ASSESSING THE INFLUENCE OF VULNERABILITY ON FLOOD DISASTER GOVERNANCE:

A STUDY OF INFORMAL SETTLEMENTS IN CHENNAI, INDIA

MASTER OF CITY PLANNING

THESIS REPORT

Submission in partial fulfillment of the requirement for the degree of

Master of City Planning

By

NANDHINI P

23AR60R17

Under the guidance of

DR. ARUP DAS

DEPARTMENT OF ARCHITECTURE AND REGIONAL PLANNING

INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR

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DEPARTMENT OF ARCHITECTURE AND REGIONAL PLANNING

INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR

CERTIFICATE

This is to certify the project report entitled **“Assessing the influence of Vulnerability on Flood disaster governance: a study of Informal settlements in Chennai, India”** submitted by **Nandhini P (Roll No. 23AR60R17)** to Indian Institute of Technology Kharagpur, in partial fulfillment of the requirements for the Degree of **Master of City Planning** of this institute, is a bonafide work to the best of our knowledge and may be placed before the Examination Board for their consideration.

Dr. Arup Das	**Dr. Tarak Nath Mazumder**
Thesis Supervisor	Head of Department

Approved by

External Examiners

April / May 2025

DECLARATION

I hereby declare that the work presented in this report is the result of my own effort and has been carried out under the supervision of my guide. This work has not been submitted, either in part or in full, to any other institution or university for the award of any degree or diploma.

I have adhered to the ethical guidelines and norms laid out in the Ethical Code of Conduct of the Institute. All sources of information, including data, theoretical analysis, figures, and text taken from other works, have been duly acknowledged and cited appropriately in the text and listed in the references section of the report.

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ABSTRACT

Chennai, a city with population of 12 million, faces recurring flood hazards, aggravated by the city's rapid urbanization, encroachments in floodplains and changing climate patterns. Informal settlements, which house a significant portion of 28.9% of the city's population, often located in low lying and flood prone areas, face severe challenges due to poor housing conditions, insufficient infrastructure and limited access to basic services. This study investigates disaster governance in Chennai, particularly on how it addresses the vulnerability of informal settlements. The focus will be on the analysis of capital expenditure on flood management, categorizing it into structural and non-structural measures. Structural measures include physical flood barriers and drainage infrastructure, while non-structural measures involve policy reforms and awareness campaigns. By examining the distribution and impact of these expenditures, the study highlights potential gaps in addressing the needs of vulnerable population. In parallel, a vulnerability assessment of informal settlements is conducted through a composite index designed using the MCDM technique, specifically using the TOPSIS method. Factors such as socio-economic conditions, infrastructure quality, and proximity to flood prone areas are considered in the vulnerability index. By analyzing the relationship between capital expenditure and vulnerability of informal settlements, the study determines whether disaster governance in Chennai effectively addresses vulnerability or if it remains insufficient for marginalized communities.

Keywords: Vulnerability, Disaster Governance, Flood Mitigation, Informal Settlements

CHAPTER 1 – INTRODUCTION

- Background of the study
- Vulnerability and Flood risk in Informal Settlements
- Role of Disaster Governance and Financial Allocation
- Study Context: Why Chennai?
- Research Gap and Significance

1 INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Human settlements have historically developed near water bodies such as rivers, lakes, and oceans, forming the foundation of towns and cities over centuries. Over time, these settlements have increasingly expanded, often surpassing the natural carrying capacity of the land and resources available. In recent decades, rapid population growth and unplanned urbanization have drastically reshaped settlement patterns, posing significant challenges to sustainable development (Anwana, 2022). This unplanned growth, combined with the increasing impacts of climate change, has intensified the vulnerability of informal settlements to natural hazards, particularly floods.

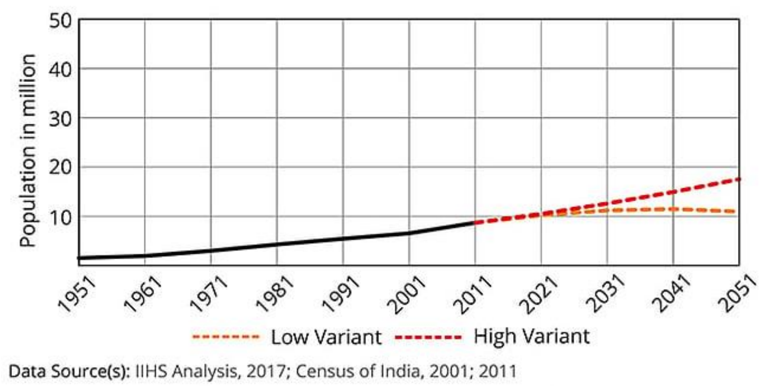


Figure 1-1 Chennai Population Growth from 1951 to 2051

Chennai, often referred to as India's 'water scarcity capital', illustrates these challenges. In late 2015, the city experienced torrential rains that led to severe and unexpected flooding, highlighting the urgent need to address the compounded impacts of unplanned urbanization and climate change on urban resilience (Arabindoo, 2016). Residents of low-income informal settlements often reside in hazardous locations such as flood-prone areas or steep slopes due to their proximity to employment opportunities, making them highly vulnerable to natural hazards, especially in the absence of adequate infrastructure and services (Review, 2024). The encroachment of wetlands, floodplains, and water bodies has significantly disrupted natural flood storage and drainage, leading to a profound alteration in drainage characteristics.

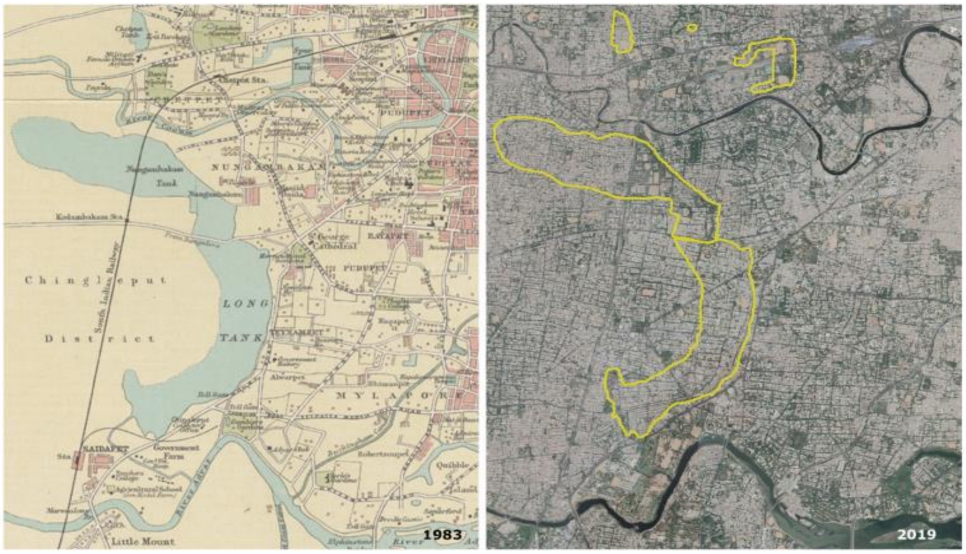


Figure 1-2 Complete land use change Chennai from 1983 to 2019

Chennai ranks fourth among Indian cities in terms of slum population, with approximately 28.9% of its residents living in slum conditions. The city's three major watercourses are heavily encroached upon, with slum families residing along their banks. These communities lack basic amenities and face recurrent flooding each year (T. Sundarmoorthy, 2009). To address these challenges, it is crucial to improve urban resilience, particularly in informal settlements, by integrating flood risk management strategies and enhancing infrastructure.

1.2 VULNERABILITY AND FLOOD RISK IN INFORMAL SETTLEMENTS

Urban flooding is not merely a result of excessive rainfall but is deeply embedded in how cities are planned, governed, and inhabited. Vulnerability in the context of flooding arises when exposure to flood hazards coincides with socio-economic and infrastructural deficiencies. Informal settlements are especially susceptible due to inadequate housing, poor drainage infrastructure, lack of legal tenure, and limited access to basic services (Jamshed, 2023).

Figure 1-3 Chennai floods during 2015

These populations are less likely to have insurance, relocation options, or political representation, which leaves them dependent on state-led interventions. Their repeated exposure to flooding leads to a cycle of loss and recovery that further deepens poverty and limits adaptive capacity. This multidimensional vulnerability necessitates not only physical infrastructure improvements but also proactive governance measures that integrate social justice, spatial planning, and financial prioritization (Khosla, 2020).

1.3 ROLE OF DISASTER GOVERNANCE AND FINANCIAL ALLOCATION

Disaster governance plays a pivotal role in managing risks, coordinating response efforts, and minimizing the impact of disasters. The government has a critical role in reducing damage from disasters and ensuring the livelihood of citizens through financial investment in disaster management (Jameson, 2016). As a result, determining the appropriate proportion of government expenditure on disaster prevention and mitigation has become a significant public concern.

If this proportion is low, it hampers the effective implementation of disaster prevention measures; if it is too high, it may crowd out other essential investments, thus hindering sustainable economic development and the long-term effectiveness of disaster reduction efforts (Benali, 2017). Therefore, it is crucial for the government to allocate an appropriate amount of expenditure for disaster prevention and mitigation. Despite this, only few studies have quantitatively analyzed the proportion of financial expenditure dedicated to these efforts, leaving a gap in addressing the true needs of disaster prevention and mitigation.

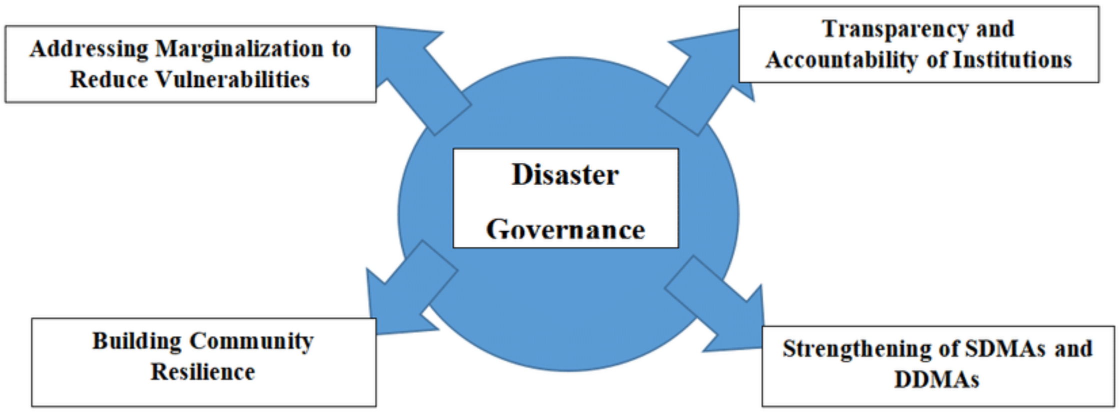


Figure 1-4 Responsibilities of Disaster Governance

This study aims to address this gap by analyzing the allocation of capital expenditure by the government across different wards of Chennai city, specifically in relation to flood prevention and mitigation.

1.4 STUDY CONTEXT: WHY CHENNAI?

Chennai presents a compelling case study for urban flood risk and disaster governance for several reasons. It is a coastal megacity prone to cyclonic storms and monsoon-related flooding. The city has experienced several major floods in the last two decades — most notably in 2005, 2015, and 2023 — each exposing the fragility of its urban systems.

Chennai is home to over 8 million residents, with a significant proportion (28.9%) living in slums (T. Sundarmoorthy, 2009). Many of these are located in low-lying flood-prone zones along the banks of the Adyar, Cooum, and Buckingham Canal — areas that were once part of the city's natural drainage system.

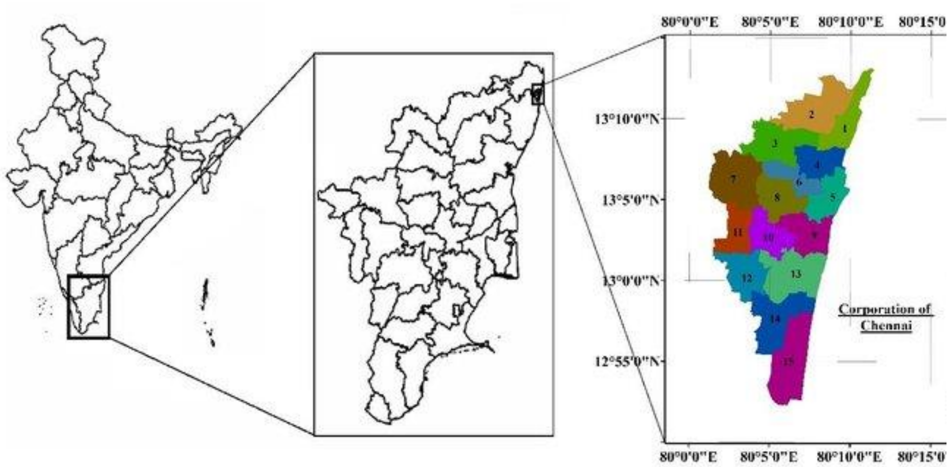


Figure 1-5 Location of Chennai City

The rapid conversion of floodplains and wetlands into built-up areas, combined with underinvestment in drainage infrastructure, has led to frequent inundation even during moderate rainfall events. Chennai's governance structure — where multiple agencies operate with overlapping roles — further complicates flood management. These factors make the city a high-risk zone and an ideal site to study the relationship between governance, vulnerability, and investment priorities.

1.5 RESEARCH GAP AND SIGNIFICANCE

While several studies have examined the causes and impacts of flooding in Indian cities, limited research has been dedicated to understanding how public investment decisions correlate with localized vulnerability patterns, especially in informal settlements. Most existing analyses focus either on hazard exposure or on infrastructural deficits without linking them to budgetary trends and governance responses.

Additionally, vulnerability assessments often lack spatial granularity and do not account for both physical and socio-economic variables in a composite framework. This study seeks to bridge these gaps by using geospatial analysis and MCDM methods to develop a nuanced understanding of vulnerability, and by comparing these patterns with actual capital expenditure from the Greater Chennai Corporation.

