risk and hydrological vulnerability

Encroachment on wetlands, floodplains and natural waterways has progressively reduced storage and infiltration capacity, increasing surface runoff during the short, intense rainstorms typical of GAMA's coastal climate. Built structures in channels and on floodplains, coupled with undersized or absent drains, amplify overland flow and raise flood peaks. Where drains exist, chronic solid-waste dumping blocks conveyance, so even 10-year return-period storms can trigger widespread pluvial flooding and deep ponding in low-lying basins such as the Odaw–Korle system (Addae & Oppelt, 2019; World Bank, 2020).

Environmental health and urban heat risks

Loss of forests, riparian vegetation and peri-urban green belts, together with the spread of sealed surfaces, heightens air and water pollution, accelerates runoff and raises land-surface temperatures. Polluted rivers, lagoons and wetlands – already under pressure from sewage, industrial effluents and solid waste – lose their capacity to buffer floods and moderate local microclimates, deepening both hydrological and heat vulnerabilities. In this context, Accra's documented urban heat island is not only a physical phenomenon but also a public-health risk, increasing thermal discomfort, heat-related illness and energy demand for cooling, particularly in dense, low-income neighborhoods with limited shade and unreliable electricity (AMA, 2020; Wemegah et al., 2020; Gyimah et al., 2023).

Social vulnerability and adaptive capacity

Exposure, sensitivity and adaptive capacity are unevenly distributed across GAMA's coastal and flood-prone districts. Coastal assemblies such as Ablekuma South, Ga South and Kpone Katamanso combine high exposure to floods, erosion and storm surge with high sensitivity linked to informal housing, insecure tenure, limited in-house water and sanitation, and heavy dependence on climate-sensitive livelihoods like fishing (Yankson et al., 2017). Although some communities exhibit moderate adaptive capacity – through more secure building materials, better access to electricity and support from NGOs – early-warning access, community-led mitigation and formal risk-governance mechanisms remain weak. The result is a pattern of "stacked" vulnerabilities, where the same households face recurrent flood losses, degrading environmental services, rising urban heat and constrained means to adjust.

5.1.c Notable strategies | GARID Project urban greening initiatives

Flooding in Greater Accra is driven by rapid urbanization, inadequate drainage and poor solid-waste management. Paved surfaces and new drains have expanded faster than design capacity, particularly in the lower reaches of major channels. Siltation, dumping of waste and lack of maintenance reduce hydraulic capacity, while informal settlements and valuable assets are increasingly concentrated in low-lying floodplains, amplifying exposure and damage risk.

The Greater Accra Flood Risk Mitigation Strategy responds with a "maintain–retain–store–drain" framework. "Maintain" prioritises regular dredging and desilting, installation of sediment traps, rehabilitation of damaged drains and works at the Korle Lagoon outlet to keep conveyance capacity close to design standards. "Retain" and "store" shift the focus upstream and at neighbourhood scale: tertiary drains are to be redesigned with berms that hold water temporarily, while yards, school grounds, public low-lying spaces and dedicated retention ponds provide micro- and meso-scale storage, delaying and attenuating peak runoff. "Drain" covers major structural works—widening riverbeds, replacing undersized bridges and culverts, lowering sections of floodplain, constructing flood walls and enlarging outlets to the sea—combined with strict enforcement of bans on building in flood zones, flood zoning, and better solid-waste management so that channels remain unobstructed.

The World Bank–financed Greater Accra Resilient and Integrated Development (GARID) Project operationalises this strategy in the Odaw River Basin, where flood risk is highest. Launched in 2019 with about US$200 million, GARID's objective is to improve flood risk management, solid-waste systems and access to basic services in vulnerable communities, ultimately protecting some 2.5 million people in Greater Accra (World Bank, 2019, 2023; Ministry of Finance, 2024). Structurally, the project funds detention and retention ponds, performance-based dredging of the Odaw and its tributaries, widening and lining of key channels, reinforcement of riverbanks, and replacement or upgrading of critical bridges and culverts in hotspots such as Kaneshie and Nima–Paloma. Non-structural measures include basin-wide flood early-warning, flood zoning and strengthened operations and maintenance regimes for drains.

Solid-waste interventions are central to GARID's logic of risk reduction. The programme supports closure and capping of the Abloragyei dumpsite, development of an engineered landfill and materials-recovery facility at Ayidan with a linked transfer station, and implementation of a Solid Waste Management and Litter Prevention Strategy to reduce dumping in watercourses (World Bank, 2023, 2024). These measures aim to break the cycle in which blocked drains and informal dumps magnify flood impacts. At the community scale, GARID finances participatory upgrading in three highly vulnerable settlements. Investments prioritise tertiary drains, basic access roads, water and sanitation, solid-waste facilities and small multifunctional green spaces that can act as local retention areas. To sustain these improvements, the project provides operations and maintenance grants and capacity-building for 17 metropolitan, municipal and district assemblies, embedding risk-informed planning and asset management in local government practice.

Institutionally, GARID is structured into five mutually reinforcing components. *Component 1* delivers climate-resilient drainage and flood mitigation works and non-structural risk-management tools, including the Flood Early Warning System. *Component 2* focuses on metropolitan solid-waste management infrastructure and behaviour-change initiatives. *Component 3* supports community upgrading and municipal capacity. *Component 4* covers project management, coordination, safeguards and monitoring. *Component 5*, a Contingent Emergency Response Component, allows rapid reallocation of funds to respond to crises—used already for COVID-19 and available for future flood emergencies—adding a financial risk-management layer to Greater Accra's broader disaster risk reduction and climate-adaptation strategy (World Bank, 2019, 2023, 2024).

Table 5.2: Strategies and highlights of the Component Frameworks under GARID.

Component	Main actions / strategies	Key implementation highlights
1. Climate Resilient Drainage and Flood Mitigation Measures	• Structural: detention/retention ponds on public land (e.g. GAEC), widening/lining of Odaw and tributary channels, bridge replacement, sand traps at bottlenecks. • Non-structural: basin-wide Flood Early Warning System, high-resolution LiDAR and monitoring, strengthened O&M for drains.	• Dredging of Odaw channel started in early 2024; several drainage contracts (e.g. Nima, Kaneshie) awarded and under implementation. (World Bank). • GAEC detention ponds fully designed with safeguards prepared, but construction slowed by land-acquisition and encroachment issues. (World Bank)
2. Solid Waste Management Capacity Improvements	• Reduce waste entering drains via stronger collection, transfer and disposal in 17 MMDAs. • Build key infrastructure: Ayidan engineered landfill, Abloragyei dumpsite capping, transfer station near GAEC. • Implement SWM & Litter Prevention Strategy and results-based incentives in vulnerable communities; integrate informal waste sector. (garid-accra.com)	• SWM & Litter Prevention Strategy and action plans completed. • Designs for Ayidan landfill, Abloragyei capping and transfer station advanced; 2024 additional financing (US$150m) explicitly earmarks resources to scale up SWM and drainage-linked works. (garid-accra.com)
3. Participatory Upgrading of Targeted Flood-Prone Low-Income Communities & Local Government Support	• Community-driven upgrading in selected flood-prone low-income areas (local drains, access, waste facilities, sanitation, lighting, multifunctional open/retention spaces). • Grants, tools and training to 17 MMDAs for drainage O&M, floodplain management and inclusive services. (World Bank).	• Community upgrading plans prepared and several civil-works packages awarded; supervision reports note "significant progress" in Components 1 and 3. (World Bank) • O&M grants already supporting routine drain cleaning and local DRR actions across participating assemblies. (d-portal.org)
4. Project Management	• Finance PCU and PIUs in key ministries and 17 MMDAs (staff, training, equipment, operating costs). • Oversee procurement, FM, safeguards, M&E, communication, GRM. • Prepare technical studies, designs, ESIAs, RAPs for all major works and for future scale-up.	• Allocation increased to about US$9 million under additional financing. (World Bank) • Implementation progress rated Moderately Satisfactory, with nine major civil works contracts in progress and several more in late design/contracting. (World Bank) • Delivered most of the analytical and safeguard backbone (designs, TORs, RAPs, ESIAs) that underpin detention ponds, drainage upgrades and SWM infrastructure. (World Bank)
5. Contingent Emergency Response (CERC)	• Provide a flexible crisis window to rapidly reallocate GARID funds to emergencies (health, floods, other shocks). • Align with national disaster and emergency frameworks to support priority response actions.	• Activated for COVID-19 Emergency Preparedness and Response, funding lab equipment, PPE, mobile labs and supplies. (World Bank). • Helped increase laboratories able to conduct COVID testing from 2 to 63, and greatly expand tests per million population. (World Bank) • Remains available for rapid financing in case of major flood or climate-related disasters in Greater Accra. (garid-accra.com).

Under the Component 1: Climate Resilient Drainage and Flood Mitigation Measures

The Detention Ponds at Various locations were identified, also the dredging sites, waste management and Community Upliftment Plan were also considered along the Odaw river.

Some of the major interventions planned across the detention ponds highlight the provisions of open large scale infiltration areas with vegetation covers drainage channels and public access. Although these are still in the process of development and invite community participation of private interests to meet its required scale and goal.

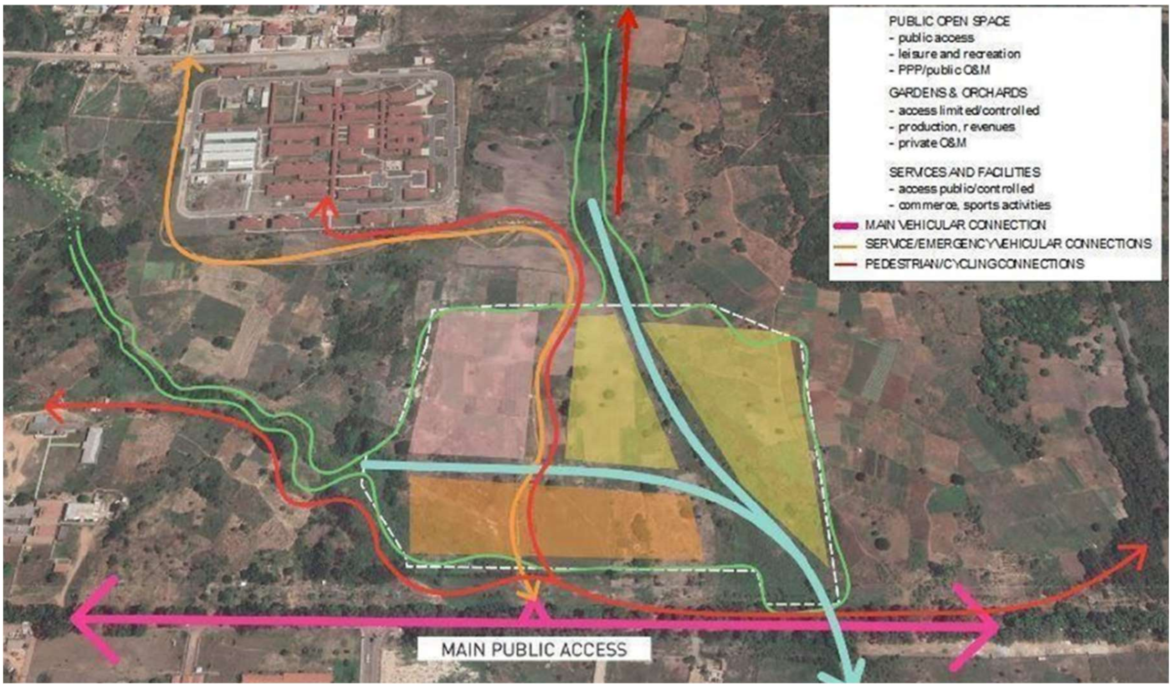


Figure 5.14: Planned Interventions across the detention ponds (source: GARID) refer Fig5.18 for location.

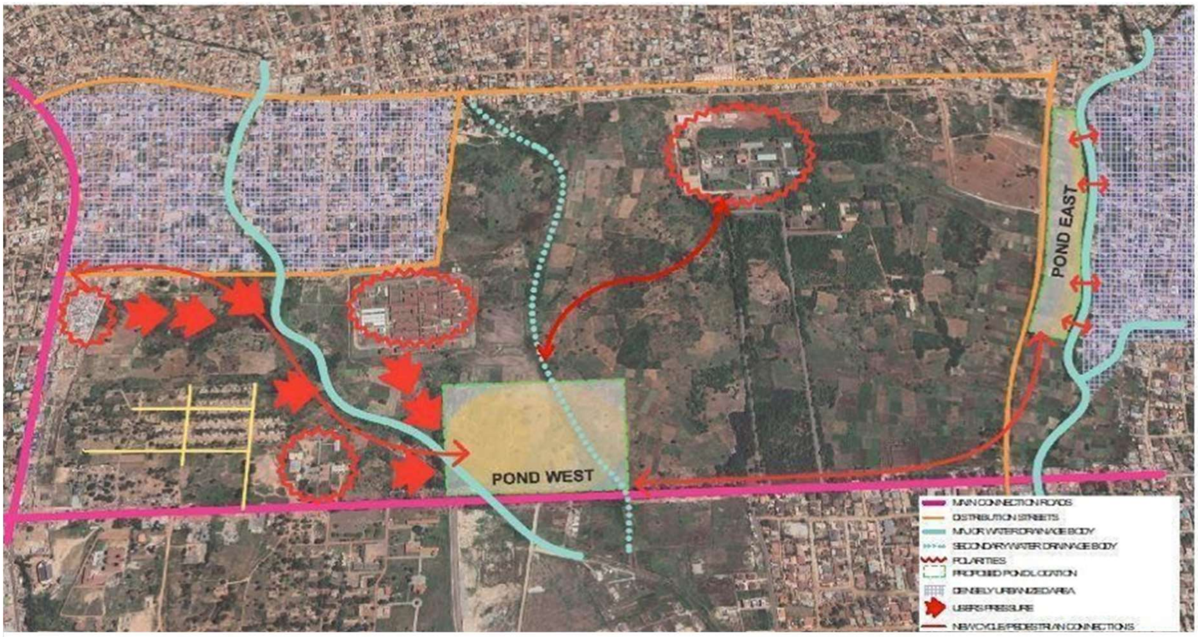


Figure 5.15: Planned Interventions across the detention ponds (source: GARID) refer Fig5.18 for location.

And structural measures that were taken into act, that are

- Deferred and routine maintenance and dredging of the Odaw channel to improve drainage and flood management
- Development of flood retention basins which will temporarily hold some volume of flood running into the Odaw channel during raining season until such a time when the water level in channel goes down before the water in the ponds will be released into the channel.
- Construction of sand traps on selected tributaries of the Odaw River Basin
- Repairing and reconstruction of major drains along the Odaw River Basin
- Replacement of critical bridges that impedes the flow of water in the Odaw Channel
- Rehabilitation of the Korle Lagoon Interceptor Weir,
- Reconfiguration of Odaw River outlet into the Sea. (Korle Lagoon area)

Figure 5.16: Existing Conditions across mutlitple locations for Bridges, informal housing, and drain openings across Odaw river. (Source: GARID)

Figure 5.16 indicates a major need of key interventions, and one of them is understood to be the citizen participation in waste management and removal of barriers and improving the local water channels along with the resettlement of the existing housing across its major catchment zones across the Odaw river. These can be located at the *figure 5.18*

In the Nima basin, the planned works focus on turning an under-sized, eroding, waste-choked channel into a higher-capacity, safer and more maintainable drainage system. The open drain is to be re-formed from a narrow, partly unlined trapezoidal section into a wider, fully lined rectangular section with a shaped base that maintains flow even in dry conditions.

Downstream, the current pair of large culverts is replaced and expanded into multiple parallel culvert cells, with a short open inspection section that includes access ladders and trash screens. The outlet into the main river is also redesigned so water enters at a smoother angle, reducing backflow and turbulence. These interventions are expected to:

- Increase hydraulic capacity, so heavy rains are conveyed without frequent overtopping.
- Reduce erosion and structural failure, thanks to full lining and better geometry.
- Cut silt and waste accumulation, via smoother sections and screened inspection points that make maintenance easier.
- Lower local flood depths and duration in adjacent low-income areas, protecting homes, shops and infrastructure.
- Improve environmental and public-health conditions, by limiting stagnant water, bank collapse and exposure to contaminated runoff.

The Community Upgrading Plan across Nima, the propose ensures an integrated package of drainage, access, solid-waste, water and sanitation upgrades that directly target chronic flooding and environmental health risks. Stormwater interventions add about 1.6 km of new, well-sized drains and upgrade priority channels (e.g. Mei Zani, Koo-oho, Abenase) where substandard or missing drains, siltation and backflows currently cause frequent inundation of homes, shops and roads. Paved access roads (≈3.2 km) with side drains address collapsed or unfinished streets that hinder drainage, waste collection and emergency access, while also improving livelihoods and connectivity.

Figure 5.18: Location of Interventions across the Odaw River and its basin areas for Dredging, Detention Ponds, Community Upliftment Plan and Korle Lagoon. (source: GARID)

Figure 5.17: NIMA Drainage Channels in deteriorated condition (source: GARID)

Figure 5.19: Conditions of the drains and channels in NIMA fringe (source: GARID).

Solid-waste measures, community clean-up, a sanitary site/transfer station, buy-back centre, cooperative office and waste vehicles; respond to widespread illegal dumping and choked gutters that amplify flood risk. Sanitation and water packages tackle overcrowded, dilapidated public toilets, open defecation, sullage discharge to drains, and unreliable water supply through rehabilitation of existing blocks, construction of 800–1,000 household toilets linked to DEWATS/sewers, plus 6 km of new distribution mains and prepaid kiosks.

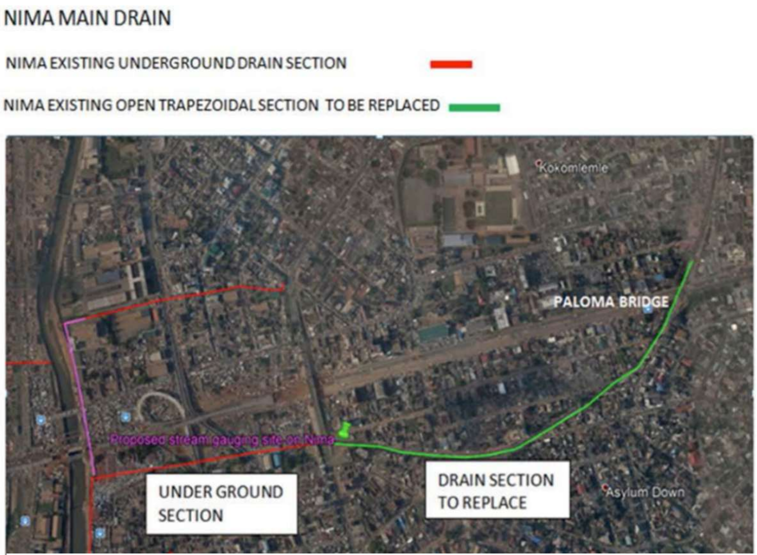


Figure 5.20: Map Showing Existing Drainage channel planned to be replaced in NIMA. (source: GARID)

Public-space designs introduce roadside greenery, trees and planting strips that cool streets, improve air quality and allow some infiltration, while new pedestrian walkways and alleys are planned with inclusive features (shade, tactile paving) to make movement safer and more accessible. Street and area lighting is added along roads and in green/open spaces to reduce crime and fear at night and protect users during floods or emergencies. Socially, the plans respond to stakeholder concerns about flooding, poor sanitation, unsafe toilets and weak enforcement by pairing physical works with community structures such as sanitation taskforces and Community Development Committees, expected to support awareness, by-laws and long-term O&M.

In Old Fadama, GARID combines river engineering with green-public-space upgrading to tackle flooding, pollution and unsafe living conditions. Hydraulically, the Odaw section through Old Fadama will be dredged and widened by 15 m on the right bank, with re-profiling and lining to restore capacity while limiting soil disturbance and erosion. Dredging material is to be safely disposed of off-site, and the area will be subject to regular maintenance dredging, so the channel does not re-silt.

Figure 5.21: Old Fadama neighborhood drainage networks and opening, management and revival connections to Odaw river. (source: GARID)

On the western bank, the plan is to create a non-accessible green belt with dense riparian vegetation and a hidden safety fence, both to stop waste dumping and encroachment and to use phytoremediation species for contaminated soils. While on the eastern bank, the project proposes a linear urban park: a raised green berm as a barrier to the river, a 1.8 km pedestrian–cycle path with lighting and trees, pocket gardens, three playgrounds, sports courts (~1,000 m²), public squares (~4,300 m²) and a small outdoor market area (~1,800 m²). *see figure 5.21.*

Overall, the strategy is to reduce flood risk and erosion, prevent further pollution and informal encroachment, and at the same time upgrade Old Fadama's public realm and livelihoods through safer, multifunctional riverside spaces. Things are currently looking brighter in Accra. Dredge Masters have just completed another phase of the restoration plan, and the Odaw River is in considerably better condition (*see figure 5.22*) than in previous years. The waters are now expected to flow smoothly during the rainy season.

BEFORE RESTORATION

AFTER RESTORATION

Figure 5.22: A before and after of Odaw River restoration project by Dredge Master Private organization. (source: Watermaster)

Sanitation and Water Project

The GAMA *Sanitation and Water Project*- SWP (2014–2020) targeted critical urban WASH (Water, Sanitation and Hygiene) deficits in Greater Accra, especially in low-income communities, and is assessed as highly effective. It tackled three main problems: lack of household and school toilets, limited access to safe piped water, and poor drainage and fecal sludge management. The project more than doubled its original target for household toilets, enabling about 240,000 people to gain improved household sanitation, and delivered 406 school toilet blocks serving over 250,000 pupils. It complemented this with two simplified sewerage systems in dense, low-income areas, benefitting ~44,500 people.

On water supply, the project supported over 10,000 new household water connections and rehabilitated services for 83,000 existing customers, bringing improved piped water to more than 420,000 people. It also developed an Urban Water Supply Master Plan and a calibrated network model. For flood and environmental risk, GAMA SWP reconstructed or expanded four priority tertiary drains and desilted 19 additional drains, reducing local flooding.

Institutionally, it strengthened ministries, utilities and MMDAs (*Metropolitan, Municipal and District Assemblies*); created a Low-Income Customer Support Unit within GWCL (Ghana Water Company Limited); rolled out ESICApps (*digital monitoring platform - a mobile/ web app system*) for real-time sanitation monitoring; supported policy and by-law reforms; and met all safeguards targets with full ESIA, compensation and grievance redress. These measures, combined with behavior-change campaigns and a 70% household toilet subsidy, allowed the project to exceed most targets by 50–100% and be recognized as the "Most Impactful Urban WASH Project" in 2018. *See figure 5.23.*

Figure 5.23: Major set of interventions toward building resilience across the neighborhoods in Accra. (Source: Ministry of Sanitation and Water Resources, Ghana).

The GAMA Sanitation and Water Project reduced everyday flood-related risk by:

- getting faecal waste out of drains (household toilets, school toilets, sewers),
- improving drainage capacity in key hotspots, and
- expanding safe piped water, which matters hugely after floods when contamination is high.

That experience gives GARID three big advantages:

- Technical lessons for collective, measured and phasing of drainage infrastructures, sewers, and tertiary works in dense low-income areas; combining hardware (toilets, drains, pipes) with software (subsidies, behaviour change, mobile monitoring).
- Institutional capacity – MMDAs, GWCL and ministries have already been through large-scale ESIA, Rapid Action Programmes, by-law reforms, pro-poor targeting and grievance redress. GARID has reused those channels for solid waste, drainage O&M, and community upgrading instead of inventing them anew.
- Pro-poor, climate-resilient framing – GAMA SWP proved that focusing on low-income communities, subsidised access and behaviour change can hit and exceed targets. GARID extends that logic from WASH into flood risk management, detention ponds, solid-waste systems and resilient upgrading, making DRR and climate resilience much more socially grounded and implementable.

In the Odaw–Korle basin, KLERP and GARID can be read as two generations of *flood-risk governance*. KLERP (from ~2000) concentrated on restoring Korle Lagoon as an outlet "safety valve" through dredging, sewage infrastructure and planned waterfront parks, but was undermined by top-down evictions and weak basin-wide controls on waste and encroachment.

GARID (from 2019) reframes the same problem as a *basin-scale resilience challenge*, combining upstream drainage and solid-waste investments, detention ponds, downstream dredging and community upgrading to lower flood peaks and vulnerability across Greater Accra, under stronger social and environmental safeguards.

Accra Resilient Strategy 2019, Climate Action Plan (2020-2025) & GAMA Urban Resilience Strategy

Accra's Resilience Strategy (ARS), developed with support from 100 Resilient Cities and adopted in 2019, provides a roadmap for how the city intends to anticipate and manage a wide spectrum of shocks and chronic stresses rather than simply reacting to crisis events (Accra Metropolitan Assembly [AMA], 2019). The strategy is structured around three pillars, eight goals and twenty-seven initiatives, which together aim to improve infrastructure performance, optimize resource use and embrace the role of informality in building resilience in Greater Accra.

ARS 2019 strategy's core priority is to make Accra "a smart, sustainable, and resilient city that anticipates and plans for shocks, rather than reacts to them", by turning everyday stresses into opportunities. It focuses on:

- improving safe and equitable access to jobs, services and infrastructure.
- tackling flooding, sanitation and waste; strengthening mobility and infrastructure systems
- and doing this through better governance, accountability, and regional coordination across the Greater Accra Metropolitan Area.

In practice, this means using resilience as a lens for infrastructure investment, climate adaptation, land-use decisions, and social inclusion, instead of treating shocks and stresses as isolated sectoral problems. The ARS 2019 has its own set of Priority Stresses and Shocks for discussion

Priority stresses in the ARS are high cost of living, an inefficient and unsafe transport system, poor waste management, and inadequate sanitation and water services. Together they erode household incomes, limit access to jobs and services, and keep many neighborhoods in unhealthy, degraded conditions. These everyday pressures quietly weaken social and physical systems and make residents far more vulnerable when big events such as floods or epidemics occur.

Priority shocks are identified as floods, fires (especially in markets), disease outbreaks such as cholera, infrastructure and building collapses, and the potential for damaging earthquakes. These are acute events that can cause deaths, destroy assets and severely disrupt services. In the ARS, they are treated not in isolation, but in relation to the underlying stress and weak governance that magnify their impact across Accra's low-lying and densely populated areas.

Together, these stresses and shocks define where resilience action is most urgently needed. The Pillars of the Accra Resilient Strategy can be seen structured as shown in the figure below (*see figure 5.24*).

Pillar 1

Integrated infrastructure, environment & services

Focus: closing infrastructure gaps in transport, drainage, waste, sanitation, energy and flood management, while embedding climate and population growth considerations into planning.

Goals under this pillar revolve around safer and more efficient mobility, reduced flood and sanitation risks, and more reliable basic services.

Typical initiatives: road safety and public transport improvements, drainage upgrades, better waste systems, greening and flood-mitigation projects.

GAMA Sanitation and Water Project; Emerging: Integrated Korle Lagoon "Smart City" concept for Blue-Green Infrastructure based Urban Development;

Pillar 2

Optimise new and existing resources with accountability and transparency

Focus: making limited financial, human and information resources work harder through better data, planning, regulation, and revenue generation.

Goals include strengthening data-driven planning, improving enforcement (e.g. waste and building control), and enhancing AMA's revenue and staff capacity.

Typical initiatives: improving oversight of waste contractors, training building inspectors, enhancing revenue systems, and building the Resilience & Sustainability Unit.

Clean Accra Project & 'Operation Clean Your Frontage;

Pillar 3

Embrace informality's contributions to resilience

Focus: recognising that informality underpins ~80% of Accra's economy and treating it as a resilience asset rather than a liability.

Goals: Improve quality of life in informal settlements and for informal workers (services, safety nets, health, upgrading).
Better integrate formal and informal economies and systems (e.g. waste, mobility, markets).

Typical initiatives: settlement upgrading; community-driven flood-hazard land-use guidelines; creating an informal trade department; integrating informal waste pickers; exploring legalisation/management of okada taxis; and expanding social protection for informal workers.

Community-based waste recycling & urban gardening (Korle–Odaw catchment); Grassroots flood-response and adaptation in informal communities - Case projects of Glefe, Old Fadama and Agbogbloshie for developed adaptive capacities to recurrent floods.

Figure 5.24: Accra Resilient Strategy Pillars, Focus and Goals. (source: Author, adopted from Accra Resilient Strategy, 2019)

Accra's Urban Resilience Strategy and Climate Action Plan (CAP) focus on a core set of climate-related hazards. Across resilience studies for GAMA, the main risks are recurrent urban flooding, coastal erosion and sea-level rise, extreme heat and related health impacts, alongside secondary shocks such as urban fires, cholera outbreaks and low-frequency earthquakes, all intensified by rapid, largely unplanned urbanization (World Bank, 2017; AMA, 2020).

Flooding is consistently identified as the most severe hazard. Low-lying coastal plains, silted drains in the Odaw–Korle system, extensive construction on floodplains and waterways, and drains clogged with solid waste generate "perennial floods," where even moderate storms trigger widespread inundation

(Owusu & Obour, 2021; World Bank, 2020). Risk modelling for the Odaw Basin suggests that roughly 100,000 people are exposed each year, with annual average flood damages of about US$34 million in the basin and US$48 million across GAMA; without additional measures, these losses could quadruple by 2050 (World Bank, 2020).

Coastal erosion and sea-level rise form the second major hazard cluster. Around 80% of GAMA's 225 km coastline is considered erosion-prone, with houses and fish-landing sites already lost and projected shoreline retreat of about 189–202 m by 2100 if current trends continue (Appeaning Addo, 2013; World Bank, 2017). The CAP further notes that a 20 cm rise in sea level under high-emissions scenarios could erode an additional ~150 m of waterfront in Accra, threatening livelihoods and infrastructure (AMA, 2020). A third pillar concerns heat and health risks: national projections indicate more frequent hot days and nights and a several-fold increase in heat-related mortality by 2080, while dense coastal settlements continue to face recurrent cholera outbreaks and emerging food and energy security pressures (World Bank, 2017; AMA, 2020).

On the ground-level progress side, the city has:

- Prepared its first city-level GHG inventory and a Climate Action Plan with 20 priority measures across waste, energy/buildings, transport and land-use, aiming for resilience and carbon neutrality by 2050 (AMA, 2020).
- Launched a Greater Accra Climate and Flood Risk Mitigation Strategy and GARID investments, underpinned by hydraulic and damage modeling, to design basin-wide measures such as retention ponds, Odaw widening, outlet reconfiguration and maintenance programs (World Bank, 2020).
- Initiated institutional reforms: a Resilience & Climate Change Steering Committee, climate-risk and impact assessment (including hazard maps for flooding, heat and water scarcity), coastal management plans, Disaster Volunteer Groups, and early-warning linkages with GMet and NADMO (World Bank, 2017; AMA, 2020).

Table 5.3: Alignment of Projects/ practices, Targetted Stress and hazards, and Spatial Focus areas.

	Project / practice	Resilient Accra pillar(s)	Type (EbA/ NbS vs "grey")	Main hazard / stress targeted	Spatial focus (within GAMA)
1	**Sustainable Greening & Beautification of Accra** (road medians, parks, junctions)	**P1, P2**	**Primarily EbA / NbS** (urban trees, lawns, planted medians) with minor grey elements (hard edging, irrigation)	Urban heat, local flooding from impervious surfaces, poor public-realm quality	Core AMA: main arterial roads, intersections, medians, ceremonial routes, selected parks and open spaces
2	**GAMA Sanitation and Water Project (GSWP) & Integrated Urban Environmental Sanitation Strategy & Master Plans (IUESSMP)**	**P1, P2**	**Hybrid** – mainly **grey infrastructure** (sewers, drains, toilets) but guided by **catchment-based, ecosystem-conscious planning**	Flooding, waterborne disease, pollution of streams & lagoons, inadequate sanitation	Wider **GAMA**: low-income communities and flood-prone basins, especially Odaw–Korle and other urban streams
3	**Korle Lagoon Ecological Restoration Project (KLERP)** and follow-up dredging/restoration efforts	**P1, P3**	**EbA / NbS core** (restore lagoon storage, tidal exchange, wetlands) combined with **grey** (dredging, embankments, weirs)	Pluvial & fluvial flooding along Odaw; backwater and tidal flooding; severe water pollution	**Korle Lagoon & lower Odaw basin**, including environs of Agbogbloshie, Old Fadama, central market/transport corridors
4	**Korle Lagoon / Odaw "waterfront regeneration & smart city" concepts** (various proposals)	**P3, P1**	Intended as **hybrid**: restored blue-green corridors, public spaces, plus compact mixed-use "smart" development (grey)	Chronic flooding, degraded waterfront, underutilised land, informal and unsafe working conditions	Lower **Odaw–Korle corridor**, extending inland from the lagoon into central Accra

5	**"Clean Accra" initiative** & **"Operation Clean Your Frontage"** (by-law enforcement & logistics for waste)	**P2, P1**	Mostly **grey / institutional** (trucks, skip containers, enforcement, by-laws, digital monitoring), but with co-benefits for ecosystems (cleaner drains, streams, beaches)	Blocked drains, flood exacerbation from solid waste, environmental health risks, visual blight	AMA-wide and **Greater Accra Region**, with focus on busy streets, markets, transport corridors and flood-prone areas
6	**Accra Road Safety Strategy** with Bloomberg Initiative for Global Road Safety (BIGRS)	**P1, P2**	**Grey / systems resilience** – intersection redesigns, traffic-calming, enforcement, data systems	Traffic crashes (a major urban "shock"), pedestrian vulnerability, emergency response burden	Key high-risk corridors and junctions across AMA and adjoining municipalities
7	**Informal settlement upgrading & planning support** (e.g. Ga Mashie, Nima, Old Fadama, Agbogbloshie – various UN-Habitat & NGO-led actions)	**P3, P1**	**Hybrid** – small-scale **EbA elements** (improved drainage channels, sometimes trees/green buffers) plus **low-cost grey** (pathways, toilets, standpipes, raised floors)	Flooding, fire risk, poor WASH, overcrowding, insecure tenure	Dense inner-city areas and waterfront slums of **central Accra**, esp. along the **Odaw–Korle** and coastal fringe
8	**Community-based waste recycling & urban agriculture using wastewater/organics**	**P3, P2**	**EbA / NbS-like** converting organic waste and nutrient-rich wastewater into soil fertility; often in low-lying floodplains	Waste accumulation, soil degradation, food insecurity, polluted waterways	Peri-urban floodplains and low-lying corridors (e.g. **Dzorwulu–Roman Ridge** and other urban–peri-urban fringes)
9	**Grassroots flood adaptation practices in informal communities** (raised plinths, footbridges, informal early warning, savings groups)	**P3, P2**	**Non-engineered / social EbA** – locally improvised micro-infrastructure, behaviour change, social capital	Pluvial & fluvial flooding, loss of assets and livelihoods, recurrent small-scale disasters	Hotspots such as **Glefe**, **Old Fadama**, **Agbogbloshie**, coastal and lagoon-edge communities

Accra's shift toward a climate-resilient city is still constrained by persistent governance and capacity gaps. NADMO and many MMDAs remain chronically under-resourced, limiting proactive planning, enforcement and maintenance. Buffer-zone policies and building regulations are weakly applied, so encroachment into floodplains, waterways and coastal setbacks continues. Basin governance is fragmented, solid-waste management and drain maintenance are inadequate, and risk data are often limited or outdated. Everyday practices such as littering and informal construction quickly undermine new engineering works, meaning that many efforts remain reactive rather than transformative (World Bank, 2017; Owusu & Obour, 2021; World Bank, 2020). This implies that Accra's resilience and CAP agenda must move beyond individual projects to strengthen governance capacity, spatial-planning enforcement and pro-poor upgrading in hazard-exposed informal areas.

The city's project portfolio shows a strong emphasis on Sendai Priority 3 – "Investing in disaster risk reduction for resilience" – with selective progress on Priorities 1 and 2. Major programmes such as the GAMA Sanitation and Water Project and Korle Lagoon restoration channel resources into drainage improvement, flood control and sanitation in key basins like Odaw–Korle. Smaller, dispersed actions – roadside greening, tree planting and corridor beautification – act as nature-based micro-interventions that support urban cooling, infiltration and everyday livability. At the same time, governance-focused initiatives such as "Clean Accra," "Operation Clean Your Frontage" and the Accra Road Safety Strategy operationalise Sendai Priority 2 by using by-laws, enforcement tools, monitoring systems and multi-agency coordination to keep streets, drains and mobility systems functional under stress.

Sendai Priority 4 – preparedness and "Build Back Better" – is most visible in informal and low-income settlements. In areas such as Glefe, Old Fadama and Agbogbloshie, residents have long practised bottom-up adaptation through raised plinths, informal early-warning, savings groups, waste recycling and urban agriculture. The Resilient Accra Strategy's third pillar, which aims to "embrace informality," can be read as an attempt to align formal DRR and climate-resilience agendas with these existing adaptive practices, rather than treating them solely as problems to be removed.

5.2 Case Study 2: City of Chennai, India

5.2.a General Background –Geography, Urban Density and Climate

Chennai, formerly known as Madras, is the capital of Tamil Nadu and one of India's four largest metropolitan centers. Located at 13°N, 80°E, on the Coromandel Coast of the Bay of Bengal, it serves as a strategic economic, cultural, and industrial hub in South India. What began as a cluster of fishing villages has grown into a global urban agglomeration, with a population of nearly 8.6 million in its metropolitan region (Directorate of Census Operations Tamil Nadu, 2011). Its trajectory of growth has been shaped by its port economy, manufacturing sector, and more recently, its emergence as a centre for automobile production, IT services, and healthcare (Chennai Corporation, 2006; Water as Leverage, 2018).

Administrative Boundaries: GCC and CMA

The Greater Chennai Corporation (GCC), established in 1688 and expanded in 2011, governs the core urban area of 426 km². It is divided into 15 zones and 200 wards, managing water supply, drainage, solid waste, public health, and disaster response (Chennai Resilience Strategy, 2019). Within the GCC, approximately 29% of the population resides in informal settlements, highlighting the city's socio-economic vulnerabilities (Chandramouli, 2003). By contrast, the Chennai Metropolitan Area (CMA) is the statutory planning region under the Chennai Metropolitan Development Authority (CMDA). Recently expanded to ~5,900 km², it spans multiple districts to accommodate urban growth and peri-urban expansion (CMDA, 2008). While the CMA frames long-term land-use planning, the GCC remains the critical focus for resilience interventions due to its dense population, infrastructure concentration, and exposure to floods and cyclones.

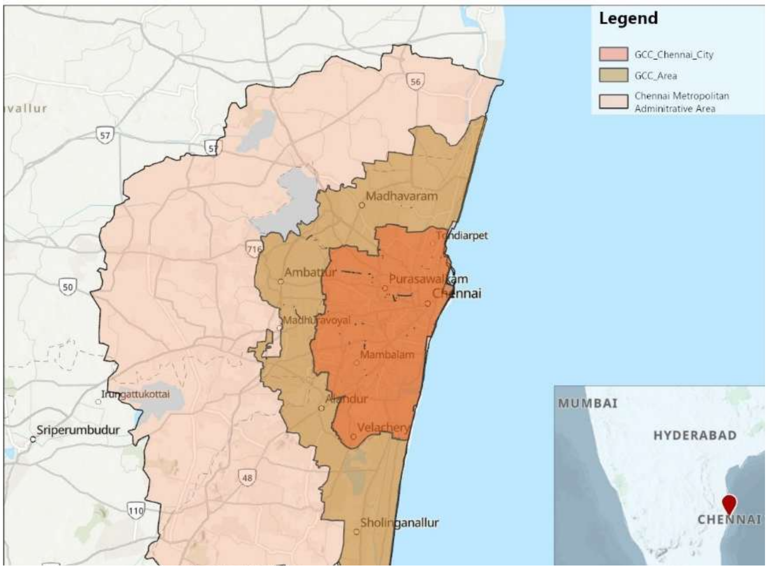


Figure 5.25: Administrative boundaries of Chennai and Metropolitan Area. (source: Author; Database: Open-City Data Portal).

Geology, Geomorphology, and Topography

Geologically, Chennai rests on a mosaic of Archaean gneisses and granites in the west, Gondwana clays in central belts, and Quaternary alluvium along its eastern coastal stretches (Ramasamy, Vijay, & Dhinesh, 2018). These substrata are low in permeability, hindering groundwater recharge and aggravating urban flooding, while over-extraction has induced saline intrusion into aquifers (Pal & Suresh, 2022). Geomorphologically, the city is defined by flat coastal plains, river floodplains, wetlands, and marshes. Historically, the ery system of tanks and interconnected lakes regulated floods and ensured water storage. Today, however, less than 15% of wetlands remain, compared to 80% in the 1980s, largely due to urban expansion and encroachment (Water as Leverage, 2018). Topographically, the city lies at an average elevation of 6–7 m above sea level, with poor natural drainage gradients, making it especially vulnerable to waterlogging, storm surges, and sea-level rise (Chennai Resilience Strategy, 2019). As discussed in the studies of Kaaviya and Devadas (2021) primarily across the GCC area, the soil depth of the region has been described with (59%) of the city area falling under the extremely shallow category having a depth of less than 10 cm while 41% being moderately shallow (>50cm) with an area of 173km^2. Saying that, the 252Km^2 have less infiltration capacity accounting for drought and urban flood and are subjected to very low water resilience.

The landforms across the GCC area are constituted with coastal plains, paleo–beach ridges, swales, and low swamps altogether determining where its water lingers or evacuates. Flat, low-lying tracts and reclaimed wetlands concentrate surface water and slow drainage, whereas slightly raised sandy ridges shed water faster.

The Deltaic plain (53%) is susceptible to periodic flooding due to its moderate infiltration rate. The coastal plain (28%) includes are prone to storm surges because of this zone's silty clayey soil deposits. The Pediment pediplain (16%) have a much-reduced infiltration capacity active as a runoff zone. The Flood plain (3%) are the areas of seasonal floods because of its gravel, sand, and silt deposits. These contrasts explain the mosaic of flood-prone pockets and the persistence of hotspots along marsh edges (Kaaviya & Devadas, 2021).

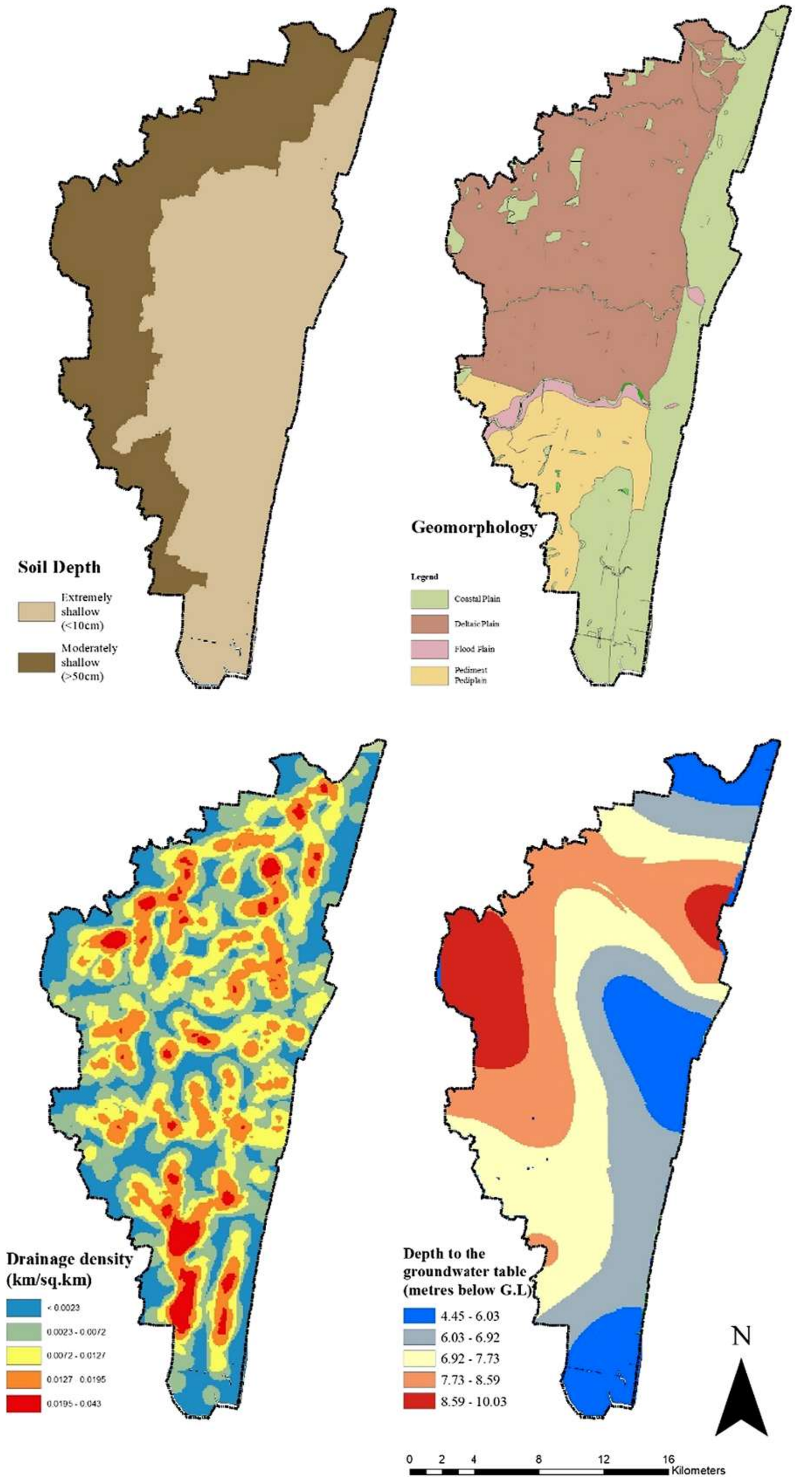


Figure 5.26: Soil Depth, Geomorphology, Drainage Density and Depth to Ground Water table (source: Kaaviya & Devadas, 2021)

Drainage Density, Ground water Table

The Surface runoff is more significant in zones with higher drainage density. Based on water resources data of the government of India, Kaaviya and Devadas (2021), shared that 'very high' and 'high' classes of drainage density area accounted for 21% of the GCC area, subjected to very low and low water resilience. Respective breaks or constrictions can flip neighbourhoods into stagnation even under comparable rainfall, aligning with mapped inundation belts. Also, the depth to groundwater table across the GCC area, has been found that large swathes exhibit shallow–moderate groundwater depths (~7.7–

10 m below ground level with over ~50% of the area), signaling limited subsurface storage and rapid saturation during heavy rain. Once soils fill, additional rainfall converts directly to runoff, amplifying street-level flooding.

Table 5.4: Data from the studies of Kaaviya and Devadas (2021)

Parameters	Water resilience	Area (km^2)	Percentage (%)
Soil depth (cm)	Very low	252.119	59.18
	Moderate	173.881	40.82
Geomorphology	Very low	119.28	28.00
	High	225.78	53.00
	Very low	12.78	3.00
	Moderate	68.16	16.00
Drainage density (km/ km^2)	Very high	99.388	23.33
	High	127.863	30.01
	Moderate	110.933	26.04
	Low	72.059	16.92
	Very low	15.757	3.70
Depth to water table (metres below ground level)	Very high	44.625	10.48
	High	76.715	18.01
	Moderate	92.535	21.72
	Low	162.091	38.05
	Very low	50.035	11.75
Flood inundation depth (feet above ground level)	Very high	32.525	7.64
	High	125.521	29.47
	Moderate	130.275	30.58
	Low	102.470	24.05
	Very low	35.210	8.27
Rainfall (mm)	Very low	223.545	52.48
	Moderate	72.061	16.92
	High	35.872	8.42
	Low	32.241	7.57
	Very low	62.280	14.62

Flood Inundations, Rainfall and Slope%

With the data from Tamilnadu State Disaster Management Authority, the studies (Kaaviya & Devadas, 2021) dictate that the Flood Inundation depths of 4–5 ft cover roughly one-quarter of the city in the flood layer, tracing corridors where terrain, blocked flow paths, and high imperviousness combine. These belts mirror past events and mark zones where mobility, livelihoods, and services are repeatedly disrupted.

The rainfall in the GCC region were recorded as annual normals range from ~1092–1264 mm, but the isohyet map shows both very heavy and scanty pockets (≈22% heavy; ~52% scanty). Risk arises from sharp temporal bursts rather than totals alone, overwhelming drains due to heavy downpours, while frequent deficits stress supply and aquifers. About three-quarters of Chennai sits on very gentle slopes (0–5%), inherently favouring ponding during cloudbursts. Small gradient breaks matter;

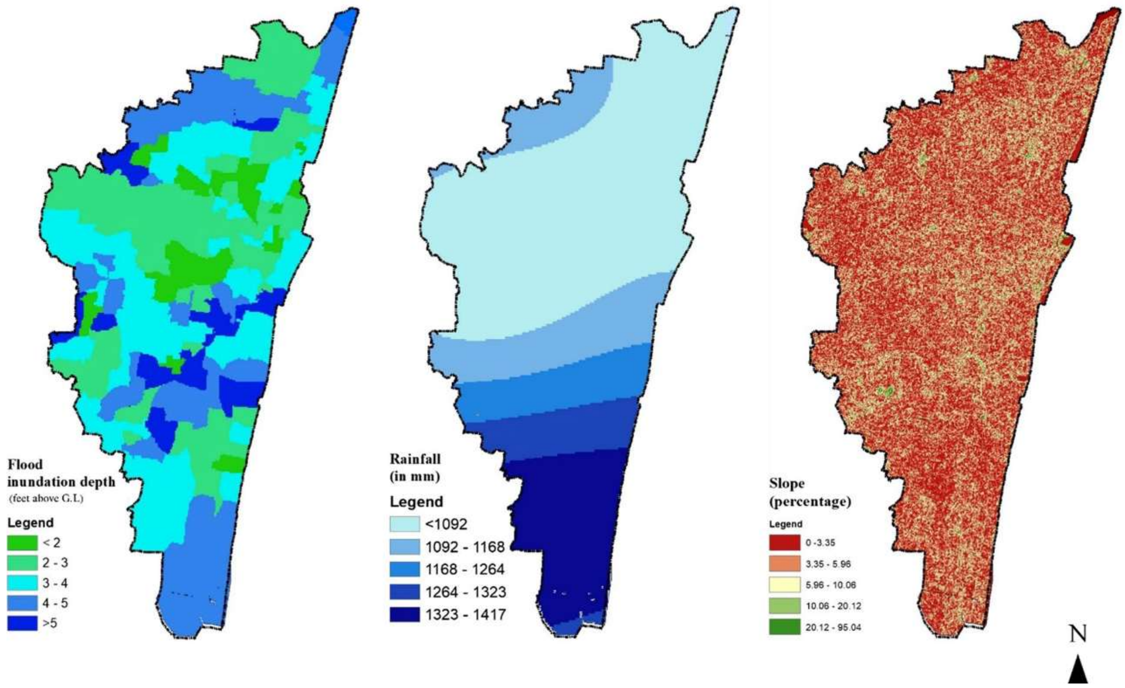


Figure 5.27: Flood Inundation depths, Rainfall and Slope % across the GCC region (source: Kaaviya and Devadas, 2021)

minor rises or road crowns redirect flows; low pockets trap them and around 73.41% falls in the range of 0 to 5 per cent slope which most affected during the floods (Kaaviya & Devadas, 2021).

Population Density, Water Supply Network, Per Capita Water Supply and Distance from Water Bodies/ Wetlands.

As per the World Urbanization Prospects UNDESA, 2024 the current urban population growth rate for Chennai is estimated at 2.34% and it is the 4th most populous metropolitan area in India. 2020 recorded a population of 11mllion and it is expected to be at 12.3 million by 2025. Many wards (30.1%), recorded with a population density of 20,000 – 50,000 persons/km², making them extremely susceptible and intensely exposed, complicating rescue and evacuation, restoration during the events of flooding coinciding with service outages.

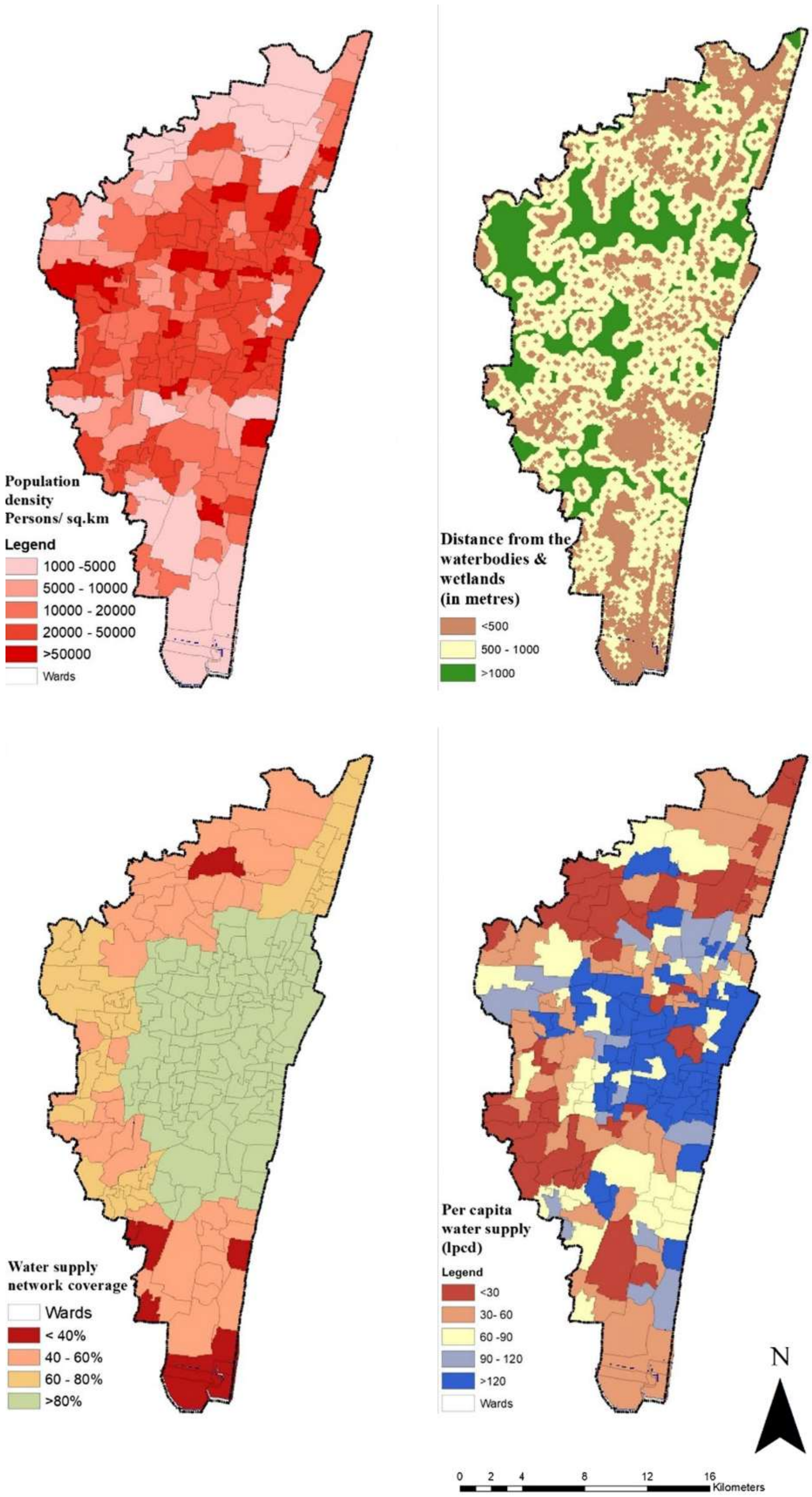


Figure 5.28: Population Density, Water Supply Network, Per capita Water supply, and Distance to water bodies (source: Kaaviya and Devadas, 2021).

On the other note, Kaaviya and Devadas (2021), mentioned that over one-third of wards present low direct piped coverage (≈40–60%), and about half receive only 40–90 lpcd, with ~24% below 40 lpcd. Thin network reach and low per-capita provision heighten everyday water stress and slow recovery after floods, when alternative safe supplies are critical. These are some extreme vulnerable populations that face the stress during dry conditions of drought and water scarcity. Also, a substantial share of built area lies within the 500 m sensitive belt around tanks, wetlands, and channels; landscapes that naturally accommodate water. About one-third of the total area (33.23%) is observed to fall under this sensitive zone with 48.88%

being considered moderate resiliency and the settlements here face recurrent ponding; safeguarding this belt supports storage, recharge, and conveyance functions.

As per the Resilient Chennai strategy in 2019, Chennai has been city with large set of water bodies that has been historically connected with the local water networks, and they have been supporting the local occupations and local communities.

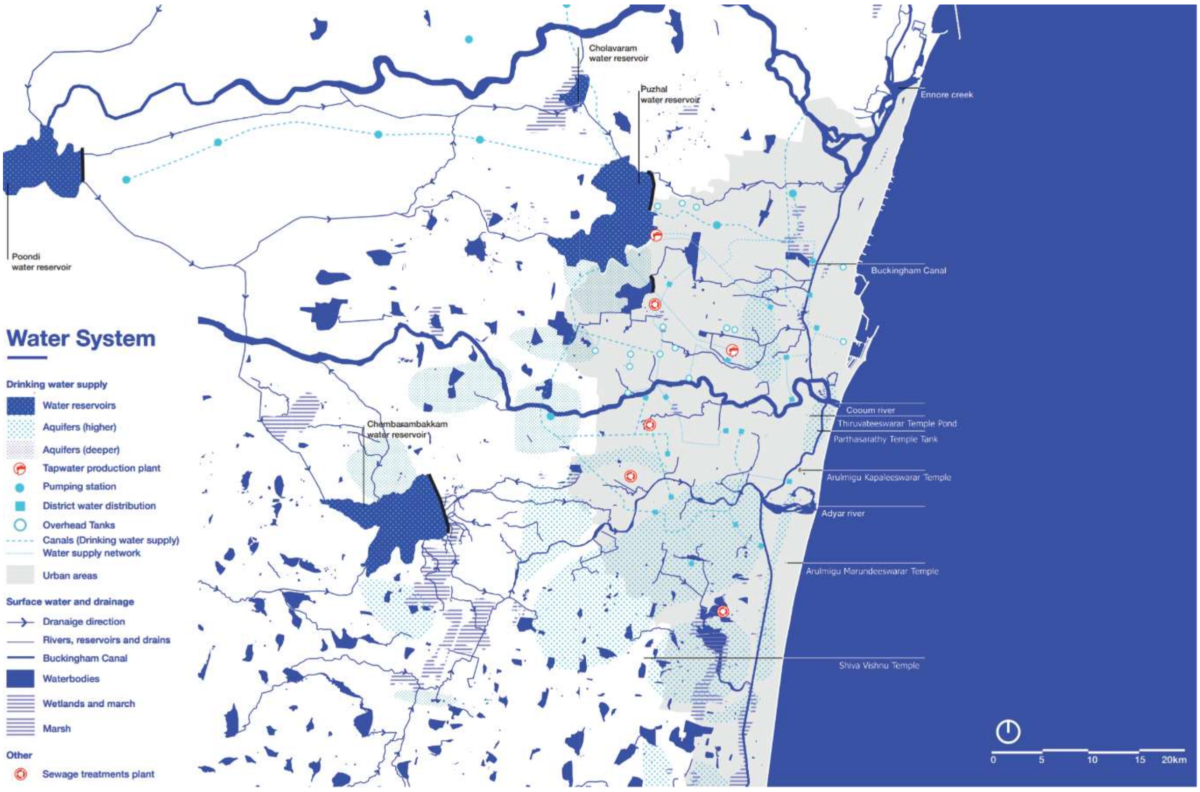


Figure 5.29: The Network of Water Systems across the Chennai Metropolitan Area (source: Water as Leverage, 2018)

The historical map from 1816 by Barry Lawrence, marked the water networks and the Tank systems across Chennai. These systems have disintegrated over the period with each other. Chennai, being a low-lying coastal region, primarily agricultural fields, and over the years has spread across different wetland areas through different time periods. The surge in urban expansion, industries, local business, population explosion and unregulated developments with mismanagement of land resources has been the keys of extreme effects during seasonal weather events.

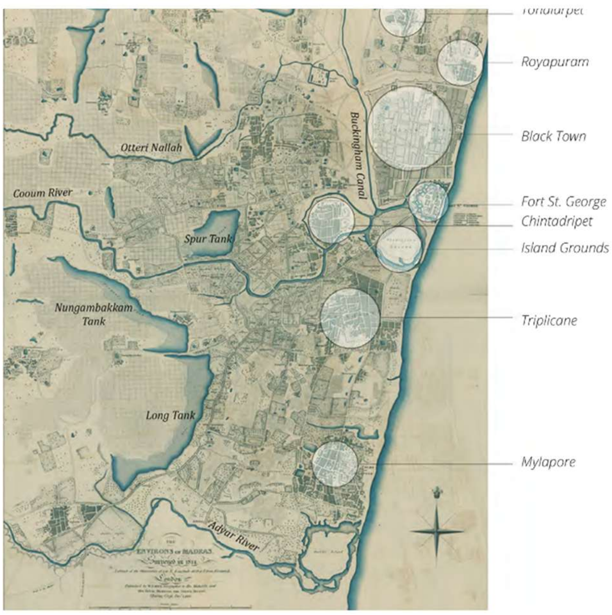


Figure 5.30: Figure 5.5: Historical map of Chennai 1816, by Barry Lawrence Ruderma Ertique. (source: Resilienct City Strategy, 2019)

Kaaviya and Devadas (2021) in their findings for water resilience mapping where they used data until the year 2020, have considered multiple parameters. If we look at the series of maps that were developed for each parameter and its data, we can understand that the city has always modelled its functioning around the water resources for its regular activities, primarily for its agricultural practices. The rapid urbanization and industrialization have made the scenarios worse for its resiliency to water related hazards.

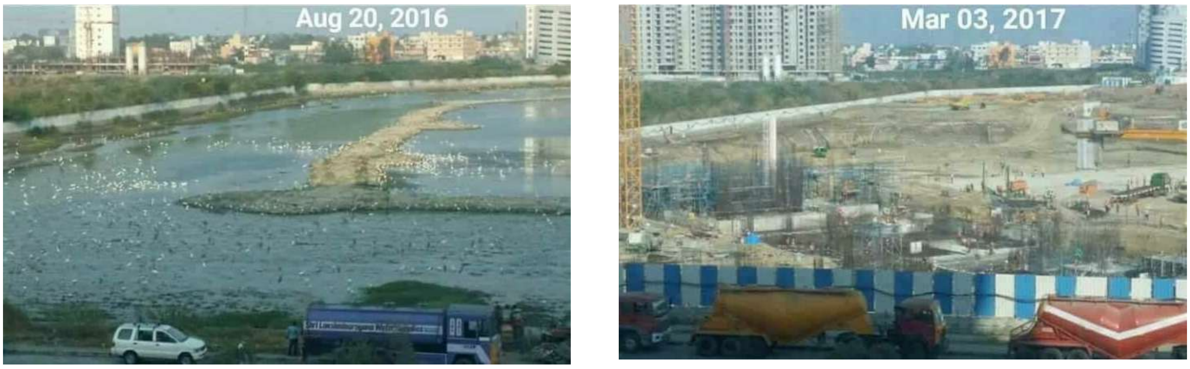
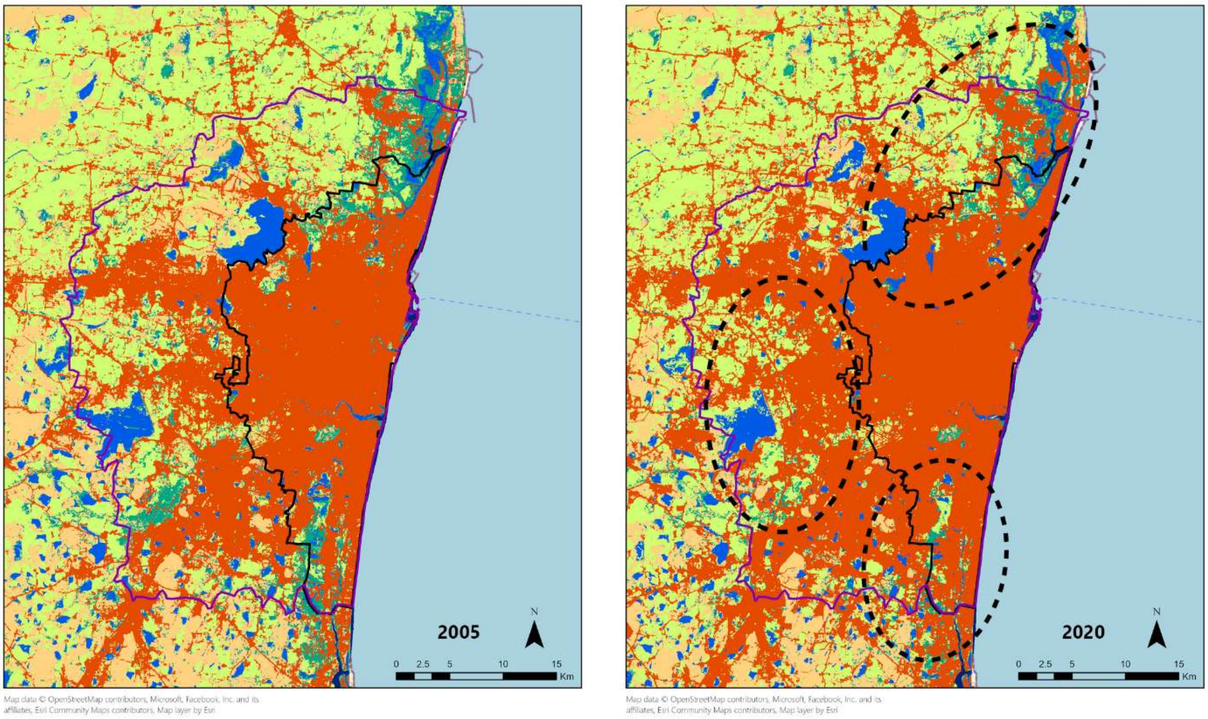


Figure 5.31:Example of the areas adjacent to Pallikaranai marshland region undergoing urban transformation (source: Stockholm resilience center)

The Wetlands, Marshlands and open water surface areas are increasingly under threats, with the pressure of being a coastal city, low water resilience due to its geomorphology, consistent development and soil sealing activities put a larger question to city's active measures towards managing its resources for extreme events and drought days. The water networks area play a crucial role in maintaining a water resilient ecosystem across the metropolitan region and its expanding urban areas.

Land Cover, Urban Expansion



Changes in the Land Cover Area over the years (sq.Km)					
Year	Built Up or Urban Areas	Croplands	Open Dry Lands	Wetlands	Open Surface Water
2005	662	223	130	93	72
2020	807	201	61	44	68

Areas where urbanization are evident and cab be seen adjacent o major water bodies or encroached lands across the wetland ecosystem.

Figure 5.32: Landcover across the Chennai Metropolitan Area: 2005 on left and 2020 on Right ((source: Author based on the data Global Landcover data by Potapov et al., 2022; Frontiers in Remote Sensing)

The Landcover has changed since the 90s and the above map from the year 2005 and 2020 shows a growth of 145 Km^2 in its Built area across Chennai Metropolitan Area in merely 15years, which is close to 10Km2 every year. The metropolitan port city allows numerous new industries and business across its region the agricultural fields have lost around 22Km2 of its cropland to the expanding city. Half of the open dry lands have been lost along with the wetlands, that serve a major role in maintaining local biodiversity and ecosystem services have been reduced to only 44 Km^2. These changes can be evidently seen across the map on the marked locations in the figure 5.2.

Over the last two decades, Chennai has experienced drastic land cover change, with built-up areas rising from 29.5% in 1991 to over 64% by 2013 (Pal & Suresh, 2022). This growth has come at the expense of open spaces, agricultural lands, and ecologically sensitive wetlands such as the Pallikaranai Marsh. Encroachment on rivers and canal systems has amplified flood risks and eroded biodiversity services. According to a biodiversity index assessment, nearly 20% of Chennai retains natural ecosystems, but these are fragmented and under severe anthropogenic stress (The Hindu, 2022). The GCC alone accommodates over 4.6 million residents, with a density of nearly 65 households per hectare (Census of India, 2011). Informal settlements along rivers and coasts are disproportionately exposed to climate hazards, underscoring the intersection of poverty, housing insecurity, and disaster vulnerability (Chandramouli, 2003).

5.2.b Local Climate conditions, Hazards, Risks and Vulnerabilities and Challenges

Figure 5.33: Floating Conditions in Winters and Fighting for Water in Summers (source: Wetlands International. 2019)

Chennai sits on a tropical savanna climate with dry-summer (As) closely bordering dry-winter (Aw), under the Köppen-Geiger system. Heat is persistent year-round, and a large share of rainfall arrives with the Northeast Monsoon (Oct–Dec). (Beck et al., 2018). The unique feature of Chennai's rainfall is that the major share is received during the northeast monsoon in the months of October to December. In November and December of 2015 (*see top image of figure 5.33*), Chennai received unprecedented levels of rainfall leading to the overflow of the arterial Adyar river, which in turn led to floods in the city. Multiple low-lying areas in the city were inundated for days together; massive rescue and evacuation efforts had to be undertaken in areas where houses were getting submerged.

In the past decade the city has swung between water scarcity and deluge. After a severe Northeast Monsoon failure in 2016—reported as the driest NEM in ~140 years across Tamil Nadu; remote-sensing analyses show the southern zone (incl. coastal districts feeding Chennai's supply) repeatedly experienced moderate–severe drought conditions, indicating frequent drought days/spells in recent years (Lalmuanzuala et al., 2023). Conversely, flood risk has intensified. The December 2015 floods were driven by extreme NEM rainfall had caused

>400 deaths and multi-billion-dollar losses; geospatial analyses link impacts to both heavy rain and geomorphic/anthropogenic factors such as encroached waterways and wetlands (Ramasamy et al., 2018).

Chennai is highly exposed to climate-related hazards, including cyclones, storm surges, coastal erosion, heat waves, drought, and pluvial and fluvial flooding. The 2015 flood, triggered by record-breaking monsoon rainfall, resulted in over 400 fatalities and USD 7–15 billion in damages, making it one of India's costliest disasters (Pal & Suresh, 2022). Vulnerability is compounded by unplanned urbanization, encroachment of wetlands, inadequate stormwater drains, and the concentration of informal settlements along riverbanks and coastal margins (Ramasamy et al., 2018). In December 2023, Severe Cyclone Michaung again inundated Chennai, with reported fatalities and mass evacuations across Tamil Nadu, underscoring compound coastal-pluvial hazards (Mishra et al., 2024).

Figure 5.34: Pallikaranai Marshland Conditions during April 2015, and during November 2015 floods. Encroachment and Waste Disposal along Canals (source: Resilient strategy Chennai, 2019; City of 1000 Tanks, 2019)

Regionally, studies also note growing mid-monsoon "dry phases" (i.e., more dry-day clusters), which, together with intense but episodic downpours, amplify Chennai's flood–drought paradox (Chakraborty et al., 2019; cf. Roxy et al., 2017 on increasing extremes in India).

The Resilient Chennai programme (2019) identified five interconnected resilience challenges:

- Rapid and unplanned urbanization, leading to the loss of ecological buffers.
- Poor water systems and waste management marked by contamination, over-extraction, and flood-drought cycles. (*see the bottom image in figure 5.34)*.
- High disaster risks, particularly flooding and cyclones.
- Poor governance ecosystem
- Disadvantaged vulnerable communities, disproportionately impacted by hazards.

Water management is central to resilience. Post-2015, GCC implemented an Integrated Storm Water Drain (ISWD) network of 405 km, funded by the World Bank, at a cost of INR 1,261 crores in the Adyar and Cooum basins. Similar projects are planned for the Kosasthalaiyar and Kovalam basins, while INR

500 crores have been spent in core Chennai for flood mitigation since 2016. Complementary efforts focus on lake restoration, sewage reforms, and coastal protection. The Resilience opportunities discussed on the the

The Chennai Climate Action Plan (CCAP) 2022 describes Chennai's climate risk profile reflects compound hazards that are intensifying with urban growth: extreme precipitation drives frequent pluvial flooding; sea-level rise (SLR) threatens permanent inundation of low-lying coasts and estuarine settlements; and heat and water scarcity disproportionately burden vulnerable groups. Spatial analyses for 2018–2050 scenarios show large shares of the city, critical transport/utility assets, and high-density slums exposed under plausible flood return periods. Concurrently, SLR jeopardizes coastal infrastructure and social facilities, while heat stress is amplified by housing materials, limited cooling access, and nighttime urban heat island effects. These patterns underscore the need for integrated adaptation across drainage, coastal management, and social protection.

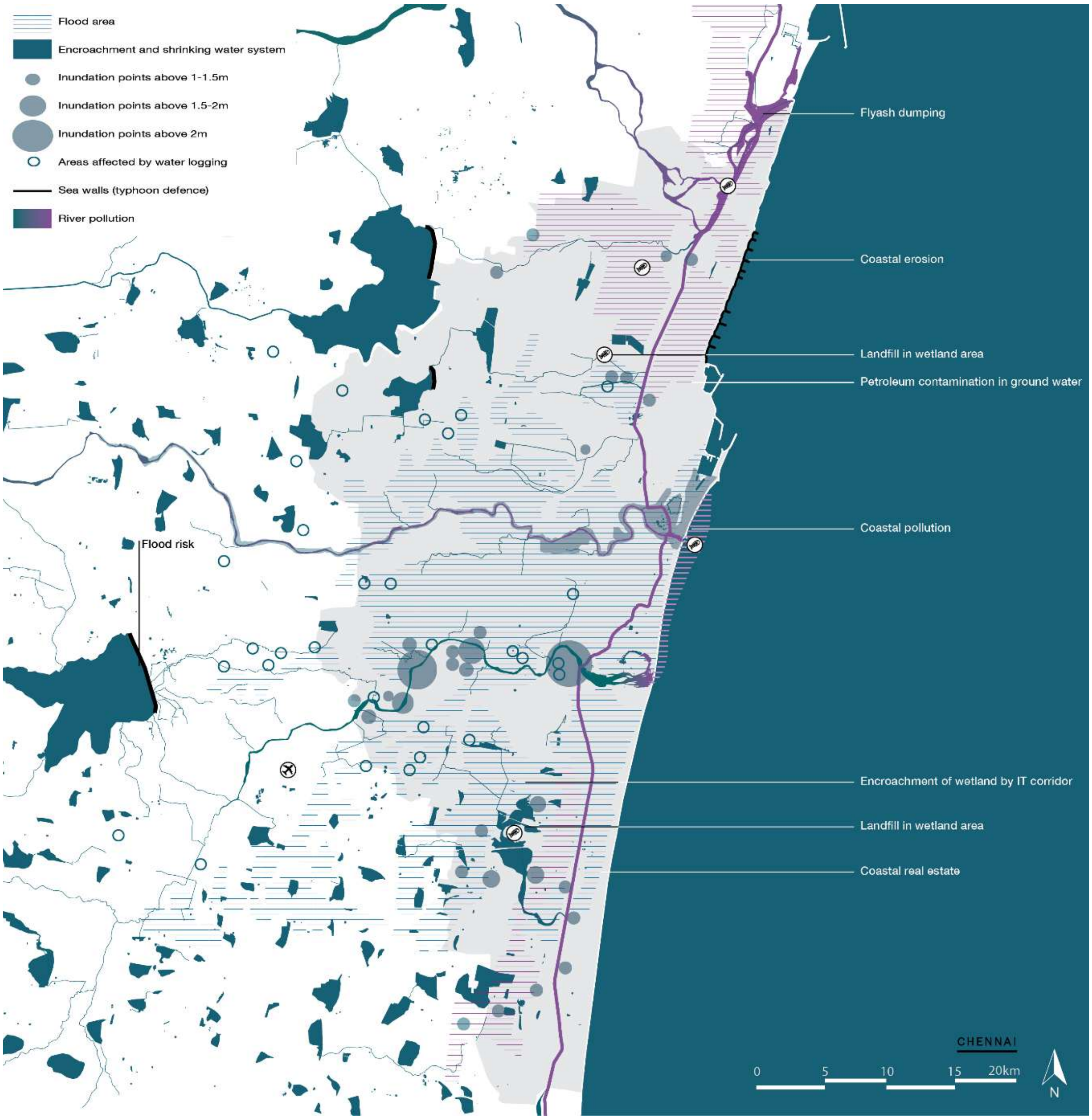


Figure 5.35: Water Stress issues across the Chennai Metropolitan region highlighted under the Water as Leverage programme (source: World Water Atlas)

Floods & storms (pluvial/coastal exposure).
Modeling indicates 29.1%, 46%, and 56.5% of GCC area at inundation risk for 5-, 25-, and 100-year events, respectively; 41–68% of slums are affected across these scenarios, with up to 21% facing >5-ft depths at 100-year return periods. About 45% of mapped physical infrastructure is impacted at 100-year events, including bus stops, metro/suburban stations, and charging assets.