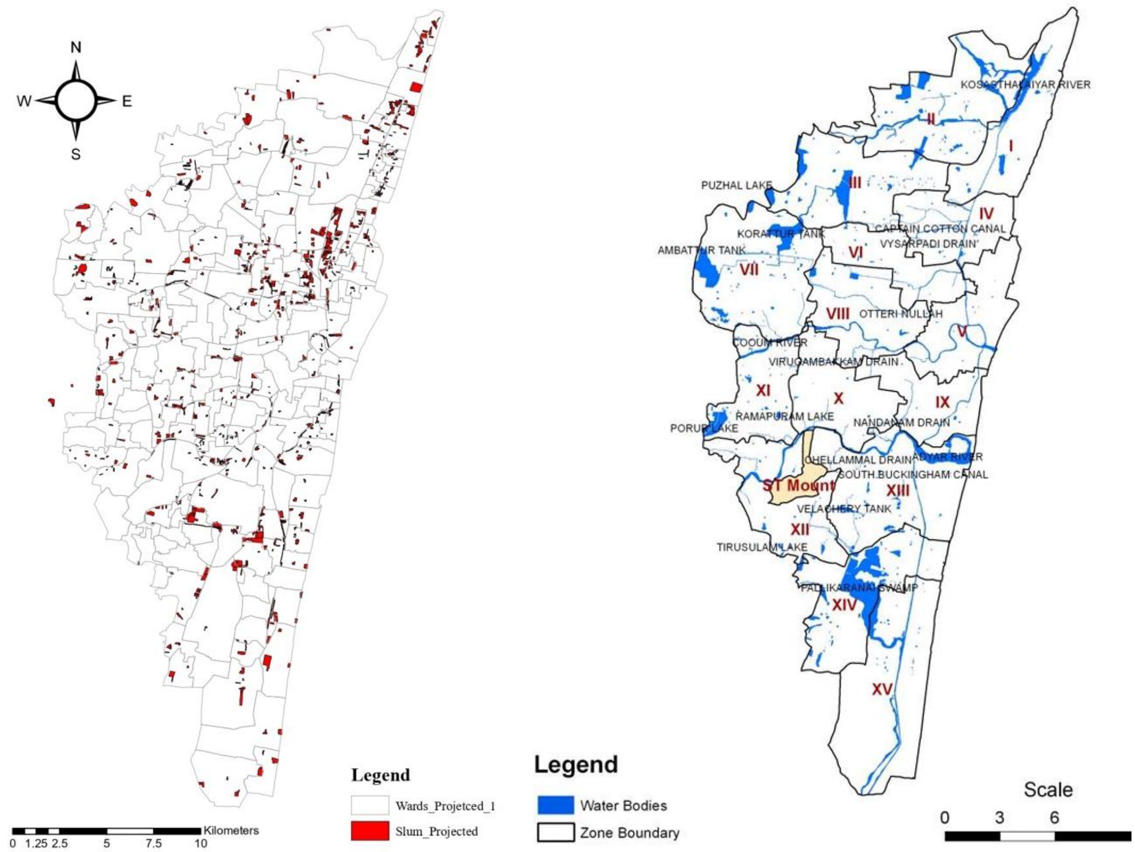


Figure 1-6 Slum boundaries (left) and waterways (right) of Greater Chennai Corporation

By doing so, this research contributes to the emerging discourse on equity in disaster governance, aiming to inform policy frameworks that prioritize vulnerable populations and ensure that disaster risk reduction (DRR) efforts are both targeted and justified.

CHAPTER 2 – RESEARCH OUTLINE

- Research aim
- Research Objectives
- Research Questions
- Conceptual Framework
- Scope of the study
- Limitations of the study

2 RESEARCH OUTLINE

2.1 RESEARCH AIM

The aim of the project is to propose integrated strategies for reducing flood risk by studying the interplay between different vulnerability factors and urban governance in influencing flood management in Chennai.

2.2 RESEARCH OBJECTIVES

The objectives of the research are as follows.

1. To analyze the spatial distribution of vulnerability in Informal settlements.
2. To examine the relationship between governance expenditure and vulnerability.
3. To assess the effectiveness of local body governance in addressing vulnerability.
4. To propose integrated strategies for mitigating flood in Chennai.

2.3 RESEARCH QUESTION

The main question of the study will be 'Is disaster governance driven by vulnerability of exposed population?'

2.4 CONCEPTUAL FRAMEWORK

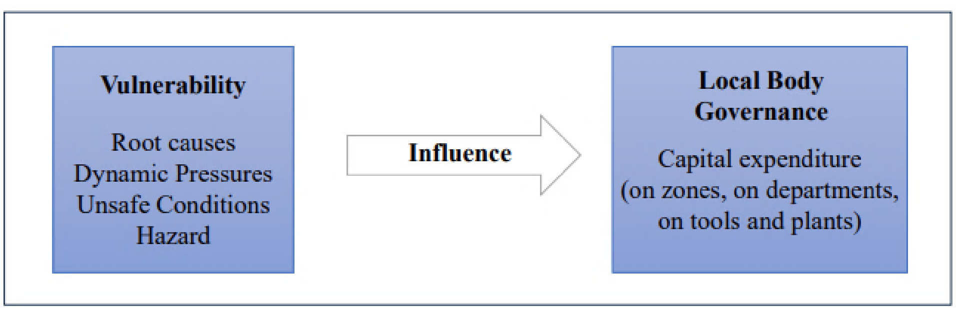


Figure 2-1 The conceptual Framework

The conceptual framework of this study explores the relationship between vulnerability and local body governance in flood disaster management within informal settlements. Vulnerability is understood through four components: root causes, dynamic pressures, unsafe conditions, and hazards, which together increase the exposure of informal settlements to flood risks. The framework investigates how these vulnerabilities influence governance decisions, particularly focusing on the capital expenditure by the Greater Chennai Corporation (GCC) on flood mitigation across zones, departments, and tools. Ideally, areas with higher vulnerability should receive more resources for flood management, but this study aims to assess whether that alignment exists. To do this, the study employs TOPSIS**,** a multi-criteria decision-making method, to rank vulnerable areas, and uses regression analysis to evaluate how vulnerability impacts governance decisions related to flood risk. By linking vulnerability to financial governance, this framework aims to highlight gaps and propose ways to make flood disaster management more effective and equitable.

2.5 SCOPE OF THE STUDY

The scope of this study is centered on informal settlements in Chennai, with a particular emphasis on the role of urban local body governance in flood disaster management. The study conducts a comprehensive vulnerability analysis using a variety of indicators to assess the susceptibility of these settlements to flood risks. It also investigates the governance strategies employed by the Greater Chennai Corporation (GCC) in managing flood risks and how effectively these strategies address the vulnerabilities of informal settlements. The study employs models such as Pressure and Release (PAR)**,** TOPSIS**,** and regression analysis to analyze the relationship between vulnerability and governance decisions, with the goal of identifying areas for improvement in flood disaster management policies.

2.6 LIMITATIONS OF THE STUDY

The complexity of the urban local body governance system poses challenges in quantifying factors such as leadership and community resilience**,** as these qualitative aspects may not be fully captured in the models used. Additionally, data acquisition can be inconsistent, especially in terms of financial details, as the information may vary across wards. This variation stems from differences in the way budget statements are reported by urban local bodies (ULBs) and other line departments.

CHAPTER 3 – LITERATURE STUDY

- Floods
- Flood Risk
- Vulnerability
- Flood risk Governance
- Flood risk Governance – Best Practices
- Flood Risk Governance – Challenges
- Flow of Funds in a Governance system

3 LITERATURE STUDY

3.1 FLOODS

Flooding is considered one of the most extreme and significant natural disasters that threaten the world's cities. Oxford dictionary (1989), defines flood as "An overflow or irruption of a great body of water over land in a built-up area not usually submerged." *(Abhas K. Jha, 2011)*

Floods are grouped into different categories based on the combination of its causes and human influence.

Table 3-1 Types of Floods

Types of Flooding	Causes	Human Influence
Urban Floods	Flash, Pluvial, Fluvial, coastal, & Ground water	Inadequate drainage and sewage capacity increase impermeability, poor management
Pluvial and overland flood	Extreme rainfall, Thunderstorms, melting of ice jam, glacial lake burst and landslides	Improper land management, encroachment, urbanization, surface runoff
Coastal (Tsunami, storm surge)	Subsidence, Coastal erosion, Earthquakes	Destruction of natural flora, Development of coastal zones (e.g., mangrove)
Groundwater	High water table level combined with heavy rainfall, Embedded effect	Interference with natural aquifers, Development around low-lying areas;
Flash flood	Caused by combination pluvial, river or coastal floods; thunderstorms	Catastrophic failure, Inadequate drainage capacity

Source: (Abhas K. Jha, 2011)

3.2 FLOOD RISK

Risk refers to the likelihood or probability that a hazard will occur at a specific time and place, resulting in potential negative consequences for people, property, and the environment. It is an essential concept in disaster management, particularly in urban areas like Chennai, where natural hazards such as floods frequently impact vulnerable communities. Understanding risk involves analyzing its key components: Hazard**,** Exposure, and Vulnerability**.** These components are interconnected and collectively determine the overall risk faced by a community. *(Hufschmidt, 2011)*

Figure 3-1 Components of Risk

Source: (Dewan, 2013)

3.2.1 HAZARD

A hazard is the probability of a damaging event occurring, characterized by its magnitude, duration, frequency, and spatial extent. In the context of floods, hazards include the likelihood of extreme rainfall events, river overflows, or coastal surges that may lead to inundation of specific areas within a defined time period. The hazard component not only considers the physical event but also its intensity—such as how severe the flooding will be and over what geographic area it is likely to occur. Accurate hazard prediction requires meteorological data, historical records of past floods, and simulations to anticipate future events. *(Hufschmidt, 2011)*

3.2.2 EXPOSURE (ELEMENTS AT RISK)

Exposure refers to the people, property, infrastructure, and economic activities that are likely to be affected by the hazard. These are often referred to as the "elements at risk." In urban areas, high population density, especially in informal settlements, leads to greater exposure to hazards like flooding. This means that more people, homes, public services, and economic assets are likely to be impacted when a flood occurs. Critical infrastructure such as roads, bridges, drainage systems, and public buildings may also be exposed to damage. Identifying exposure is essential to understanding who and what is at risk during a hazard event, and it forms the basis for developing protective measures. *(Hufschmidt, 2011)*

3.2.3 VULNERABILITY

Vulnerability is the degree to which the exposed elements are susceptible to damage or loss, based on their physical, social, economic, and environmental characteristics. Vulnerability determines how severely a hazard will affect the exposed population. Vulnerability varies across different segments of society; for instance, marginalized groups may have fewer resources to recover from flood events, and poorly built homes are more prone to damage. Vulnerability assessment involves analyzing factors such as housing quality, access to emergency services, and the resilience of critical infrastructure. The greater the vulnerability, the higher the potential for damage, even from relatively moderate hazards. *(Hufschmidt, 2011)*

3.3 VULNERABILITY

3.3.1 VULNERABILITY: SCHOOLS OF THOUGHT

Vulnerability Research has been based on two key paradigms: Human Ecologist School and Sen.’s Entitlement Approach.

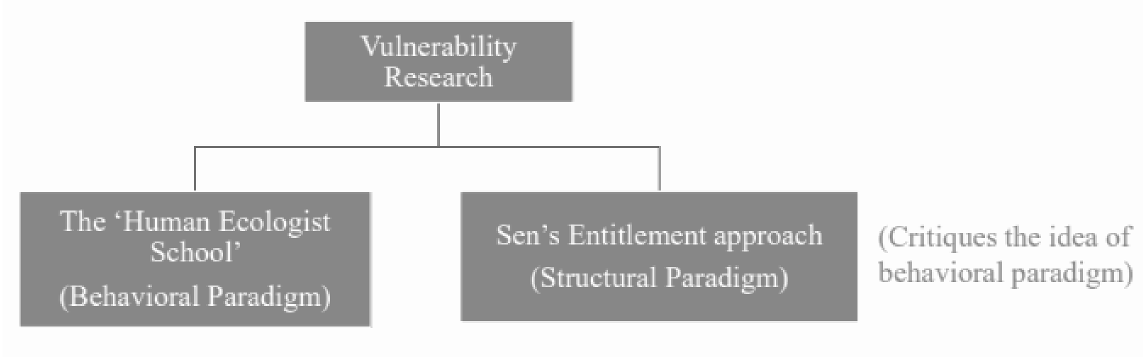


Figure 3-2 Vulnerability: Schools of Thought

Source: (Hufschmidt, 2011)

3.3.1.1 HUMAN ECOLOGIST SCHOOL (BEHAVIORAL PARADIGM)

The Human Ecologist School**,** often referred to as the Behavioral Paradigm, explores vulnerability through the lens of human behavior and interactions with the physical environment. This approach focuses on how individuals' decisions, actions, and behaviors influence their exposure to risk. It examines the ways people interact with their surroundings and the choices they make, which can increase or reduce their vulnerability to hazards. For example, individuals may choose to live in flood-prone areas due to economic necessity, despite the known risks.

Moreover, this paradigm emphasizes the adaptive capacity of individuals. It considers how people modify their actions and adapt to threats, shaping their ability to cope with hazards such as floods. Adaptation might include constructing makeshift flood barriers or altering daily routines to avoid risks. This paradigm highlights the importance of local-level coping strategies and risk management, recognizing the proactive measures individuals and communities take to mitigate their vulnerability. However, it also acknowledges that individual choices alone cannot fully eliminate risk, as adaptive actions are influenced by available resources and information. *(Hufschmidt, 2011)*

3.3.1.2 SEN'S ENTITLEMENT APPROACH (STRUCTURAL PARADIGM)

On the other hand, Sen.'s Entitlement Approach, or the Structural Paradigm, focuses on the political, social, and economic structures that shape vulnerability. This approach argues that individual actions and decisions are not entirely free but are constrained by institutional forces such as inequality, governance, and market systems. Vulnerability, in this context, is not just about personal choices but is shaped by the larger socio-political and economic framework within which people live. For instance, poor governance, weak infrastructure, and social inequality can exacerbate the vulnerability of marginalized populations, limiting their capacity to respond effectively to hazards.

In this paradigm, accessibility of resources is a key determinant of vulnerability. It asserts that the ability of individuals and communities to access resources—such as financial aid, health services, or emergency infrastructure—is governed by broader political and economic structures. For example, in flood-prone areas of Chennai, informal settlements may have limited access to municipal services, making them more vulnerable to the impacts of flooding. The Structural Paradigm, therefore, highlights the role of power, inequality, and institutional shortcomings in shaping vulnerability, making it clear that vulnerability is not just a personal or local issue but is deeply intertwined with governance and economic systems. *(Hufschmidt, 2011)*

3.3.2 VULNERABILITY MODELS

There are five most commonly used vulnerability models.