Heat and water scarcity (health & equity).
With 53% of households relying on external drinking-water sources and 27% of slum homes using heat-prone asbestos roofs (vs. 8.9% citywide), heat risk and cooling poverty are pronounced; nocturnal UHI slows cooling, increasing health and fire risks.

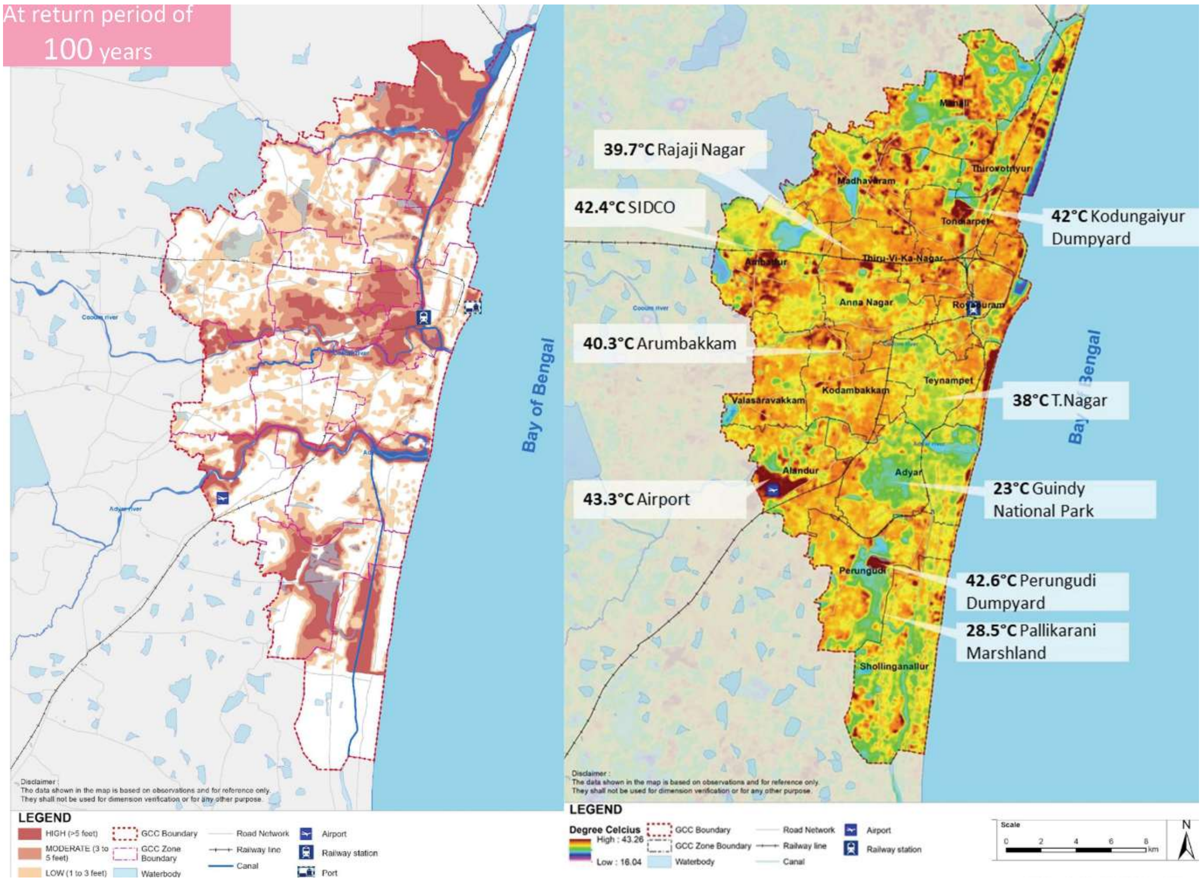


Figure 5.36: Floods at 100 years return period and Urban Heat Efffects across Greater Chennai Corporation (source: Chennai Climate Action Plan)

Sea-level rise (permanent loss & asset risk).
The issue of Sea Level Rise could permanently inundate ~16% (≈67 km²) of GCC by the 2100s, affecting ~1 million people; ~17% of slums (~260,000 residents) and 7,500 resettlement tenements lie in risk zones. Coastal/utility assets—including power plants and metro stations—show notable probabilities of submergence by 2100.

Table 5.5: Risks and Vulnerabilities across Chennai, with Flooding, Heating and Water Scarcity, Sea Level Rise (source: Climate Change Adaptation Plan, 2022)

Event Types (Hazards)	Risk % / Share	Vulnerability %	Exposure %
Flood & Storm (25-yr)	46% of GCC area at inundation risk	60% of slums inundated (14% >5 ft; 13% 3-5 ft; 32% 1-3 ft)	38% physical infrastructure; 41.4% social infrastructure inundated
Sea-level Rise (to 2100)	16% of GCC area (~67 km^2) permanently inundated	17% of slums (~260,000 people) in SLR risk zones	~13% of population (~1 million) affected
Heat, Drought & Water Scarcity	Qualitative increase: UHI and warm-night risks highlighted	27% slum houses with asbestos roofs (8.9% citywide)	53% households depend on external drinking-water sources

Coastal erosion, Urban biodiversity & ecosystem protection.

Chennai's coastal vulnerabilities emerge along two linked fronts: shoreline morphology and rain–runoff dynamics. On the shore, long-term interruption of northerly littoral drift by harbour works has driven accretion south of Chennai Port and chronic erosion to the north, with the Ennore reach showing terminal erosion that migrated with each extension of hard defences. Nettukuppam lost ~78.7% of its beach area between 2004 and 2017, while the Ennore creek mouth (*see figure 5.37)* oscillates and silts, degrading tidal flushing in a waterbody already pressured by sewage, cooling water and effluents (Buckle. S. et al, 2018).

Inland, new evidence shows urbanization does not just intensify storms; it shifts where the heaviest rain falls—about 16–20 km inland over urban Chennai (vs. ~8–12 km in rural analogs). This downwind shift raised modelled reservoir inflows by ~42% and river inflows into the city by ~49%, heightening riverine flood risk even without stronger storm cells (Vineeth et al., 2025). A complementary review frames the built environment as a lever for coastal resilience, emphasizing climate-responsive design, nature-based buffers, and passive cooling to reduce exposure and cascading heat–flood risks (Murali & Patil, 2025).

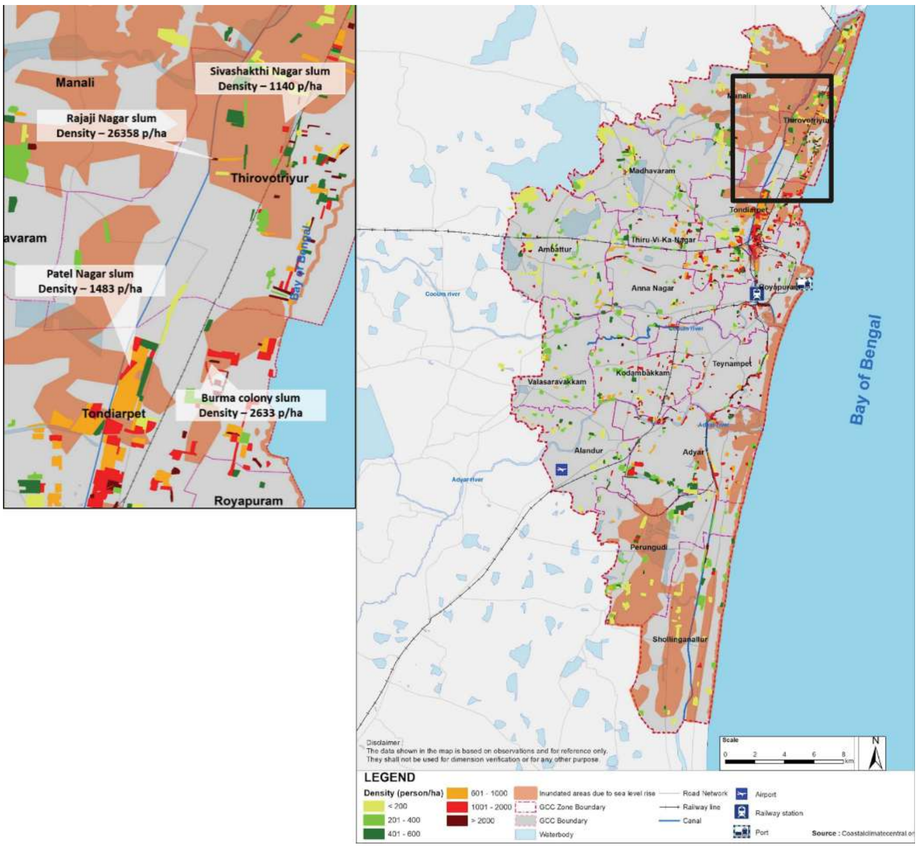


Figure 5.37: Inundated areas due to sea level rise along the Ennore Creek (source: Chennai Climate Adaptation Plan)

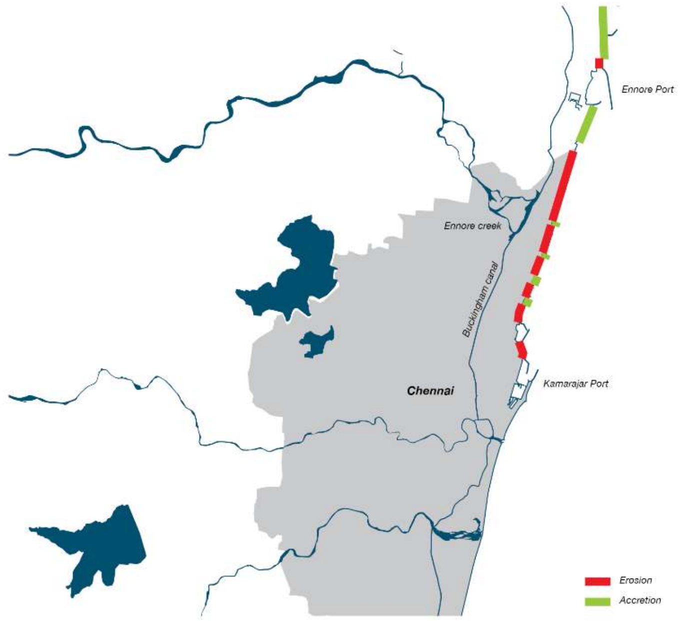


Figure 5.39: Vulnerable coastal edge of Greater Chennai Corporation (source: Chennai Climate Adaptation Plan)

Measures undertaken so far on the coast are predominantly hard engineering: seawalls and groins from Royapuram to Ennore, a revetment on the south bank of Ennore creek, rotine dredging, and proposed training walls at the creek mouth. Modeling suggests a northern training wall reduces monsoonal siltation efficiently; two-sided walls work best when residual southward inputs occur (Buckle. S. et al, 2018). *see figure 5.39*. On the urban side, researchers urge climate-responsive standards (cool roofs/green roofs, blue-green corridors, flood-aware siting) and hydro-meteorological integration (UHI-aware weather prediction, reservoir operations keyed to shifted storm tracks) to curb compound flood risks (Murali & Patil, 2025; Vineeth et al., 2025).

Figure 5.38: Shoreline Change along the Ennore Creek Mouth (source: Buckle. S. et al, 2018)

Table 5.6: Change in Area from baseline and in percentage over the years (Source: Buckle. S. et al, 2018)

Year	2004	2008	2012	2013	2016	2017
Area(m^2)	86900 m^2	70381 m^2	51952 m^2	38736 m^2	24525 m^2	18461 m^2

Year	2008	2012	2013	2016	2017
Percent	19 %	40.2%	55.4%	71.77%	78.7%

Taken together, the threats are: structural interruption of sediment cells causing hotspot erosion and creek siltation; (ii) urban-induced inland migration of rainfall maxima, amplifying river inflows and flood peaks; and (iii) pollution-stressed estuarine habitats that lose resilience under altered hydraulics. A strategic response couples sediment-cell management and selective coastal works (with retreat where feasible), restoration of tidal exchange and wetlands, and UHI-aware flood forecasting and operating rules—so that shoreline stability, estuarine health, and city flood safety are managed as one system (Buckle. S. et al, 2018; Murali & Patil, 2025; Vineeth et al., 2025).

Water as Leverage (2018) describes coastal erosion as a growing hazard for Chennai, driven mainly by harbour construction that disrupts the northward longshore sediment transport. Sediment now accumulates south of harbour structures while erosion accelerates to their north. The Madras Harbour stretch is highlighted as especially vulnerable: interrupted sediment supply and unstable shorelines during the Northeast Monsoon coincide with long-term retreat of several hundred meters, damage to the coastal aquifer, and repeated impacts on the coastal highway, affecting corridor traffic. North of Ennore Harbour, erosion is advancing most rapidly, putting roughly 5,500 households at near-term risk of relocation. Conventional hard-engineering responses, such as seawalls and groynes, have had limited success and may intensify downdrift erosion, underscoring the need for integrated, system-scale coastal management and conservation initiatives (Water as Leverage, 2018).

Projects such as Ennore Creek restoration aim to reverse decades of pollution from thermal power plants and fly ash dumping. Yet biodiversity remains under pressure as encroachments and industrial activities degrade Pallikaranai and the Cooum and Adyar river systems, reducing ecosystem services and increasing mosquito-borne diseases (Water as Leverage, 2018). These efforts signal a shift towards ecosystem-based adaptation (EbA) through urban agriculture, wetland regeneration, and blue–green infrastructure, though governance capacity, informal settlements, and economic pressures challenge long-term sustainability.

Building on existing strategies, the CCAP aligns with a collective vision of a "Resilient and Pro-active Chennai" through two pathways: achieving "Carbon Neutrality" and "Water Balance" by 2050. It defines six priority sectors: 1) Decarbonizing the electric grid and scaling renewable energy; 2) Energy-efficient buildings; 3) Transport; 4) Sustainable waste management; 5) Managing urban floods and water scarcity; and 6) Protecting vulnerable populations and health.

Figure 5.40: CCAP 6 priority factors. (source: CCAP)

Decarbonizing Electric Grid & Renewable Energy

The sector targets 100% renewable power with decentralized generation and storage, coupling tariff reform, rooftop solar integration (including shared roofs), and grid-scale storage (pilots to pumped hydro) while phasing out coal over time. Land-use planning is used to maintain storage and urban generation. Highlights: 100% renewable grid; rooftop solar acceleration; storage pilots and large-scale options; gradual coal replacement.

Energy Efficient Buildings
Aims for *100% efficient appliances and efficient building design*, using IEC programs, certified design support, EWS upgrades, authorized retrofitting services, disclosure of energy performance, and fiscal/FSI incentives to shift markets. Highlights: appliance efficiency; thermal retrofits; performance disclosure; price signals via taxes and property-value thresholds.

Transport
Pursues *fossil-fuel-free public transport* and *80% trips by walk/cycle/PublicTransport*, via e-bus rollout and charging, real-time transit data, street design standards, block-size reduction, bicycle "highways," and targeted EV/NMT incentives. Highlights: e-bus shift; walk/cycle priority; network/streetscape standards; data-enabled user experience.

Sustainable Waste Management
Moves from dumpsite dependence to *100% segregation, 100% collection, and decentralized processing*, pairing behaviour change with capacity augmentation and siting rules that avoid flood-risk zones. Monitoring of legacy remediation and scientific landfills safeguards long-term outcomes. Highlights: door-to-door collection gap closure; home/ward-level composting; decentralized units; enforcement of SWM byelaws; flood-safe siting.

Managing Urban Floods and Water Scarcity
Shifts from reactive pumping to *proactive blue-green hydraulics*: capacity-right stormwater drains, regular O&M, citywide RWH enforcement, permeable surfaces, sponge parks and OSRs, natural-drain preservation, groundwater monitoring/pricing, encroachment control, green belts along Adyar/Cooum, and stronger forecasting/first-response systems. Highlights: drainage upgrade & maintenance; BGI retrofits; demand governance (meters/charges); encroachment eviction; disaster readiness.

Vulnerable Population and Health
Centers *climate-proof housing* and *resilient health systems:* relocate from floodplains/creeks, heat-resilient retrofits, affordable-housing codes (ECO-Niwas; TNCDBR: Tamil Nadu Combined Building Regulations), basti-level clinics, worker heat-safety, monitoring of facilities in risk zones, and operationalization of TNSAPCCHH (Tamil Nadu State Action Plan on Climate Change & Human Health). Highlights: risk-informed resettlement; heat-resilient design; primary health access; climate–health surveillance and awareness.

Overall, the pillars and principles drive a whole-of-city shift toward carbon neutrality and water balance by 2050. Grid decarbonisation and efficient buildings and transport cut emissions, while demand-side programmes and market signals speed adoption. Waste reforms reduce methane, site facilities away from hazard zones, and foster neighbourhood circularity. Floods–water scarcity measures reconnect Chennai with its hydrology through right-sized drains, RWH, permeable surfaces, blue–green retrofits, and governance tools such as meters, volumetric tariffs, and groundwater monitoring. Climate-proof housing and resilient health systems protect exposed groups, while strong institutions and ward-level co-production turn projects into a coherent resilience pathway.

The implementation of CCAP is organised in tiers. A dedicated Climate Unit in GCC leads citywide strategy, climate budgeting, data standards, and monitoring and evaluation, while sector agencies deliver actions. Mitigation-focused Sectors 1–3 are led by the Tamil Nadu Generation and Distribution Corporation/Tamil Nadu Energy Development Agency, with GCC Electrical & Buildings units and the Metro Rail Department/Metropolitan Transport Corporation handling grid decarbonisation, building efficiency, and low-carbon transport. Adaptation-focused Sectors 4–6 are led by the SWM Department, Storm Water Drain Department, CMWSSB, and Public Health/Urban Habitat Development Board for waste, water–floods, and health. At zonal and ward levels, climate officers coordinate works, enforce byelaws (e.g., RWH, siting), and track indicators, while Ward Committees, Area Sabhas, and community groups co-produce segregation, BGI upkeep, and heat–health outreach. An EOC-backed alert system and the annual "State of Climate in Chennai" review align roles, budgets, and timelines.

Chennai's water-resilience pattern is shaped by four fundamentals: geomorphology, groundwater depth, rainfall, and soil depth. Sensitivity analysis shows geomorphology drives the largest reclassification shift, as beach-ridge–swale systems and marsh edges steer storage and conveyance. Excluding groundwater depth inflates mapped "high resilience" areas, since shallow tables choke infiltration and prolong ponding during cloudbursts. Monsoonal pulses rapidly shift risk, while soil depth sets near-surface storage and infiltration capacity. These factors define baseline hydrologic behaviour; drainage connectivity, flood corridors, service networks, and urban form then modulate local risk. Strategy must combine landscape-scale actions (protect marshes and ridges, reopen conveyance, enhance infiltration) with network fixes (drains, sewerage, supply) and demand-side measures to temper exposure and speed recovery (Kaaviya & Devadas, 2021, pp. 17–19).

The 2019 Resilience Strategy seeks to repair Chennai's relationship with water, communities, and planning by reviving locally grounded practices. It calls for water-wise urbanism that protects wetlands, reconnects the historic ery (tank) network, and places hydrology at the centre of growth to preserve blue–green corridors. Housing shifts from distant high-rise resettlement to adapting the Sites & Services legacy and prioritising in-situ upgrading near jobs, schools, and services. The strategy promotes decentralised waste segregation and composting, and people-first mobility to cut costs, emissions, and disaster exposure, underpinned by meaningful participation and better data on "invisible" vulnerable groups.

Table 5.7: Resilience Opportunites broken down from the Resilient Strategy Chennai, 2019.

Opportunity	Core Actions	Example levers or programs	Primary co-benefits
Restore water-wise commons	Protect wetlands/poromboke; reconnect tanks & canals; design for infiltration/ retention	Lake/tank restoration; blue-green buffers in land-use rules; watershed maintenance	Flood moderation; groundwater recharge; urban heat relief
Make growth hydrology-led	Use flood & erosion mapping to guide zoning and infrastructure siting	Master Plan updates; 'room for water' setbacks; risk-based EIAs	Lower disaster losses; safer densification; reduced drainage conflict
Re-adopt Sites & Services & in-situ upgrading	Serviced plots, tenure security, micro-finance; avoid distant high-rise relocation	Modernized MUDP S&S model; flexible/collective tenure instruments; slum upgradation	Affordability; livelihood continuity; intact social networks
Community-scale solid-waste systems	Segregation at source; decentralized composting/MRFs; drain & stream stewardship	Ward-level facilities; GCC vendor reforms; plastics reduction	Cleaner drains; less flood blockage; neighbourhood health gains
People-first mobility	Walk/cycle networks; last-mile feeders; bus fleet renewal & accessibility	Complete Streets; public bicycle sharing; bus priority & upgrades	Safer, cheaper access; lower emissions; better disaster egress
Meaningful participation & vulnerability data	Co-design with fisher/migrant/low-income groups; maintain dynamic vulnerability datasets	Multi-stakeholder working groups; community surveys; city data observatory	Context-fit projects; fair benefit sharing; stronger trust & compliance
Institutional glue for resilience	Cross-agency coordination; capacity building; monitoring & learning loops	Resilient city office/taskforce; project prioritization dashboards; KPIs	Consistent delivery; scalability; accountability

Going forward, a water-resilience strategy for Chennai should act as a first-step planning tool, pinpointing system vulnerabilities and guiding targeted action. It can steer area-development in very-low/low-resilience belts, align blue–green restoration with drainage and supply upgrades, and embed continuous, data-led monitoring. Above all, it should institutionalize cross-agency and community collaboration to reduce susceptibility to floods, droughts, and storm surges and to accelerate recovery when they occur (Kaaviya & Devadas, 2021). The following table discusses ongoing water-resilient strategies in Chennai across the priority actions and goals.

Table 5.8: Resilient Chennai Strategy List of Priority Actions for immediate active measures.

Priority Actions	Goals	Lead / Key Partners	Early steps / Status	Pillars	Indicative Timeframe
01 Chennai Urban Horticulture Programme	Scale household/community food gardens to improve nutrition, micro-economies and urban greening; build community stewardship for public spaces.	GCC; TNCDW; NGOs; Resident Welfare Associations (indicative)	Pilots underway in rooftops and community spaces; needs citywide scale-up	Healthy & Planned Urbanisation; co-benefits for Water Systems	Short–Medium term
02 Water as Leverage (WaL) for Resilient Cities Asia	Co-develop bankable, nature-based, water-centric projects (e.g., Mambalam Canal, City of 1000 Tanks) for flood mitigation, groundwater recharge, and public realm upgrades.	Resilient Chennai; WaL consortia; GCC SWD; CMWSSB; TN Water Investment Co.; FMO/RVO; World Bank; GCF (indicative)	Concepts prepared; agency engagement ongoing; financing pathways being pursued	Water Systems; Disaster Preparedness; Public Space	Short–Long term (phased)
03 Urban Data Observatory	Create a physical + virtual platform to aggregate, update and analyze civic data to enable coordinated, evidence-based decisions; interface with ICCC.	NIUA; CSCL; CUBE–IIT Madras; MCCI; GCC; CMDA; CMWSSB; TNSCB	Stakeholder discussions initiated; architecture and governance model to be formalized	Governance Ecosystem (4.1); supports Water Systems & Disaster Preparedness	Short term (set-up) + ongoing
04 Advisory Consortium for Co-building Resilient Resettlement	Establish a multi-stakeholder advisory body (with community reps) to co-design resilient homes and monitor inclusive resettlement / in-situ redevelopment along waterways.	TNSCB; community reps; local & international experts; World Bank (indicative)	Consortium formation proposed; blueprint and process monitoring envisaged	Vulnerable Communities; Governance Ecosystem	Short–Medium term
05 Climate Change Adaptation Plan (City)	Develop a comprehensive climate adaptation strategy aligned with the updated TN State Action Plan; reduce exposure, share risks, and build adaptive capacity.	GoTN; GCC; GIZ (technical support); line departments	To be developed building on TNSAPCC revision	Cross-cutting; Water Systems; Disaster Preparedness; Governance	Medium–Long term
06 Resettlement & Rehabilitation (R&R) Policy (State)	Frame state-level guidelines/standards to minimize livelihood and social disruption from resettlement; ensure fair, humane processes.	Housing & Urban Development Dept.; TNSCB; line departments	Policy formulation proposed	Vulnerable Communities; Governance Ecosystem	Medium term (policy cycle)

07 Capacity - Building Opportunities (07a–d)	Citywide capacity push via: (a) Awareness Campaigns (waste, recycled water, disaster preparedness, welfare schemes); (b) Training Programmes (green/NBS & water-centric design; school Trashonomics); (c) Knowledge-sharing Websites (CAPS; water-centric design; participatory governance best practices); (d) Other Knowledge Products (lake restoration guidebook; catalogue of disaster-resilient materials).	Resilient Chennai; Ogilvy/Rubecon/Tinacca; CityWorks & SWMRT; CUBE–IITM; CMDA/GCC; CMWSSB; NGOs; academia	PSA creative underway; Trashonomics piloted & scaling; CAPS site launched; guides/catalogues proposed	Governance (4.1–4.3); Water Systems (2.1–2.3); Disaster Preparedness (3.4); Healthy Urbanisation (1.2)	Short term (roll-out) + ongoing

Figure 5.41: Examples of Detention Ponds redevelopment and restoration (source: Chennai Resilience Strategy, 2019)

Chennai's priority actions begin with the Urban Horticulture Programme, scaling home and community gardens to support food security, livelihoods and stewardship of public space. Water as Leverage (WaL) advances bankable, nature-based water projects such as Mambalam Canal upgrades and City of 1000 Tanks, combining flood mitigation, recharge and public-realm improvements while mobilising multilateral finance. A citywide Urban Data Observatory, anchored by NIUA, CSCL, CUBE–IIT Madras and MCCI, will aggregate and analyse civic data (linked to the ICCC) to enable coordinated, evidence-based decisions. For socially just transformation, an Advisory Consortium will co-design resilient resettlement and in-situ redevelopment with community representation and independent monitoring.

The Climate Change Adaptation Plan, aligned with the updated Tamil Nadu SAPCC in partnership with GIZ, sets the overarching roadmap to reduce exposure, share risks and strengthen coping capacity. A state-level Resettlement & Rehabilitation Policy will codify humane standards to minimise livelihood disruption. A bundled Capacity-Building Opportunities track (07a–d) targets behaviour and practice change: public awareness campaigns (waste, recycled water, disaster preparedness, welfare schemes); training for planners and designers (green/NBS and water-centric design) and school-based "Trashonomics"; knowledge portals (CAPS plastics portal, water-centric design hub, participatory governance library); plus tools such as a lake-restoration guidebook and disaster-resilient materials catalogue.

However, "readiness risks" cut across these actions. Urban horticulture may stall without micro-grants, technical extension and reliable water. WaL pipelines depend on early clarity on land, utilities and multi-year finance. The Data Observatory needs enforceable inter-agency data-sharing MOUs and standards. The Resettlement Advisory Consortium requires a formal mandate and real community voice. The Adaptation Plan must be tied to departmental KPIs and budgets, while the State R&R Policy must navigate political cycles. Capacity-building is relatively execution-ready, but its impact hinges on consistent curricula, trained facilitators and regular updates. Quick-win pilots—rooftop and school gardens, a beta public data dashboard, rapid "design-with-water" sprints, early publications and pre-feasibility notes for WaL corridors—can build momentum and legitimacy.

5.2.c Key Partnerships and Response Typologies in Chennai | Assessing City Climate change strategies - Notable strategies

Urban Horticulture Programme| Chennai Urban Farming Initiaitve – Chennai Resilience Centre (*Ongoing*)

Chennai's urban horticulture push is moving from concept to citywide practice through a two-track rollout: resident rooftops and corporation schools. The Resilient Chennai concept note sets a clear near-term plan, start in two localities with strong Resident Welfare Associations, pair gardens with source-segregation/composting, and pilot kitchen gardens in an initial cohort of 15 GCC schools tied to the Nutritious Meal Programme: before scaling across hundreds of campuses and neighbourhoods.

The program frames gardens as "green infrastructure": cooling terraces, buffering food insecurity, and turning waste into compost, while enlisting state agencies (Horticulture Dept., TNAU) and civic partners to train gardeners and supply subsidized kits. In parallel, the Chennai Urban Farming Initiative (CUFI) under "*Urban Thottam*" operationalizes this vision through outreach, training and DIY garden kits, using rooftops and vacant urban spaces as quick-start sites to build food security and reduce heat exposure.

Figure 5.42: Terrace Farming and Vegetable Production (Source: CRC- Urban Thottam)

The early focus areas are schools in low-income neighbourhoods and apartment terraces where RWAs can coordinate adoption, with a scale plan that moves from 15 school pilots to a broader pipeline (dozens to hundreds of schools and residential clusters) as funding, training, and maintenance systems lock in. Examples already documented include GCC school gardens feeding into noon-meal kitchens and neighbourhoods terrace gardens supported by training and composting routines; CUFI adds mobile/DIY kits and community engagement to reach households without land, with published updates on training, focus-group learning, and household uptake. External profiles of the initiative reinforce the scale intent, using 2,000-sq-ft school plots in Phase-1 and expanding to citywide models, while mobilizing parents to replicate gardens at home.

Chennai's urban farming and horticulture programme approach is practical, modular, and equity-aware, start where governance and enthusiasm are strongest, prove value quickly (cooler roofs, fresher produce, less waste), and then replicate through standard kits, curricula, and partner networks. Effectiveness will hinge on a few enablers the documents already anticipate micro-grants and water access for continuity, enforceable data and coordination for targeting, and steady coaching to keep gardens productive across seasons. If those holds, Chennai's "gardens-as-infrastructure" can scale credibly from dozens to thousands of rooftops and schools.

Figure 5.43: Ground Level Plantation and Urban Farming Saplings, Rooftop Terrace Farming (bottom left). under CUFI (Source: CRC- Urban Thottam)

The 2023/24 year-end report Chennai Resilience Centre (CRC) highlights the operationalizing Chennai Urban Farming Initiative (CUFI) across institutions serving vulnerable groups through modular Mobile-vegetable Garden Kits (MVGKs), step-by-step training, and continuous maintenance support. In 2023, CRC maintained 169 gardens (144 ICDS centers, 15 homeless shelters, 6 schools, 3 RWAs, 1 resettlement colony) and scaled model farms (~800–1,500 sq ft) that yielded 15–100 kg per site in 6–8 months; produce fed mid-day meals and ICDS kitchens.

Capacity building paired onsite sessions with video micro-learning and refresher workshops, training 245 Self Help Groups women (TNULM) and 706 teachers/community members, while "maintenance kits," routine site visits, WhatsApp groups, and Garden/Composting Champion incentives sustained engagement. Early evidence on heat mitigation (average 2–3°C cooler rooms under gardens; up to 7°C) underpins the gardens-as-cool-roof case. Awareness campaigns ("Greener & Cooler Cities Mission") reached middle/upper-income areas and generated thousands of workshop sign-ups and digital interactions, creating demand for SHG "Madras Mali" gardeners.

Since 2020, CUFI has worked in 48 shelters, 267 ICDS centres, 10 government-aided schools, 3 informal settlements, and 3 resettlement colonies, reaching 33,062 direct beneficiaries and training 951 people. Priority sites include ICDS centres and shelters where gardens double as food, learning, and mental-health supports; in Perumbakkam resettlement, women maintain ~1,000 sq ft farms and sell produce, signalling livelihood potential. Focus groups and monitoring frameworks (surveys, ratings, M&E) inform course correction and targeting.

CUFI sits squarely inside Chennai's Resilience Strategy and CCAP intent: it turns rooftops and institutional courtyards (ICDS centres, shelters, schools) into small, repeatable "green infrastructure" that cools buildings, supplements diets, and builds community skills. The official concept note frames a phased roll-out; start with RWA-ready neighbourhoods and corporation schools, pair gardens with segregation/composting, and scale through standard kits, training, and partner agencies (Horticulture Dept., TNAU), while the Urban Thottam program documents the delivery mechanisms, beneficiaries, and city partnerships. In practice, this directly advances pillars on healthy/just urbanization (food, livelihoods), disaster/heat preparedness (cool roofs), water-solid waste integration (compost back to soil), and governance/capacity (teacher/SHG training, maintenance protocols). The emphasis on proximate, everyday sites in low-income and resettlement areas matches the Strategy's proximity and inclusion principles and the CCAP's call for community-level adaptation.

Table 5.9: Year-wise table for the beneficiaries through CUFI (source: CRC-Urban Thottam)

Year	Type of Beneficiaries	No of centres/ shelters / families	Total Kit Beneficiaries	People Trained
2020	Pudiyador families	65	260	
	Homeless Shelters	55	2,795	
	Perumbakkam		750	
	Total for 2020		**3,805**	
2021	ICDS	226	10,619	43
	Homeless Shelters	46	1,277	72
	Pudiyador	100	400	10
	Chitra Nagar	30	120	10
	Semmanchery	10	40	40
	Govt. Aided Schools	6	1,328	
	Total for 2021		**13,784**	**175**
2022 [1]	ICDS	120	5,057	81
	Homeless Shelters	27	1,112	30
	Pudiyador	78	312	10
	Chitra Nagar	30	120	
	Perumbakkam		15	
	Govt. Aided Schools	8	2,150	100
	TNULM Women		25	160
	Valmiki Nagar Residents			30
	Total for 2022		**8,791**	**411**
2023 [2]	ICDS (existing)	103	4,343	
	ICDS (new)	41	1,312	41
	Homeless Shelters	15	417	
	Perumbakkam		15	15
	Govt. Aided Schools	6	585	20
	Domestic Workers			10
	TNULM Women		85	85
	RWAs	3	10	
	Residents		194	194
	Total for 2023		**6,682**	**365**
	Grand Total (2020 to 2023)		**33,062**	**951**

Highlights | Critical Effectiveness

The effectiveness is high where CUFI anchors gardens in institutions with daily use (schools, ICDS, shelters) and builds a care economy around them (teacher/SHG champions, refresher training). Two external evidence streams reinforce the design logic: green/rooftop gardens can reduce indoor temperatures by several degrees (daytime cooling with potential 10 °C+ differentials when optimized), supporting heat-action goals; meanwhile, urban agriculture in low-income contexts shows consistent contributions to food security and diet quality, albeit with variability tied to water, tenure, and support services. These findings align with CUFI's observed benefits (cooler rooms, fresh produce, skills).

The year-wise table shows a deliberate shift from maximizing counts (e.g., 2021–22 kit deployments) toward *depth and sustainability in 2023*, more model farms, maintenance, and M&E – consistent with a "quality over volume" trajectory. Effectiveness stems from: (*1) institutional anchors (ICDS, shelters, schools*) that ensure space, staffing, and daily use*; (2) skills-to-jobs linkage (TNULM SHGs → Madras Malis)* converting training into income; *(3) behavioural nudges (competitions,* peer WhatsApp learning) that normalize composting and care; and *(4) evidence*-building (yield, heat, education/health signals) that strengthens the policy case. Remaining gaps are mainly *O&M financing, water reliability, and scale governance*: gardens need micro-grants for inputs and irrigation; long-run impact requires formalized agency roles, data standards, and CSR/public budgets. Still, the program's integrated model – food, cooling, skills, and dignity, demonstrates credible pathways to embed urban horticulture within everyday services for Chennai's poorest households.

In short, CUFI mostly fits what the Resilience Strategy and CCAP ask for: local action, equity, cooling, food, skills, and better use of waste. What's still needed is simple and practical:

- Small, steady funds for seeds, tools, and seasonal restocking.
- Reliable water, rainwater/greywater links so gardens don't fade in summer.
- A basic, shared way to track results (survival, yield, cooling).
- Light MOUs so each agency "owns" the garden after pilots.

If Chennai locks these four pieces in, the small wins' from rooftops, schools, ICDS centers and shelters can stack up into big, citywide resilience gains.

By adding fresh vegetables to ICDS centres, shelters, and school meals, improving diet quality for low-income children and families and through better nutrition and cooler indoor spaces under rooftop gardens, which ease heat stress it advances clearly for zero hunger and good health & well-being (SDG 2 & 3). As schools use gardens as "living labs," CUFI contributes to SDG 4 (Quality Education), building practical skills in nutrition, ecology, and waste-to-compost cycles. By training and employing women's self-help groups as gardeners, it advances SDG 5 (Gender Equality) with income opportunities and leadership roles. Neighbourhood gardens and greener public facilities strengthen SDG 11 (Sustainable Cities and Communities) by fostering local stewardship and climate-resilient public spaces. Composting and kitchen-garden practices reduce waste and encourage circular habits, pushing SDG 12 (Responsible Consumption and Production). Finally, heat-risk reduction and nature-based adaptation at building and neighbourhood scale make CUFI a direct, practical contributor to SDG 13 (Climate Action). Together, these outcomes show targeted progress where it matters most: food, health, learning, women's livelihoods, greener local environments, and everyday climate resilience.

Pallikaranai Marshland Restoration (Ongoing, 2007–present)

The Pallikaranai Marshland with an area of 1247.5 hectares was designated as the Ramsar Sites on 8th April 2022. The wetland area is a freshwater marsh and partly saline wetland situated about 20 kilometres south of the city of Chennai serves as an aquatic buffer of the flood-prone Chennai and Chengalpattu districts. The diverse ecosystem of the marshland supports some 115 bird species, ten mammals, 21 reptiles, ten amphibians, 46 fish, nine molluscs, five crustaceans, and seven butterfly species. As per the local government it has been categorized as reserve forest under the state department of forest, Tamilnadu.

Apart from its biodiversity value, the wetland also plays a vital role in the prevention of flooding for the city of Chennai, soaking up water during wet periods and releasing it during dry spells. Inhabitants of seven surrounding villages partially depend on the wetland for their subsistence.

Figure 5.44: View of the Pallikaranai Marshland (source: Ramsar Information Sheet, 2022)

The Site is threatened by invasive and non-native species, household sewage, urban wastewater and droughts. In response, the Conservation Authority of Pallikaranai Marsh of the state forest department is currently implementing a site-specific management plan. (Ramsar Sites Information service, 2022).

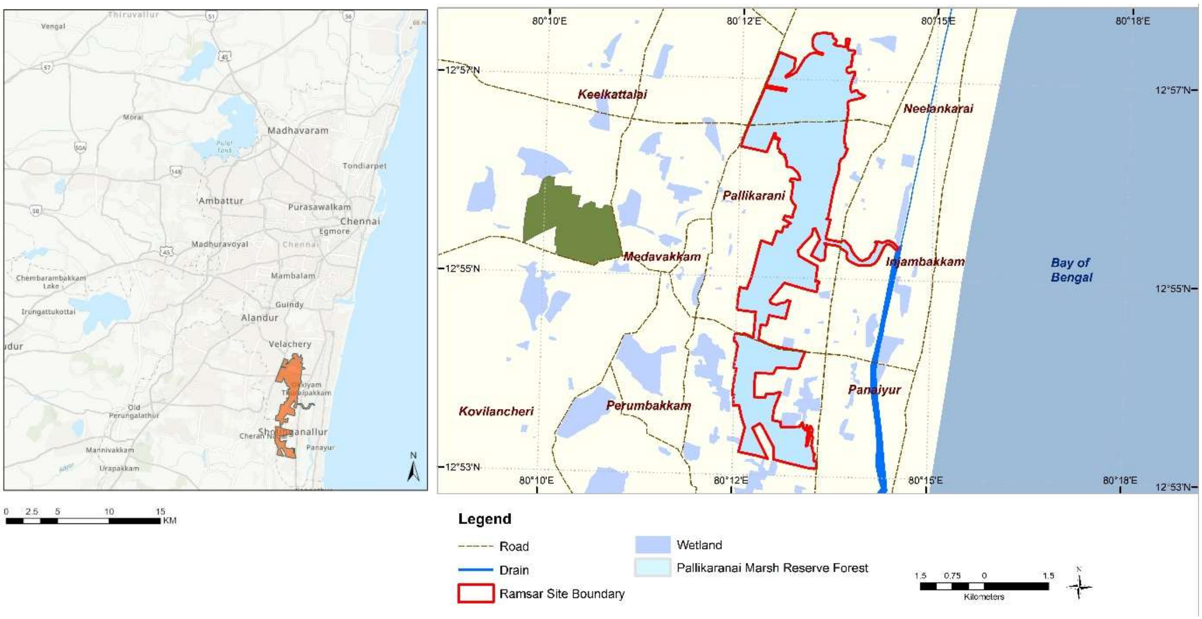
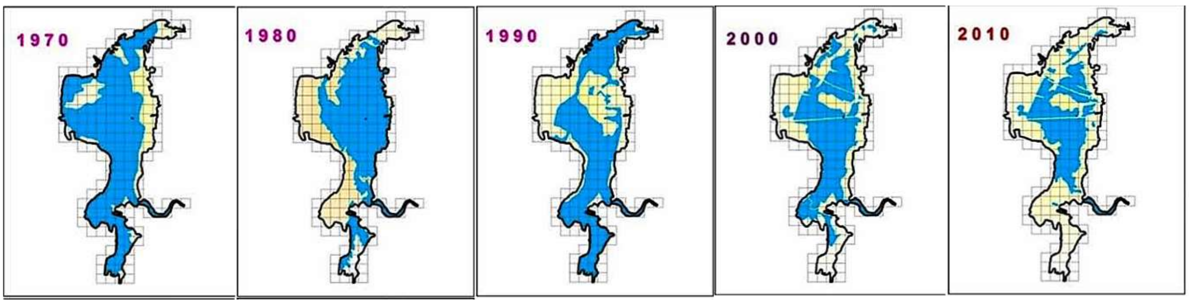


Figure 5.45: Location map of the Ramsar site of Pallikaranai Marshland Area (source: Ramsar Information Sheet, 2022)

Historically, the marshland has been protected since 2007, when 317 hectares were declared reserve forest. Through international partnerships, local collaborations, government agencies, NGOs, and scientific involvement, the reserve area has expanded, and Pallikaranai was designated a Ramsar wetland site in 2022.

As per Bhaskar et al. (2016), the area around Pallikaranai Marsh, once a low-lying floodplain, is now a mosaic of industrial, residential, institutional and commercial developments interspersed with remnant natural habitats. In this peri-urban context, water security is shaped by intertwined processes of urbanisation and climate change (Narain, 2010). Rapid development, new roads, encroachments that block natural channels, and discharge of domestic sewage into the marsh have driven major degradation of wetlands in southern Chennai.



YEAR	1970	1980	1990	2000	2010
WATER SPREAD AREA in %	76	57	60	50	35

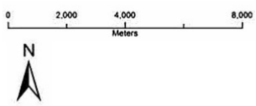


Figure 5.46: Changes over the decades across Pallikaranai region until 2010 (source: Bhaskar et al., 2016b; Vencatesan et al., 2014)

Because these wetlands form a connected system of water bodies that enable crucial groundwater percolation, their loss will severely affect long-term water sustainability in the region (Chandramohan

& Bharthi, 2009; Bhaskar et al., 2016). Numerous studies show that wetland degradation reduces water retention and increases flood risk (Brody, Highfield, Ryu, & Spanel-Weber, 2007; Bhaskar et al., 2016). Pallikaranai Marsh in southern Chennai thus remains a key storage area for stormwater runoff from surrounding neighbourhoods, safely conveying overflow towards the sea.

Over the years changes in the Pallikaranai region can be seen in the following figure 5.4 (source: Vencatesan, 2014; Bhaskar et. al, 2016).

The Care Earth Trust supported the Government of Tamil Nadu (Forest Department, CMDA, GCC) in assessing the reduced water-holding capacity of the Pallikaranai marsh. In partnership with local agencies (CMDA, GCC), the regional forest department, national wetland conservation bodies and UN partners, the marsh has been recognised as a natural sponge. The Resilient City Chennai (2019) report identifies this zone as a key carbon sink and aquifer recharge area.

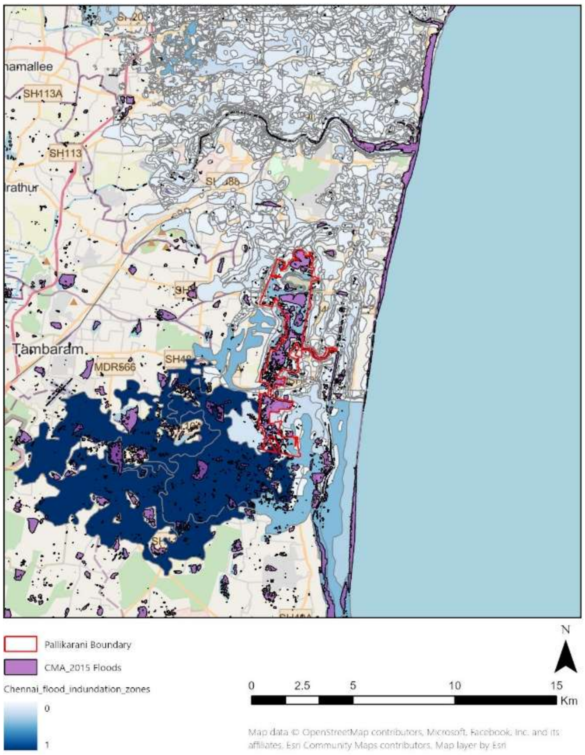


Figure 5.47: Flood Inundation areas near Pallikaranai (source: Author, Ramsar Wetlands, ESRI, Opencity Urban Data Portal)

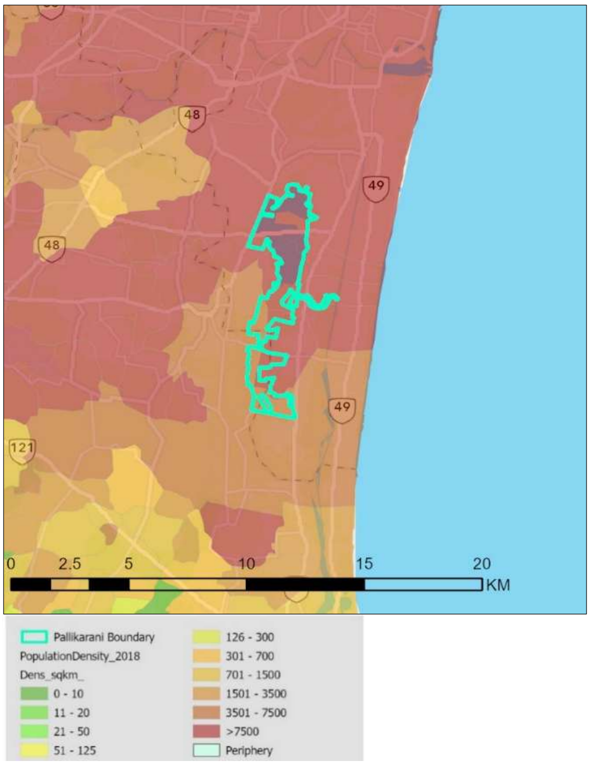


Figure 5.48: Population density of around the Pallikaranai region (source: Author, Open city urban data portal and ESRI)

As a port city and industrial hub, Chennai has driven national and regional economic growth but surrounding GCC regions have experienced rapid population increase and urbanisation, with extensive development in low-lying areas for residential, commercial and industrial uses. Pallikaranai is a prime example of shrinking wetlands. Figure 5.45, shows that, by 2018, average population density had reached about 7,500/km² around the marsh, with many areas falling in flood inundation zones based on the 2015 floods (0 = low risk, 1 = highest risk, *see image 5.46*). The figure also illustrates flood accumulation during the December 2015 event, underscoring that dense populations and built-up areas around the wetland face persistent flood risk.

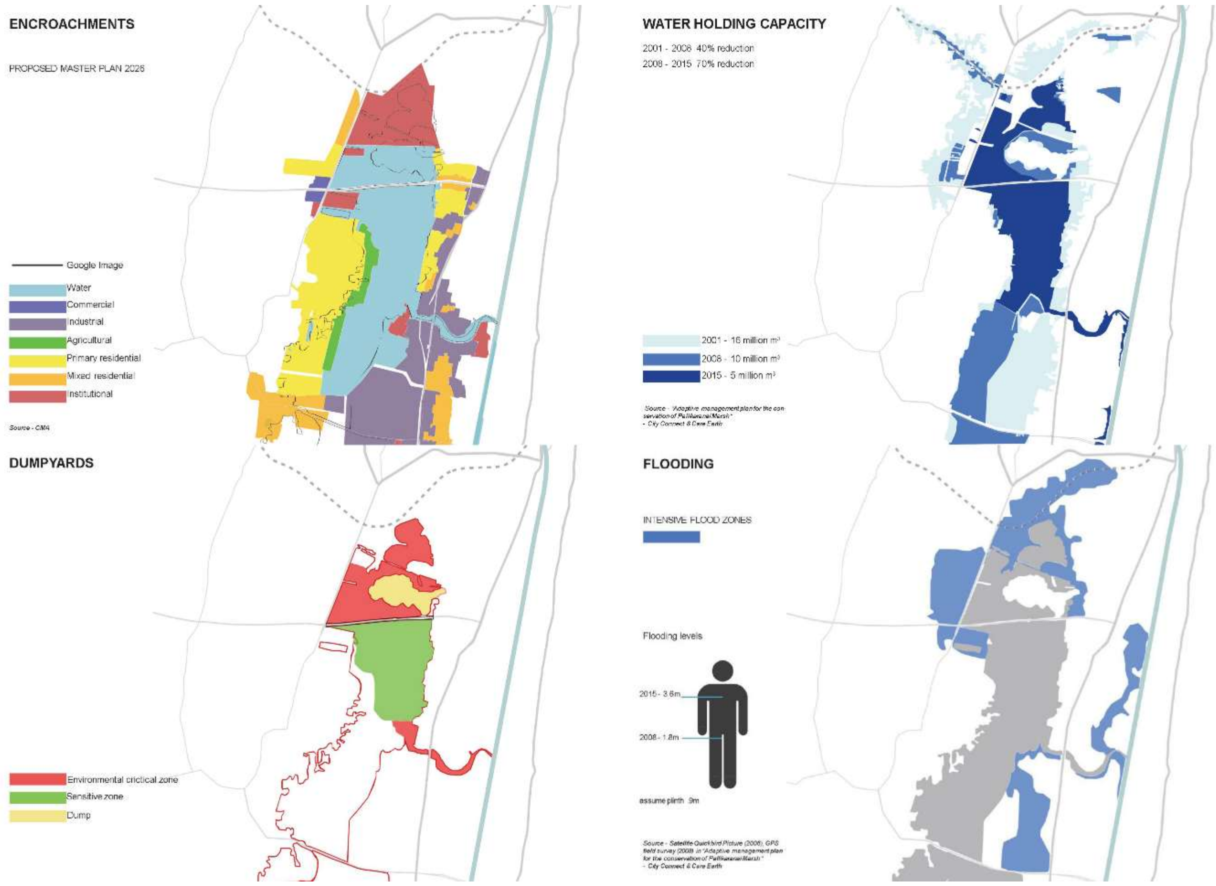


Figure 5.49: Anthropological issues and natural capacity across Pallikaranai wetland region. (source: Care Earth Trust)

In the Chennai Metropolitan Area Master Plan 2026, Pallikaranai, located at the GCC border, is surrounded by major land-use changes with limited climate-adaptive flood mitigation. A large dump yard occupies the centre of the marsh; the eastern and western edges are densely settled, and new industrial developments are planned to the south, further threatening water storage capacity. Care Earth Trust's analysis and associated figures highlight how inefficient water channels and undersized culverts displace and concentrate

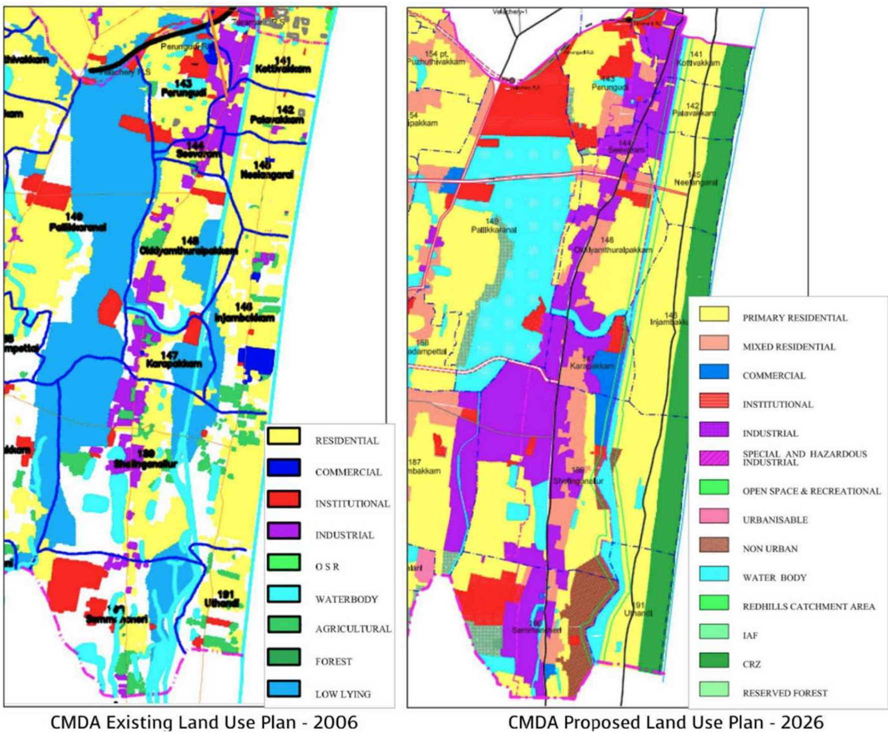


Figure 5.50: Land use Planning and changes over the years since 2006 around the Pallikaranai Area.

water, funnelling flows from the north and west towards the southern and eastern margins, then into the Buckingham Canal and finally the Bay of Bengal, exacerbating local flood hazards.

The Master Plan of 2026 (figure 5.50 .) illustrates shifts in land-use around Pallikaranai, notably increasing industrial activity along the eastern edge of the marsh. Although the Care Earth Trust report proposes mitigation focused on conserving existing marsh boundaries, the area requires more than a narrow conservation approach: enhancing water-holding capacity, safeguarding biodiversity, and building resilience demand integrated, system-wide interventions. There is a marked lack of coordination between mitigation and adaptation strategies for DRR and resilience, reflected in the proposed land-use pattern along this corridor.

Bhaskar, et. al, (2016), in assessing Pallikaranai's water resources, highlight anticipated water stress under combined climate and anthropogenic pressures. Key concerns include the need to regulate informal water-tanker markets and to protect the wetland ecosystem, which once comprised entirely floodplains with 29 large and 13 small water bodies.

Table 5.10: Refence table for ongoing challenges, risks, changes and climate change adaptations measures for the Chennai's Pallikaranai Marshland area.

Major changes (past years)	Ongoing challenges/risks	Climate impacts & adaptation
Marsh shrank from ~6,000 ha to ~593 ha; roads fragmented hydrologic links (e.g., Adambakkam IRR, Thoraipakkam radial).	~30 wells overdrawn; urban imperviousness curbs recharge â†' well failure risk, higher costs, biodiversity loss, saline intrusion.	NE monsoon extremes increasing; multiple recent flood years in Chennai. Low-rainfall years heighten drought; reduced recharge area linked to falling groundwater levels.
Rapid southward growth (IT parks, housing, informal settlements) converted wetlands/pastures; >50% of 474 wetlands lost/encroached.	Encroachments, road-laying, sewage inflows, garbage dumping â†' reduced storage, poor water quality, weaker flood buffering.	Higher saline intrusion risk with sea-level rise + over-pumping. Protect/restore wetlands and village tanks; halt encroachments; reconnect severed hydrologic links.
Groundwater dominant; municipal/village tanks refilled by tankers from agricultural/private wells; direct lake pumping occurs.	Weak regulation of tanker/groundwater trade; violations of 1987 regime; limited volume/quality oversight.	License, meter, and monitor abstraction; restrict borewells within wetland influence zones. Quality/volume oversight, transparent pricing to curb over-extraction incentives.
Informal water tanker market of ~700â€"800 fills/day; delivery costs far exceed filling price.	Blocked drainage, lost tank connectivity, inadequate stormwater systems â†' more frequent/severe floods.	Quality/volume oversight, transparent pricing to curb over-extraction incentives. Modernize stormwater network; reopen historical channels to the marsh for safe flood conveyance.
1970â€"2010 maps show shrinking water-spread; densest new habitation on N/NW margins that now flood intensely.	Communities reliant on costly tanker water; livelihoods shift from farming to extraction trade.	Maintain tanks, add recharge structures, mainstream NBS in planning and development control.

Although it will be very challenging to displace the current urban settlements and would need more efforts for integrating ecosystem-based approach towards managing the existing challenges and risks around the marshland. Integrated bioswales and water retention canals, channels, water retention ponds, along public infrastructures such as roads, streets and open parks can be a solution towards channelizing the water overflows, reduce effects of extreme flooding conditions, help ground water recharge through rainwater harvesting.

Water as Leverage – Chennai (2017–present)

Water as Leverage (WaL) for Resilient Cities: Asia was launched in 2017 at the 23rd Climate Conference in Bonn, Germany. The program kickstarted in 2018 that called for transformative resilience project proposals in the fields of water, climate adaptation, and urban planning for the cities of Chennai (India), Khulna (Bangladesh), Semarang (Indonesia) (World Water Atlas, 2017). Facilitating resilient solutions, it connects long-term urban planning with short-term innovative transformations; ambitious climate adaptation plans with bankable projects; and water system knowledge for developing resilient cities through science and research, design, finance and implementation practices with inclusive urban partnerships. (Netherlands Enterprise Agency, 2018).

WaL has been an multinational multi-organization participation headed by the Dutch Government office for International relations that also pledged to monitor and guide the project proposals in terms of their replicability, scalability, systemic approach, knowledge production, governance principles, sustainability, viability, bankability and, of course, their contributions to the UN 2030 Agenda for Sustainable Development and the Goals of the COP21 Paris Climate Agreement. The overall set of partners for the program comprised: The Global Center on Adaptation, Asian Infrastructure Investment Bank, International Architecture Biennale Rotterdam (IABR), UN-Habitat Design Lab, Global Resilient Cities Network (formerly known as 100 Resilient Cities), Architecture Workroom Brussels, WWF, Pegasys, Water Youth Network, Partners for Resilience, Dutch Development Bank FMO, the cities of Chennai, Khulna and Semarang and the Netherlands government. The Water as Leverage programme is also endorsed by the UN/World Bank High Level Panel on Water. (World Water Atlas, 2018).

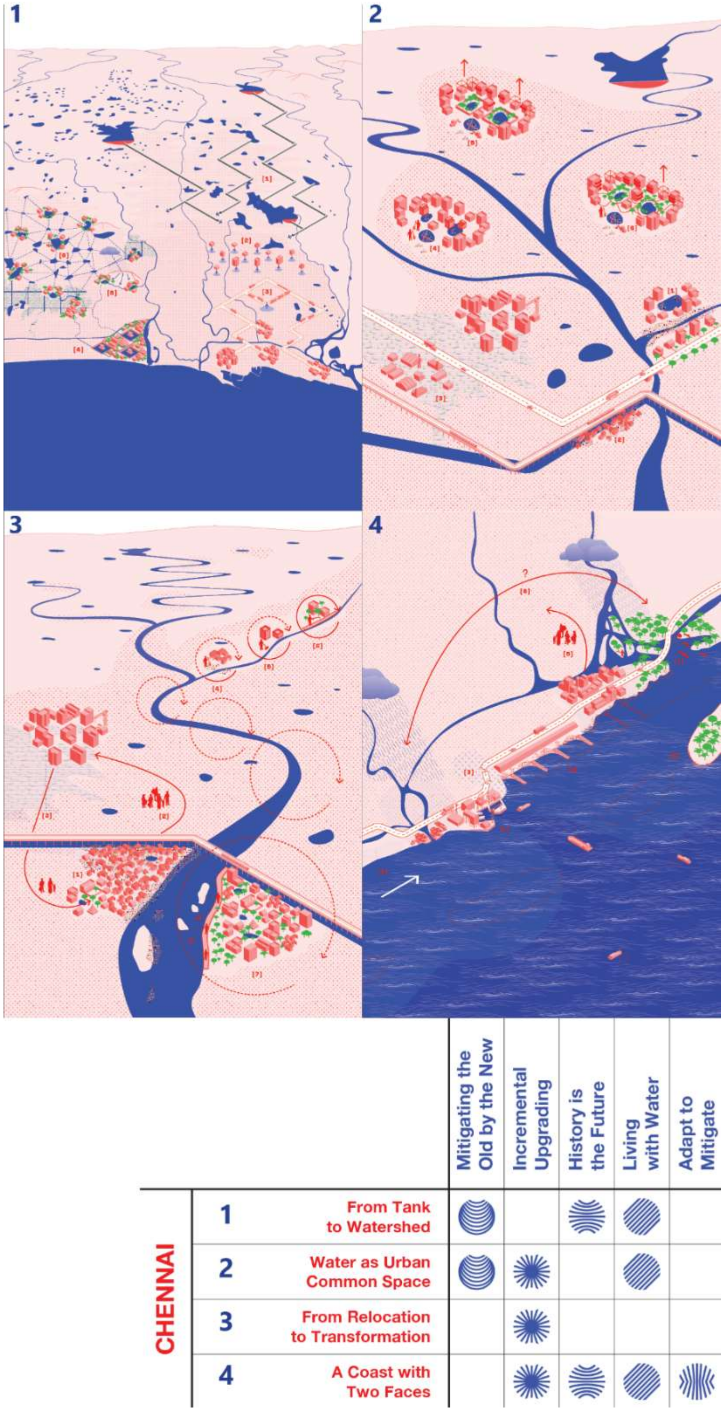


Figure 5.51: The Four preliminary approaches/ pathways (source: World Water Atlas)

Addressing the key importance of urban water issues and the risks of water-related hazards in the Asian cities, the WaL program for the city of Chennai called for two major initiatives which are under operation since 2018. Highlighting key issues of poor waste management along the natural and man-made drainage channels, degraded ecosystems, exploitation of urban wetlands and marshlands, excessive ground water extraction, soil sealing, coastal erosion and extensive urbanization near the wetlands, lakes and natural water bodies these initiatives collectively bring different partners and contributors towards collaborating for strengthening resiliency in accordance with the water stress in the urban area.

In its preliminary call for actions, among the partner cities, the program assessed a few approaches and pathways towards addressing the challenges and issues in strengthening water resiliency across Chennai, which can be seen through the illustrative images in the figure 5.49

From Tank to Watershed: The approach to synthesize and smartly develop a sustainable network of well-connected water bodies tailored to the city's current scale, play multiple roles of storing, delaying, retaining or reusing the available water that functions as a natural backbone to manage the existing and future urban development. **Water as Urban Common Space:** This approach called for a desired link between the urban fabric and the protected water bodies where the administration and the citizens recognize water as a shared responsibility, with defined ownership and care rather than simply address it as qualitative public spaces that structure the city. **From Relocation to Transformation:** This approach discusses the need for an inclusive and strategic way of incorporating the dwellers and users within the formal and informal settlements by making them a part of the solution rather just the problem. A co-creative process of incremental upgrading can unfold in three beneficial steps that brings transformation of the settlements in the riverbeds, along canals and adjacent to water bodies implemented as a part of a greater and larger plan at city scale. With an attempt of effective restoration of the water system, the living conditions, and transfer of responsibility for maintenance and restoration, and further leading to an upgrade of both the ecological environment and the urban surroundings of the water system. **A Coast with Two Faces:** The path discusses the possibilities of implementing safer and intelligent solutions for an integrated coastal system to act on the current challenges of sedimentation, erosion, salinization and flood protection with a larger perspective.

`As a result of these approaches, the WaL program brought two initiatives, the first initiative being *Rise Chennai: Rising waters, Raising Futures Chennai Project* and the second initiative *City of 1000 Tanks*.

Rise Chennai: Rising Waters, Raising Futures Chennai project talks about interventions at two locations: *Mambalam Canal (Muthucharam Mambalam) and Muttukadu Kovalam (Neithal Muttukadu)* along with other two locations which are under its initiatives (Kosthalaiyar and Manimangalam).

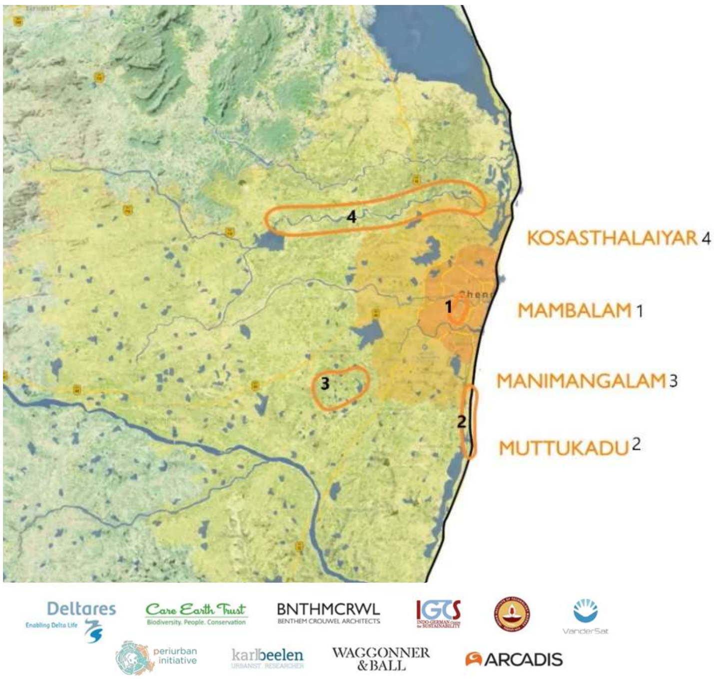


Figure 5.52: Rise Chennai (source: Benthem Crouwel Architects)

Mambalam Canal

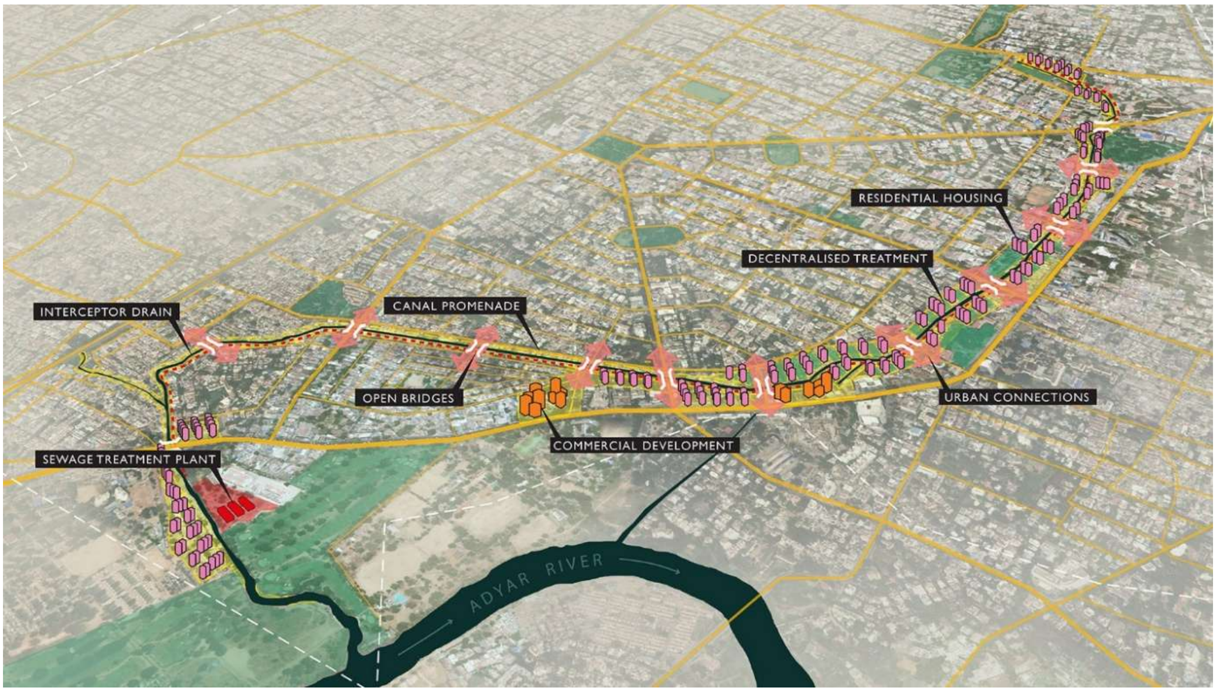


Figure 5.53: Revitalization Plan of the Mambalam Canal (source: Benthem Crouwel Architects, World Water Atlas, 2018)

The Mambalam Canal project is collective efforts and collaboration of the team: Benthem Crouwel Architects, Deltares, IGCS (Indo-German Centre for Sustainability), Arcadis, Karl Beelen, Care Earth Trust, IIT Madras, Karlsruhe Institute of Technology, Waggonner & Ball,VanderSat, PeriUrban initiative in putting together the idea and the concept of reviving the canal as per the discussed approach of the program for the city of Chennai. The canal, is a central storm-drain link to the Adyar River, has become polluted, unsafe, and clogged by waste and sewage from surrounding land uses, undermining drainage and fuelling floods along key commercial districts. The team's planned to restore it by combining water-treatment technologies and green infrastructure, while tying the upgrade to local economic activity and social cohesion. The strategy reimagines Mambalam Canal as a resilient, attractive public corridor that catalyzes mixed-use and real-estate growth while improving urban water quality and reliability.

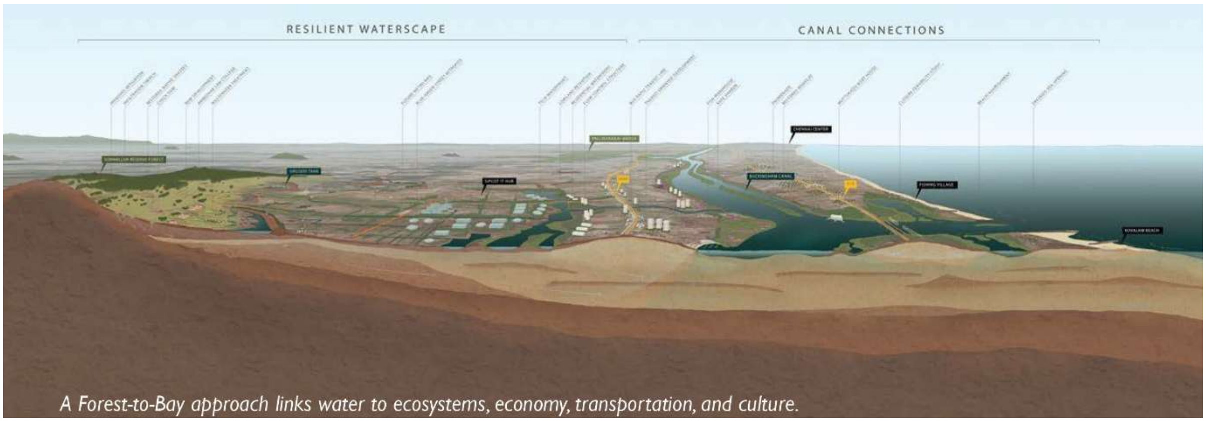
Figure 5.54: World Water Atlas, Key strategy points identified for the Chennai water management systems. (source: Author, adopted from World water atlas)

Based on World Water Atlas, 2018 the key points in the strategy are: *Think regional, act local*: Understand the storm water drainage system to be able to implement local interventions that improve the downstream functioning of Chennai's water management system. *Space for the water*: Redevelop the embankments, providing more space for the flexible functioning of the canal and new uses along it. *Strengthening connections*: Transform the canal into a social corridor along a mix-use zone for both residents and visitors, redesign key bridges as solid waste filters, and connect the canal to pocket parks that serve as infiltration trenches. *Decentralization*: Keep clean water clean, by separating and removing sewage water and waste, purify the remaining water for a clean and healthy environment in decentralized water treatment plants. *Collaboration*: Involve the community in the development of specific interventions, along with government agencies and privates.

Figure 5.55: 3D illustrations of Mambalam canal (source: Benthem Crouwel Architects)

Although these are only the initiatives and plans, but the project at the ground level struggles to provide concrete evidence of changes or transformations, which is very common among most cities among developing nations, as these locations have rigid informal economies that often find it challenging to cope with new interventions and disrupt their daily livelihoods.

Muttukadu Kovalam is another site of intervention which is primarily another backwater basin at the Chennai's southern edge that hosts booming IT corridor growths alongside long-standing coastal fishing villages, creating a fast-changing mosaic of settlements, informal and formal economies with sensitive wetlands. Regulars stress on the wetlands due to the ad-hoc developments creates intensified water challenges in the area. The transformation under the RISE Chennai partnership for the Muttukadu area pledged to improve water quality, supply, and salinity management, while mitigating flooding and seal-level-rise risks. The project offered solutions that pair green infrastructure with decentralized water-treatment technologies, aligning new and existing developments smartly incorporating within regional urban and transport planning strategies. Cohesive Eco-urban system strengthens coastal safety (barrier + wetlands), restoring natural processes, upgrading water quality in backwaters, and enabling sustainable economic growth protecting the dwellers and business bind the framework for its long-term goal.



To discuss its strategies for Muttukadu, it has been to develop an *integrated, adaptive coastal-defense and water-quality program* that *restores the backwaters* and *redesigns multimodal links* from the IT corridor across the Buckingham Canal to Muttukadu and Kovalam, strengthening resilience, connectivity, and livelihoods.