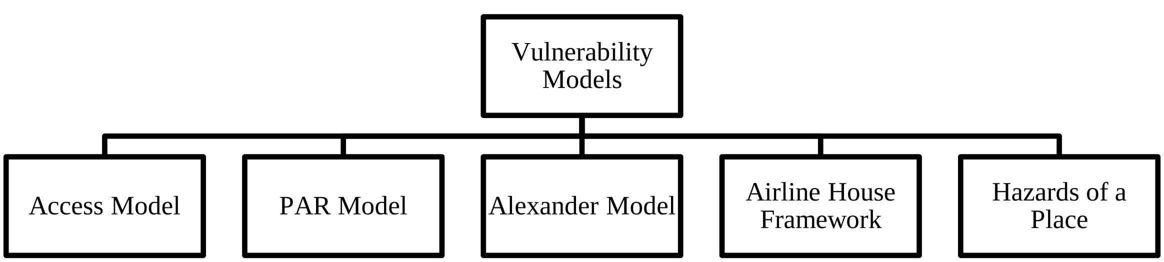


Figure 3-3 Vulnerability Models

Source: (Hufschmidt, 2011)

3.3.2.1 ACCESS MODEL

The Access Model focuses on how vulnerability is shaped by people's access to resources such as land, housing, employment, and information. The model argues that individuals' ability to cope with hazards is influenced by their access to these critical resources. Differentiation based on social, economic, or political status plays a crucial role in determining how well individuals can respond to disasters, with wealth inequality, land ownership, and government policies being key factors that exacerbate vulnerability. For instance, people with limited access to land or secure housing are more likely to live in flood-prone areas, making them highly vulnerable during flood events. *(Hufschmidt, 2011)*

3.3.2.2 PAR MODEL (PRESSURE AND RELEASE)

The Pressure and Release (PAR) Model examines vulnerability by identifying the root causes, dynamic pressures, and unsafe conditions that contribute to risk. Root causes refer to the underlying social and economic factors, such as poverty and inequality that create the foundation for vulnerability. Dynamic pressures include processes like rapid urbanization and deforestation, which translate these root causes into actual risks. Unsafe conditions are the specific circumstances, such as poor housing, lack of infrastructure, and living in hazard-prone areas, that leave people exposed to disasters. The PAR model is widely used to explain how socio-economic pressures transform into physical risks during events like floods. *(Hufschmidt, 2011)*

3.3.2.3 ALEXANDER MODEL

The Alexander Model breaks vulnerability down into four interconnected components: physical, social, economic, and environmental. The physical factor refers to the susceptibility of the built environment, such as poorly constructed buildings in flood zones. The social factor focuses on demographic characteristics, including age and education levels, which influence how different groups experience risk. The economic factor highlights the role of poverty, which limits access to resources needed to mitigate or recover from disasters. The environmental factor examines the role of poorly managed ecosystems in exacerbating risk, such as deforestation leading to increased flooding. This model provides a comprehensive view of how various factors contribute to vulnerability. *(Hufschmidt, 2011)*

3.3.2.4 AIRLINE HOUSE FRAMEWORK

The Airline House Framework focuses on housing-specific vulnerabilities, recognizing that inadequate housing quality, such as poor maintenance and construction, increases susceptibility to disasters like floods. It also examines tenant vulnerability, particularly how socio-economic factors—such as income levels and employment status—affect a person's ability to cope with and recover from disasters. Additionally, the framework considers environmental and climate factors, such as the impacts of climate change, which can worsen housing conditions in disaster-prone areas, making recovery efforts more difficult. *(Hufschmidt, 2011)*

3.3.2.5 HAZARDS OF A PLACE FRAMEWORK

The Hazards of a Place Framework emphasizes the localized nature of vulnerability, focusing on how geographic location and specific risk exposures—such as proximity to flood-prone areas—affect different communities. It also examines social vulnerability**,** highlighting how demographics (e.g., age, education, health) shape the risk of exposure to hazards. The interaction between physical exposure (such as living near rivers) and social conditions (like poverty) defines how a community experiences and responds to hazards, making this framework particularly useful for assessing vulnerability at a neighborhood or community level. *(Hufschmidt, 2011)*

3.3.3 PRESSURE AND RELEASE MODEL (PAR)

This model depicts the Pressure and Release (PAR) framework, illustrating how risk is a product of multiple interconnected factors that escalate from root causes to hazards. The model begins by identifying root causes such as limited access to power, resources, and political ideologies that marginalize certain groups. These foundational issues are magnified by dynamic pressures, including a lack of local institutions, rapid urbanization, and environmental degradation, which further constrain communities' ability to respond to disasters. Together, these forces lead to unsafe conditions, where populations live in hazardous environments with inadequate infrastructure, putting livelihoods and lives at constant risk. *(Christopher G. Burton, 2018)*

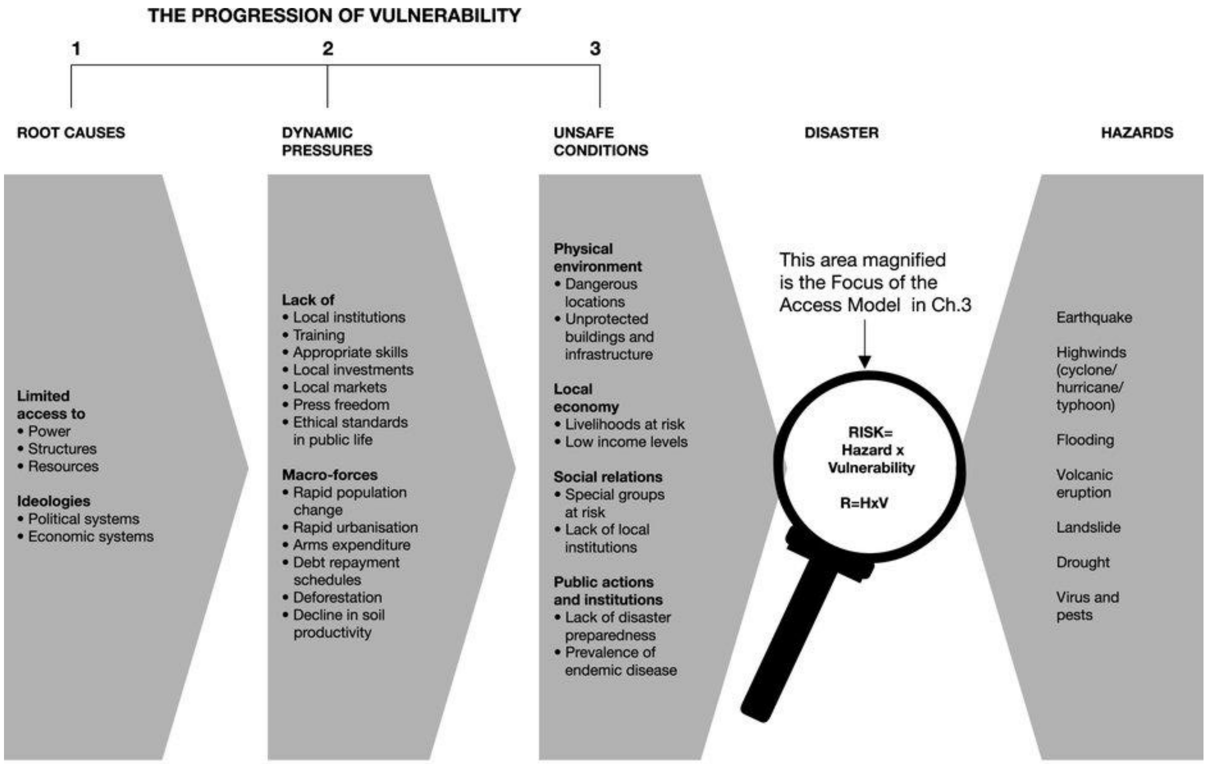


Figure 3-4 PAR Model

Source: (Christopher G. Burton, 2018)

In this framework, risk is conceptualized as a combination of hazard and vulnerability (R = H x V), emphasizing the need to focus on vulnerability to understand disaster risks fully. By addressing underlying social, economic, and institutional vulnerabilities**,** we can mitigate the impacts of hazards like floods, droughts, and cyclones. The model underscores the importance of a holistic approach, where understanding and mitigating risk involves addressing root causes, dynamic pressures, and unsafe conditions simultaneously. This approach is critical for flood risk management, particularly in vulnerable, low-income communities exposed to high disaster risk. *(Christopher G. Burton, 2018)*

3.4 FLOOD RISK GOVERNANCE

Flood risk governance plays a crucial role in determining how flood risks are managed, as well as how the costs and benefits of flood management are distributed across society. *(Tullos, 2018)*

3.4.1 COMPONENTS OF FLOOD RISK MANAGEMENT

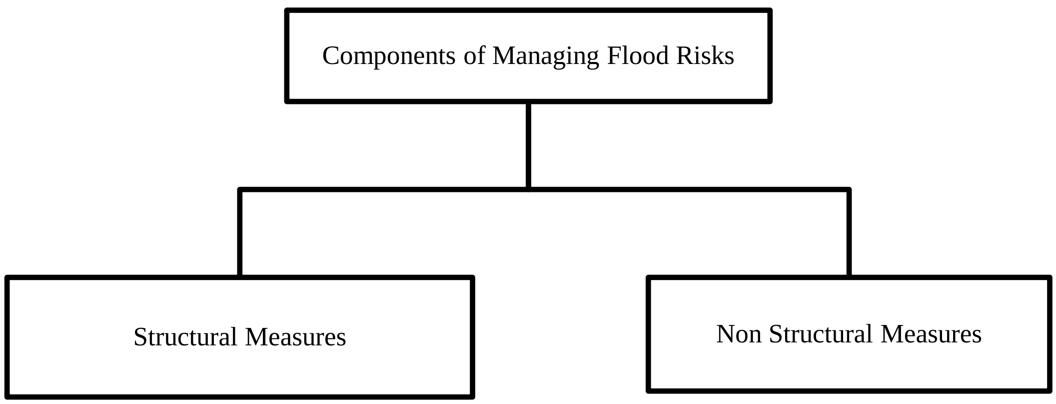


Figure 3-5 Components of Flood Risk Governance

Source: (Abhas K Jha, 2011)

Effective governance involves a balanced approach that integrates both structural and non-structural measures to address flood risks. Structural measures focus on physical infrastructure, such as dams, levees, dikes, reservoirs, storm water systems, and drainage networks**.** These solutions require significant capital investment and long-term maintenance but provide physical protection against floodwaters. By creating barriers and redirecting water flow, structural measures can prevent widespread damage and protect large populations. However, they are often expensive and can have negative environmental impacts if not managed carefully. *(Abhas K Jha, 2011)*

On the other hand, non-structural measures encompass policy-driven and management-based strategies, such as floodplain zoning, land use planning, disaster preparedness, and financial mechanisms like insurance. These measures focus on minimizing flood risk through regulatory frameworks, early warning systems, and sustainable land use. Although they typically involve lower initial costs compared to physical infrastructure, non-structural measures can be more sustainable in the long run by promoting resilience and adaptability. They aim to reduce the vulnerability of communities to floods without requiring extensive physical alterations to the environment, making them an integral part of modern flood risk management strategies. *(Abhas K Jha, 2011)*

3.4.2 APPROACHES TO EVALUATING FLOOD GOVERNANCE

The three approaches discussed in this study — Risk Governance Assessment Tool**,** Social Milieu Approach**,** and Fit for Purpose Governance Framework — provide a comprehensive toolkit for assessing and improving flood governance. They highlight the importance of stakeholder engagement, resource adequacy, social and cultural factors, and the need for inclusive governance that responds to the needs of marginalized communities.

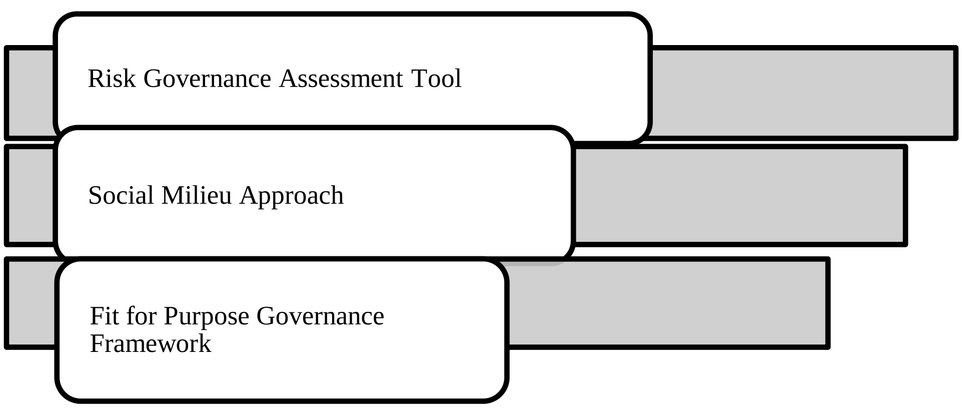


Figure 3-6 Approaches to Evaluating Flood Governance

Source: (M. Fleischhauer, 2012)

3.4.2.1 RISK GOVERNANCE ASSESSMENT TOOL

The Risk Governance Assessment Tool focuses on identifying and evaluating flood risks based on their impact and probability of occurrence. It emphasizes the importance of including all relevant stakeholders in the governance process, particularly vulnerable communities who are disproportionately affected by floods. By assessing how well these communities are involved, the tool ensures that flood management strategies reflect the needs and concerns of those most at risk. Additionally, it examines whether the available resources—financial, human, and technical—are sufficient to effectively manage and mitigate flood risks. This holistic approach ensures that all aspects of flood governance are aligned to minimize risk and improve resilience. *(M. Fleischhauer, 2012)*

3.4.2.2 SOCIAL MILEU APPROACH

The Social Milieu Approach provides a deeper understanding of the population characteristics in flood-prone areas**.** It investigates various cultural, social, and economic factors that contribute to the community's vulnerability, such as income levels**,** access to resources**,** and overall social structures. This approach also studies how individuals and communities react to flood risks—whether they take proactive measures to mitigate risk, rely on external assistance**,** or choose to ignore the risks altogether. By analyzing these behaviors, policymakers can develop more tailored strategies that enhance flood preparedness and response, making sure that interventions consider local contexts and needs. *(M. Fleischhauer, 2012)*

3.4.2.3 FIT FOR GOVERNANCE FRAMEWORK

This framework evaluates the adaptability of governance systems in the face of changing circumstances, such as increasing flood frequency or severity due to climate change. It emphasizes the importance of collaboration between various sectors, including government**,** civil society**,** and the private sector**,** to ensure that flood governance is effective and inclusive. A key feature of this approach is its focus on involving marginalized communities in decision-making processes, ensuring that flood governance frameworks are equitable and that vulnerable populations are not left out of critical planning and response efforts. The "Fit for Purpose" governance model ensures that strategies are flexible and responsive, adapting to new challenges while prioritizing inclusive and collaborative governance practices. *(M. Fleischhauer, 2012)*

3.5 FLOOD RISK GOVERNANCE – BEST PRACTICES

The following are some of the best practices followed around the world in terms of Flood risk governance.