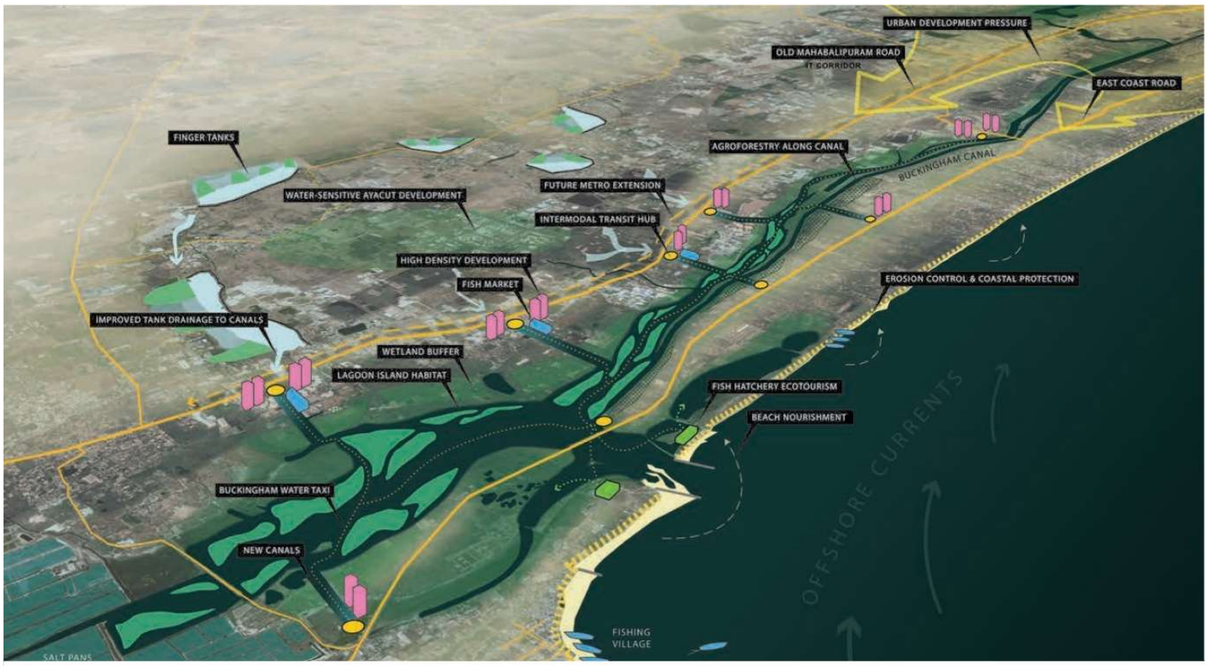


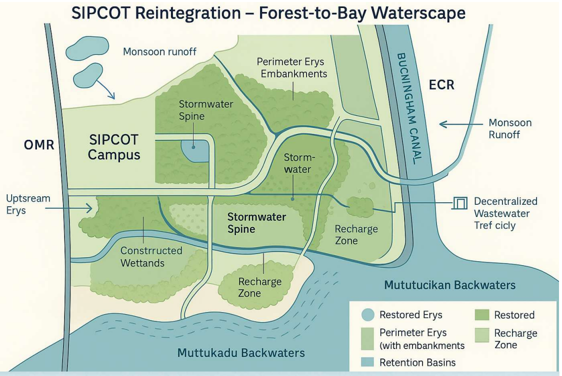
Figure 5.56: The Muttukadu Backwaters Planning Illustration (source: World Water Atlas, 2018)

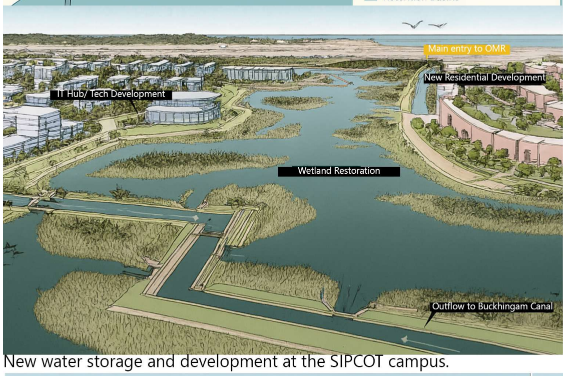
As per the World Water Atlas, 2018, the team for this project defined specific strategies that can be seen in the figure.

Figure 5.57: Interpretation of the strategies (source: Author based on World Water Atlas, 2018)

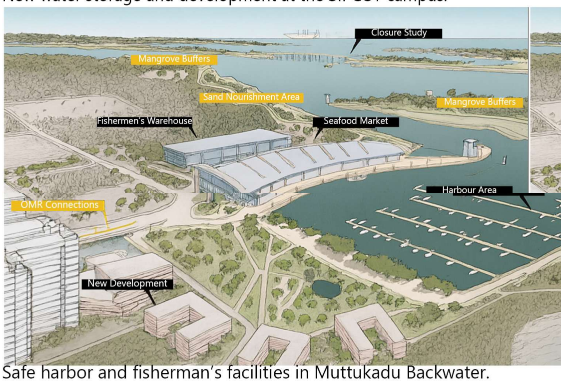
Based on these specific strategies, Interventions at first **SIPCOT | Reintegrated Waterscape:** The plan stitches the sub-basin, so SIPCOT secures supply and reduces flood risk. It tackles unplanned growth, encroached Erys, and tanker over-extraction by linking upstream Erys to canals and campus outlets, restoring Erys through desilting, regrading, and no-build buffers, and adding on-campus retention wetlands. Managed aquifer recharge and blue-green zoning are enforced so downstream peaks drop while non-potable reliability, biodiversity, and amenity corridors improve.; and the second **Coastal**

Protection & Adaptation (East Coast Road): The strategy protects the coast from erosion and sea-level rise, cleans the backwaters, and aligns tourism with fisheries.





New water storage and development at the SIPCOT campus.



Safe harbor and fisherman's facilities in Muttukadu Backwater.

Figure 5.58: Illustrations of the two interventions at Muttukadu-Kovalam (source: World Water Atlas, 2018; Artificial Intelligence Illustrations)

It addresses shoreline loss, inlet siltation, and habitat decline via sand nourishment with periodic top-ups, inlet dredging and maintenance, and flap gates or pumps on the canal. Living shorelines, mangroves, dunes, habitat islands; combine with decentralized wastewater treatment and wetland polishing, functional coastal zoning and a safe harbour, and new multimodal links between OMR and ECR so the shoreline becomes safer, water quality improves, and livelihoods and ecotourism grow more resilient. The illustrations could be understood on the following image.

City of 1000 Tanks (2018–present)

Unlike the RISE Chennai project, City of 1000 Tanks project has been a breakthrough across Chennai in developing major initiatives and efforts towards realization of the water resource management and overall strengthening water resiliency under the Water as Leverage program through wastewater collections and ground water recharge. The city of 1,000 Tanks is a multidisciplinary initiative led by OOZE Architects with local and international partners (e.g., IIT Madras, Care Earth, Paperman, Biomatrix, Pitchandikulam, Rain Centre, IRCDUC, TU Delft, IHE Delft, HKV). It replaces hard, 20th-century flood control with blue-green infrastructure—temple tanks, new ponds, bioswales, cleansing channels, and constructed wetlands—to capture rain, treat wastewater, recharge aquifers, and reduce flooding. Framing Chennai as a seasonal landscape, it stores monsoon water for dry months. Through pilots, art, and community programs, the team advances an incremental, decentralized approach that empowers neighbourhoods, revives ward-level stewardship, and manages floods locally while improving water security. The effort also aligns policy and finance to scale projects citywide and strengthens social cohesion by linking water management with culture and everyday public space.

Figure 5.59: The city of 1000 Tanks key major water managmenet concepts. (source: World Water Atlas)

The project creates an active relationship between water management and the community instead of the top-down management approach that is currently in place. Empowering local communities and reviving ward-level management power helps create water capacity and the possibility to manage flood events locally.

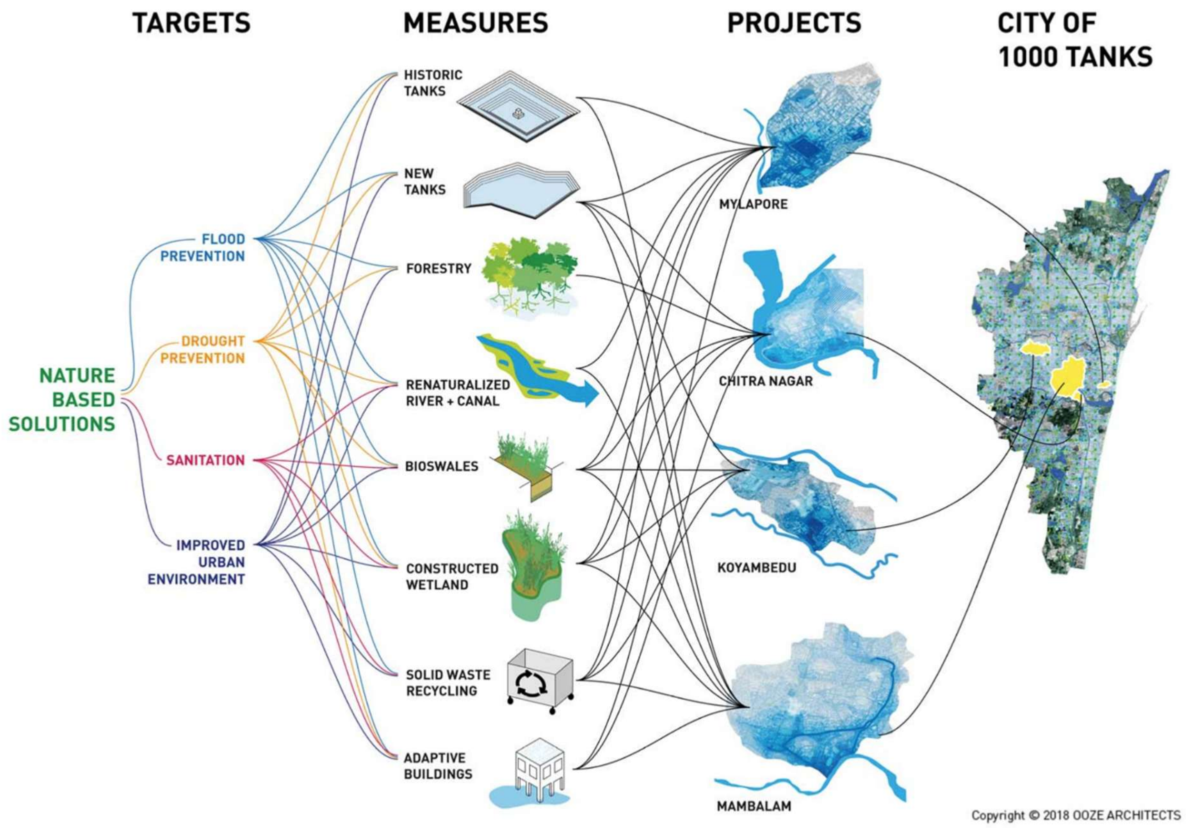


Figure 5.60: Integrating NBS in a systemic approach (source: Ooze Architects)

It identifies the interrelationships between the underlying causes of floods, water scarcity and pollution in Chennai and offers a holistic solution to these three problems. *to 1,000 Tanks* intends to develop a Water Balance Model across the city by collecting rainwater, treating wastewater and runoff pollution with decentralised Nature-Based Solutions (NBS), and by recharging both to the underground aquifer.

This will prevent climate-change-induced droughts by increasing groundwater reserves and prevent saline intrusion from sea-level rise. Simultaneously, it will mitigate risks associated with high-frequency floods as well as sewage pollution. The project has been realized on the ground and is still ongoing, however the project is divided into 3 phases as seen in the figure 5.59.

Phase 1

Feasibility study with field trials | $2.5–5.0 million USD
Technical measures will be tested and communicated to the public to create an enabling environment for nature-based solutions. A project Preparation Grant of is needed.

Phase 2

Flagship Projects | $221 million USD
Four flagship projects with the potential for citywide upscaling in the areas of Mylapore, Chitra Nagar, Koyembedu and Mambalam. These flagship projects are uniquely chosen based on cultural, geographical and social nuances and can show how City of 1000 Tanks can be used to build a sustainable groundwater supply.

Phase 3

Citywide Upscaling | $ 1.3 billion USD
Techniques from flagship projects are replicated to build a citywide water-balance model, requiring dedicated investment. The programme benefits Chennai's economy, livelihoods, and public health by sustaining groundwater resources. State institutions gain long-term structural solutions and upgraded capacities for sound groundwater management.

Figure 5.61: Project phases of city of 1000 tanks (source: Author, adopted from World Water Atlas)

The city of 1000 tanks initiative has developed pilot projects in the areas of Chitra Nagar and Mylapore so far and working actively with the government bodies and local communities towards incorporating more participations across the city.

The City of 1000 Tanks in Chennai acts as a collective network of reformed and redefined sites for better water management practices and built water resiliency over times. In terms of socio-economic vulnerability, these locations are very much prone to the frequent risks of seasonal flooding and drought conditions and the major challenges identified under the Water as Leverage program has been to incorporate the local communities in strengthening the solid waste and water waste management. One such example can be seen the Little Flower School pilot project which is named as Water as Balance. It is funded by the Government of the Netherlands and co-financed by the Excellence Program of the Goethe Institute and the Wipro Urban Ecology Small Grants Program which is a demonstration project showcasing the transformative capacity of the Water as Leverage programme, which envisions a water abundant Chennai.

The following images are post execution images of the infiltration gardens ad artificial wetlands that were built within the school areas to help recharge the ground water through a set of collection tanks and discharge wells. Although this being a pilot project that has been executed, several other projects within the city of 1000 tanks initiative of the WaL programme has been on the pipeline to be realized. Until these initiatives do not realize on the ground

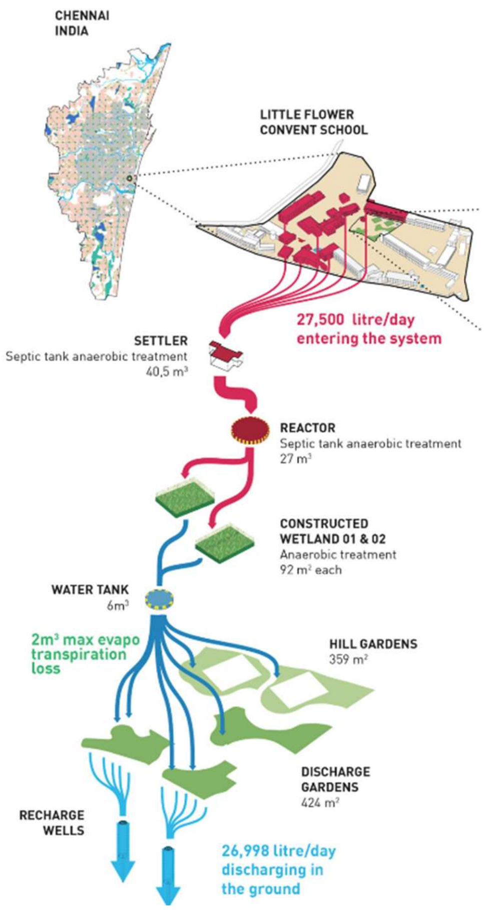


Figure 5.62: The Little Flower School initiative under the City of 1000 Tanks (source: Ooze Architects)

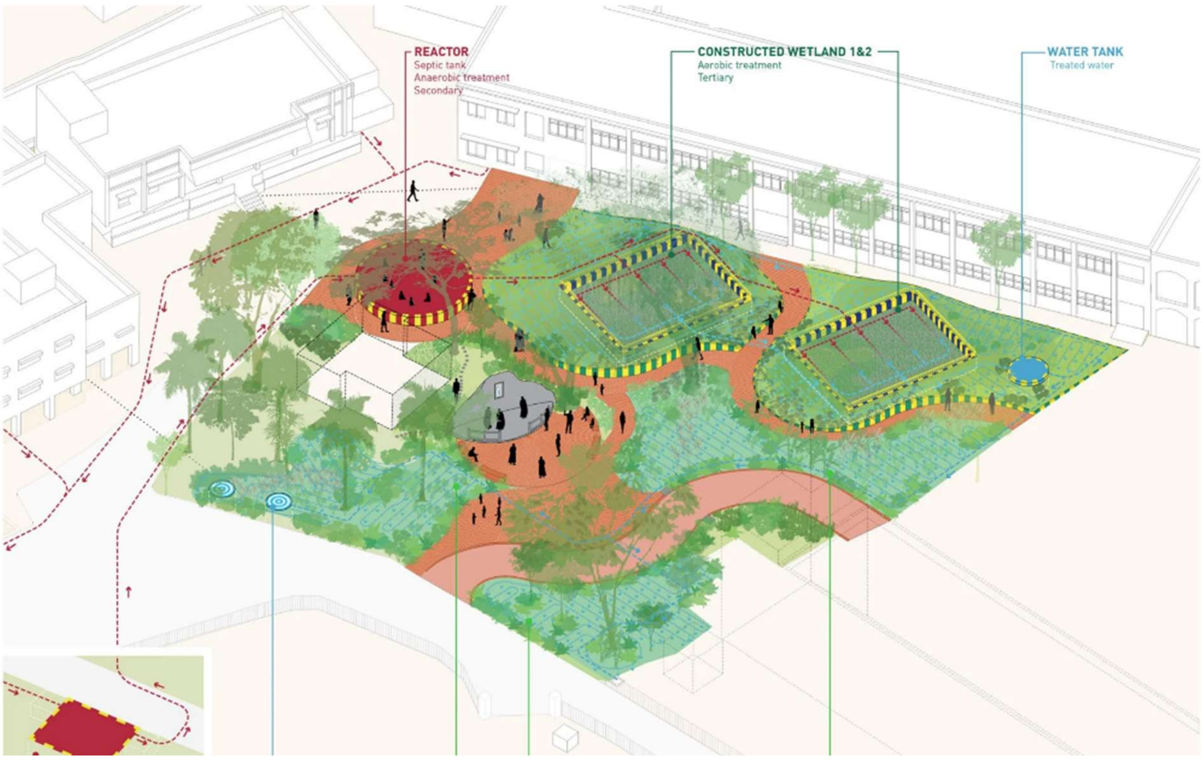


Figure 5.63: Rain Gardens with underground groundwater recharge and storage tanks in the Little Flower School (source: Ooze Architects).

level, the approximate number for reduced vulnerabilities and risks and the effective impact of DRR strategies, the Ecosystem based Approach in Chennai merely becomes circumstantial. The little flower school is simply a model that helps in shortlisting sites and demonstrate the process for inhabiting artificial wetlands and infiltration trenches across the city of Chennai. But the existing conditions of the low-lying areas through the informal economic and slum dwelling locations that thrive across the natural water networks and creeks of Chennai impose a serious challenging in resolving the socio-economic liabilities much before these solutions could be even realized.

Figure 5.64: Little Flower School underground rainwater recharge and waste water discharge tanks (source: City of 1000 Tanks)

Following figure 5,63, is another project under development within the City of 1000 Tanks initiative that is still yet to be realized.

Figure 5.65: Mylapore Tank project illustration (top left) of connecting with main canal networks for excess stormwater discharge, Bottom left we have the street shops right at the edge of the Mylapore tank along a busy road network, then top-right an illustrative view of redefined edge of Mylapore Tank (source: City of 1000 Tanks, Author)

The area is the Mylapore Tank, and the project's main concept image shows the idea to develop a network of bioswales or infiltration trenches around the tank's perimeter to maintain water networks and connect them with the main creek, which carries water to the Adyar river and helps recharge groundwater. However, the ground reality of the tank's periphery is that it supports large-scale livelihoods tied to religious activities. Disrupting these and replacing them with blue-green infrastructure offering minimal socio-economic benefits will not be an easy choice for the local neighbourhood and will pose a municipal challenge. Google Street View also shows the lake edge heavily occupied by shops, street parking, and transit infrastructure. The Ecosystem-based Approach in the City of 1000 Tanks scenario is less efficient in two major areas: first, providing a "transformative" solution within the WaL program and incorporating a transit-oriented model. The impact and relationship of these interventions with the neighbourhood could become an active case of daily activities and interactive exchange, which seems lacking in the proposed Mylapore strategy. Similar to Mylapore, the initiative targets other locations identified for interventions of varying scale and agenda. For example, Chitra Nagar, housing 10,000 people, is a low-income slum settlement on the inner banks of a horse-shoe bend of the Adyar river, one of the hardest-hit areas during the November–December 2015 floods. Under the initiative, the area is part of a resettlement program aiming to close the water loop in the Chitra Nagar Disaster Resilient Housing scheme by retrofitting systems for water collection, recycling, recharge, and solid waste management. At Koyambedu Market, severe flooding in 2015 disrupted the transit system, halted food distribution citywide, and compromised assets worth $191.3 million. The ground's absorption capacity has steadily decreased, with over 85% of surfaces now impervious. Solid waste management remains a key issue alongside depleting groundwater levels; this site is another intervention under the initiative.

Figure 5.66: Other Pipeline Pilot projects under City of 1000 Tanks (source: Ooze Architects, World Water Atlas, thecityofthousandtanks.org) - Chitra Nagar Slum resettlement (left) and Koyembedu Market Area (Right).

Overall, the city of 1000 tanks is a global partnership and will take its own course, but the need to have more active role of the local administration and the communities in the urban neighbourhoods require large scale participation and commitment.

5.3 Case Study 3: City of Cape Town, South Africa

5.3.a General Background –Urban Density and Geography

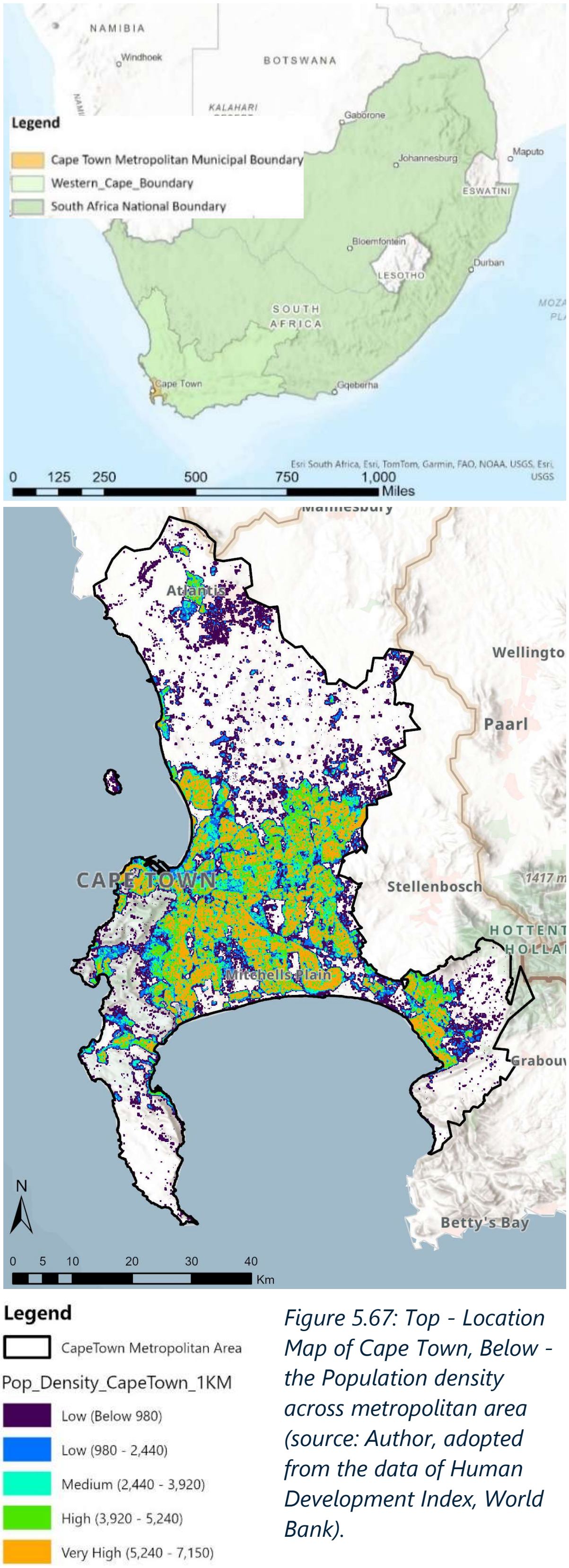


Figure 5.67: Top - Location Map of Cape Town, Below - the Population density across metropolitan area (source: Author, adopted from the data of Human Development Index, World Bank).

Among the coastal cities in South Africa, city of Durban and Cape Town have been the most prominent and fast-growing cities, apart from Pretoria and Johannesburg, that are widely contributing to country's manufacturing, tourism and overall economic growth. However, the provincial (Kwazulu-Natal and Western Cape respectively) contribution to the national GDP has been the highest in 2022 with 15.9% and 13.9% respectively as per the Department of Statistics, South Africa. Although Kwatzulu-Natal and Western Cape's annual provincial growths in 2022 were 1.1% and 2.6% of the national GDP while their provincial population share being 20% and 12% of the overall Nation's population of 62 million ranking second and third respectively in the population share. However, on the contrary, as per 2022 census the population recorded in the city of Durban (eThekwini metropolitan municipal area) being 4.23 million rising from 3.47 million from 2011 census and the city of Cape Town recorded 4.77 million in census 2022 rising from 3.74 million since 2011 census.

Cape Town with rich history and cultural background serves both the capital of Western Cape and as well one of the national capitals (legislative) of South Africa along with the Bloemfontein (Judiciary) and Pretoria (administrative and largest in population). Cape Town city with a 294km coastline and 2441km2 of geographical area, has nearly escaped the "Day Zero" event between 2015 and 2018 where it faced severed water shortages across the region pushing 4.6 million residents at the risk. Since then, Cape Town has made extensive measures and investments in water and sanitation infrastructure to ensure sustainable development, such as its New Water Programme that pledges to deliver around 300million liters of water per day until 2030 from new alternative water sources. (Lewis, 2023).

In figure 5.65, we can see the population is more concentrated across the central flat regions of Cape Town city. Throughout these regions population density is a mixture of the medium, high and very high densities.

Climate, Geology and Geomorphology

Cape Town lies in South Africa's southwest "winter-rainfall zone" and has a temperate Mediterranean climate (Köppen Csb): warm–hot, dry summers (roughly Nov–March) and cool, wet winters (April–October).

Long-term daily rainfall records (1841–2018) show that:

- Wet seasons are becoming shorter (about −1.4 days per decade since ~1940).
- The number of wet days is declining, and
- Dry spells >5 days are more frequent, especially since the early 20th century.

These changes mean a higher probability of both drought and intense, concentrated winter rainfall events. (Ndebele, Grab, & Hove, 2022).

Figure 5.68: (Geology of Cape Town overlapped on an aerial image of the Table Mountain | University of Cape Town)

Ggeomorphologically, Cape Town is defined by a steep mountain rim draining onto the low-lying Cape Flats, a sandy coastal plain (~30 m a.s.l.) between Table Bay and False Bay with dune fields and shallow depressions that once formed marshy vleis linked to the sea (Adelana & Xu, 2006). Drainage from the uplands flows north via the Salt and Diep Rivers into Table Bay and south via the Eerste River and Zeekoevlei into False Bay, so steep, fast-responding catchments discharge onto a flat, poorly drained plain (Adelana & Xu, 2006).

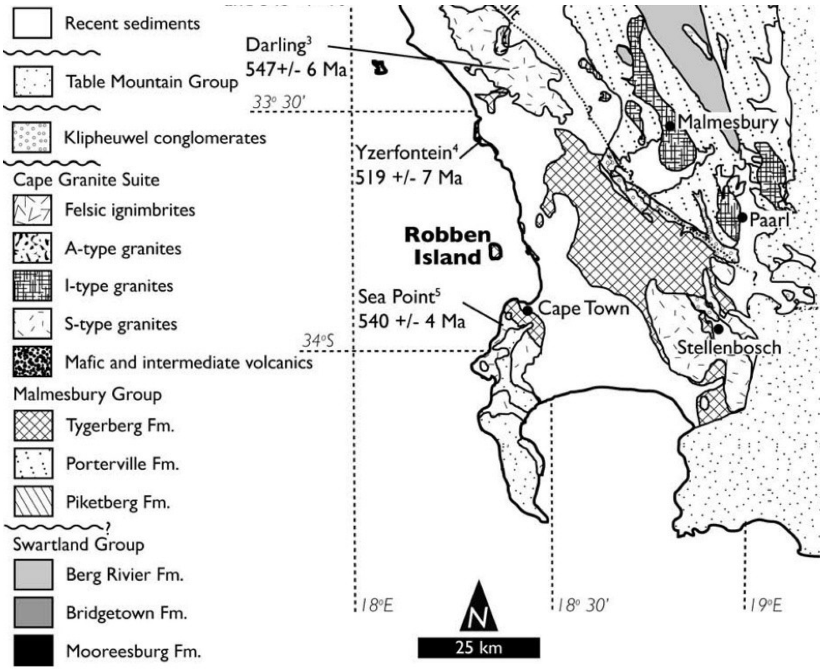


Figure 5.69: Geological Map of the Cape Peninsula region (source: Rowe et al., 2010)

Figure 5.67 shows the deposits above Malmesbury Group basement, Cape Granite Suite intrusions and Table Mountain Group sandstones.

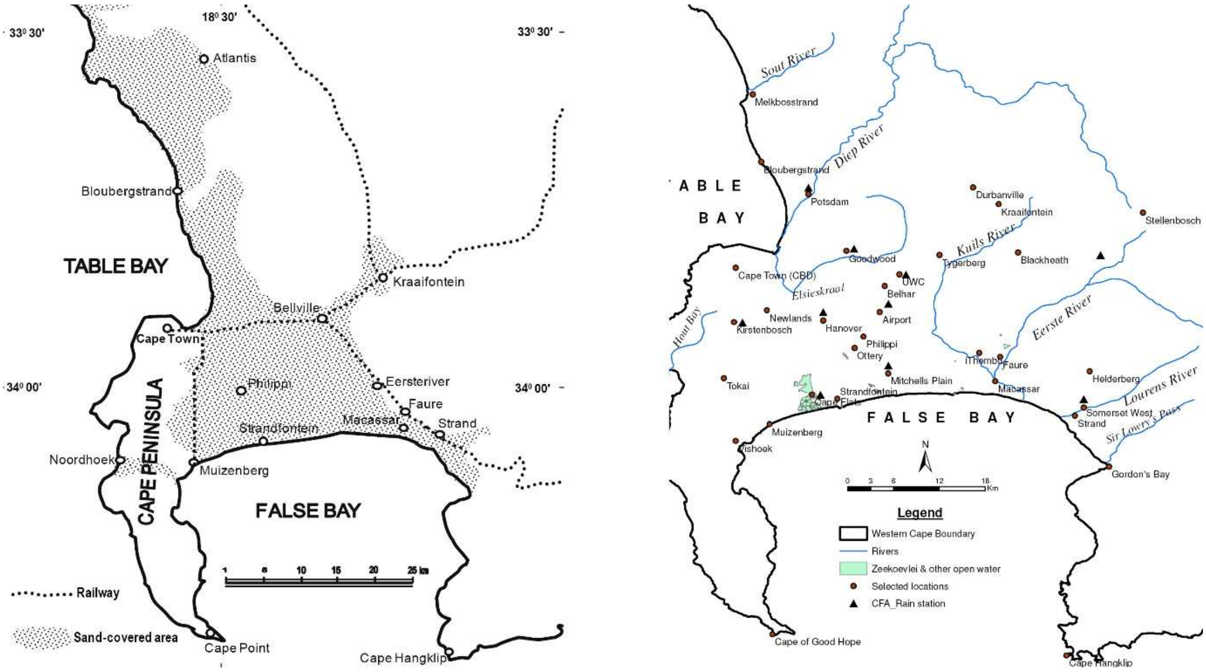
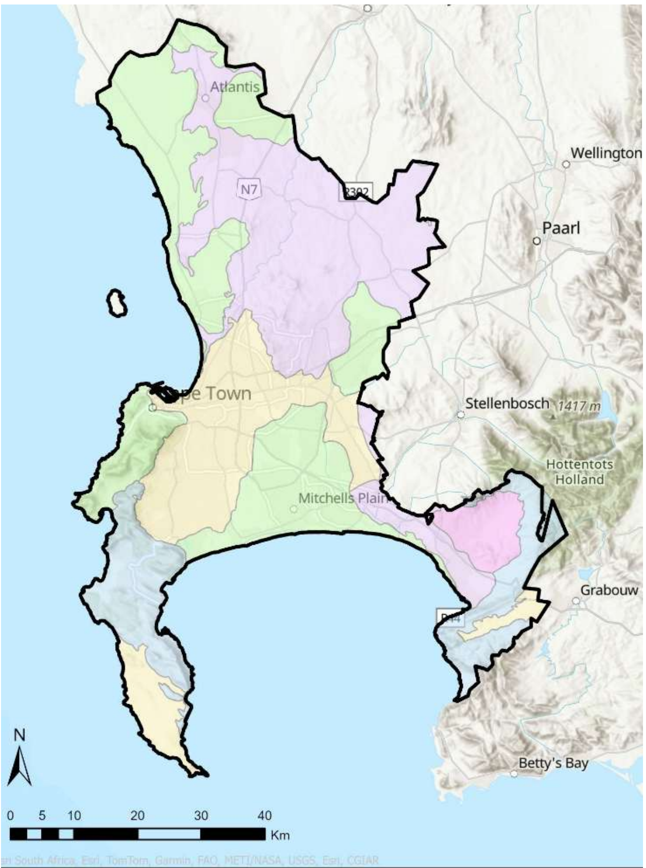


Figure 5.70: Cape Peninsula and the River networks Map (source: Adelana et al., 2010).



Legend

- Podzolic soils
- Red-yellow well drained soils lacking a strong texture contrast
- Rocky areas
- Soils with a strong texture contrast
- Soils with limited pedological development
- CapeTown Metropolitan Area

Figure 5.71: Soli Typologies across the Cape Town metropolitan area. (adopted from the open data cape town city portal)

Figure 5.68 shows how major rivers from the mountain front cross this sand-covered basin before reaching Table Bay and False Bay, the combination of shallow, weakly developed sands and flat topography on the Cape Flats favours rapid infiltration but also high groundwater tables, making low-lying settlements vulnerable to waterlogging, groundwater flooding and contamination (Adelana & Xu, 2006). Figure 5.69 highlights broad soil zones across the Cape Town Metropolitan Area, with podzolic and red–yellow well-drained soils on the Peninsula slopes, rocky areas in the mountains, and weakly developed sandy soils over much of the Cape Flats. Steeper rocky slopes shed runoff quickly into confined river corridors, amplifying flash-flood peaks and erosion during intense winter storms. These soil–geology patterns therefore reinforce the spatial concentration of climate risks in the sandy, low-lying basin.

The city's structural frame is the Cape Fold Belt, an orogenic system of parallel folds and thrusts formed during Palaeozoic collision of Gondwana and Laurasia (Flint & De Beer, 2016). Late Precambrian Malmesbury Group metasediments are intruded by the Cape Granite Suite and overlain by resistant Table Mountain Group sandstones, producing the steep Table Mountain–Devil's Peak–Lion's Head–Twelve Apostles chain and a dissected radial drainage network (Flint & De Beer, 2016; King, 1984). East and north, this relief drops abruptly into the Cape Flats, underlain by Late Quaternary marine, lagoonal and aeolian sands infilling a structural depression between peninsula and inland mountains (Flint & De Beer, 2016).

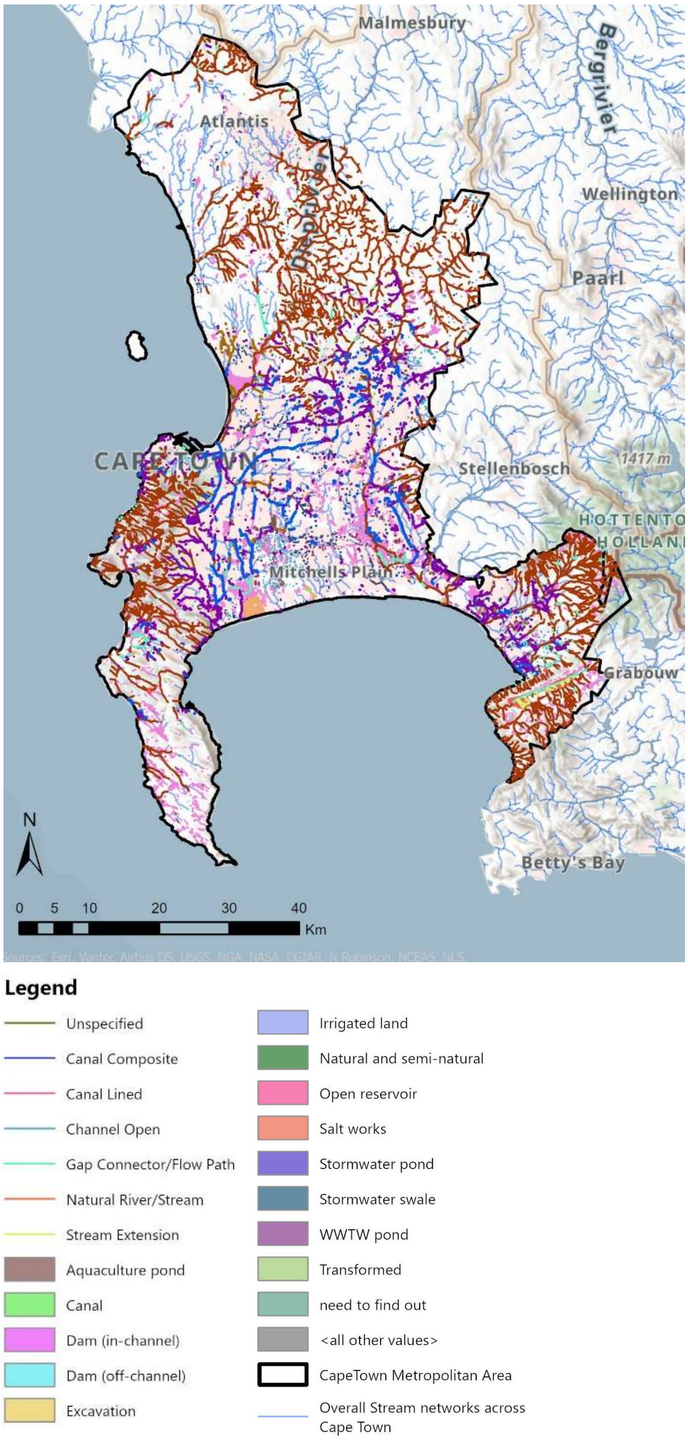


Figure 5.72: Drainage Networks and Wetlands Across the Cape Town metropolitan (source: Author, Copericus 30M DEM, and adopted from Open data portal of Cape town city)

The coastline mixes sandy beaches, rocky cliffs and coastal dunes shaped by wave action, erosion and sediment deposition, creating variation in exposure to storm surge and coastal erosion (Flint & De Beer, 2016). Urban heat risk is driven more by land cover than bedrock: remote-sensing studies show urban heat islands over dense, low-vegetation neighbourhoods on the sandy plain in Cape Town (Ngie et al., 2020). Overall, this geological–geomorphological template—steep slopes draining onto a flat sandy basin and complex coasts—both enables ecosystem-based buffering and amplifies flood, drought and heat risks under current urbanization and climate change (Flint & De Beer, 2016; Ngie et al., 2020).