3.5.1 UK: STRATEGIC NATIONAL FRAMEWORK AND "MAKING SPACE FOR WATER" (2005)

The UK's "Making Space for Water" policy represents a strategic shift in flood risk management by promoting natural flood management methods. This approach emphasizes restoring natural floodplains and wetlands, which act as buffers, allowing rivers to overflow into these areas during heavy rainfall events. By prioritizing these natural flood defenses, the UK aims to reduce the impact of floods on built-up areas. *(Ishiwatari, 2019)*

Figure 3-7 UK - Making Space for Water (MSW) Framework

Source: (Ishiwatari, 2019)

The framework also integrates flood risks into land-use planning processes, ensuring that urban development is conducted in a way that considers potential flooding. This holistic approach involves collaboration with local communities, engaging them in decision-making, and supporting local-level planning to create resilience against future floods. The strategy balances engineering solutions with environmental sustainability, recognizing the need for adaptive, long-term planning. *(Ishiwatari, 2019)*

3.5.2 NETHERLANDS: "ROOM FOR THE RIVER" PROGRAM (EARLY 2000S)

The Netherlands, long recognized for its expertise in water management, launched the "Room for the River" program as part of a broader strategy to adapt to climate change and increasing flood risks. The program aims to reduce flood risks by expanding river channels, lowering floodplains, and creating new ones, allowing rivers to safely flood during periods of heavy rainfall. This reconnection of rivers to their natural floodplains reduces the threat to urban areas. One significant aspect of the program involves relocating some settlements away from rivers to safer areas, with zoning laws enforced to prevent development in vulnerable flood-prone regions. The program is also notable for its participatory approach, involving local communities in decision-making processes related to land use and flood management. This inclusion ensures that the solutions adopted are both technically sound and socially acceptable, making the strategy more effective and sustainable in the long term. *(Ishiwatari, 2019)*

3.5.3 GERMANY: REVISED FRM APPROACH AFTER 2003 FLOODS

Following the catastrophic floods of 2003, Germany implemented substantial revisions to its flood risk management (FRM) approach, focusing on natural flood retention and improving governance structures. One of the key components of the revised approach is the expansion of natural flood retention zones, which involves utilizing open spaces to absorb excess water and mitigate the impact of floods. The country also placed a stronger emphasis on emergency preparedness, recovery planning, and coordination between different levels of government—federal, state, and local. By improving this coordination, Germany has been able to respond more effectively to flood emergencies and ensure faster recovery. Another important element of the revised strategy is the introduction of private flood insurance in areas prone to flooding, which encourages property owners to take responsibility for their own flood risk management while also reducing the financial burden on the government. This multi-tiered approach has strengthened Germany's ability to cope with and recover from flooding events. *(Ishiwatari, 2019)*

3.5.4 JAPAN: FLOOD RISK GOVERNANCE IN TSURUMIGAWA RIVER BASIN IN THE TOKYO METROPOLITAN REGION

In the Tsurumigawa River basin of the Tokyo Metropolitan Region, Japan’s flood risk governance is considered a best practice, particularly due to the collaborative efforts initiated in response to the rapid urbanization that heightened flood risks during the 1950s and 1960s. By the 1970s, a river basin committee was established by a national ministry field office to coordinate integrated flood risk management (FRM) among a broad range of stakeholders, including local leaders, communities, government offices, and civil society organizations. *(Ishiwatari, 2019)*

Figure 3-8 Concept of Collaborative actions in Japan

Source: (Ishiwatari, 2019)

While national government offices led these efforts in Japan, local governments typically play this role in other countries, highlighting that effective FRM requires collaboration regardless of the governmental level. A key success factor was the trust built between government engineers and local communities, which allowed the integration of local knowledge into the planning process. Additionally, Japan benefited from the exchange of technical expertise through long-term relationships with academic experts and a staff rotation system between field offices and national headquarters, allowing personnel to apply their experience across different regions. *(Ishiwatari, 2019)*

3.6 FLOOD RISK GOVERNANCE – CHALLENGES

3.6.1 CHINA: SPONGE CITY INITIATIVE AND BUREAUCRATIC CHALLENGES

In China, the Sponge City Initiative focuses on utilizing urban green infrastructure like green roofs and permeable surfaces to absorb, store, and reuse rainwater, reducing flood risks. However, the initiative faces challenges due to its top-down approach, where the central government mandates flood management programs while local governments struggle with limited capacity and resources to implement them effectively. The complexity of the country's bureaucratic structure, with multiple agencies managing different aspects of flood risk, further complicates cohesive flood management efforts.

3.6.2 CAPE TOWN, SOUTH AFRICA: TECHNOCRATIC DOMINATION AND CAPACITY CONSTRAINTS

In Cape Town, South Africa, flood risk management is heavily dominated by technocratic solutions, prioritizing engineering approaches over more inclusive, participatory methods. This has been compounded by a lack of sufficient financial and human resources to implement comprehensive flood management plans. Furthermore, the roles and responsibilities for managing and sharing flood risks between the government, private sector, and communities remain unclear, posing additional challenges to effective flood risk governance.

3.6.3 UNITED STATES: POLITICIZATION AND INTERDISCIPLINARY CHALLENGES

In the United States, flood risk management is shaped by initiatives like the National Flood Insurance Program (NFIP) and other disaster response frameworks. However, the politicization of flood management often affects decisions regarding where and how to allocate resources for flood mitigation infrastructure. Additionally, there are significant interdisciplinary challenges, particularly in integrating knowledge and practices from engineering, legal, and social sciences, making it difficult to create holistic and balanced flood risk management strategies.

3.7 FLOW OF FUNDS IN A GOVERNANCE SYSTEM

The financial structure of flood risk governance and urban management in Chennai involves both revenue and capital accounts**,** starting with an opening balance**,** which represents the initial capital available for expenditures. The revenue account includes revenue receipts, such as income from taxes and fees, which fund revenue expenditures—expenses related to services and administration. The balance on this account is determined by the surplus or deficit between income and expenditures.

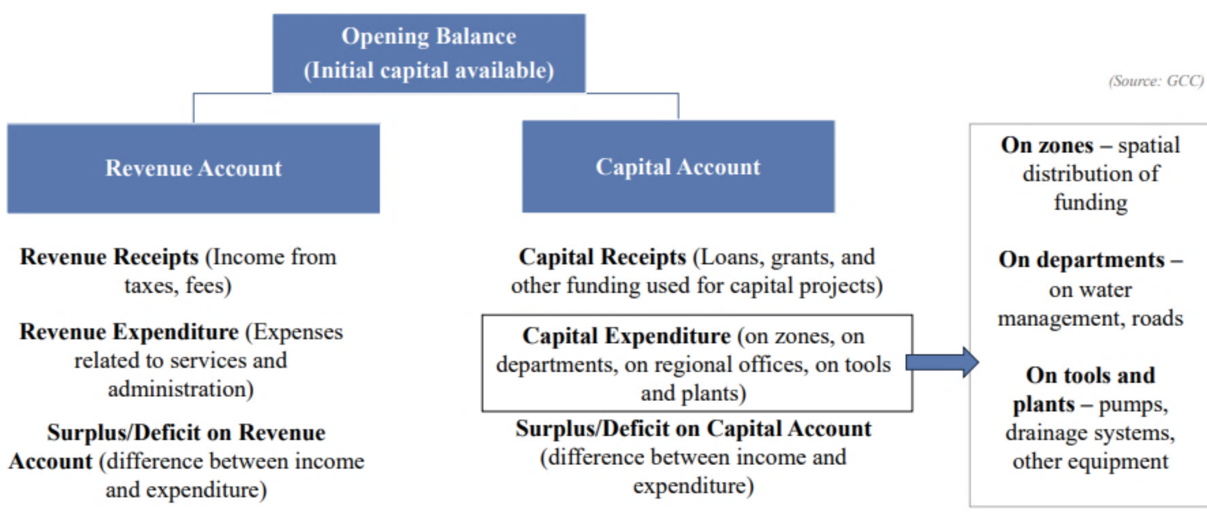


Figure 3-9 Flow of Funds

Source: (Greater Chennai Corporation)

Similarly, the capital account covers capital receipts**,** including loans, grants, and other funding for long-term projects. These receipts finance capital expenditures on critical projects like water management, infrastructure for roads, and the procurement of tools and equipment such as pumps and drainage systems. The surplus or deficit on the capital account reflects the difference between the funds allocated for projects and the actual expenditures. The capital is further allocated based on spatial distribution**,** where funds are spent across different zones and departments to ensure that resources are invested where they are needed most, such as in regional offices, flood management, and infrastructure upgrades.

CHAPTER 4 – METHODOLOGY

- Research Design
- Vulnerability Index of Informal Settlements
- Regression analysis of Governance expenditure and Flood vulnerability

4 METHODOLOGY

4.1 RESEARCH DESIGN

The research design outlines the overall approach used to address the research objectives and questions. This study employs a mixed-methods approach, combining both qualitative and quantitative methods to gain a comprehensive understanding of flood risk governance in Chennai’s informal settlements. The study integrates spatial analysis techniques with primary data collection to assess vulnerability and governance effectiveness. The focus is on understanding the relationship between governance expenditure and flood vulnerability using tools like GIS, TOPSIS, and spatial regression models. This design ensures a systematic analysis of both governance strategies and socio-economic conditions in flood-prone areas.

Figure 4-1 Research Design

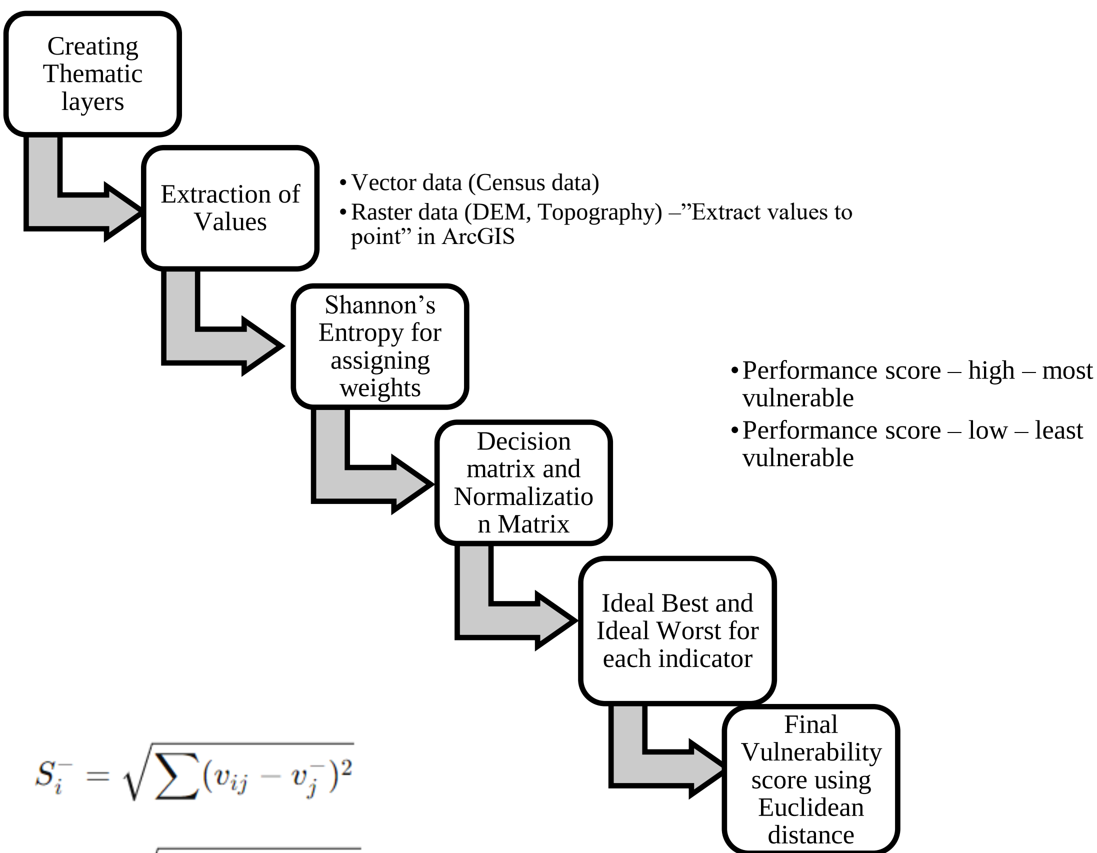
4.2 VULNERABILITY INDEX OF INFORMAL SETTLEMENTS

The TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method is used in this study to rank wards based on their flood vulnerability. First, spatial layers for various indicators, such as population density and land use, are created. Data is extracted from these layers using tools in ArcGIS, with raster data (like topography) processed through the "Extract values to point" tool and vector data (like census data) taken from attribute tables. *(Mitra, 2023)*

Weights for each indicator are assigned using Shannon’s Entropy, reflecting their importance. These weights are then incorporated into the data to form a decision matrix, which is normalized using the Field Calculator in ArcGIS. The ideal best and worst values for each indicator are calculated, and the Euclidean distance is used to measure how close each ward is to these ideal values, determining their vulnerability. *(Mitra, 2023)*

A final vulnerability score is calculated for each ward, with higher scores indicating higher vulnerability. Using the Natural Breaks (Jenks) method, the wards are classified into high, medium, and low vulnerability zones. These are then mapped using a Choropleth map, which is combined with a governance expenditure map to analyze how resources are allocated relative to flood vulnerability across the study area. *(Mitra, 2023)*. Performance score can be calculated using the formula:

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-}$$



$$S_i^- = \sqrt{\sum (v_{ij} - v_j^-)^2}$$

$$S_i^+ = \sqrt{\sum (v_{ij} - v_j^+)^2}$$

Figure 4-2TOPSIS analysis of Vulnerability Index

Source: (Mitra, 2023)

4.3 REGRESSION ANALYSIS OF GOVERNANCE EXPENDITURE AND FLOOD VULNERABILITY

The Akaike Information Criterion (AIC) is a statistical measure used to compare the goodness of fit between two models. A lower AIC value indicates a better fit, as it suggests that the model has less error. In the context of Aspatial regression analysis**,** such as Ordinary Least Squares (OLS)**,** the model does not account for spatial dependency between variables like vulnerability and governance expenditure. A lower AIC in this scenario means that there is no spatial autocorrelation. However, in spatial regression analysis**,** models like Spatial Lag Model (SLM)**,** Spatial Error Model (SEM)**,** or Spatial Durbin Model (SDM) are used to account for spatial dependencies. A lower AIC here would indicate that spatial patterns, or dependencies between data points, do exist, and that the model has accounted for these dependencies effectively.

In spatial regression analysis**,** the relationship between governance expenditure and flood vulnerability is examined across different wards. The dependent variable is governance expenditure**,** while the independent variable is the flood vulnerability index. The process begins with creating spatial layers for the data and performing a spatial join in GIS, linking governance expenditure data with vulnerability data using ward boundaries as the base layer. Exploratory Spatial Data Analysis (ESDA) is then performed to identify spatial patterns.

Key tools in this process include Moran's I**,** which checks for spatial autocorrelation. A positive value for Moran's I indicate that high vulnerability and high expenditure are spatially clustered; while a negative value shows that these factors are dispersed. LISA (Local Indicators of Spatial Association) helps identify clusters, hotspots (areas of high vulnerability and high expenditure), cold spots, and outliers.

The Spatial Lag Model (SLM) is used to determine how governance expenditure in one ward is influenced by the expenditure in neighboring wards. In this model, the dependent variable is expenditure**,** and the independent variable is the flood vulnerability index. A spatial weights matrix is applied to account for the geographic relationships between wards. If the lag term is significant, it indicates that governance expenditure in a particular ward is indeed influenced by surrounding wards. The model's coefficient will show a positive relationship when higher vulnerability leads to higher expenditure in neighboring wards, and a negative relationship when lower vulnerability corresponds to lower expenditure in adjacent wards.

CHAPTER 5 – DATA COLLECTION

- Physical Vulnerability Factors
- Socio Economic Factors
- Capital Expenditure

5 DATA COLLECTION

5.1 PHYSICAL VULNERABILITY FACTORS

Indicators are identified for the flood vulnerability map that can be used to access the likelihood of a flood recurring and its potential impact. Here are few:

- **Land Use Land Cover:** Refers to how land is used (residential, industrial, vegetation, water bodies) and the physical cover on the surface (built-up, forest, grassland, etc.). Its relevance to the thesis is such that the impervious surfaces (like concrete) increase surface runoff, reducing infiltration and exacerbating flood risks in informal settlements. LULC maps are developed through Landsat 9 satellite images.
- **Drainage Density:** The total length of all streams and rivers in a drainage basin divided by the total area of the basin gives the drainage density. Higher drainage density usually means faster runoff, while low density can lead to waterlogging. It's essential in analyzing flood risk areas.
- **Rainfall:** Measures the amount of precipitation (in mm) received over time. This directly influences flood potential. Intense or prolonged rainfall overwhelms urban drainage, especially in vulnerable informal settlements. Rainfall data is taken from the IMD.
- **Distance from River:** The straight-line (Euclidean) distance of a location from the nearest river or stream gives the distance from river. Settlements closer to rivers are more prone to flooding. Informal settlements often encroach riverbanks due to land access. This is a GIS based analysis from river shape files.
- **Slope:** The steepness or incline of the terrain is slope. Steep slopes increase surface runoff, while flatter areas may lead to stagnant water accumulation. Both affect flood risk differently. These are extracted from DEM images.
- **Elevation:** The height of a location above mean sea level is elevation. Low-lying areas are more prone to flooding. Many informal settlements in Chennai are in such areas. Elevation map can also be made through DEM images.

- **Stream Power Index (SPI):** SPI is a measure of the erosive power of flowing water, calculated using slope and upstream contributing area. Higher SPI areas are more prone to erosion and concentrated flow paths, indicating flood risk zones. This is derived from DEM using GIS Hydrology tools.
- **Topographic Wetness Index (TWI):** TWI is a measure of the potential for water accumulation in the landscape, based on slope and upstream area. High TWI values indicate areas likely to retain water – potential hotspots for waterlogging or flooding. This is derived from DEM using GIS Hydrology tools.
- **Groundwater Levels:** The depth of groundwater below the surface or its fluctuation across seasons. High groundwater tables reduce infiltration capacity, increasing surface runoff and flood risk. These are got from the CMWSSB for Chennai city.
- **Length of Storm water Drains:** It is the total length of formal drainage infrastructure in a given area. A lower density of storm water drains indicates poor infrastructure, making areas (especially informal settlements) more vulnerable to flooding. This is got from Greater Chennai Corporation department.

5.2 SOCIO ECONOMIC FACTORS

The data collection is done through primary surveys and secondary sources. The primary survey includes interviews, observations and opinions of the public. The secondary data is collected for the indicators of Vulnerability as defined by the PAR model.

Table 5-1 Socio Economic factors and its sources

Data	Source
Housing condition (building materials, building type)	Primary Survey
Awareness and perception of flood risks	
Coping mechanisms during floods (evacuation plans, assistance received)	

Impact of flood on livelihood, health, property	
Perceptions of local governance and flood disaster management	
Informal Settlements population	Slum Free Action Plan – RAY, AAY beneficiaries
Land ownership	TNSCB
Access to Infrastructure	Slum Free Action Plan – RAY, AAY beneficiaries
Employment type	Census data
Population Density	GIS mapping
Encroachment	GCC, CMDA
Access to services (water, sanitation)	Master Plan
Proximity to Hazardous zones	GIS Flood mapping
Building density	GIS mapping
Health risks	Health Department records
Flood spots	Flood reports
Tenability Analysis	Satellite Imagery
Cooking Fuel type	GIS mapping
Sanitation	Aquifer Report
Roof type, Floor type	DEM
Objection ability of the slums	Slum Free Action Plan – RAY, AAY beneficiaries
Amma Unavagams	GCC & Disaster Management Plan
Flood and Rain relief centers	GCC & Disaster Management Plan
Schools	GCC & Disaster Management Plan

5.3 CAPITAL EXPENDITURE

Factors are identified and are taken from the Chennai annual Budget to analyze the use of capital in different forms. The following factors are some of which are relevant to the study.

- **Financial Plan – Tenable and Untenable slums:** Classification of slums as tenable (legal and can be upgraded in-situ) or untenable (located on environmentally sensitive or hazardous lands and often marked for relocation) helps assess if public spending (e.g., infrastructure or flood protection) is being directed to areas that are actually permitted to receive it. A mismatch could indicate governance gaps or inefficiencies in investment. The plan is taken from the RAY – Slum free action plan for Chennai.
- **Revenue receipts and revenue expenditure in GCC Budget statement:** Revenue receipts are income from taxes, fees, fines, and user charges. Revenue expenditure is spending on services such as salaries, maintenance, and other recurring operational costs. This helps evaluate how much of the city's financial resources are available for ongoing flood management services and whether enough is being spent on maintaining infrastructure in informal settlements.
- **Capital receipts & capital expenditure:** Capital receipts are income from loans, grants, or asset sales used for long-term investment. Capital expenditure is the spending on creating or upgrading physical assets like roads, storm water drains, and water bodies. This shows the city's long-term flood resilience investments**.** It is critical to assess whether capital spending aligns with vulnerability zones in informal settlements.
- **Capital expenditure on zones:** The Ward- or zone-level distribution of capital expenditure by GCC is used to compare capital expenditure with vulnerability to test the hypothesis—whether disaster governance (i.e., spending) is driven by vulnerability levels.
- **Capital expenditure on tools & plants on zones:** Capital spending on equipment like dewatering pumps, storm water cleaning machines, desilting machines, etc.

This is directly tied to flood management preparedness and response. Indicates how well-equipped a zone is in terms of disaster response tools.

- **Community perception of Public Expenditure:** This shows how local residents perceive government spending—whether it reaches them, whether it is useful, and how fairly it is distributed. It is important for understanding the governance deficit from a bottom-up perspective. Reveals whether capital expenditure translates into visible and functional infrastructure.
- **Relief and compensation accessibility:** This refers to how easily flood-affected households can access government relief such as financial aid, food, or shelter support post-disaster. It is critical for assessing response effectiveness and social safety nets. Poor accessibility reflects weak governance or poor targeting mechanisms.
- **Household investment in flood preparedness:** It is the extent to which families invest in self-protection (e.g., raising plinths, buying sandbags, building storage platforms). This indicates the gap in public support—if households invest a lot, it may show mistrust in public preparedness or insufficient coverage.

CHAPTER 6 – ANALYSIS

- Characteristics of Chennai City
- Vulnerability Analysis
- Capital Expenditure Analysis
- Correlation and regression between vulnerability and expenditure
- Final classification of wards and informal settlements
- Conclusion: synthesizing vulnerability and governance insights

6 ANALYSIS

6.1 CHARACTERISTICS OF CHENNAI CITY

Chennai is a coastal city in the Indian state of Tamil Nadu, facing the Bay of Bengal. Its geographical location and urban development patterns make it particularly susceptible to urban flooding. Over the years, the city has witnessed multiple flood events that have severely impacted the population, especially those living in informal settlements. These settlements are typically located along water bodies such as rivers, canals, and marshlands, as well as in low-lying zones that are naturally prone to inundation.

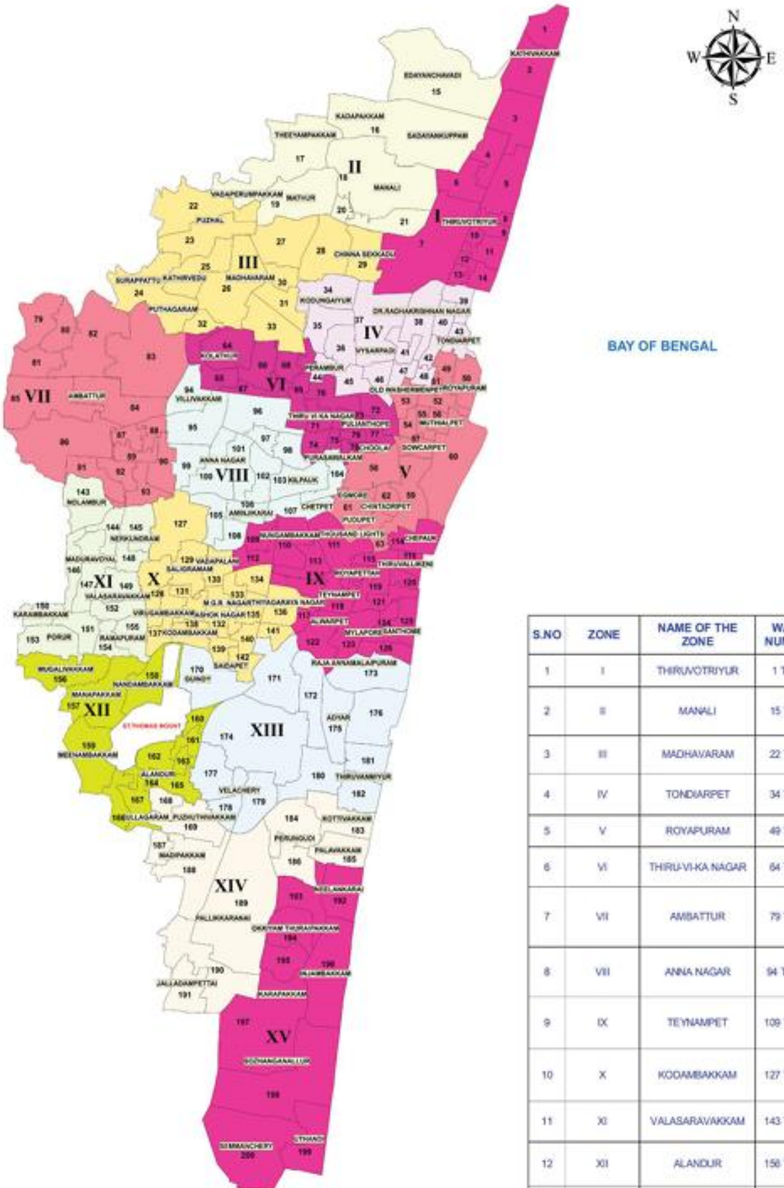
Table 6-1 Statistics of Chennai City

Data	Value
Area of CMA	1189 sq.km
Area of GCC	426 sq.km (30% of CMA area)
Population (2011)	66.85 lakhs (75% of CMA population)
Population 2022 (est)	77.56 lakhs (71% of CMA population)
Number of Zones (GCC)	15
Number of Wards (GCC)	200

The study area encompasses numerous informal settlements distributed across different administrative zones within the Greater Chennai Corporation (GCC). These settlements have evolved over time, often without formal planning or infrastructure support, increasing their vulnerability to floods.

Demographically, the population density in these areas is extremely high. A significant portion of residents belong to marginalized communities, including Scheduled Castes

(SC), Scheduled Tribes (ST), and Below Poverty Line (BPL) households. These groups are often economically and socially disadvantaged, with limited access to basic services, secure housing, and formal employment opportunities.



S.NO	ZONE	NAME OF THE ZONE	WARD NUMBER
1	I	THIRUVOTRIYUR	1 TO 14
2	II	MANALI	15 TO 21
3	III	MADHAVARAM	22 TO 33
4	IV	TONDIARPET	34 TO 48
5	V	ROYAPURAM	49 TO 63
6	VI	THIRU-VI-KA NAGAR	64 TO 78
7	VII	AMBATTUR	79 TO 93
8	VIII	ANNA NAGAR	94 TO 108
9	IX	TEYNAMPET	109 TO 126
10	X	KODAMBAKKAM	127 TO 142
11	XI	VALASARAVAKKAM	143 TO 155
12	XII	ALANDUR	156 TO 167
13	XIII	ADYAR	170 TO 182
14	XIV	PERUNGUDI	168,169 183 TO 191
15	XV	SOZHANGANALLUR	192 TO 200

Figure 6-1 Zones and Wards of Chennai District

Source: GCC

Physically, the terrain of Chennai is predominantly flat with low elevation levels, particularly in the northern and central parts of the city. This topography limits natural drainage and increases the risk of waterlogging. In addition, the widespread encroachment of natural waterways and inadequate storm water infrastructure has further aggravated flood vulnerability.