Rainfall, Slope and Drainage Networks

Mean annual rainfall over the metropolitan area is roughly 500–600 mm, but it is highly seasonal: about 70–80% falls between April and October, when mid-latitude cold fronts bring multi-day rainfall events, occasionally intensified by cut-off lows. Summer (November–March) is typically dry, with only light, convective or orographic showers on windward slopes. Long-term records (1841–2018) show a shortening wet season, fewer rain days and more long dry spells, indicating growing inter-annual variability and a higher likelihood of both multi-year drought and intense winter storm rainfall (Ndebele, Grab, & Hove, 2022).

Cape Town Metropolitan region is home to nearly 2000 km of rivers, 480 km of canals, over 800 stormwater ponds, and thousands of hectares of biodiversity-sustaining wetlands and vleis.

The city also has Ramsar City status, an international accreditation recognizing cities that demonstrate exceptional commitment to conserving their wetlands and ecosystem services. Referring to the figure 5.70 the natural stream and river networks contribute to the major share across the entire metropolitan region, but the open channels and composite canals have been some of the major sources of distribution of stormwater across different neighbourhoods of the cape flats region connecting to the major wetlands and open surface water sources.

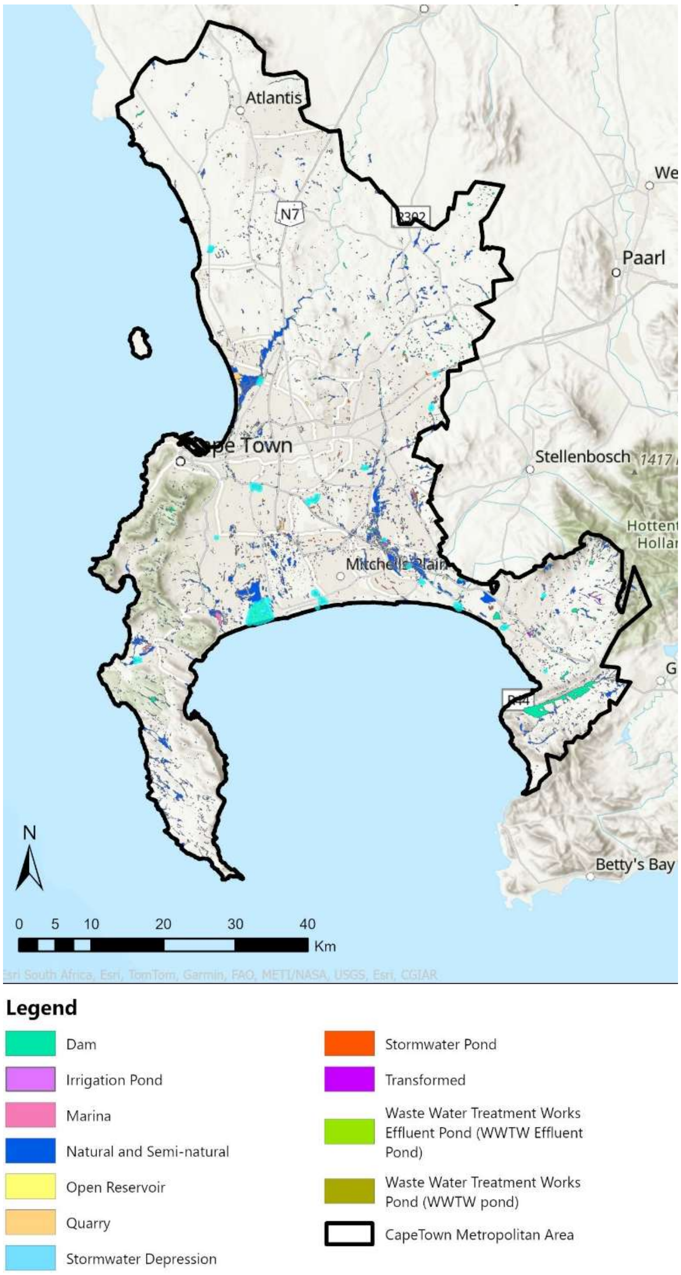


Figure 5.73: Stormwater Waterbodies across the Cape Town metropolitan (source: Adopted from Open data portal of Cape town city)

The Cape Flats Aquifer, one of three aquifers in the region, underlies most of the plain as a shallow unconfined sand aquifer that interacts strongly with surface wetlands and rivers (Adelana, Xu, & Vrbka, 2010; Mauck, 2017). High groundwater tables and low relief favour waterlogging and "groundwater flooding" in wet winters, while canalization, infilling of vleis and paving of natural drainage routes have reduced storage and infiltration capacity (Dube et al., 2021). Intensified urban and agricultural land use around rivers and vleis has increased pollution risks to both surface water and the aquifer, weakening the buffering role of wetlands during extreme events (Dube et al., 2021; Adelana & Xu, 2006). Together with remnant wetlands and coastal ecosystems, the aquifer provides key ecosystem services: water supply, flood attenuation, habitat support and potential cooling through green–blue infrastructure (Adelana et al., 2010; Mauck, 2017).

These same conditions shape climate-risk patterns. Flat topography, a high-water table and the loss or canalisation of wetlands on the Cape Flats heighten urban flood susceptibility, especially where dense, low-income settlements occupy former depressions (Dube, Nhamo, & Chikodzi, 2022). Reliance on distant mountain reservoirs left the city exposed during the 2015–2018 "Day Zero" drought, prompting conjunctive use of the aquifer as a buffer (Brühl et al., 2021). Shorter wet seasons with long intra-season dry spells support droughts like "Day Zero", when reservoirs and aquifers are not adequately replenished (Ndebele et al., 2022).

Intense winter storms over low-lying areas and former wetlands, combined with blocked or undersized drainage and the Cape Flats topography, promote ponding and rapid runoff concentration, driving recurrent flood losses (Dube, Nhamo, & Chikodzi, 2022). Overall, the modified wetland–aquifer system exposes the city to drought and groundwater-driven urban flooding, making protection and restoration of rivers, vleis and the Cape Flats Aquifer essential for managing extremes.

The mapped (*figure 5.71*) stormwater waterbodies show a dense mosaic of canals, lined channels, detention ponds, open reservoirs and natural or semi-natural wetlands across the Cape Town Metropolitan Area, with strong clustering on the Cape Flats and around Mitchells Plain. This pattern illustrates how engineered ponds and canals increasingly substitute for the original 'vleis' and streams but also reveals opportunities for multi-functional design. Empirical work on Cape Town's urban wetlands and detention ponds shows that they can substantially attenuate peak flows and, when designed for infiltration, support managed aquifer recharge of the Cape Flats Aquifer while still providing flood storage.

Land Use and Land Cover

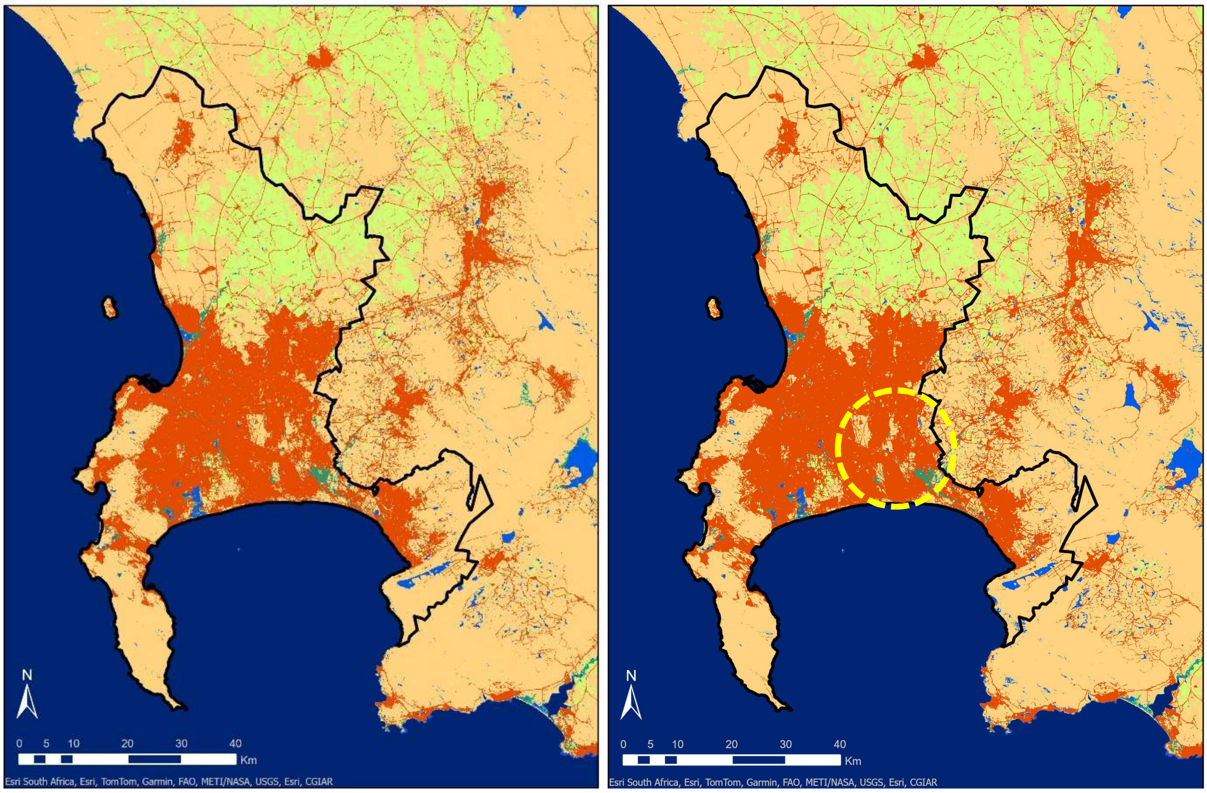


Figure 5.74: LULC of Cape Town since 2005(left) until 2020 (right).

Table 5.11: Details of LULC- General Class (areas in sq.Km)

Changes in the Land Cover Area over the years (sq.Km)					
Year	**Built Up or Urban Areas**	**Croplands**	**Open Dry Lands of Terra Firma**	**Wetlands**	**Open Surface Water**
2005	*1256*	*412*	*1683*	*38.3*	*35*
2020	*1347*	*463*	*1550*	*30*	*36*

Since 2005, the changes across the land use and land covers have not been major on the map views seen on the figure 5.72, however upon a closer look, the city has grown its urban areas adjacent to some of the wetlands and natural streams (marked encircled region on map). A decline in 8 km^2 and an increase in 111 km^2 of its Wetland area and Urban built area reflects upon the need of increased measures for interventions to channelize the urban development practices to ensure the ecosystem services are well maintained through its course. The loss of 51km^2 of cropland is another major concern as Cape Town, with decreasing precipitation levels, needs its urban farming lands well intact for ensuring both carbon footprints and as well as mitigating urban flooding scenarios.

5.3.b Urban Hazards, Risks and Vulnerabilities and Challenges

Flooding

Around 15% of Cape Town's population lives in informal settlements, and these communities are particularly exposed to flooding during the winter rains, especially on the Cape Flats – a flat, sandy, low-lying and poorly drained area where water tends to accumulate (PlanAdapt & CDKN, 2021). Urban flooding in the region reflects both a long-term increase in extreme rainfall and deep social inequalities. Regional records for 1900–2018 document 334 major flood events in the Western Cape, with a statistically significant rise in frequency over the past four decades and a peak of 20 events in 2008 (Dube et al., 2022).

Figure 5.75: Flooding in Malema informal settlements of Cape Town (source: Sandiso Phaliso, 2023)

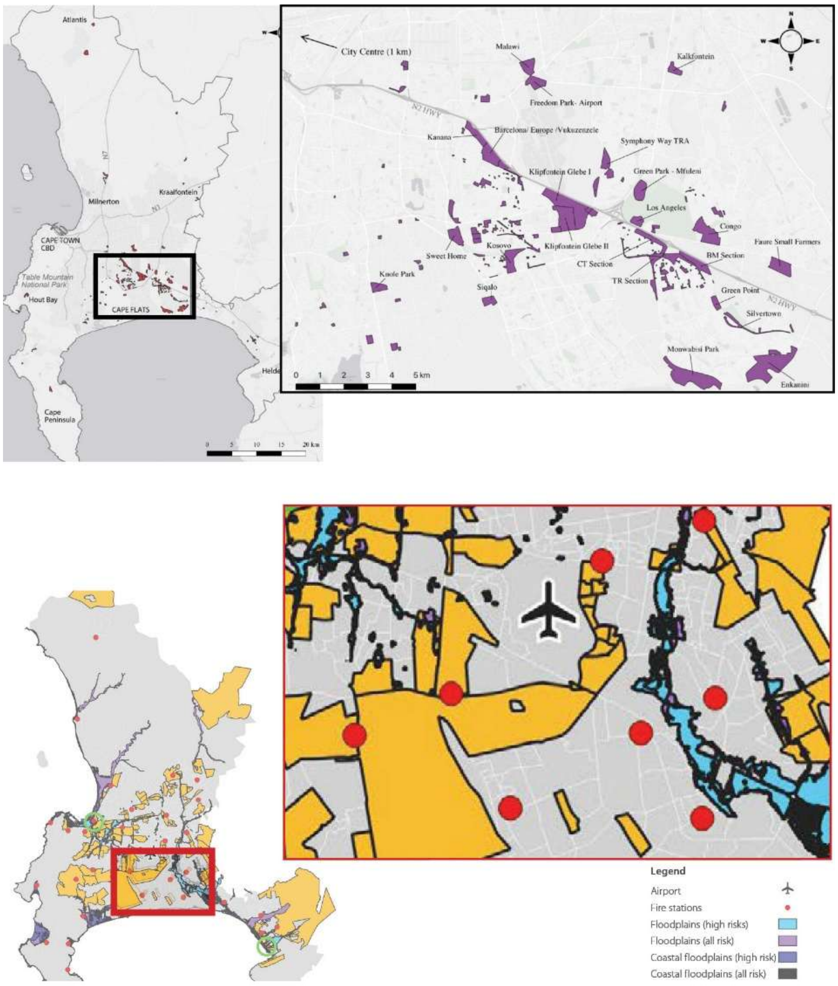


Figure 5.76: Climate related hazard exposed areas (below) and Informal settlements (above) {source: Lane-Visser & Vanderschuren, (2024);Cinnamon & Noth, (2023)}.

A key vulnerability driver is urbanization on unsuitable land: informal settlements and low-income neighborhoods often occupy wetlands, floodplains and other marginal spaces, leaving residents exposed to pluvial and groundwater flooding (*example can be seen in figure 5.73*) as well as coastal impacts such as sea-level rise and storm surge along the city's shoreline (PlanAdapt, 2021). An example of informal settlements can be seen on the figure 5.74. The neighborhood is also known as Khayelitsha.

Within the metropolitan area, the most affected zones are low-lying parts of the Cape Flats and high-density townships such as Khayelitsha, Mitchells Plain and informal settlements like Masiphumelele, where apartheid-era planning concentrated Black and colored communities on flood-prone sandy plains and wetlands (Enqvist & Ziervogel, 2019; OneWorld, 2019; PlanAdapt, 2021). Here, shallow groundwater, limited drainage infrastructure and intense winter storms combine to produce recurrent inundation, sometimes even in wider drought years (PlanAdapt & CDKN, 2021).

Floods frequently damage informal housing, disrupt transport networks and basic services, and expose residents to contaminated water, heightening disease risks and eroding already fragile livelihoods (Dube et al., 2022; Enqvist & Ziervogel, 2019). The PlanAdapt–CDKN study emphasizes that these urban floods are highly localized but socially differentiated: poorer, more exposed communities bear a disproportionate share of health impacts, asset losses and livelihood disruption. Overall, Cape Town's flood risk emerges from the interaction of climate variability, historical land-use decisions, infrastructure deficits and entrenched social inequality (PlanAdapt, 2021).

Drought and Heat Waves

The 2015–2018 multi-year drought in the Western Cape, when dam levels supplying Cape Town fell from about 92.5% to 23% and the city announced a looming "Day Zero" in 2018, forcing the municipal taps to be turned off and restricting residents to 25 L/person/day. This was the worst drought since the early 1900s, with 2017 recording the lowest rainfall since 1933, and human-driven climate change is estimated to have made such an event five to six times more likely. Theewaterskloof and Voëlvlei, the largest-capacity dams, reached the lowest levels, exposing the system's vulnerability to prolonged drought and high evaporation over large surface areas.

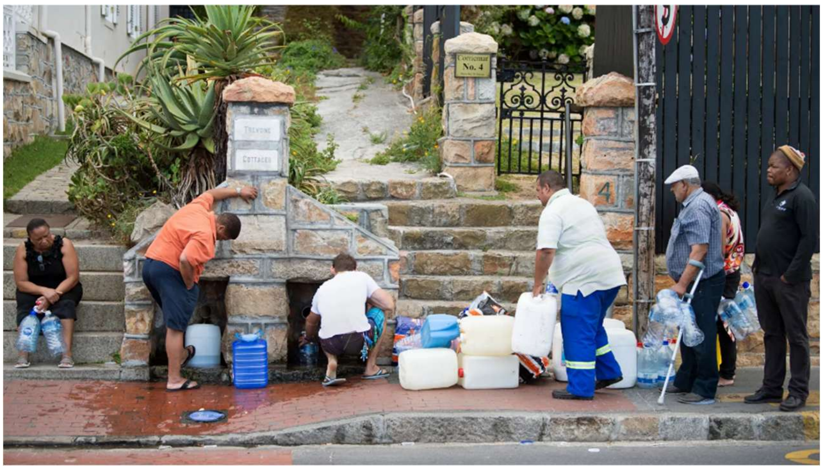


Figure 5.77: People collecting drinking water in 2018 drought (source: Samantha Raphelson)

Socially, risk is highly unequal: formal (mostly wealthier) households consume about two-thirds of the city's water, while informal settlements—where many low-income residents live and rely on communal taps—use only about 4%, with average consumption as low as 10–40 L/day for up to 15 residents per unit. During the crisis, the city implemented emergency measures: critical water-shortage disaster phases, household water quotas and management devices, pressure reduction, strict restrictions on outdoor use, hard caps for agriculture, temporary tariff hikes, and intensive communication campaigns (notably the Day Zero narrative and neighborhood water-use maps).

In longer-term, the 2019 Cape Town Water Strategy commits to secure, climate-resilient water through demand management, daily monitoring dashboards, smart metering, permanent efficiency regulations, and diversification of supply expanding desalination, groundwater abstraction, and treated wastewater reuse by 2040. Cape Town's crisis is framed within a broader trend of semi-arid Southern Africa warming faster than the global average (≈0.16 °C/decade nationally), with highly variable but generally declining rainfall in the Western Cape. Extreme droughts like Day Zero are projected to become more frequent under climate change, turning water scarcity into a recurring shock rather than a one-off anomaly. Therefore, the drought crisis is attributed to an interplay of physical stressors (low, variable rainfall; high evaporation; semi-arid climate), rising urban and agricultural demand, population growth, and governance weaknesses, including fragmented dam management, delayed national support, an inequitable tariff model, and deep socio-spatial inequality. (Calverley & Walther, 2022).

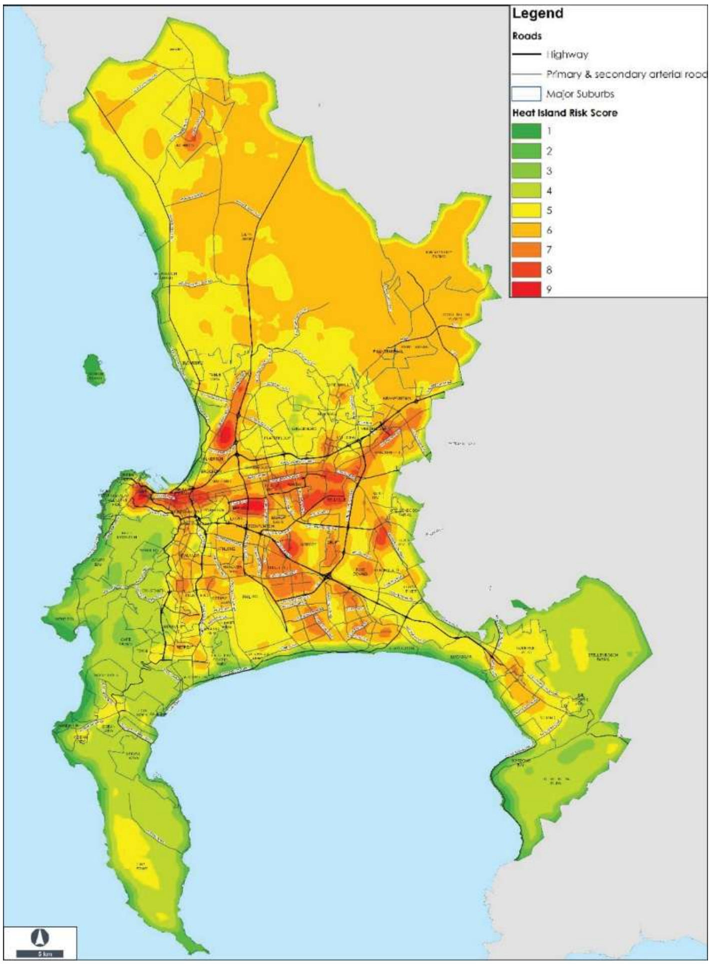


Figure 5.78: Urban Heat Island effects across the metropolitna area of Cape Town (source: Resilient City strategy, City of CapeTown Isixeko Sasekapa Stad Kaapstad)

Although Cape Town is cooler than many inland South African cities, extreme heat is intensifying under climate change.

- A heat–mortality study for Cape Town (2006–2010) found that increases in apparent temperature were associated with higher all-cause mortality, indicating that hot days already have measurable health impacts (Wichmann, 2017).
- Detailed mapping of urban heat islands (UHI) shows that dense, built-up parts of the city (especially the Cape Flats, industrial zones and parts of the CBD) can be several degrees warmer than surrounding rural or coastal areas, particularly at night (Beuster, 2019).
- A national assessment of extreme heat in South African cities identifies Cape Town as a hotspot where the frequency of very hot days is projected to increase, with vulnerable communities (informal settlements, low-income neighbourhoods) facing the greatest exposure. (Kadihasanoglu, 2022)

Cape Town's heatwaves are shaped by the interaction of urban heated islands and deep social inequality. Davison (2022) shows that the hottest zones are dense CBD and industrial areas, the airport corridor, and large informal settlements with few trees or green spaces, where dark surfaces and cramped tin structures trap heat (see fig. 5.76 for reference, red and orange colors could be seen in the main city center, while the regions adjacent to Table Bay, while the similar heat waves could be expected at the south above the False Bay). Impacts include increased heat stress and mortality, crowding and safety issues at already busy beaches, high demand on public health facilities, also homes in informal and older public housing areas are "not designed for heat": poor thermal envelopes and limited access to cooling devices make recovery from night-time heat particularly difficult (Davison, 2022).

Recent policy work notes rising numbers of high-heat days and has led to a Heat-Health Action Plan for the Western Cape, reflecting official concern about future heatwaves and their health implications. Overall Heatwaves in Cape Town are still less frequent than in interior cities but warming trends and the UHI effect are making short, intense hot spells more dangerous, especially for residents of dense, poorly serviced townships.

Storm surge and Coastal Erosions

Cape Town's 307 km coastline (Atlantic + False Bay) is increasingly affected by sea-level rise, storm surges and erosion:

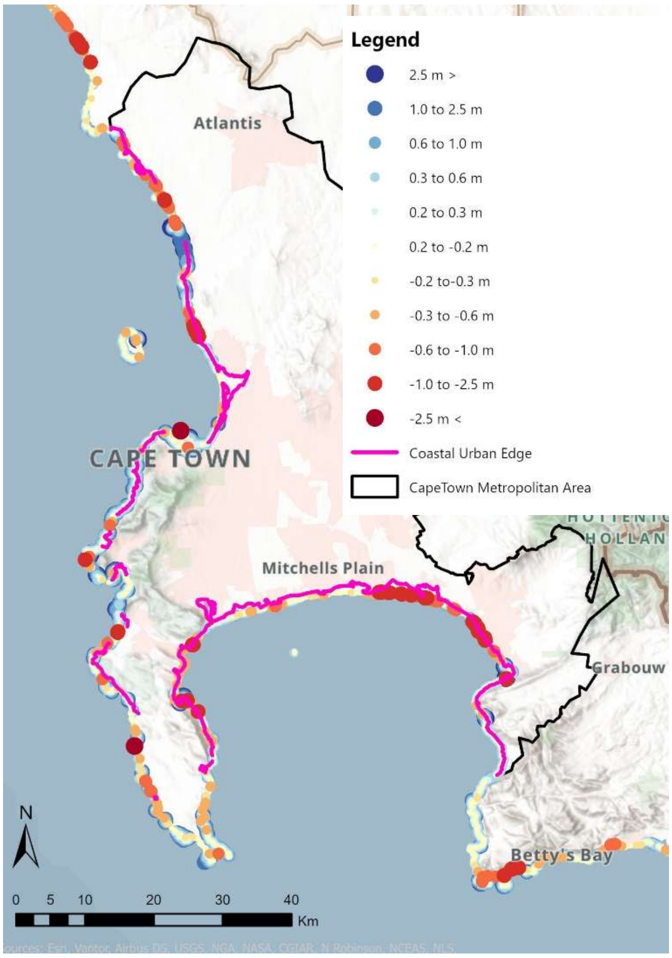


Figure 5.79: Coastal region hotspots across the Cape Town Coastal periphery (source: Author, adopted from Africa Geoportal by ESRI, and Cape Town City open data portal)

Figure 5.80: Monwabisi Beach post coastal erosion events{source: Fourie et al. (2015)}

- A study of sea-level rise and coastal tourism finds that around 80% of Cape Town's 2019/2020 Blue Flag beaches are threatened by rising sea levels and associated coastal erosion, including popular sites along False Bay and the Atlantic seaboard. (Dube et al., 2020)
- Long-term synthesis work for False Bay reports that increasing sea level and exposure to storm surges are already eroding sandy shorelines, damaging coastal infrastructure and raising risks for coastal communities and ecosystems. (Pfaff et al., 2019).
- Recent remote-sensing analyses of Cape Town's beaches show measurable shoreline retreat and sediment redistribution, with storms and higher water levels driving episodic but significant erosion; these impacts are projected to worsen as storms and sea level intensify under climate change. (Fanikiso, 2022; Stockholm Environmental Institute, 2008)

The figure__ highlights some of the key coastal hotspot locations across the coastal stretch of the Cape Town city

Cape Town's coastal risk is dominated by the interaction of gradual sea-level rise with episodic extreme waves and surges, particularly along exposed sandy beaches and low-lying waterfront infrastructure (coastal roads, rail, tourism nodes).

Evolving Risks and Vulnerabilities

The future of Cape Town as per the OneWorld's report has been projected to be drier and significantly warmer, with first-order climate shifts cascading through biophysical, social and economic systems. The five priority climate hazards are drought, fire, heatwaves, floods and strong winds, all projected to become more frequent and/or intense. Drought heavily threatens the Western Cape Water Supply

System, with knock-on impacts for the economy, ecosystems and household wellbeing. Fire risk rises with hotter, drier conditions, threatening human life, property and conservation areas. Intensifying heatwaves affect health and productivity, while floods and strong winds become particularly dangerous where buildings and services are structurally weak.

As per the OneWorld, Cape Town's Spatial and socio-economic vulnerabilities identified through risk hotspot mapping, shows that, over time, exposure and vulnerability concentrate along the municipal periphery, especially in the northern parts of the metro. By contrast, the southern peninsula, southern coast, Table Mountain area and parts of the west coast are comparatively less vulnerable. Areas at greatest risk are those with limited access to basic services and very low financial buffers to absorb shocks. A capital–risk scatter analysis highlights that the most climate-vulnerable districts—Tygerberg, the Cape Flats and the Mitchells Plain/Khayelitsha planning area—combine high population densities with low economic capital, making residents especially exposed to climate hazards and with few resources to recover.

Systemic risks and cross-cutting vulnerabilities across Cape Town, has been stressed that climate risks manifest through multiple pathways that simultaneously affect people, the built environment, local economies and ecosystems. Livelihoods, poverty and inequality, informal settlement patterns, and existing disaster risk all interlink to deepen vulnerability: climate hazards hit hardest where economic capital (financial, human, social, environmental) is weakest and densities highest. Economic risk analysis therefore calls for integrated and cross-cutting investments in both low- and high-capital areas, since damage to critical economic nodes can ripple through the wider city, while neglecting poorer areas locks in chronic vulnerability and escalating climate risk.

5.3.c Notable Strategies | Liveable Urban Waterways, Green Infrastructure Programme - Philippi Horticultural Area

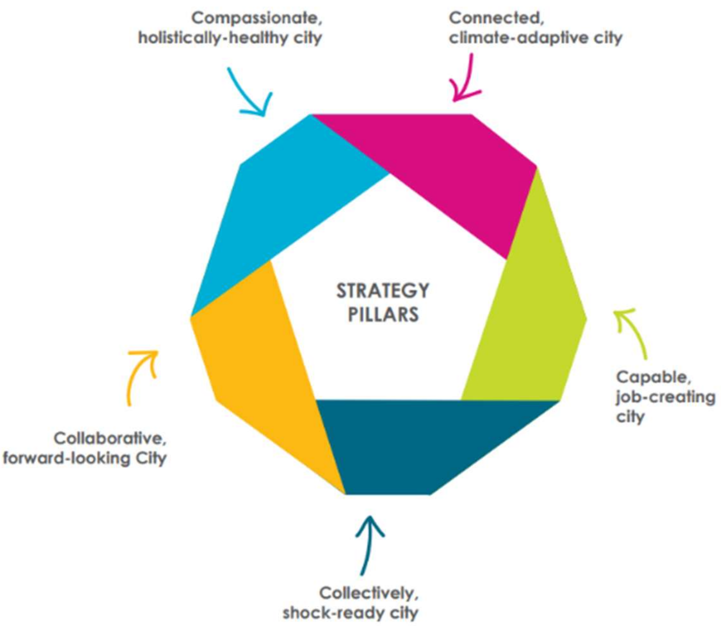


Figure 5.81: Resilient Cape Town Strategy Pillars

Cape Town's Resilient City Strategy (2019) and Climate Change Strategy (2021) identify multiple observed and projected climate hazards: declining and more variable rainfall, more very hot and heatwave days, stronger winds, sea-level rise and increased coastal erosion. These hazards translate into key risks, including severe drought and water shortages, flooding of vulnerable settlements and infrastructure, heat stress, storm and wind damage, coastal inundation and erosion, and increased wildfire risk in both fynbos and dense informal settlements.

The Resilience Strategy organises action under five pillars (*see Figure 5.72*): a compassionate, holistically healthy city; a connected, climate-adaptive city; a capable, job-creating city; a collectively shock-ready city; and a collaborative, forward-looking city. These pillars translate Day Zero lessons into DRR priorities such as securing water systems, managing fire and flood risks, and reducing social vulnerability, especially in informal settlements, through extensive engagement with over 11 000 residents and community experts.

EbA-type interventions include protecting water sources via the Greater Cape Town Water Fund through clearing alien invasive vegetation in catchments, restoring flows and reducing wildfire risk; managed aquifer recharge using treated effluent and stormwater detention ponds; and creating coastal management forums to jointly manage coastal hazards. The strategy also requires a "resilience lens" in new district plans, integrating environmental frameworks and shock-and-stress mapping key for DRR-oriented spatial planning.

The Mayoral Urban Regeneration Programme co-creates Community Action Plans and public-space upgrades that simultaneously improve safety, social cohesion and reduce flood/heat risks; informal settlement initiatives co-produce data with NGOs and residents, use GIS visualisation, and move projects towards co-design and co-ownership; and DRM's fire-risk initiative in informal settlements works with sub-councils, NGOs/CBOs and households to implement guidelines, strengthen prevention, and enable "build back better" support. Additional DRR actions include developing a portfolio of flood-prevention capital projects, innovative fire-risk solutions and build-back-better protocols, as well as education, early warning and disaster-risk management actions explicitly aligned with the Sendai Framework and SDGs.

Cape Town - Climate change Adaptation Plan and Strategy

The *Climate Change Strategy* frames climate response around resilience, economic inclusiveness and "embedded sustainability," explicitly committing to retain, restore and expand ecosystem functioning and green infrastructure for adaptation and carbon sequestration, an explicit EbA orientation. Strategic Focus Areas (SFAs) from 1–5, are its key adaptation-focused (urban cooling, water security, coastal and flood risk, etc.), with SFA1 combining urban greening and disaster-management protocols for heatwaves, and SFA2 linking drought-readiness to diversified supplies and demand management.

The *Climate Change Action Plan* operationalises this strategy as an implementation roadmap aligned with C40's Deadline 2020, aiming at carbon neutrality and climate resilience while prioritising climate justice for vulnerable communities, central to CbA and DRR. It organises actions into SFAs (e.g., SFA2 water security) and cross-cutting work areas such as mainstreaming, governance, research and knowledge management, including Goal 26 on integrating climate risk into all sector plans and strategies and using a climate hazard, vulnerability and risk assessment as the DRR evidence base.

The City's Water Strategy (2019) reframes water as far more than a supply-and-demand problem: urban water systems are recognized as central to city identity, neighborhood amenity, ecosystem services, property values and community health and liveability. In this context, Cape Town transitioning towards a *water-sensitive city by 2040*, integrating the full urban water cycle to enhance resilience and protect sensitive ecosystems, while optimizing stormwater and urban waterways for flood management, aquifer recharge, water reuse, conservation and recreation.

Liveable Urban Waterways- Diep/Sand- and Zeekoe catchments.

The Liveable Urban Waterways (LUW) Programme is a strategic, cross-departmental initiative of the City of Cape Town that aims to rehabilitate degraded rivers, canals and wetlands using water-sensitive design, nature-based solutions and green infrastructure. It sits under the City's Environmental Strategy and Water Strategy commitment to become a water-sensitive city by 2040, and treats waterways as critical green infrastructure, not just drainage channels. The "liveable" waterway has been defined (as one that:

- has acceptable water quality,
- makes space for water (flood capacity),
- has a functioning ecology,
- is connected to the water table and floodplain,
- connects communities and is used and enjoyed, and
- provides a range of ecosystems, economic and social benefits.

On the ground, the programme focuses on **rehabilitation and public-space upgrades** along priority river corridors and canals. Typical interventions include removing concrete canal linings, creating wetlands and retention ponds, reshaping and naturalizing riverbanks, installing litter traps, planting indigenous vegetation and trees, extending or upgrading footpaths and park areas, and adding community gardens and outdoor learning spaces. Pilot projects are concentrated in the *Sand River catchment* (Westlake, Grootboschkloof, Spaanschemat, Prinskasteel, Sand & Langevlei Canal, Keyser River), with support from partners like C40 Cities Finance Facility to scale similar nature-based solutions to the *Diep/Sand and Zeekoe catchments* and to build a city-wide GI/NbS masterplan.

The LUW Programme principles include collaboration and partnering, seeing waterways as connectors and catalysts, designing with nature and for many uses, building resilience, creating attractive public places, ensuring post-project maintenance, and adopting catchment-scale systems thinking.

Progress is tracked through strategic KPIs: number of waterways reaches made "liveable," share of residents using a waterway in the past year, satisfaction with their nearest waterway, and the number of catchments with developed LUW project pipelines. There are also output metrics (hectares of rehabilitated wetlands/riparian zones, metres of restored channels and pathways, trees planted, co-design workshops, community members engaged, jobs created). While the original intent was to roll out multiple projects in the 2020s, budget cuts have delayed many implementations into the 2030s, which is why civil society campaigns are now pushing for *full funding to meet the city's 2040 water-sensitive city goal.*

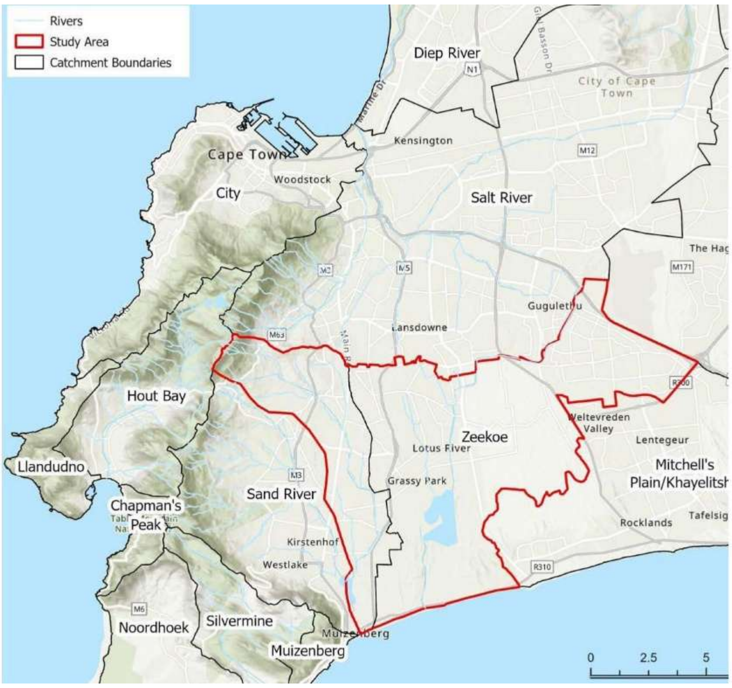


Figure 5.82: Location map of Diep/Sand and Zeekoe Catchment area. (source: IISD, 2025)

In the **Diep/Sand system**, the Diep River Alphen greenbelt (upper Sand catchment) is a key LUW site. Here, river and wetland rehabilitation has involved flood-detention ponds, removal of invasive alien vegetation, construction of gabion weirs, reshaping eroded banks, and re-establishing indigenous riparian vegetation, while maintaining a heavily used greenbelt trail network. hese measures reduce downstream flood peaks and erosion while restoring more natural hydromorphology—an approach consistent with ecosystem-based adaptation (EbA) and South African water-sensitive urban design (WSUD) guidelines (Armitage et al., 2014).

Downstream in the Sand catchment, the Zandvlei Estuary Nature Reserve combines estuarine habitat protection, pollution-reduction programmes and community co-management via bodies such as the Zandvlei Trust, aligning ecological restoration with recreational access and estuarine flood-management functions (Climate Change Strategy, 2022; Brown & Magoba, 2009). A broader "Source to Sea" pilot in this catchment targets the Diep and Prinskasteel–Keyser River corridors to restore riparian habitats, create mobility and recreation routes, and generate jobs, explicitly linking LUW interventions to climate resilience and social cohesion (IISD, 2025).

In the **Zeekoe catchment**, Edith Stephens Nature Reserve illustrates how LUW combines EbA and community-based adaptation (CbA). The project links a stormwater detention pond on the Lotus River with a large seasonal wetland and endangered Cape Flats vegetation, adding boardwalks, bird hides, an amphitheatre, environmental education centre, medicinal and biodiversity gardens, and an urban-agriculture area co-designed with surrounding communities. These interventions enhance flood attenuation, groundwater recharge, biodiversity conservation and local livelihoods, while EPWP-based invasive-species clearing and veld restoration demonstrate how GI investments can support employment and stewardship in low-income neighbourhoods (Liveable Urban Waterway, 2022; Brown & Magoba, 2009). Other LUW rehabilitation and public-space upgrades, such as Khayelitsha Wetland Park's regional park with wetland restoration, boardwalks, play spaces and a community-run canoe club further show how re-naturalised wetlands and river corridors can simultaneously manage flood risk, improve water quality, provide recreation, and strengthen local ownership (IISD, 2025). Together, these Diep/Sand and Zeekoe catchment projects exemplify how Cape Town is operationalising EbA and CbA principles through concrete on-the-ground WSUD practices.

Combined area of interventions across Diep/Sand subcatchment and Zeekoe Catchments involve 27 hectares of wetland rehabilitation/ creation and 10.7 kms of river/canal rehabilitations. See figure 5.81 for key interventions planned for both locations, and both plans prioritize vibrant, people-centric spaces will integrate,

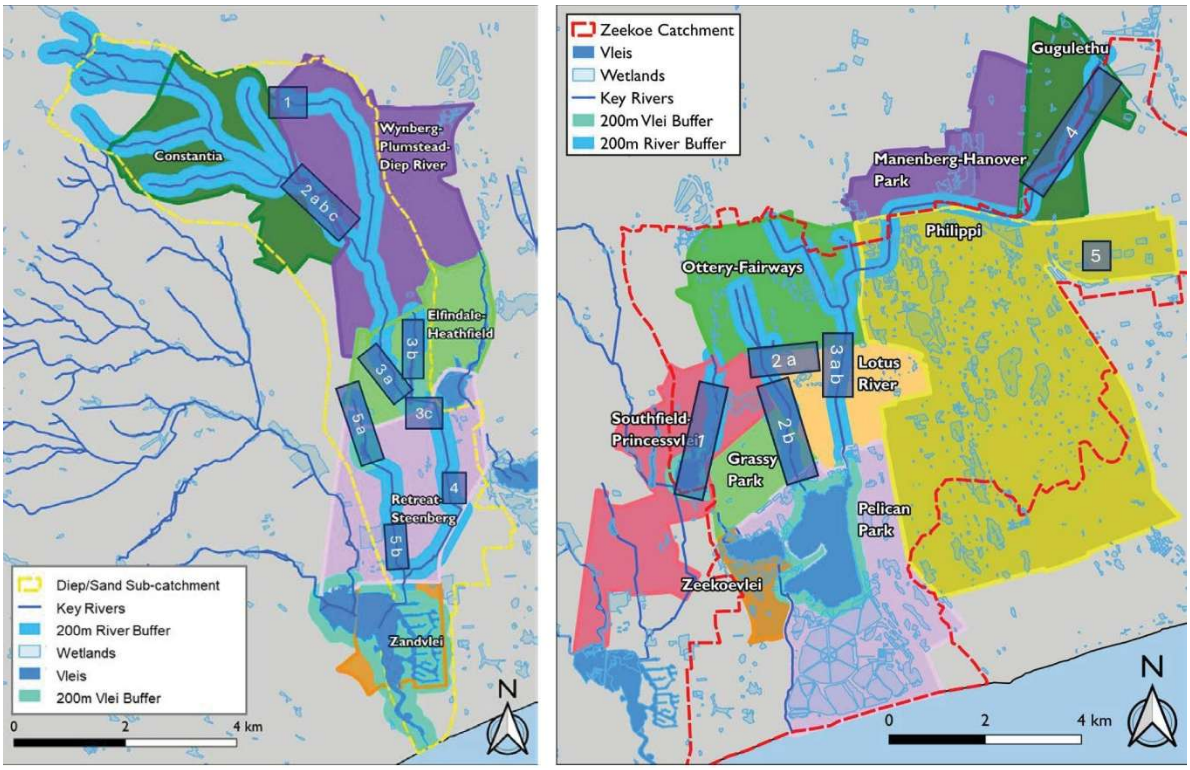


Figure 5.83: Intervention Maps of the Diep/Sand and Zeekoe Catchment area. (source: IISD, 2025, City of Cape Town)

- Pedestrian pathways, learning hubs, and recreational zones enhanced by tree planting and landscaping.
- Community initiatives: food gardens, public parks, and educational programs.
- Infrastructure upgrades to boost safety and accessibility for 19,200 nearby households—benefits reaching far beyond.

Following figure 5.82, shows a causal loop diagram (CLD) interacting dynamics between water quality, soil and nutrient status, riverine ecology, socio-economic conditions, climate extremes, and interventions in the two catchments (IISD, 2025). Balancing loops emerge where catchment restoration, green open space, and vegetation management improve soil structure, water retention, and ecosystem health, thereby reducing flood risk, heat-island effects, and health impacts. The CLD thus clarifies where NBI and improved services can shift the system toward resilience.

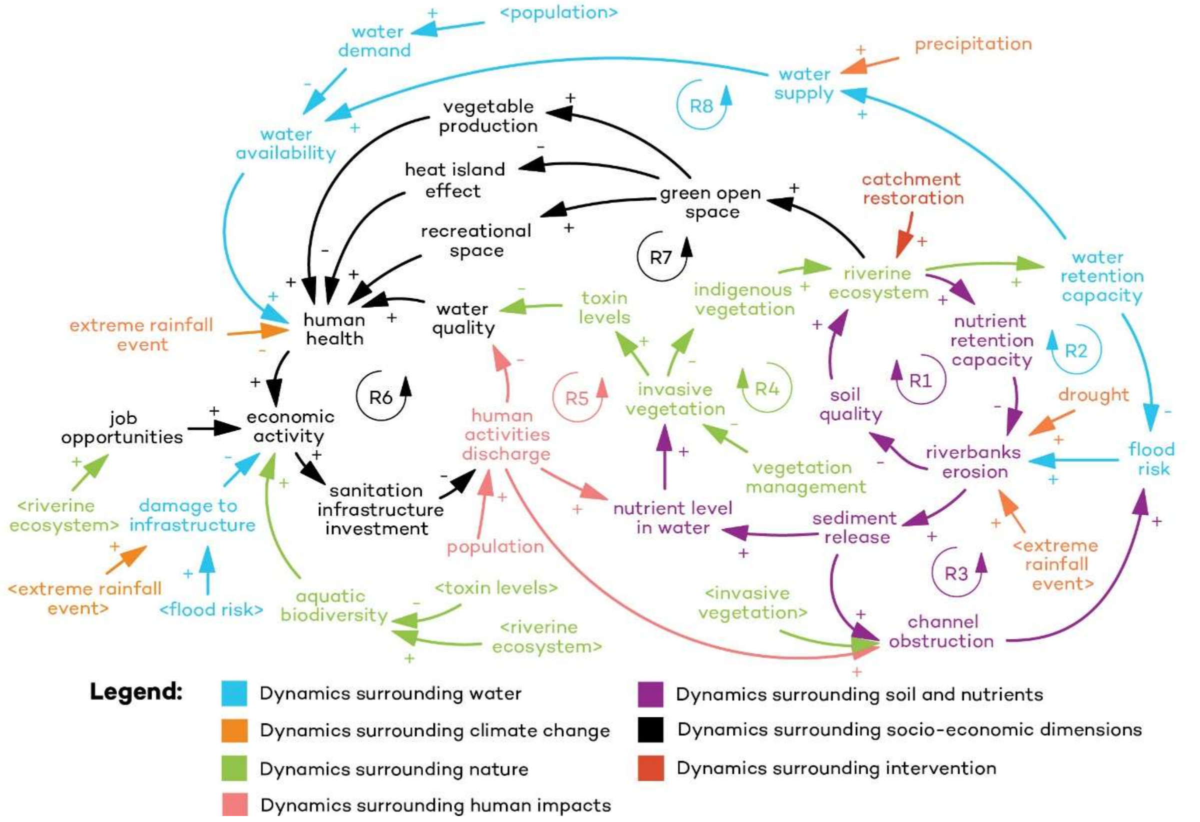


Figure 5.84: A Casual loop diagram from the Water Rehabilitation SAVi assessment, sourced from IISD, 2025.

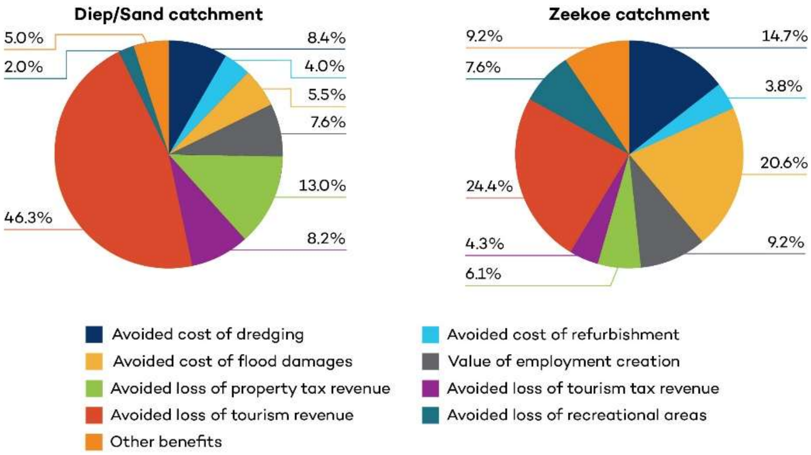
Under the SAVi (Sustainable Asset Valuation) assessment, NBI/BGI interventions in the Diep/Sand and Zeekoe catchments are evaluated across Shared Socioeconomic Pathways (SSPs), especially SSP2-4.5 ("middle of the road") and SSP3-7.0 ("regional rivalry") (IISD, 2025). The results could be understood from the following table

Table 5.12: Table of SSPs with Benefits and Costs values in ZAR across the intervention zones.

SSPs	Intervention zone	Project costs (ZAR million)	Total benefits (ZAR million)	Benefit–cost ratio (BCR)	Avoided flood damages (ZAR million)
SSP2-4.50 (middle of the road)	*Diep/Sand*	124	245	≈ 1.97	13.4
	Zeekoe	122	190	≈ 1.56	39.2
SSP 3-7. (regional rivalry)	*Diep/Sand*	124	≈ 256.7	≈ 2.07	24.3
	Zeekoe	122	≈ 246.4	≈ 2.02	89.6

- *SSP2-4.5 ("middle of the road")*
This pathway assumes moderate population and economic growth, partial progress on sustainability, and gradual improvements in institutions and technology. Emissions peak and then decline, leading to a medium level of climate change. Risks (e.g., flooding) increase compared to today but are not as extreme as in high-emission futures.

- *SSP3-7.0 ("regional rivalry")*
This is a pessimistic, high-risk world with weak international cooperation, high population growth in some regions, slower economic development, and limited investment in sustainability and adaptation. Emissions remain high, leading to stronger warming and more frequent and severe extremes, such as damaging floods—so the avoided damages from NBI/BGI in your SAVi results become even larger.



The image on the left can be understood how the interventions planned will project a different share of economic costs and benefits at both catchment areas.

Figure 5.85: The distribution of benefits projected at discounted 8% for optimistic climate scenarios by IISS (2025)

The following figure 5.84 shows the best possible understanding of the range of damage in ZAR value, reflected by each scenario of interventions or not across the catchment sites by all the different SSPs as per IISD, 2025 for the Liveable Urban Waterways programme.

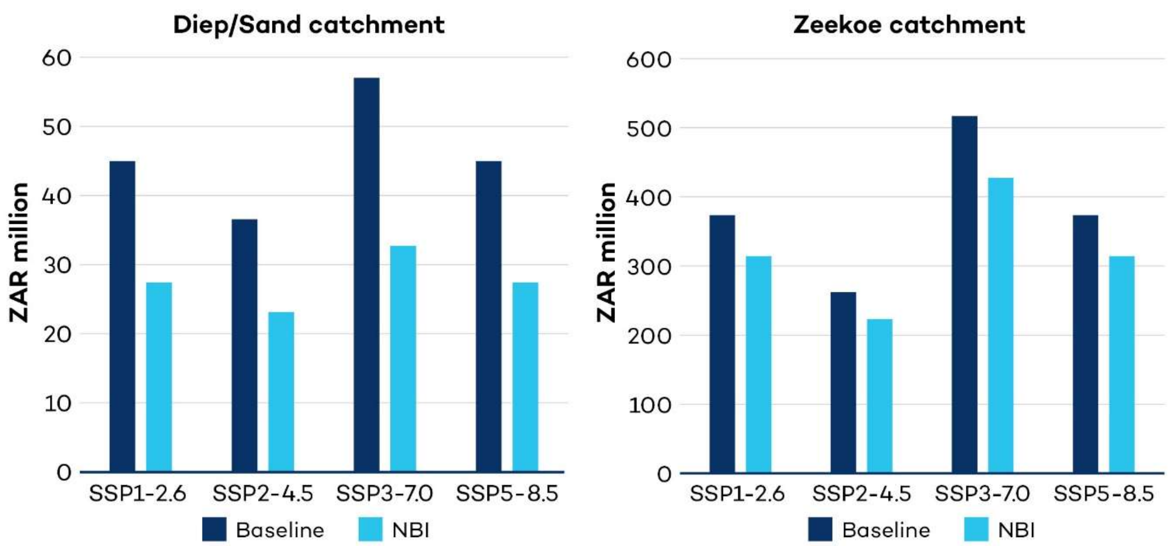


Figure 5.86: Flood damage across climate scenarios - discounted at 8% (sourced from IISD, 2025)

This shows that as climate risks worsen, the relative value of NBI/BGI investments increases.

Under the Liveable Urban waterways project, with a few projects already delivered and ongoing across multiple canals and wetlands, the following table highlights key measures undertaken under the similar strategies. (*see figure 5. 85 for reference)*

Table 5.13: LUW interventions across different locations in Cape Town. (source: Adoped from the City of Cape Town, LUW programme)

LUW project / waterway	Catchment & location	Key interventions (EbA / NbS, WSUD)	Public-space & social highlights	Key insights for DRR / resilience
Heerengracht Street canals & fountain	CBD	Repurposing historic canals and fountain; supplying them with a sustainable non-potable source; potential reuse of water for nearby irrigation.	Precinct upgrade and creation of an attractive civic space along Heerengracht.	Demonstrates how central-city water features can be shifted from purely aesthetic to functional blue-green infrastructure that supports water reuse and urban cooling.
Asanda Village Wetland Park	Soet catchment, Strand	Wetland rehabilitation; upgraded stormwater system to handle upstream flows; formalised non-motorised route; hard/soft landscaping and multi-use play areas.	New neighbourhood park linking schools and housing; outdoor educational areas; 19 construction jobs and ~200 long-term maintenance jobs.	Completed flagship that shows how flood attenuation, wetland ecology and safe recreation can be combined in a low-income area; strong model for CbA-oriented public-space upgrading.
Sand & Langevlei Canals (Coniston Park)	Sand catchment, upstream of Zandvlei	Removal of concrete canal base/walls; creation of treatment and polishing wetlands; stilling basin; new litter traps; bank naturalisation; indigenous planting and biodiversity area.	New footpaths, seating, lighting, signage and improved interfaces with future school, nature-reserve entrance and market.	First large-scale canal "de-hardening" in Cape Town; critical to improving Zandvlei water quality and reducing flood levels while creating a high-quality green corridor.
Keyser River	Sand catchment (Tokai–Blue Route Mall)	Rehabilitation of two reaches; new wetlands and instream habitat; repair of erosion; sediment and invasive removal; bank naturalisation; indigenous planting.	Pocket parks for local businesses and hospital; improved paths, lighting, signage and new footbridge.	"Must-do" project to meet statutory resource-quality objectives and support Zandvlei recovery; improves flood capacity and reduces maintenance costs over time.
Westlake River & Kirstenhof Wetlands	Sand catchment (Westlake Village & Kirstenhof)	Reconnecting river to wetlands; new wetland/instream habitat; erosion repair; invasive clearing; bank naturalisation; indigenous planting.	Upgraded paths, lighting and signage; outdoor classroom for Westlake Primary; access to Steenberg Village and future sports facilities.	Provides long-neglected township with quality green space and safer routes; reduces local flooding and supports endangered species (e.g. Western Leopard Toad) while building social cohesion.
Spaanschemat River (incl. Prinskasteel confluence)	Sand catchment (Constantia–Tokai)	Three reaches rehabilitated; new wetlands/instream habitat; bank naturalisation; erosion repair; invasive clearing; formalised parking; low-level crossings; indigenous planting.	Enhanced park-like river corridor at key road crossings and local nodes.	Part of an integrated package needed to meet downstream Keyser & Zandvlei targets; slows flows, improves water quality and enhances peri-urban recreation.
Grootboschkloof River	Sand catchment (Nova Constantia to Spaanschemat confluence)	New wetlands and instream habitat; bank naturalisation; erosion repair; invasive and sediment removal; indigenous planting; new low-level crossing.	Improved paths, seating, lighting and signage along the river corridor.	Strengthens headwater ecological condition, buffering floods and sediment delivery to Keyser River and Zandvlei; contributes to cumulative Sand-catchment benefit and property value uplift.
Vygekraal River corridor	Salt catchment, Athlone	Corridor rehabilitation between Jakes Gerwel Dr and Athlone WWTW; new wetlands and instream habitat; bank naturalisation; erosion repair; invasive and sediment removal; indigenous planting.	Footpaths, seating, lighting, signage and bridge upgrades through Nantes Park; better integration with surrounding urban fabric.	Early-stage (concept) project in a highly urbanised catchment; aims to cut flood risk, improve water quality and provide safer green space in a dense, historically marginalised community.

Cape Town's Water Strategy positions the city on a long-term trajectory toward a "water-sensitive city" by 2040, built on five core commitments: safe access to water and sanitation, wise use of water, sufficient and reliable supply from diverse sources, shared regional benefits, and transforming the city into a water-sensitive urban system. These commitments are operationalised through demand management, diversification of supply (groundwater, reuse, desalination, and surface water augmentation), and scenario-based planning to manage deep climate and demand uncertainty. Within this framework, the Liveable Urban Waterways (LUW) programme is a key implementation vehicle for Commitment 5, using nature-based and community-based approaches—such as biofilters, canal rehabilitation, and community-managed green–blue corridors—to cool the city, improve water quality, and reduce flood risk while building social cohesion. By aligning LUW with the broader climate governance architecture set out in the Climate Change Action Plan and Resilience Strategy, Cape Town links ecosystem-based adaptation, risk reduction, and inclusive service delivery, framing water not only as an infrastructure asset but as a social-ecological backbone for a more equitable, climate-resilient metropolitan future.

A number of waterway rehabilitation projects are planned, for example the naturalisation of the canal at the Roscommon Road wetlands.

A bird's-eye-view looking downstream over the Silvermine wetlands, with the boardwalk in the foreground and False Bay in the distance.

The Westlake river flows into Zandvlei and then out to sea at Muizenburg.

Figure 5.87: Aerial view of the key wetland and canal redevelopment/ restoration projects across the Cape Town under the Liveable Urban Waterways Programme (source: City of Cape Town)

Green Infrastructure Programme (GIP)

Cape Town's Green Infrastructure Programme (GIP) is a city-wide initiative to treat nature as critical urban infrastructure rather than "left-over green space". It defines green infrastructure as a strategically planned, designed and managed network of natural open spaces and engineered ecological systems that provide ecological, social and infrastructural. The programme's overarching aim is to protect and enhance existing natural assets, while creating new green infrastructure (GI) to support long-term urban sustainability, improve liveability, and build resilience to climate change impacts such as flooding, heat and coastal erosion (City of Cape Town Environmental Management Department, 2022).

A core component is the Green Infrastructure Network (GINet), mapped as a layer in the CityMap Viewer. This network identifies natural assets and open spaces larger than ~1 ha, in both public and private ownership, and evaluates them based on the ecosystem services they provide.

Each space is scored through nine general and 23 ecosystem-service questions grouped under three themes:

- infrastructural services (e.g. flood attenuation, stormwater management, coastal protection),
- ecological services (habitat, biodiversity and connectivity), and
- socio-cultural services (recreation, education, sense of place) (City of Cape Town Environmental Management Department, 2022).

The resulting GI value and "potential to improve" flags are used to guide land-use decisions, development applications and rehabilitation priorities.

Another major arm of the GIP is a set of Best Practice Guidelines, such as the *Urban Watercourses* guide, which translate GI principles into practical standards for planning, design and maintenance along rivers, canals and wetlands. These guidelines promote buffers, permeable surfaces, indigenous planting, invasive species control and community stewardship, ensuring that watercourses function as multi-benefit green corridors delivering flood mitigation, water quality improvement, cooling and public amenity (City of Cape Town). Collectively, the programme seeks to weave a connected GI network through the urban fabric that supports both ecological processes and human wellbeing.

Liesbeek River rehabilitation and community stewardship

The Liesbeek River illustrates how the GIP is implemented on the ground. In its upper reaches, riverbanks have been stabilized using gabion baskets combined with indigenous riparian vegetation, rather than purely hard concrete linings. This planting improves habitat quality, binds soil, filters pollutants, traps sediment and provides a cooling, shaded corridor along the river (City of Cape Town; *Communitree - Liesbeek River Corridor*). The *Urban Watercourses* guidelines use these sections as examples of ecologically preferred stabilization, showing how "green engineering" can still safely convey storm flows while delivering multiple ecosystem services.

Further downstream, civil society groups and "Friends of" organizations work with the city to clean litter, re-vegetate canal edges and activate public spaces along the canalized sections of the Liesbeek. The guide highlights such partnerships as models of how local stewardship, regular clean-ups and co-designed improvements can transform degraded canals into valued community assets that support recreation, biodiversity and neighborhood identity (City of Cape Town; (*Communitree - Liesbeek River Corridor*). This combination of technical GI interventions and social mobilization reflects the GIP's emphasis on co-managed, multifunctional corridors.

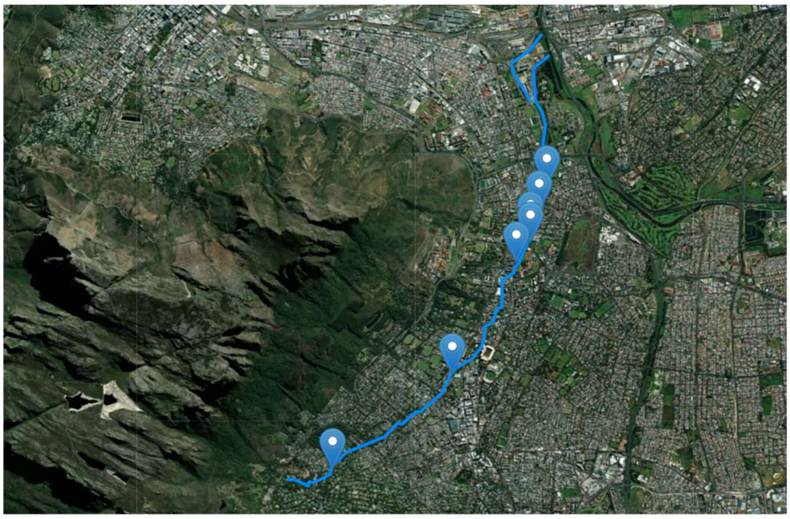


Figure 5.88: Liesbeek River Corridor (source: Communitree - Liesbeek River Corridor)

Permeable walkways, buffers and park-based GI along urban watercourses

Another set of on-the-ground practices showcased in the *Urban Watercourses* guidelines are permeable walkways and landscaped buffers along rivers and in flagship public spaces. An example is a pervious pedestrian path along the Lourens River, where a planted river edge, permeable surfacing and visually open palisade fencing together reduces runoff, limit erosion and maintain views and access to the watercourse (City of Cape Town, n.d.). The guide also references urban parks such as Green Point Urban Park as typologies that integrate wetlands, swales, detention areas and indigenous planting to manage stormwater while providing high recreational and educational value.

These projects demonstrate typical GI design moves promoted by the GIP: keeping hard surfaces outside the 1:100-year flood line, using vegetated swales and filter strips to dissipate runoff energy, maintaining or restoring natural buffers, and planting locally indigenous species adapted to floodplain conditions. Such interventions deliver everyday benefits (cooler microclimates, attractive walking routes, habitat) while quietly performing critical infrastructure functions for flood risk reduction and water quality improvement (City of Cape Town)

Philippi Horticultural Area and regeneration strategy

The Philippi Horticultural Area (PHA) is a key green landscape on the Cape Flats and sits squarely within the logic of Cape Town's Green Infrastructure Programme, even if it is discussed mainly through heritage and economic-strategy documents. The City's heritage brochure describes Philippi as one of the last remaining agricultural and natural landscapes within the metropolitan area, comprising the horticultural farmland, surrounding sand dunes and a wetlands ecological/green corridor (Edith Stephens Nature Park) that links rural and urban domains (City of Cape Town, 2007). This mosaic of high-value soils, shallow groundwater, wetlands and long-established farming forms a distinctive cultural landscape with significant ecological, hydrological and food-system functions.

From a GI perspective, the PHA provides multiple ecosystem services: provisioning (fresh produce, employment), regulating (infiltration and recharge of the Cape Flats aquifer, local cooling, flood storage in wetlands), and cultural/heritage values as a productive agricultural landscape embedded within the city. The Philippi Opportunity Area Economic Strategy treats the PHA as a strategic asset adjacent to a major transit-oriented development precinct. It proposes targeted interventions such as support for small-scale farmers to obtain LocalGAP/ GlobalGAP certification, investments in cold-chain and logistics infrastructure, and a transition towards regenerative agriculture to protect soil and water health (Pegasys, 2021). These measures are aimed at strengthening the commercial viability and sustainability of horticulture rather than replacing it with urban development.

Figure 5.89: Phillipi farm practice (Lindow, M. (2016)

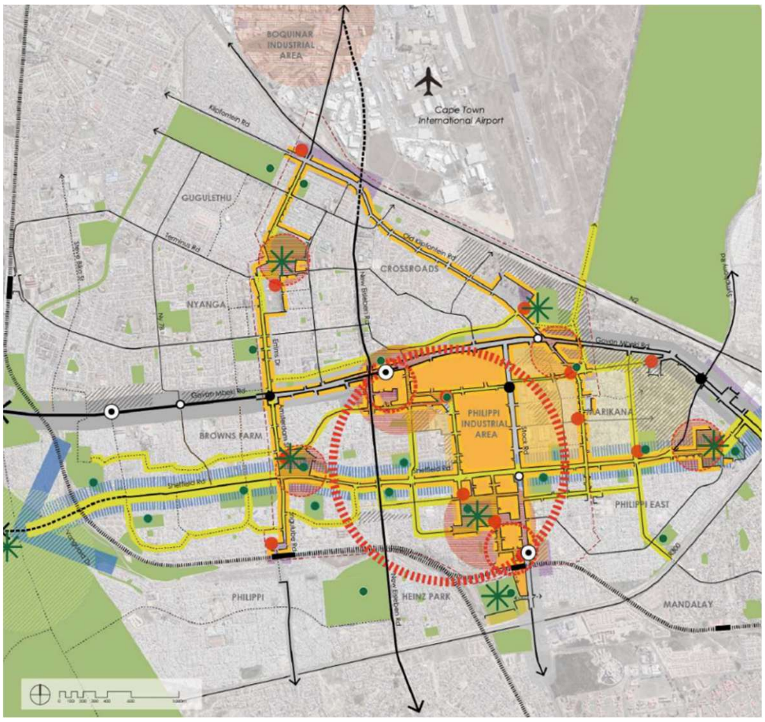


Figure 5.90: Phillipi Regeneration Strategy Plan (source: [Phillipi Opportunity Area Regeneration Strategy, 2020]())

Although the Philippi Horticultural Area (PHA) is not explicitly named in the Green Infrastructure Network overview, the Philippi Opportunity Area Regeneration Strategy identifies it as a high-order green asset and “Cape Town’s food basket and economic generator” and a vital “green lung” for the Metro Southeast. As an intensively farmed open landscape on the Cape Flats, the PHA underpins urban food security, supports livelihoods and contributes to groundwater recharge on the underlying aquifer, while maintaining habitat and buffering surrounding townships from further hard-edged urbanisation. Integrating PHA protection into Cape Town’s Green Infrastructure Programme therefore ties climate resilience, food systems and spatial justice together, by safeguarding productive land for smallholders and strengthening ecological and functional linkages between Philippi, Drift sands Nature Reserve and emerging green corridors such as the Sheffield Road stormwater and open-space spine.

The Philippi regenerative practice proposed in recent planning is centred on a shift toward regenerative agriculture within the PHA. The Philippi Opportunity Area Economic Strategy introduces a dedicated intervention to "conduct a situation analysis and roadmap to implement regenerative agriculture," recognising that intensive vegetable production is highly demanding of soil and water resources.

The roadmap is intended to diagnose current soil and water conditions, farming methods and support needs, and to outline context-appropriate regenerative practices that enhance soil health, improve water-use efficiency and build long-term productive capacity. Awareness-raising and capacity-building among farmers are identified as key components, ensuring that smallholders can adopt climate-smart techniques without compromising their economic viability. In this way, regenerative agriculture in Philippi is framed not only as an environmental intervention, but as a lever for resilient local economies, secure urban food supplies and better stewardship of the Cape Flats aquifer within the broader green-infrastructure and regeneration agenda.

Cape Town's integrated strategies spanning resilient urban waterways, green infrastructure, and regenerative agriculture, demonstrate how nature-based and community-driven solutions can transform climate risk into opportunity. By embedding resilience in planning and prioritizing vulnerable communities, the city charts a path toward a water-sensitive, inclusive future where ecosystems, livelihoods, and urban wellbeing thrive together.

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5.4 Spatial Planning Takeaways, challenges

Recollecting our theme to evaluate the tier 3 level of our projects across the case cities Accra, Chennai and Cape Town are further evaluated and Table 5.14-5.16.

For Chennai,

Table 5.14: Chennai scores as per the discussed methodologies from Chapter 3.

Theme	Indicator	Chennai score (1–5)	Brief evidence / reference
SV1	**SV1 – Population in hazard-prone zones**	**4 – High**	Flood modelling shows 29.1%, 46% and 56.5% of GCC area at inundation risk for 5-, 25- and 100-year events; SLR could permanently inundate ~16% (≈67 km²) of GCC by 2100, affecting ~1 million people (~13% of population).
SV2	**At-risk groups & informal settlements in hazard areas**	**5 – Very high**	Across flood scenarios, 41–68% of slums are affected; up to 21% of slum households face >5-ft depths at 100-year events. About 17% of slums (~260,000 residents) and 7,500 resettlement tenements fall in SLR risk zones; 27% of slum homes use heat-prone asbestos roofs (vs 8.9% citywide).
PE1	**Impervious surface & critical services exposure**	**4 – High**	Built-up area rose from 29.5% (1991) to >64% (2013), largely at the expense of wetlands and open spaces, concentrating runoff. At 25-year floods, 38% of physical infrastructure and 41.4% of social infrastructure are inundated; at 100-year, about 45% of mapped physical infrastructure is impacted, including bus stops and metro assets.
PE2	**PE2 – Critical infrastructure resilience**	**3 – Moderate / partial**	Heavy impacts in 2015 floods (>400 deaths, USD 7–15 bn losses) and Cyclone Michaung 2023 show high sensitivity of infrastructure. However, post-2015 Chennai implemented 405 km of Integrated Storm Water Drains in Adyar and Cooum basins (World Bank-funded), with further works planned in other basins and complementary lake/coastal protection projects, indicating ongoing but incomplete resilience upgrades.
EG1	**Economic loss from recent climate hazards**	**5 – Very high losses**	The 2015 floods caused >400 fatalities and estimated USD 7–15 billion in damages, among India's costliest disasters; subsequent events (e.g., Cyclone Michaung 2023) again triggered citywide disruption and evacuations, showing recurrent, large-scale economic impacts.
EG2	**DRR / adaptation governance & financing**	**4 – Strong, still consolidating**	Chennai has a dedicated Climate Action Plan (CCAP 2022) with six sectors, a climate unit in GCC, and structured roles for energy, buildings, transport, waste, water–floods and health agencies. The Resilient Chennai (2019) programme, large investments in ISWD (INR 1,261 crores) and additional INR 500 crores for core flood mitigation, plus wetland/lake restoration and coastal works, indicate substantial governance and financing capacity, though implementation gaps remain.
MT1	**MT1 – Low-carbon development with DRR co-benefits**	**3 – Several measures, not yet transformative**	CCAP sectors 1–3 promote grid decarbonisation, building efficiency and people-first mobility (bus upgrades, walk/cycle networks, last-mile feeders) which cut emissions and can reduce flood and heat exposure. Waste reforms (segregation, circularity) also support cleaner drains and reduced methane. These are substantial but still emerging relative to the scale of the city.
AD1	**AD1 – EbA / NBS & blue–green infrastructure**	**3 – Moderate, expanding**	Long-term wetland and tank loss, especially Pallikaranai Marsh, has driven risk; recent efforts include marsh and lake restoration, coastal protection, and Water as Leverage / 1000 Tanks-type blue–green approaches in select basins. CCAP emphasises protecting marshes, tanks and canals, infiltration and "room for water," but coverage is still fragmented rather than citywide.
AD2	**AD2 – Community adaptive capacity & inclusion**	**3 – Moderate, uneven**	Resilient Chennai identifies disadvantaged vulnerable communities and calls for ward-level climate officers, Ward Committees, Area Sabhas, and community-scale solid waste and BGI upkeep. There are pilots and participatory planning elements, but heat–flood burdens on low-income settlements remain high, and coverage of early warning and social protection is still uneven.

Table 5.15: Accra scores as per the discussed methodologies from Chapter 3.