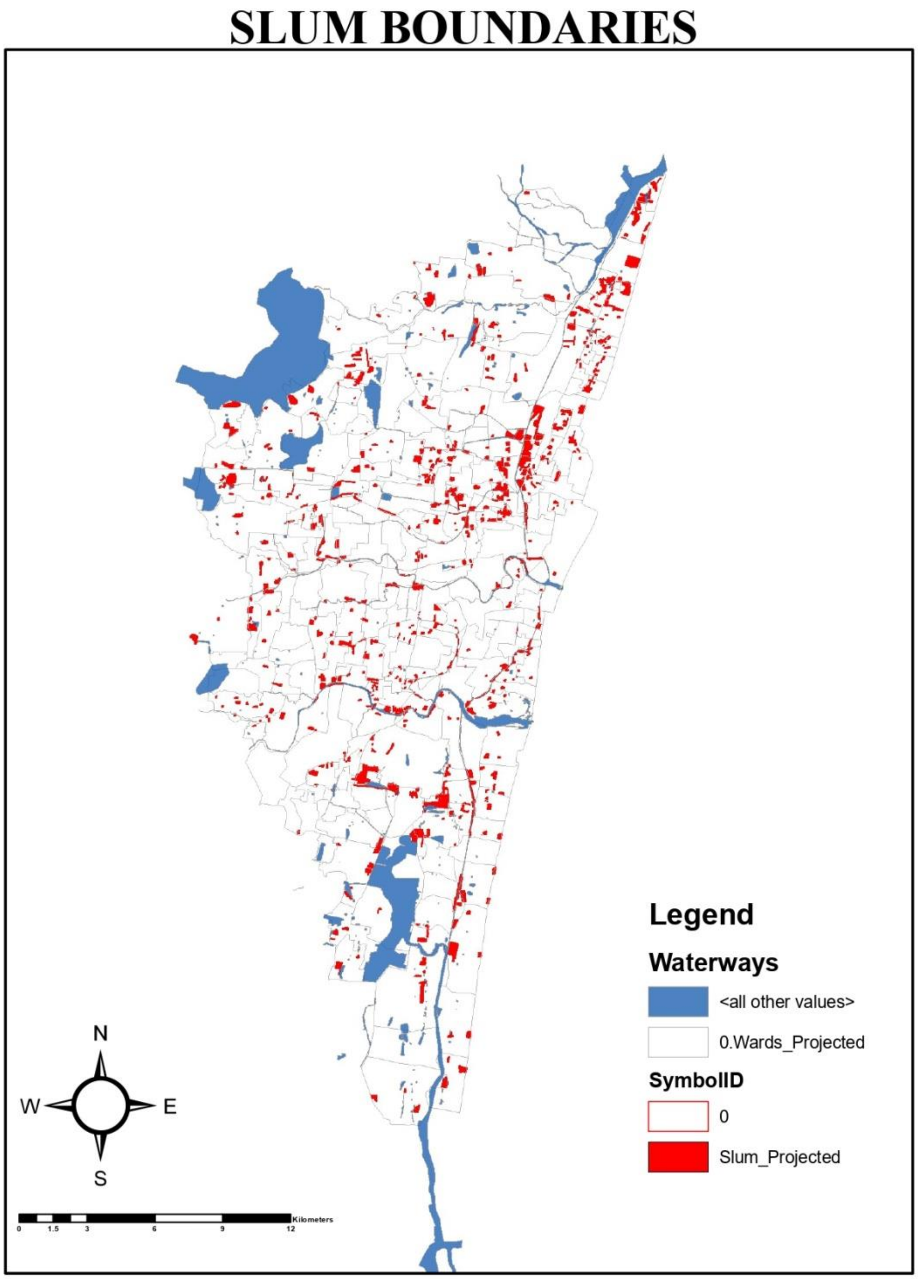


Figure 6-2 Slum Boundaries with waterways in Chennai City

6.2 VULNERABILITY ANALYSIS

6.2.1 PHYSICAL VULNERABILITY

6.2.1.1 PHYSICAL FACTORS AFFECTING THE VULNERABILITY:

- **LULC:** Water bodies show the highest flood risk, bare soil show a high risk while settlements and vegetation show moderate and low flood risk respectively.

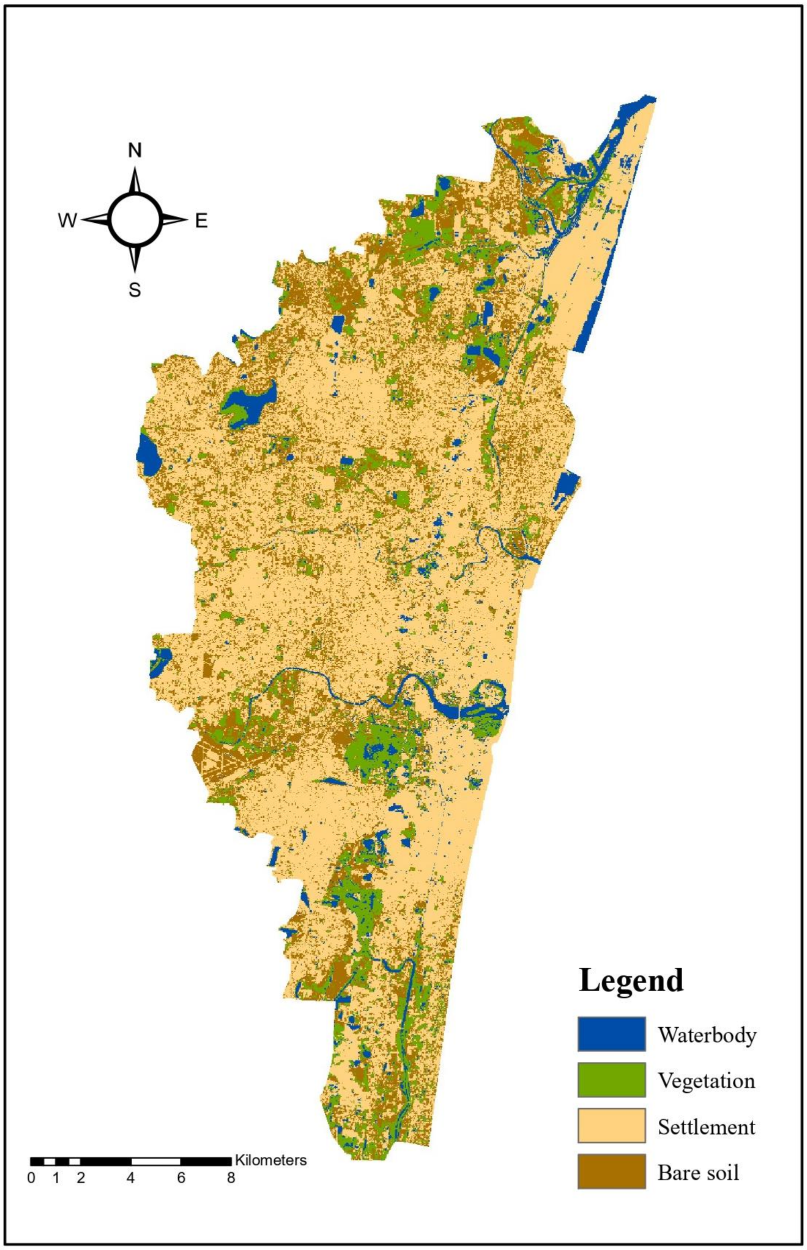


Figure 6-3 LULC

- **DRAINAGE DENSITY:** High Drainage density means increased run off and increased possibility of flood.

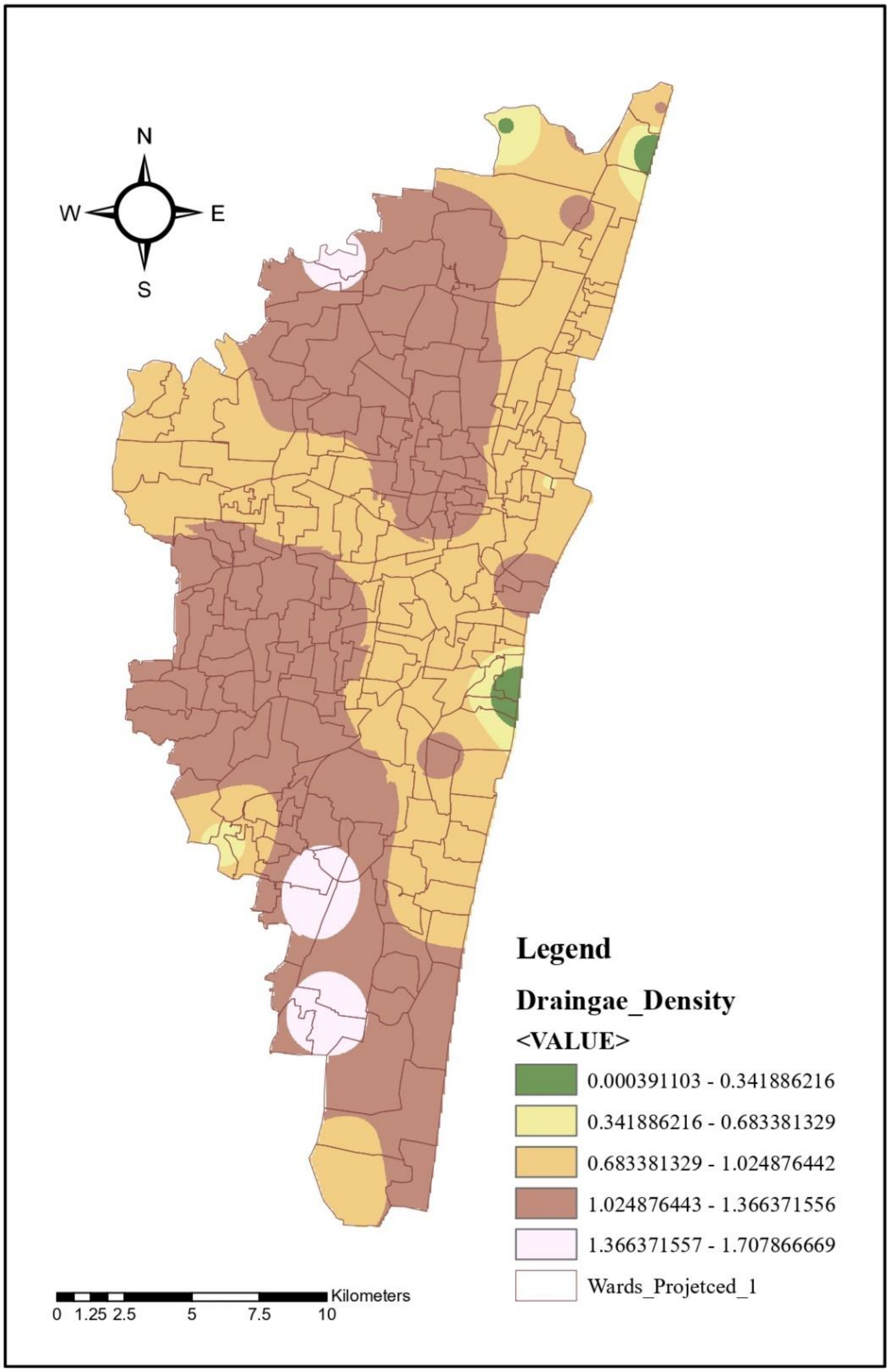


Figure 6-4 Drainage Density

- **ELEVATION:** Low elevation means high risk zones for flooding.

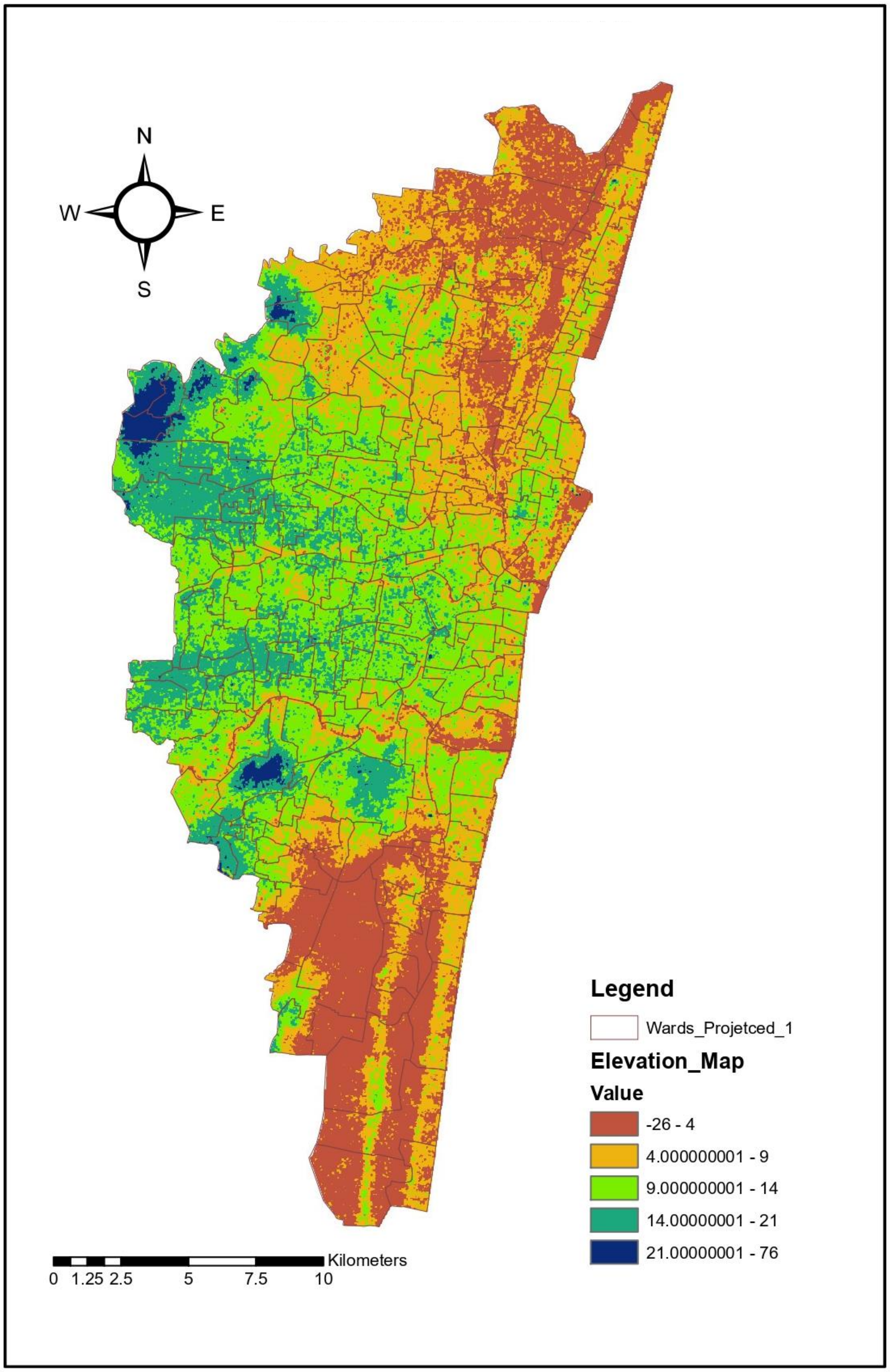


Figure 6-5 Elevation

- **STREAMS:** Stream lengths are taken to calculate the proximity.