Theme	**Indicator**	**Accra score (1–5)**	**Brief evidence / reference**
SV1	**Population & assets in hazard-prone zones**	**4 – High**	GAMA is repeatedly hit by pluvial and fluvial floods, with extensive exposure in low-lying basins such as Odaw–Korle, Densu delta, Sakumono and Kpeshie. Modelled damage from the 3 June 2015 event shows ~176,000 people and 40,000 houses exposed, US$55 million in direct damages and a further US$105 million in reconstruction needs, indicating large stocks of people and assets in flood-prone zones.
SV2	**At-risk groups & informal settlements located in hazard areas**	**5 – Very high**	Over 60% of Accra's residents live in informal settlements, many on floodplains, lagoon edges and low-elevation coastal zones, with insecure tenure, poor housing and limited in-house water and sanitation (Amoako & Inkoom; Kyeremanteng). Coastal assemblies such as Ablekuma South, Ga South and Kpone Katamanso combine high flood/erosion exposure with high social sensitivity, while NADMO maps around 1.27 million people as highly exposed in key basins. This points to very high concentration of vulnerable, low-income groups in hazard belts.
PE1	**Impervious surfaces, ecological loss & exposure of critical services**	**4 – High**	GAMA has lost ~71 km² of cropland, ~139 km² of dense short vegetation and 23 km² of tree cover, with rapid expansion of built-up areas at the expense of grasslands and wetlands. Urbanization encroaches on wetlands, riparian buffers and water-retention areas, while fragmented road and drainage infrastructure blocks natural flow paths, heightening runoff and exposure of transport and utility networks to flooding.
PE2	**Robustness of drainage, coastal & protective infrastructure**	**2 – Low–moderate**	Drainage is widely undersized, unconnected or poorly maintained; solid-waste dumping and siltation choke channels so that even 10–25-year storms generate widespread flooding. Coastal belts are part of a low-elevation coastal zone with clayey soils and limited infiltration, yet structural protection remains patchy and often reactive. While the Greater Accra Flood Risk Mitigation Strategy and GARID are upgrading drains, bridges and detention ponds, current protection still lags behind hazard intensity and exposure.
EG1	**Observed economic losses from recent climate hazards**	**4 – High**	The 3 June 2015 flood alone caused about US$55 million in direct damage and losses to housing, transport, water and sanitation infrastructure, plus ~US$105 million in reconstruction needs. Recurrent annual floods and storm-related coastal damage have led to repeated repair costs, service disruption and livelihood impacts, signalling high and recurring economic burdens linked to climate-related hazards.
EG1	**Scale of DRR/adaptation investment relative to risk**	**3 – Moderate**	GARID mobilises US$200 million for flood-risk management and solid-waste systems in the Odaw Basin, combining detention ponds, dredging, bridge upgrades and community upgrading and targeting ~2.5 million people. The GAMA Sanitation and Water Project delivered major WASH and drainage improvements in low-income communities and was recognised as a highly impactful urban WASH project. However, the scale of risk across all basins and the coastal edge still exceeds current investment envelopes, indicating moderate but insufficient financing relative to needs.
AD	**Strength of DRR & climate-resilience governance**	**3 – Moderate**	Accra has an adopted Resilience Strategy (2019), a C40-aligned Climate Action Plan (2020–2025), and basin-scale strategies such as the Greater Accra Flood Risk Mitigation Strategy, which embed DRR and climate resilience into urban development, flood management and WASH. These frameworks show clear alignment with Sendai Priorities 2 and 3 and begin to "embrace informality" rather than displace it. Yet weak enforcement of land-use controls, fragmented authority across >20 MMDAs and persistent encroachment on wetlands and waterways reveal important governance gaps.
	Data, monitoring & community-based adaptation capacity	**3 – Moderate**	Risk assessment capacity is improving flood and coastal hazard maps, terrain modelling of >5,000 depressional "sinks" in the Odaw Basin, and coastal vulnerability indices inform planning; GAMA SWP introduced ESICApps for real-time sanitation monitoring; and vulnerability surveys document differentiated exposure and sensitivity along the coast. At the same time, historical coastal data gaps, limited coverage of early-warning systems, and reliance on ad-hoc community initiatives (raised plinths, informal early warning, savings groups) indicate moderate but uneven monitoring and adaptive capacity.

For Cape Town,

Table 5.16: Cape Town City scores as per the methodologies discussed from Chapter 3.

Theme	**Indicator**	**Score (1–5)**	**Justification & key evidence**
SV1	**Population & assets in hazard-prone zones**	**4 – High**	Cape Town's steep mountain rim drains onto the flat, sandy Cape Flats, with shallow depressions and high groundwater tables that favor ponding and groundwater flooding. Nearly 2,000 km of rivers, 480 km of canals and hundreds of ponds/wetlands intersect dense development on the Flats, where repeated winter storms generate localized but recurrent flood losses. Spatial risk mapping (OneWorld) shows climate-risk hotspots along the municipal periphery (Tygerberg, Cape Flats, Mitchells Plain/Khayelitsha), indicating a large share of people and assets exposed in low-lying basins and coastal margins.
SV2	**At-risk groups & informal settlements in hazard areas**	**5 – Very high**	Around 15% of Cape Town's population lives in informal settlements, heavily concentrated on the Cape Flats and in townships like Khayelitsha, Mitchells Plain, Masiphumelele, often on former wetlands, floodplains and marginal sandy land. These areas face shallow groundwater, poor drainage and recurrent winter floods, with contaminated water, disease risk and livelihood disruption. Risk hotspot analysis highlights that Cape Flats and Mitchells Plain/Khayelitsha combine high densities with low economic capital, leaving residents highly exposed to floods, heatwaves, winds and fires and with few buffers to recover.
PE1	**Impervious surface, ecological loss & exposure of services**	**3 – Moderate–high**	LULC analysis (2005–2020) shows built-up area growing from 1,256 to 1,347 km², with urban expansion creeping closer to wetlands and natural streams. Wetlands have lost about 8 km² and open dry lands declined by 133 km², while croplands also shift, signaling pressure on ecological buffers. Although the city still retains significant wetlands and vleis, canalization and infilling have reduced storage and infiltration capacity on the Cape Flats, increasing exposure of roads, settlements and services to flooding and waterlogging.
PE2	**Robustness of drainage, coastal & protective infrastructure**	**3 – Moderate / partial**	The metro has extensive stormwater infrastructure about 480 km of canals and >800 stormwater ponds—but many channels are undersized, canalised and prone to blockage by silt and waste, while historical infilling of vleis has removed natural storage. Flat topography, high groundwater and modified wetlands make low-income settlements in depressions particularly flood prone. On the water-supply side, heavy reliance on a few large mountain reservoirs was exposed during the 2015–2018 Day Zero drought, prompting belated diversification into aquifers, reuse and desalination. Together this indicates significant infrastructure, but still with critical vulnerabilities.
EG1	**Economic loss from recent climate hazards**	**4 – High**	The Day Zero drought pushed dam levels from ~92.5% to 23%, forcing severe restrictions (25 L/person/day) and near-shutdown of the municipal system, with major socio-economic disruption. Western Cape has recorded 334 major flood events (1900–2018) with rising frequency in recent decades, repeatedly damaging housing, transport and services, especially on the Cape Flats. While precise loss figures are not always quantified, the combination of multi-year drought impact and recurrent floods indicates high, recurring economic and welfare losses.
EG2	**DRR / adaptation governance & financing capacity**	**4 – Strong, still consolidating**	Cape Town has a Resilient City Strategy (2019), Climate Change Strategy & Action Plan, Cape Town Water Strategy (2019) and multiple thematic programmes (e.g. Greater Cape Town Water Fund, Heat-Health Action Plan). It holds Ramsar City status and aims to become a water-sensitive city by 2040, with cross-departmental initiatives like LUW and the Green Infrastructure Programme. However, budget cuts have delayed some LUW implementations into the 2030s, and governance challenges remain around inequality and enforcement, so capacity is strong but not yet fully realized.
MT1	**Low-carbon development with DRR co-benefits**	**3 – Several measures, not yet transformativ e**	The Climate Change Strategy and C40-aligned Action Plan pursue carbon neutrality and climate resilience, linking mitigation with equity. While the excerpt you provided focuses more on water and GI, these plans include actions on energy efficiency, cleaner mobility and embedded sustainability that can reduce heat exposure and improve air quality.

			However, mitigation with explicit DRR co-benefits is still emerging compared with the depth of work on water and ecosystems, warranting a mid-range score.
AD1	**Ecosystem-based / nature-based & blue–green measures**	**4 – Substantial, though not citywide**	Cape Town has a very strong EbA / GI portfolio: Ramsar-listed wetlands; stewardship of the Cape Flats Aquifer; hundreds of detention ponds; and major programmes such as Liveable Urban Waterways (LUW) and the Green Infrastructure Programme (GIP). LUW projects in Diep/Sand and Zeekoe catchments rehabilitate rivers, wetlands and canals (≈27 ha of wetlands and 10.7 km of channels), with benefit–cost ratios around 1.5–2.1 and significant avoided flood damages. GIP's GI Network and Urban Watercourses Guidelines promote buffers, permeable surfaces, indigenous planting and co-managed corridors. Coverage is still incomplete and some projects delayed, but relative to many Global South cities, EbA/BGI are well-developed and scaling.
AD2	**Community adaptive capacity & inclusion**	**3 – Moderate, uneven**	The Resilience Strategy was built through engagement with >11,000 residents, and programmes like the Mayoral Urban Regeneration Programme, informal settlement initiatives, LUW pilots (e.g. Edith Stephens Nature Reserve, Khayelitsha Wetland Park) and GIP projects (e.g. Liesbeek River "Friends of" groups) all foreground co-design, environmental education, job creation and community stewardship. Yet OneWorld's assessment shows that the poorest, densest areas on the periphery remain the most vulnerable with limited financial buffers, and many informal settlements still lack adequate services, heat protection and DRR coverage. Adaptive capacity is therefore significant but spatially uneven.

Across the three case cities, Cape Town stands out for having relatively strong governance and a mature ecosystem-based adaptation portfolio, while still sharing many of the structural vulnerabilities seen in Accra and Chennai. Indicator scores show that all three cities face high exposure of people and assets in hazard-prone zones (SV1), but Accra and Chennai score slightly higher on social vulnerability (SV2) because an even larger share of their informal settlements is entrenched on floodplains, low-lying coastal fringes or poorly serviced wetlands. Cape Town's townships on the Cape Flats and in areas like Khayelitsha and Mitchells Plain are similarly exposed, which justifies a very high SV2 score, yet the absolute scale and density of informality and poverty remain more severe in Accra and Chennai, where basic service deficits and chronic underinvestment are more pronounced.

In terms of physical–environmental risk and economic losses (PE1, PE2, EG1), all three cities are strongly affected by flooding and, in Cape Town's case, by the compound drought–flood dynamic. Chennai's 2015 floods and Cape Town's 2015–2018 Day Zero drought represent systemic events that exposed deep infrastructure fragilities and generated very high losses, while Accra's recurrent floods impose a heavy but more incremental economic burden. Where Cape Town clearly differentiates itself is under governance and adaptation capacity (EG2, AD1, AD2). It combines a comprehensive climate and water strategy, a resilience agenda and substantial investment in green infrastructure, wetland and aquifer management, and programmes such as Liveable Urban Waterways and the Green Infrastructure Programme. Accra and Chennai also show progress—through GARID, GAMA WASH, Chennai's Climate Action Plan and wetland restoration—but from a lower baseline and with more fragmented implementation. Overall, the indicator profiles suggest that Cape Town is further advanced in institutionalizing DRR and ecosystem-based measures, yet persistent inequality and spatial injustice on the Cape Flats mean that, in practice, the lived vulnerability of poor communities remains closer to that of Accra and Chennai than the sophistication of its strategies alone might imply.

6 Conclusions: Strengthening DRR and Climate Resiliency in Case cities.

This thesis compared three Global South coastal cities, Chennai, Accra and Cape Town with selected Global North exemplars to understand how disaster risk reduction (DRR) and climate-resilience strategies can be strengthened through spatial planning. Across all three case cities, the analysis confirms a pattern of high exposure and sensitivity, especially for informal settlements and low-income communities located in floodplains, lagoon margins, low-lying sandy plains and coastal belts. In Chennai and Accra, indicator scores and spatial analyses highlight that a large share of population and critical assets lie in flood- and erosion-prone zones, with recurrent floods, coastal hazards, heat extremes and episodes of water stress generating substantial economic and social losses. Cape Town shows a similar concentration of risk on the Cape Flats, where shallow groundwater, canalized wetlands and dense townships such as Khayelitsha and Mitchells Plain experience recurrent winter flooding, while the 2015–2018 "Day Zero" drought exposed the vulnerability of a system heavily reliant on distant mountain reservoirs. Overall, the indicator framework points to high exposure (SV1 = 4) and very high social vulnerability (SV2 = 5) in all three cities, alongside emerging but uneven governance capacity: climate and water strategies, resilience plans and basin-scale projects exist, yet enforcement gaps, fragmented mandates, budget constraints and data limitations still constrain implementation in practice.

Global North cities such as Copenhagen, Amsterdam and Barcelona demonstrate that integrating DRR into spatial planning through cloudburst plans, blue-green roofs, nature-based coastal defense and water-sensitive urban design – can substantially reduce hazard impacts while improving liveability. Cape Town's more advanced ecosystem-based adaptation portfolio, including the Liveable Urban Waterways Programme, Green Infrastructure Programme and Cape Town Water Strategy, shows how similar logics can be adapted in a Global South context to rehabilitate rivers and wetlands, protect aquifers and co-produce multi-functional public spaces with communities. However, the comparative review makes clear that these models cannot be transferred as fixed templates. Instead, they offer directional lessons that must be adapted to the socio-economic realities of Chennai, Accra and Cape Town, including informality, constrained fiscal space, governance fragmentation, rapid land-cover change and deep spatial inequalities. Geospatial analytics in this thesis further illustrate how risk "hotspots" can be mapped and prioritized in all three cities, providing an evidence base for more targeted, cost-effective DRR investments that combine structural measures with ecosystem-based and community-driven approaches.

6.1 Opportunities for Adapting Global North Lessons to the Global South DRR as a Response in Spatial Planning: Mitigations and Adaptation in Global South Cities

6.1.a Cross regional learnings

The cross-regional comparison shows that both Global North and Global South coastal cities face converging hazards—pluvial and fluvial floods, storm surges, coastal erosion, urban heat and drought—but from very different starting conditions. In Chennai and Accra, rapid urbanization, loss of wetlands and expansion of impervious surfaces intensify runoff and concentrate exposure of social and physical infrastructure. Large shares of population and assets are located in low-lying basins, lagoon margins and coastal fringes, with informal settlements and peri-urban expansion zones experiencing the highest risk levels and very high social vulnerability scores (SV2 = 5). Cape Town faces similar multi-hazard pressures but within a distinctive geomorphological setting: steep mountain slopes draining onto the flat, sandy Cape Flats with high groundwater tables and canalized wetlands. Here, dense townships such as Khayelitsha and Mitchells Plain sit on former vleis and marginal sandy land, exposed to recurrent winter floods, groundwater inundation, heatwaves and the long "Day Zero" drought, which revealed the fragility of a system heavily reliant on distant surface reservoirs.

In contrast, cities like Copenhagen and Amsterdam have leveraged decades of investment in drainage networks, retention landscapes and multi-functional public spaces to manage cloudbursts and sea-level rise, while Barcelona's water-sensitive strategies respond to combined drought, flood and heat risks. Amsterdam's Rainproof programme, floating neighborhoods and green–blue networks treat the entire city as a "sponge," coupling EbA/CbA measures with strong governance and equity objectives. Cape Town occupies an intermediate position: still marked by deep inequality and peripheral vulnerabilities, yet more advanced in institutionalizing ecosystem-based and water-sensitive approaches through its Resilience Strategy, Climate Change Strategy, Water Strategy, Liveable Urban Waterways and Green Infrastructure Programme. The key cross-regional lesson is that risk reduction succeeds where climate and DRR are treated as core spatial-planning questions, integrated into zoning, density, transport, public space and blue–green systems—and where adaptation is explicitly linked to social justice and community co-production, so that cities "design with water" and "design with heat," rather than against them.

6.1.b Opportunities

The comparison highlights multiple opportunities for adaptation and re-interpretation of Global North practices in Chennai, Accra and Cape Town. Copenhagen's cloudburst streets and park-basins suggest how road hierarchies and open spaces in all three cities could be retrofitted as flood-retention corridors, especially in high-risk basins such as the Adyar–Cooum system in Chennai, the Odaw – Korle catchment in Greater Accra and the canalized waterways on the Cape Flats. Amsterdam's Rainproof "sponge city" approach and floating neighbourhoods illustrate how stress-mapping, de-paving, water squares, green roofs and multi-functional canals can be bundled with community participation to cut pluvial damage and heat stress while improving public space quality. Barcelona's WSUD interventions offer further low-impact measures that can be combined with informal-settlement upgrading and social-housing programmes to simultaneously manage runoff, enhance cooling and improve housing conditions.

For Accra, ongoing programmes such as GARID and GAMA WASH already move in this direction by integrating detention ponds, channel upgrades and community-scale interventions; the comparative frame suggests scaling these efforts into basin-wide blue-green systems that connect wetlands, lagoons and drains instead of treating them as isolated projects. In Chennai, wetland and tank restoration, marsh conservation and Water as Leverage/ 1000 Tanks-type pilots offer an entry point to build a citywide network of "room for water" spaces inspired by Dutch and Danish examples. Cape Town's Liveable Urban Waterways and Green Infrastructure Programme show how river corridors, wetlands and canals can be progressively "de-hardened" and redesigned as green–blue corridors that store water, recharge aquifers and provide safe public space in vulnerable townships, while the Philippi Horticultural Area demonstrates how productive landscapes can be protected as climate buffers within a metropolitan growth strategy. Overall, Global North lessons provide a menu of design logics and governance tools, not finished solutions that can support more climate-sensitive planning in the three cities.

6.1.c Adaptability

A core finding of this thesis is that the adaptability of DRR strategies depends less on technology and more on governance, equity and finance. Many of the solutions used in Global North cities such as retention parks, permeable streets, canal rehabilitation, cooling corridors and even floating or amphibious development could, in principle, be applied in Chennai, Accra and Cape Town. Technical knowledge exists, and the physical conditions in many neighborhoods would allow such interventions.

However, whether these measures work on the ground depends strongly on who lives in risk-prone areas and what rights and resources they have. In Chennai and Accra, and in much of Cape Town's periphery (especially the Cape Flats, Khayelitsha and Mitchells Plain), high-risk zones are often occupied by informal or low-income settlements. These communities typically face insecure tenure, limited basic services and high everyday vulnerability. This makes it unrealistic to simply "copy and paste" solutions like cloudburst streets or green–blue boulevards from Amsterdam or Copenhagen.

To be effective, adaptation in these areas must combine physical risk reduction (better drainage, raised plinths, safer housing, shaded and green corridors) with social measures such as tenure regularization, livelihood support, affordable services and, where necessary, rights-based and participatory relocation or in-situ upgrading. The case studies show that when projects treat residents as partners rather than obstacles and link spatial design with social protection, they are more likely to be accepted, maintained and scaled up over time.

Institutional coordination: The multi-level coordination that underpins cloudburst plans and rainproof in Copenhagen and Amsterdam contrasts with more fragmented authorities and overlapping mandates across MMDAs in Greater Accra and the complex institutional landscape in Chennai's metropolitan region. Cape Town sits between these poles: it has relatively strong, integrated climate and water strategies and cross-departmental programmes such as LUW and the Green Infrastructure Programme, but still faces challenges around inequality, enforcement and budget constraints.

Financing models: While Global North cities can rely more heavily on stable domestic revenues and green funds, Chennai, Accra and Cape Town must often blend international finance, national transfers, earmarked climate funds and constrained municipal budgets. Cape Town's experience - strong strategies but LUW phases postponed into the 2030s due to budget cuts - illustrates how even relatively capable cities must phase investments and prioritise high-leverage corridors. Chennai and Accra, starting from a lower fiscal and infrastructure baseline, may need even more incremental, basin-by-basin approaches.

Therefore, adaptability is strongest where strategies are modular, incremental and co-produced with communities: where citywide frameworks (e.g. Amsterdam Rainproof, Cape Town's Water Strategy, Chennai's CCAP or Accra's resilience agenda) are translated into neighbourhood-scale projects that can be expanded over time as capacity, data and financing improve, rather than relying on single, comprehensive "big-bang" solutions.

6.1.d Ways/ Possibilities to Strengthen

The indicator framework and geospatial analysis suggest several concrete pathways to strengthen DRR in **Chennai, Accra and Cape Town**, informed by cross-regional lessons from Amsterdam and other European cities:

- *Re-zoning and risk-sensitive land-use controls*

  Integrate updated flood, coastal and heat maps into master plans, zoning regulations and development control rules, including basin- and catchment-scale overlays. In Chennai, this implies stricter controls in the Adyar–Cooum floodplains and around residual wetlands and tanks, while in Accra it requires safeguarding the Odaw–Korle, Chemu and lower Densu floodplains. In Cape Town, risk-sensitive zoning can build on the BioNet, Green Infrastructure Network and protected area system to steer growth away from the most flood- and erosion-prone parts of the Cape Flats, while protecting strategic landscapes such as the Philippi Horticultural Area as food and climate buffers.

- *Citywide blue-green infrastructure networks*

Move from isolated pilot sites to *continuous blue–green corridors* that link tanks, marshes, rivers, lagoons, wetlands and parks. Rotterdam, Copenhagen and Amsterdam show how cloudburst streets, water squares, green–blue roofs and "sponge city" measures can be mainstreamed into streetscapes and neighbourhood renewal, increasing storage and infiltration while improving public space. In Cape Town, the Green Infrastructure Programme and Liveable Urban Waterways initiative already outline catchment-based rehabilitation of rivers and canals using water-sensitive design and nature-based solutions; similar basin-wide networks can be structured around the Adyar – Cooum and Coovum – Pallikaranai systems in Chennai and the Odaw–Korle and Sakumo–Densu systems in Accra.

- *Risk-informed upgrading of informal and low-income areas*

  Combine drainage improvements, elevating plinths, safer building materials, tree planting and micro-green spaces with tenure regularisation and livelihood support in the most exposed informal and low-income neighbourhoods. In Accra and Chennai, this includes dense settlements along channels and lagoons; in Cape Town, settlements on the Cape Flats that are repeatedly flooded can be linked to LUW-type corridor projects so that upgrading, river rehabilitation and public-space provision happen together. Evidence from Cape Town's GI and LUW work shows that such projects can generate co-benefits in jobs, health and ecosystem services alongside risk reduction.

- *Embedding geospatial analytics in planning practice*

  Institutionalise the use of DEM-based screening, land-cover change analysis, indicator scoring and hotspot mapping to systematically identify priority basins, corridors and neighbourhoods for intervention, especially in data-scarce peri-urban areas. The City Water Resilience Approach used in Cape Town illustrates how system mapping and indicator-based assessments can guide the sequencing of interventions and investment pipelines; similar approaches can be adapted to Chennai and Accra to align spatial plans, climate strategies and DRR portfolios.

6.1.e Policy and Implementation Gaps

The thesis also reveals significant *policy–practice gaps*. On paper, Chennai, Accra and Cape Town all show growing alignment with the Sendai Framework and international resilience agendas. Chennai's climate action and flood-mitigation initiatives, Accra's Resilient Strategy and GARID-linked basin investments, and Cape Town's Climate Change Strategy, Water Strategy, Green Infrastructure Programme and Liveable Urban Waterways pipeline all signal strong rhetorical commitment to DRR and adaptation.

Yet, implementation lags in several areas:

- *Enforcement of land-use regulations* remains weak, with continued encroachment on wetlands, canals, river buffers and coastal setbacks in Chennai and Accra, and ongoing development pressures on Cape Town's low-lying Cape Flats and agricultural buffers. This undermines investments in drains, detention ponds and ecological restoration.
- *Maintenance and operation* of drainage and coastal infrastructure are inconsistent; solid-waste dumping, siltation, alien vegetation and delayed repairs reduce protection levels below design standards, including along Cape Town's canalised waterways targeted by LUW.
- *Data and monitoring systems* remain fragmented. While hazard mapping and vulnerability assessments are improving, early-warning systems, impact tracking and feedback loops into routine planning and budgeting are still partial, despite steps taken through the City Water Resilience Approach in Cape Town.
- *Social and institutional capacity* at ward or community level is insufficiently resourced, limiting the effectiveness of participatory mechanisms envisioned in resilience strategies, GI and LUW-type programmes.

- *Financing and phasing constraints* are acute: even Cape Town, with relatively strong institutional capacity, has had to postpone parts of the LUW implementation to the 2030s due to funding limitations, illustrating the challenge of sustaining long-term DRR investments.

"Closing these gaps requires not only better plans, but *stable, long-term funding*, cross-agency coordination mechanisms that link climate, water, housing and spatial planning, and strong accountability frameworks that connect DRR policies to everyday development decisions, such as building permissions, infrastructure maintenance and upgrading priorities."

6.1.f Challenges and Limitations for strengthening DRR strategies

Strengthening DRR in Global South coastal cities faces structural challenges that this thesis could only partially address. First, *structural inequality and informality* mean that those most exposed to floods, heat and coastal hazards - informal settlements along rivers and lagoons in Chennai and Accra, and townships on the Cape Flats in Cape Town, are also those with the least capacity to relocate, retrofit or absorb losses, reflecting long-standing socio-spatial segregation.

Second, *rapid land-cover change and urban expansion* – including the conversion of wetlands, agricultural land and biodiversity corridors to built-up areas in Chennai and Greater Accra, and continued habitat fragmentation and densification around Cape Town's ecological network - continue to generate new risk faster than resilience measures can catch up, despite efforts such as Cape Town's Green Infrastructure Network and protected area expansion.

Third, *institutional fragmentation and capacity constraints* across municipalities, utilities and sectoral departments slow down integrated, basin-scale approaches. Coordination across water, housing, transport and environmental departments remains challenging in Chennai and Accra, and even in Cape Town, cross-departmental programmes such as GI and LUW require sustained political and financial support to be fully realized.

Fourth, *data gaps and uncertainty* are substantial, especially for informal settlements, subsurface drainage conditions, compound drought–flood–heat interactions and future land-use trajectories. Finally, the research itself is constrained by reliance on secondary data, uneven availability of comparable indicators across the three cities, and the absence of primary surveys or extensive stakeholder interviews in some cases.

Despite these constraints, the thesis demonstrates that even "imperfect data and incremental interventions can significantly improve DRR decision-making" when situated within coherent spatial strategies and informed by cross-regional learning from cities such as Amsterdam and Cape Town.

6.2 Reflecting on the research questions

Across Chennai, Accra and Cape Town, and in dialogue with European exemplars such as Amsterdam, the research shows that progress on DRR and climate resilience is real but uneven. Practices and policies exist, yet their implementation and spatial reach still fall short of the scale of current and projected hazards. To respond to our research questions for the thesis,

- *How effective are current urban climate mitigation and adaptation practices in addressing climate change–induced hazards and contributing to DRR in selected Global North and Global South coastal cities?*

The case studies show that current practices have reduced some localised risks – such as improved drainage segments and basin interventions in Chennai, GARID-linked works in Accra, and ecosystem-based river and wetland rehabilitation pilots under Cape Town's Green Infrastructure and Liveable Urban Waterways programmes – but remain insufficient relative to the scale and pace of hazards, particularly for vulnerable groups in high-risk zones. In contrast, cities like Amsterdam and Copenhagen demonstrate more mature, citywide integration of DRR and climate adaptation, highlighting both the potential direction of travel and the magnitude of the gap Global South cities still need to close.

- *What innovative practices, such as Blue-Green Infrastructure, Nature-Based Solutions, Urban Farming, and water-sensitive design, that have proven successful, and what factors determine their effectiveness?*

Blue-green infrastructure, nature-based solutions, urban farming, rooftop gardens and water-sensitive designs show strong potential where they are embedded in broader spatial frameworks and long-term programmes, as seen in Amsterdam's Rainproof and floating neighbourhoods or Cape Town's GI and LUW initiatives. Their effectiveness is determined by location in relation to hazard pathways, social targeting, maintenance regimes and institutional ownership, rather than by technology alone; when these conditions are met, such measures can simultaneously reduce flood and heat risks, enhance ecosystem services and improve everyday liveability.

- *What is the scope of effective policy frameworks, governance structures, projects and initiatives to strengthen DRR strategies, particularly in data-scarce regions?*

Existing policies and projects provide a solid but partial foundation for DRR in Chennai, Accra and Cape Town. Frameworks aligned with global climate and DRR agendas exist – such as Chennai's climate action and flood-management plans, Accra's resilience strategy and GARID programme, and Cape Town's Climate Change Strategy, Water Strategy, Green Infrastructure Programme and LUW pipeline - but they must be deepened through stronger enforcement, cross-scale coordination and clearer links between climate plans, land-use decisions, infrastructure maintenance and investment pipelines. In data-scarce regions, simplified but robust indicator sets and partnership-based approaches, as used in Cape Town's City Water Resilience work, can help bridge information gaps and structure action.

- *The geospatial analytics can be used for determining sustainable cost-effective practices or areas of focus, so in what state the mitigating risk impacts were discovered and what are the hurdles towards adaptation among these regions?*

The research confirms that geospatial tools, DEM-based screening, land-cover change analysis, indicator scoring and hotspot mapping - are essential for prioritising interventions where they yield the highest DRR and co-benefits per unit cost, especially in data-scarce regions like Chennai and Accra and in complex urban systems such as Cape Town's Cape Flats. These tools help reveal where ecosystem-based measures, drainage upgrades, relocation or densification will have the greatest impact, and highlight the trade-offs and synergies between mitigation, adaptation and social equity. However, their full potential is constrained by uneven data quality, limited technical capacity in some agencies, fragmented governance and financing barriers, which together slow the translation of analytical insights into sustained, large-scale adaptation on the ground.

Conclusion

Taken together, this thesis shows that strengthening DRR in Global South coastal cities is not only a technical challenge, but a profoundly social, political and spatial one. Each chapter has highlighted how EbA and CbA approaches, geospatial analytics and the Sendai Framework can guide more integrated, risk-informed planning; yet the case evidence ultimately speaks for the Global South cities. These cities play an outsized role in global environmental and climate dynamics, but much damage is already locked in, and mitigation or adaptation will be slow where fragile infrastructure, economic dependency, overpopulation and low risk awareness constrain options. Governance quality and shifting geopolitical orders further shape what is possible, as starkly revealed during the COVID-19 pandemic. Even so, incremental, equity-centred and spatially targeted strategies offer a realistic pathway toward more resilient urban futures.

List of Abbreviations

100RC – 100 Resilient Cities (Rockefeller Foundation network, 2013–2019; transitioned to Resilient Cities Network)
AD – Adaptation (indicator/assessment framework; used for Adaptation & DRR strategies)
AD1 – Ecosystem-/Nature-based and blue–green infrastructure measures (assessment indicator)
AD2 – Community adaptive capacity and inclusion (assessment indicator)
AFD – Agence Française de Développement (French Development Agency)
AIIB – Asian Infrastructure Investment Bank
AMA – Accra Metropolitan Area / Accra Metropolitan Assembly
AR – Assessment Report (IPCC context)
ARS – Accra Resilience Strategy
As – Tropical savanna climate with dry summer (Köppen climate classification)
ASR – Aquifer Storage and Recovery
Aw – Tropical savanna climate with dry winter (Köppen climate classification)
BGI – Blue–Green Infrastructure
BIGRS – Bloomberg Initiative for Global Road Safety
BNPB – Badan Nasional Penanggulangan Bencana (Indonesia's National Disaster Management Agency)
C40 – C40 Cities Climate Leadership Group
CAG – Comptroller and Auditor General of India
CAP – Climate Action Plan
CAPS – Civic Awareness and Participation Strategy (often refers to the plastics portal in this context)
CbA – Community-based Adaptation
CBD – Central Business District
CCA – Climate Change Adaptation
CCAP – Chennai Climate Action Plan
CMA – Chennai Metropolitan Area
CMDA – Chennai Metropolitan Development Authority
CMWSSB – Chennai Metropolitan Water Supply and Sewerage Board
COCT – City of Cape Town
CRC – Chennai Resilience Centre
CRED – Centre for Research on the Epidemiology of Disasters
CRM – Climate Risk Management
CRO – Chief Resilience Officer
CSCL – Chennai Smart City Limited
CSR – Corporate Social Responsibility
CTCURC – Cape Town City University Research Centre (as used in document)
CUFI – Chennai Urban Farming Initiative
DAR – Disaster Area/Risk (context-dependent)
DEM – Digital Elevation Model
DMI – Danish Meteorological Institute
DRM – Disaster Risk Management
DRR – Disaster Risk Reduction
DTM – Digital Terrain Model
EbA – Ecosystem-based Adaptation
EEA – European Environment Agency

EG – Economic & Governance (assessment theme)
EG1 – Observed economic losses from climate hazards (indicator)
EG2 – DRR/adaptation governance and financing (indicator)
EOC – Emergency Operations Centre
EPWP – Expanded Public Works Programme
ESIA – Environmental and Social Impact Assessment
ESRI – Environmental Systems Research Institute
EV – Electric Vehicle
EWS – Early Warning Systems; Economically Weaker Sections (India housing context)
FMO – Dutch Entrepreneurial Development Bank (FMO)
FSI – Floor Space Index
GAMA – Greater Accra Metropolitan Area
GARID – Greater Accra Resilient and Integrated Development (project)
GBI – Green–Blue Infrastructure
GCA – Global Center on Adaptation
GCC – Greater Chennai Corporation
GCF – Green Climate Fund
GDP – Gross Domestic Product
GHG – Greenhouse Gas
GI – Green Infrastructure
GIBP – Green Infrastructure and Biodiversity Plan (Barcelona)
GINet – Green Infrastructure Network
GIP – Green Infrastructure Programme
GIS – Geographic Information System
GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit (German development agency)
GLULC – Global Land Use/Land Cover
GMET – Ghana Meteorological Agency (also written GMet)
GMT – Greenwich Mean Time
GoTN – Government of Tamil Nadu
GSS – Ghana Statistical Service
GSWP – GAMA Sanitation and Water Project
GWCL – Ghana Water Company Limited
HDI – Human Development Index
HFA – Hyogo Framework for Action (2005–2015)
HOFOR – Hovedstadsområdets Forsyningsselskab (Greater Copenhagen Utility)
IABR – International Architecture Biennale Rotterdam
ICCC – Integrated Command and Control Centre
ICDS – Integrated Child Development Services
IEC – Information, Education and Communication
IFRC – International Federation of Red Cross and Red Crescent Societies
IITM – Indian Institute of Technology Madras
IMD – India Meteorological Department
IMERG – Integrated Multi-satellitE Retrievals for GPM (NASA precipitation dataset)
INR – Indian Rupee(s)
IPCC – Intergovernmental Panel on Climate Change
IPR – Indirect Potable Reuse
ISWD – Integrated Storm Water Drain / Integrated Stormwater Drainage (as used)
IUESSMP – Integrated Urban Environmental Sanitation Strategy Master Plans

KLERP – Korle Lagoon Ecological Restoration Project
KPI – Key Performance Indicator(s) (also written KPI/KPIs)
LID – Low Impact Development
LPCD – Litres per capita per day
LST – Land Surface Temperature
LULC – Land Use/Land Cover
LUW – Liveable Urban Waterways (programme)
MCCI – Madras Chamber of Commerce and Industry
MCR2030 – Making Cities Resilient 2030
MESTI – Ministry of Environment, Science, Technology and Innovation (Ghana)
MMDAs – Metropolitan, Municipal and District Assemblies
MRF – Material Recovery Facility
MT – Mitigation Strategies (assessment theme)
MT1 – Low-carbon development with DRR co-benefits (indicator)
MUDP – Madras Urban Development Project
MVGK – Mobile-Vegetable Garden Kit
NADMO – National Disaster Management Organisation (Ghana)
NBS – Nature-Based Solutions (also written NbS)
NDCs – Nationally Determined Contributions
NEM – Northeast Monsoon (also written "NE Monsoon")
NEWater – Singapore's NEWater recycled wastewater programme
NGO – Non-Governmental Organization
NIUA – National Institute of Urban Affairs
NMT – Non-Motorized Transport
NRA – National Resilience Agenda / Authority (as used in document)
O&M – Operation and Maintenance
OSR – Open Space Reservation
PE – Physical-Environmental (assessment theme)
PE1 – Impervious surfaces/ecological loss/exposure of critical services (indicator)
PE2 – Drainage and coastal protective infrastructure robustness (indicator)
PPP – Public-Private Partnership
R-Cities – Resilient Cities Network (formerly 100 Resilient Cities)
RESCCUE – RESilience to cope with Climate Change in Urban arEas (EU Horizon 2020 project)
RQ1/RQ2/RQ3 – Research Questions 1/2/3 (as used in thesis)
R&R – Resettlement and Rehabilitation
RVO – Netherlands Enterprise Agency
RWA – Resident Welfare Association
RWH – Rainwater Harvesting
SAPCC – State Action Plan on Climate Change
SAVi – Sustainable Asset Valuation
SDG – Sustainable Development Goal(s) (also written SDG/SDGs)
SECO – Swiss Government Economic Cooperation Agency
SEI – Stockholm Environment Institute
SFA – Strategic Focus Area
SHG – Self Help Group
SLR – Sea-level Rise
S&S – Sites and Services
SSP – Shared Socioeconomic Pathway

SSP2-4.5 – Shared Socioeconomic Pathway 2–4.5 (middle-of-the-road scenario)
SSP3-7.0 – Shared Socioeconomic Pathway 3–7.0 (regional rivalry scenario)
SUDS – Sustainable Urban Drainage Systems
SV – Social Vulnerability (assessment theme)
SV1 – Population/assets in hazard-prone zones (indicator)
SV2 – At-risk groups and informal settlements (indicator)
SWD – Storm Water Drain
SWM – Solid Waste Management
SWMRT – Solid Waste Management Round Table
SWP – Sanitation and Water Project
TNAU – Tamil Nadu Agricultural University
TNCDBR – Tamil Nadu Combined Development and Building Regulations
TNCDW – Tamil Nadu Corporation for Development of Women
TNSAPCC – Tamil Nadu State Action Plan on Climate Change
TNSAPCCHH – Tamil Nadu State Action Plan on Climate Change and Human Health
TNSCB – Tamil Nadu Slum Clearance Board (now Tamil Nadu Urban Habitat Development Board)
TNULM – Tamil Nadu Urban Livelihoods Mission
UESP – Urban Environmental Sanitation Project
UHI – Urban Heat Island
UN DESA – United Nations Department of Economic and Social Affairs
UNDRR – United Nations Office for Disaster Risk Reduction
UNFCCC – United Nations Framework Convention on Climate Change
UN-Habitat – United Nations Human Settlements Programme
UNISDR – United Nations International Strategy for Disaster Reduction (predecessor to UNDRR)
WaL – Water as Leverage
WASH – Water, Sanitation and Hygiene
WCWDM – Western Cape Water Demand Management
WSUD – Water-Sensitive Urban Design
WWF – World Wide Fund for Nature
WWTW – Wastewater Treatment Works
ZAR – South African Rand

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