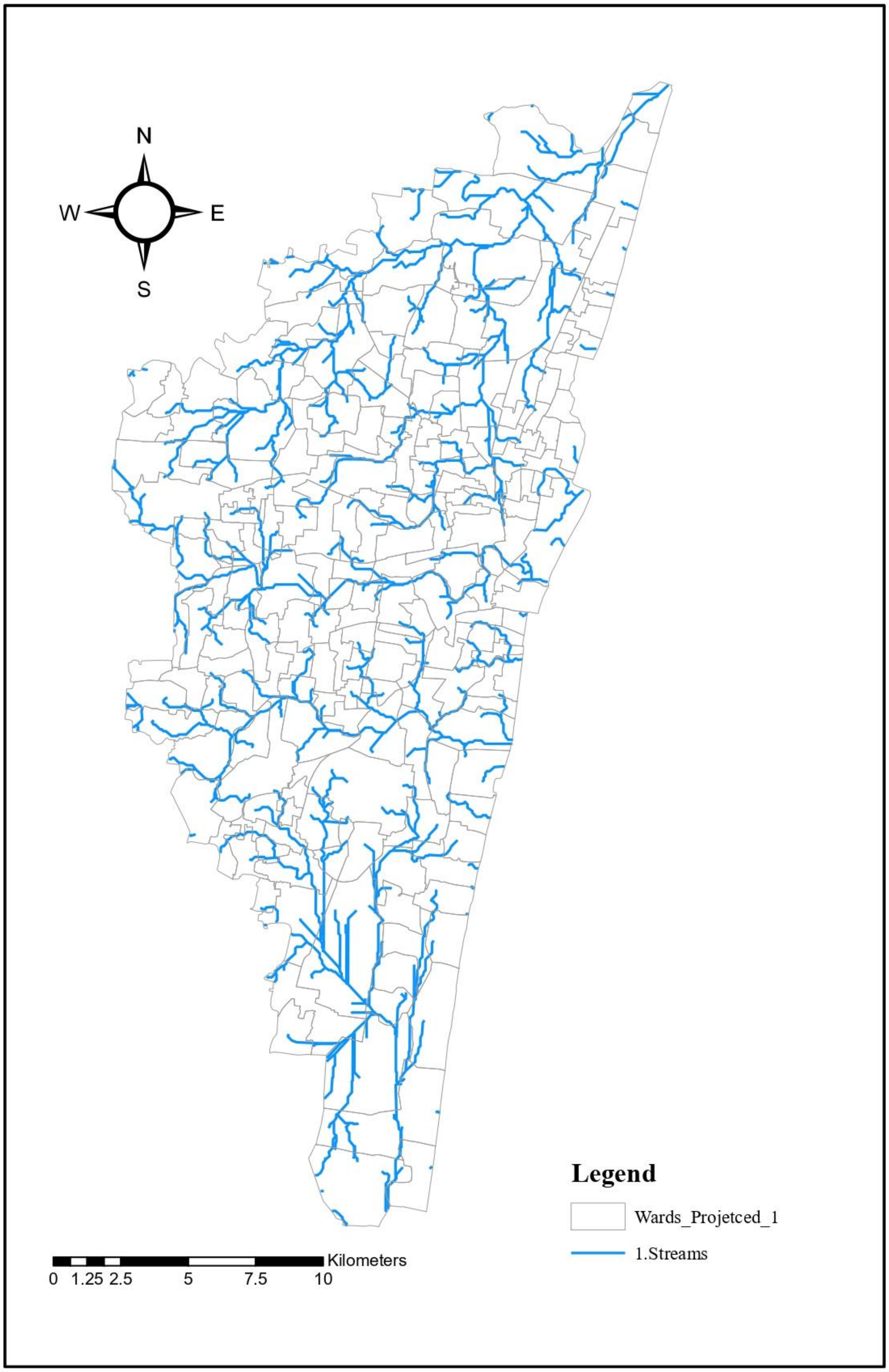


Figure 6-6Stream Lengths

- **SLOPE:** Steep slope shows the runoff and the flat areas accumulate flood water.

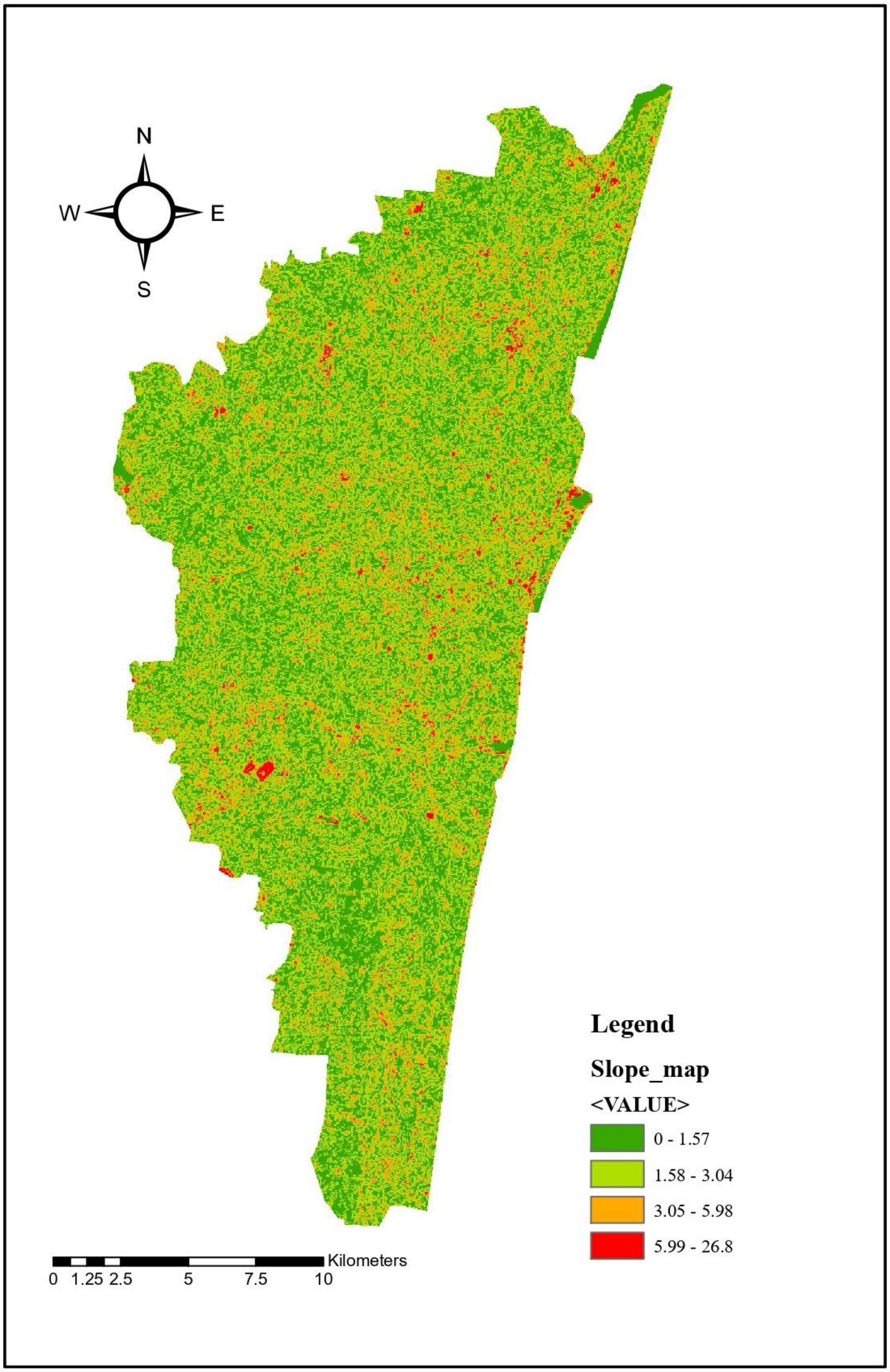


Figure 6-7 Slope

- **DISTANCE FROM WATERWAYS:** Closer proximity to rivers have high flood risk.

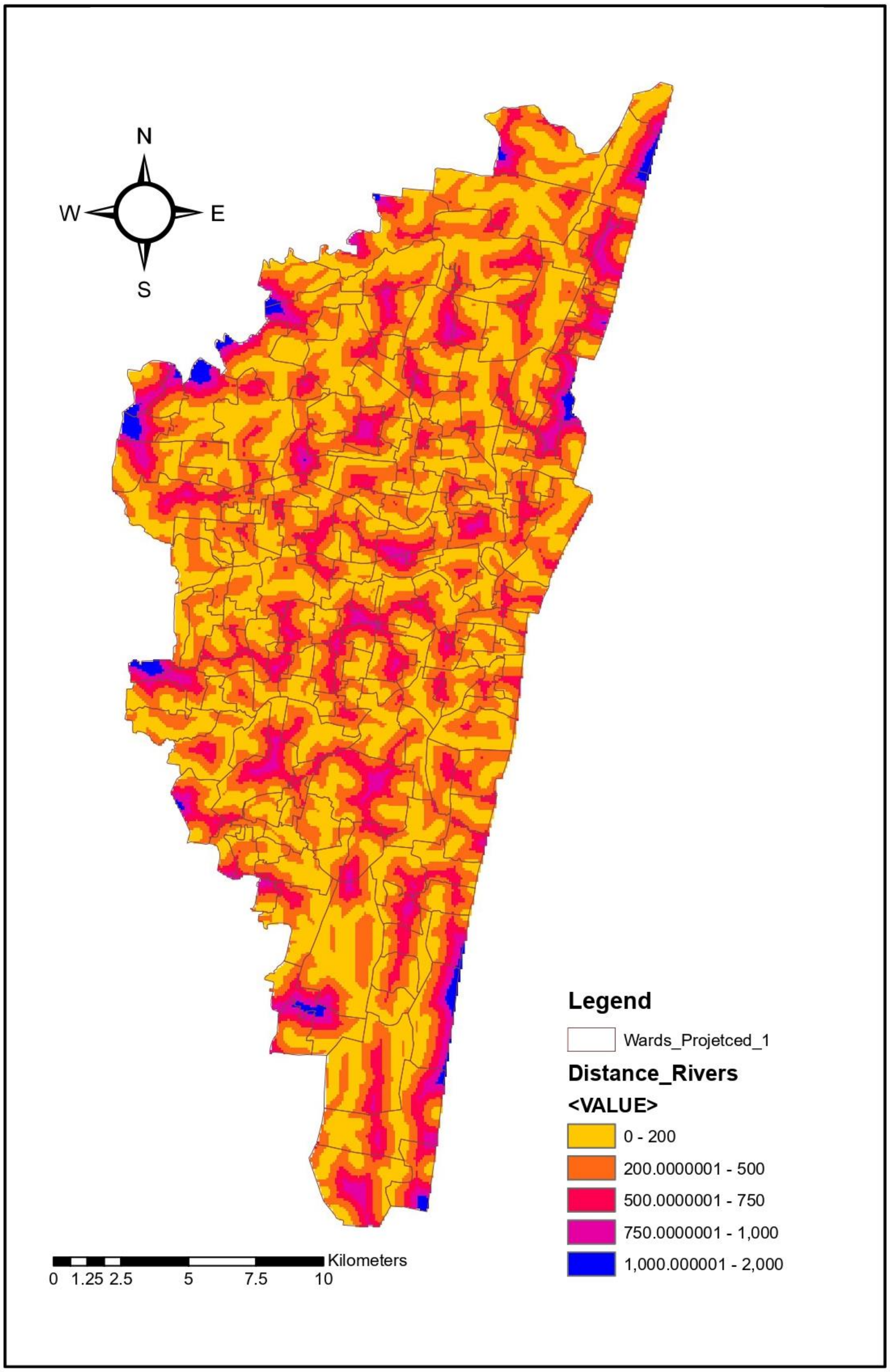


Figure 6-8 Distance from rivers

- **STREAM POWER INDEX (SPI):** Higher SPI values indicate areas that experience strong water force during floods.

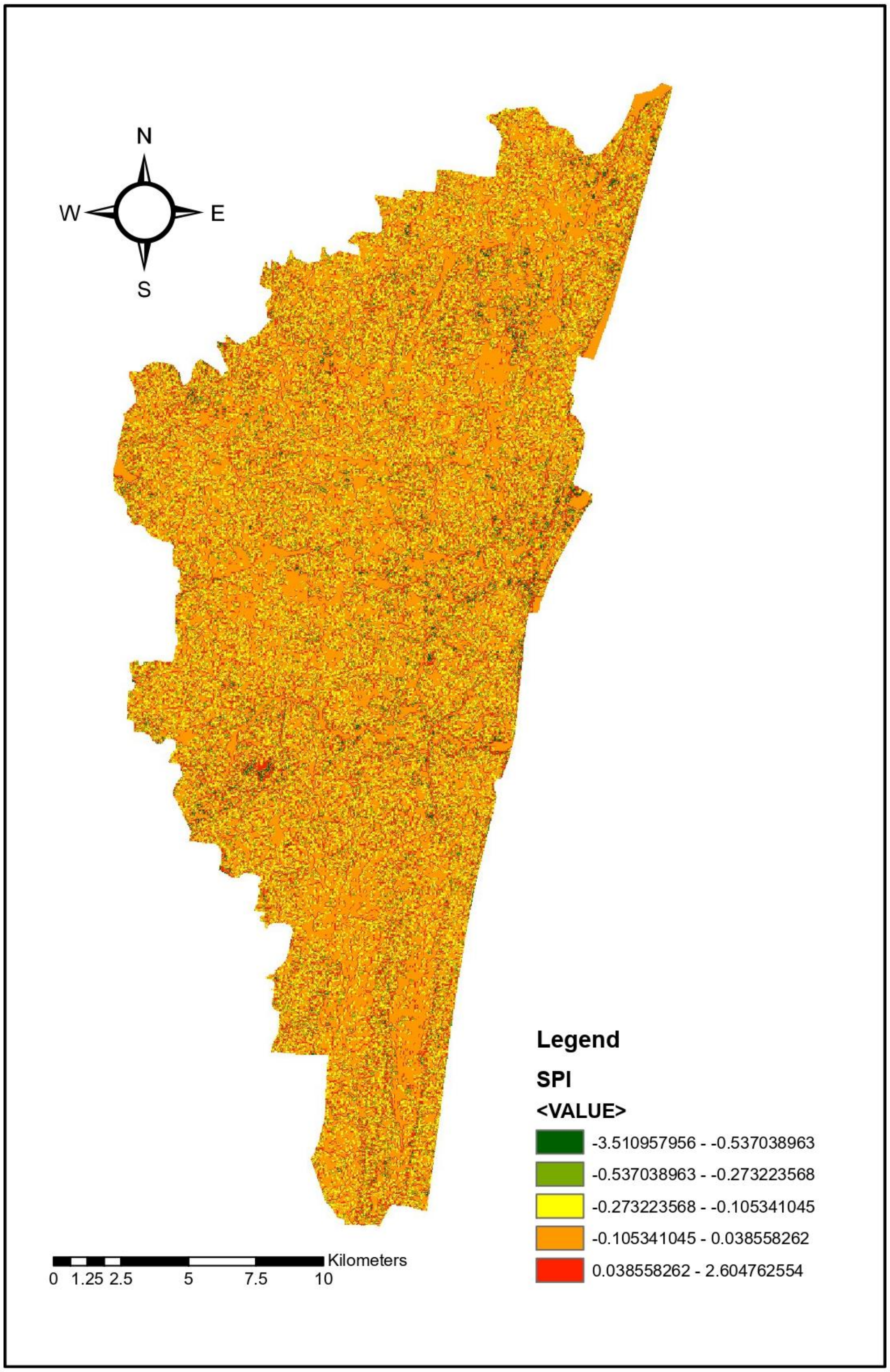


Figure 6-9 Stream Power Index

- **TOPOGRAPHIC WETMESS INDEX (TWI):** Higher value of TWI means it is more prone to water accumulation or presence of higher moisture content

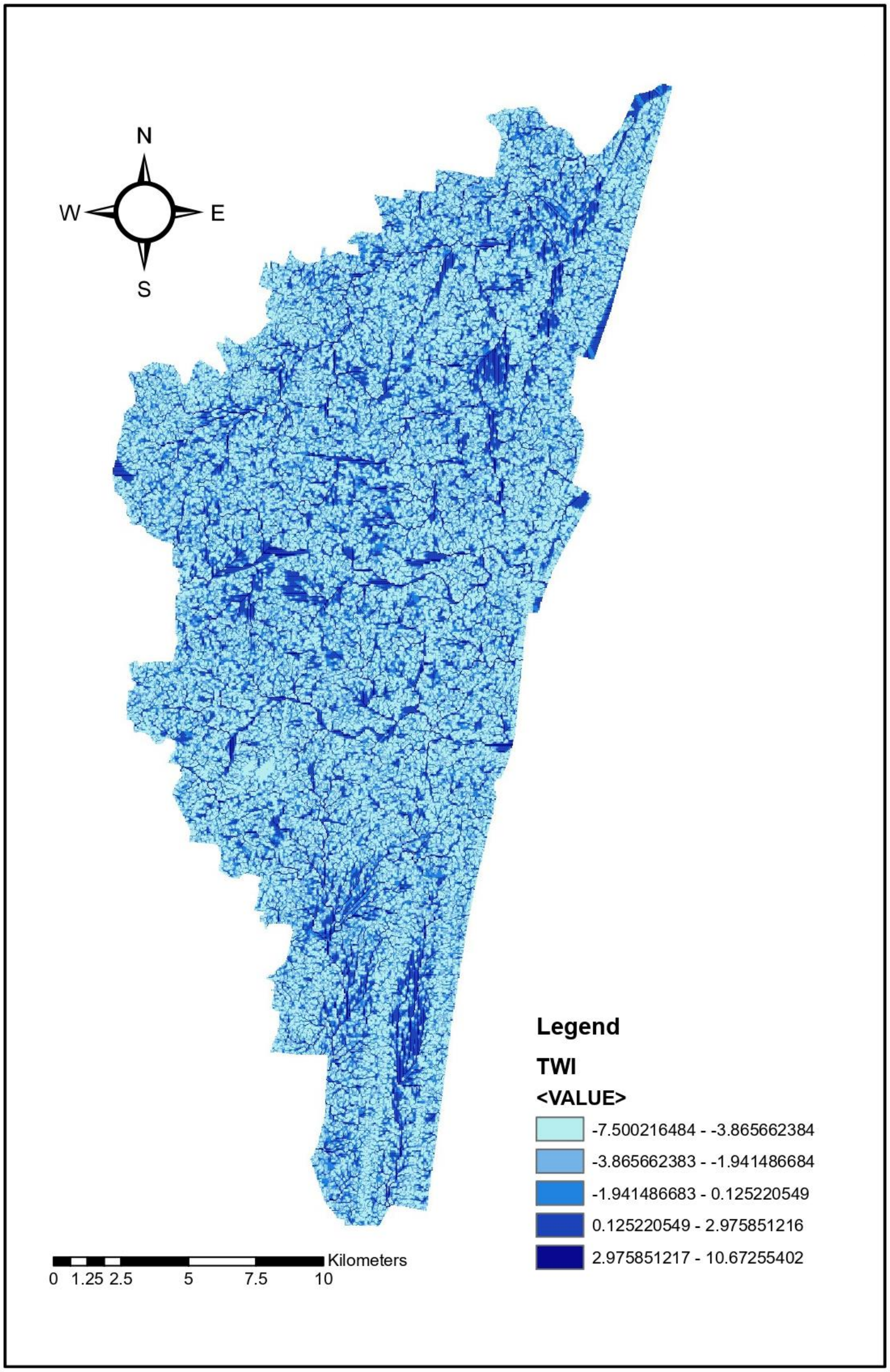


Figure 6-10 Topographic Wetness Index

6.2.1.2 GENERATION OF WARD LEVEL PHYSICAL VULNERABILITY INDEX

To assess physical vulnerability at the ward level, a weighted overlay analysis was conducted using key spatial indicators in the raster calculator. The following weights were assigned based on their relative influence on flood vulnerability: Land Use Land Cover (LULC) – 10%, Drainage Density – 15%, Distance to River – 20%, Slope – 10%, Elevation – 15%, Topographic Wetness Index (TWI) – 15%, and Stream Power Index (SPI) – 15%. These weighted raster layers were combined to generate a composite physical vulnerability map. This raster output was then integrated with the ward boundary shape file using zonal statistics, allowing for the calculation of average vulnerability scores within each ward polygon. The resulting values were normalized to a common scale to facilitate comparison and interpretation. Finally, wards were reclassified into three categories—high, medium, and low vulnerability—based on the normalized scores, providing a clear spatial visualization of flood-related physical risks across Chennai's administrative landscape.

To further refine the vulnerability assessment, the composite physical vulnerability scores were categorized into high, medium, and low vulnerability using the standard deviation classification method. This statistical approach ensures that the classification reflects the natural variation in the data, with 'high vulnerability' indicating wards with scores significantly above the mean, and 'low vulnerability' indicating those well below it. Following this, the physical vulnerability map was clipped using the boundaries of identified informal settlements. This step allowed for the isolation and visualization of flood vulnerability specifically within slum areas, highlighting the spatial concentration of risk among the most socio-economically disadvantaged populations in Chennai.

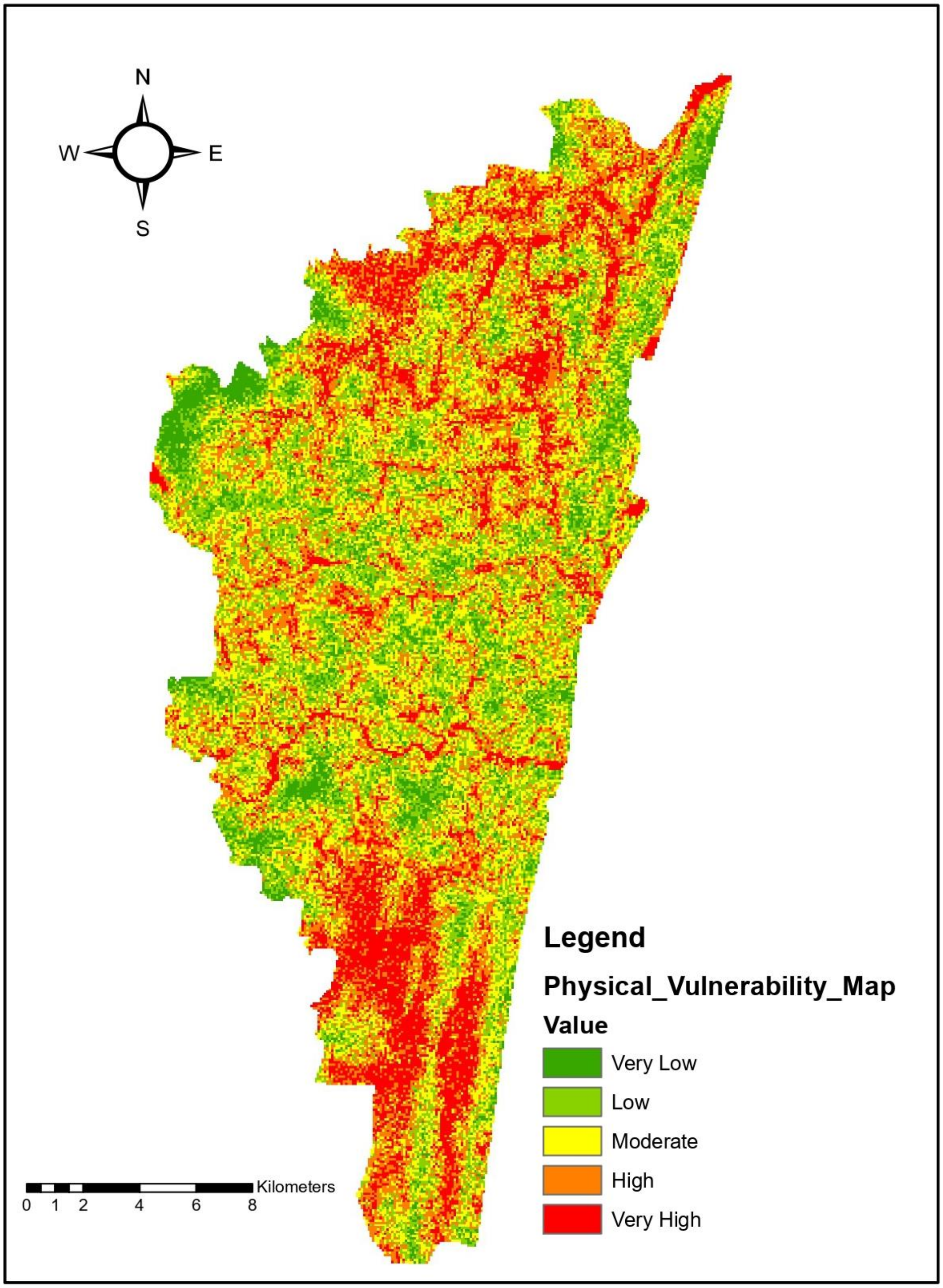


Figure 6-11 Physical Vulnerability Map

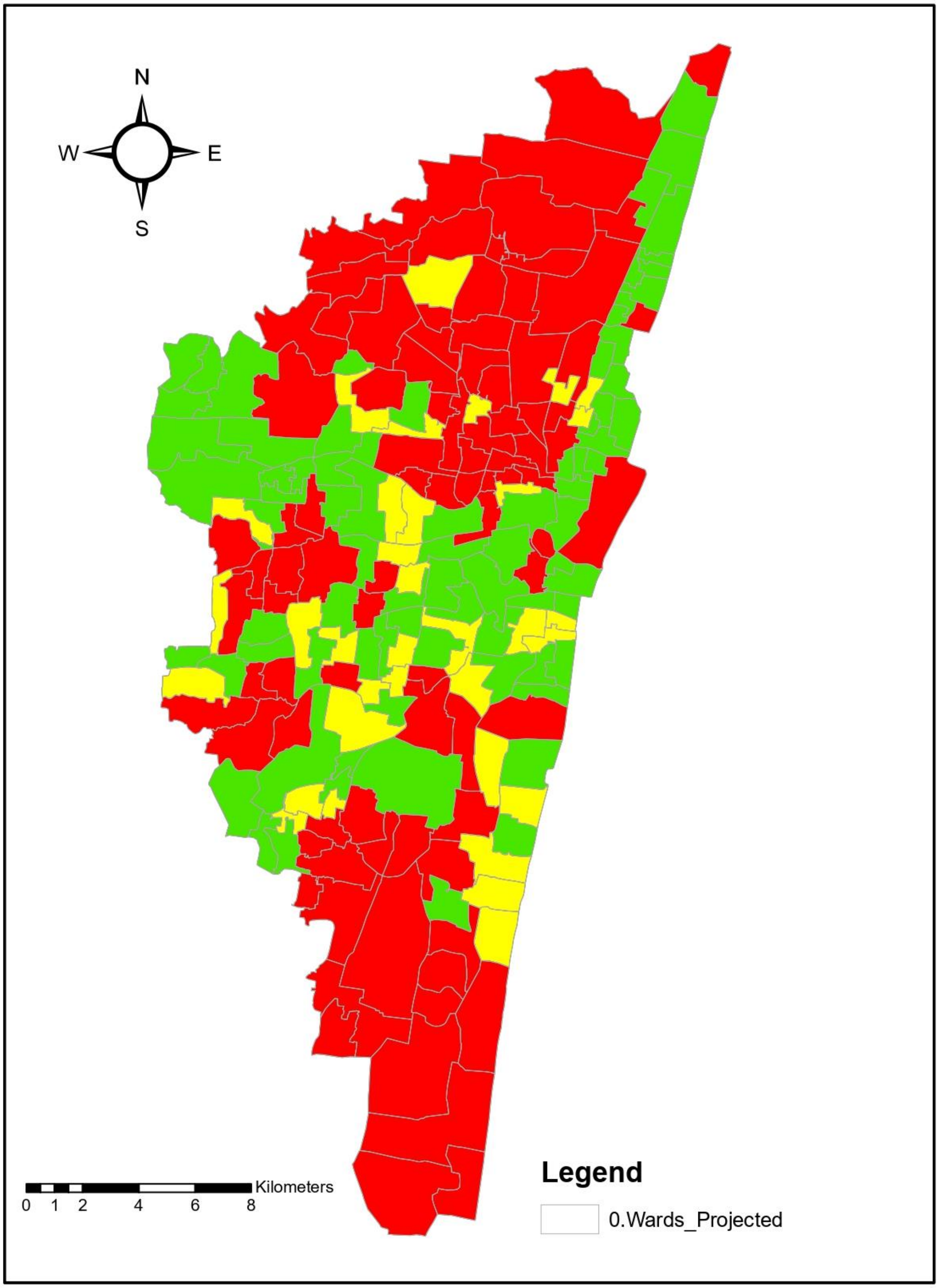


Figure 6-12 Ward wise physical vulnerability map

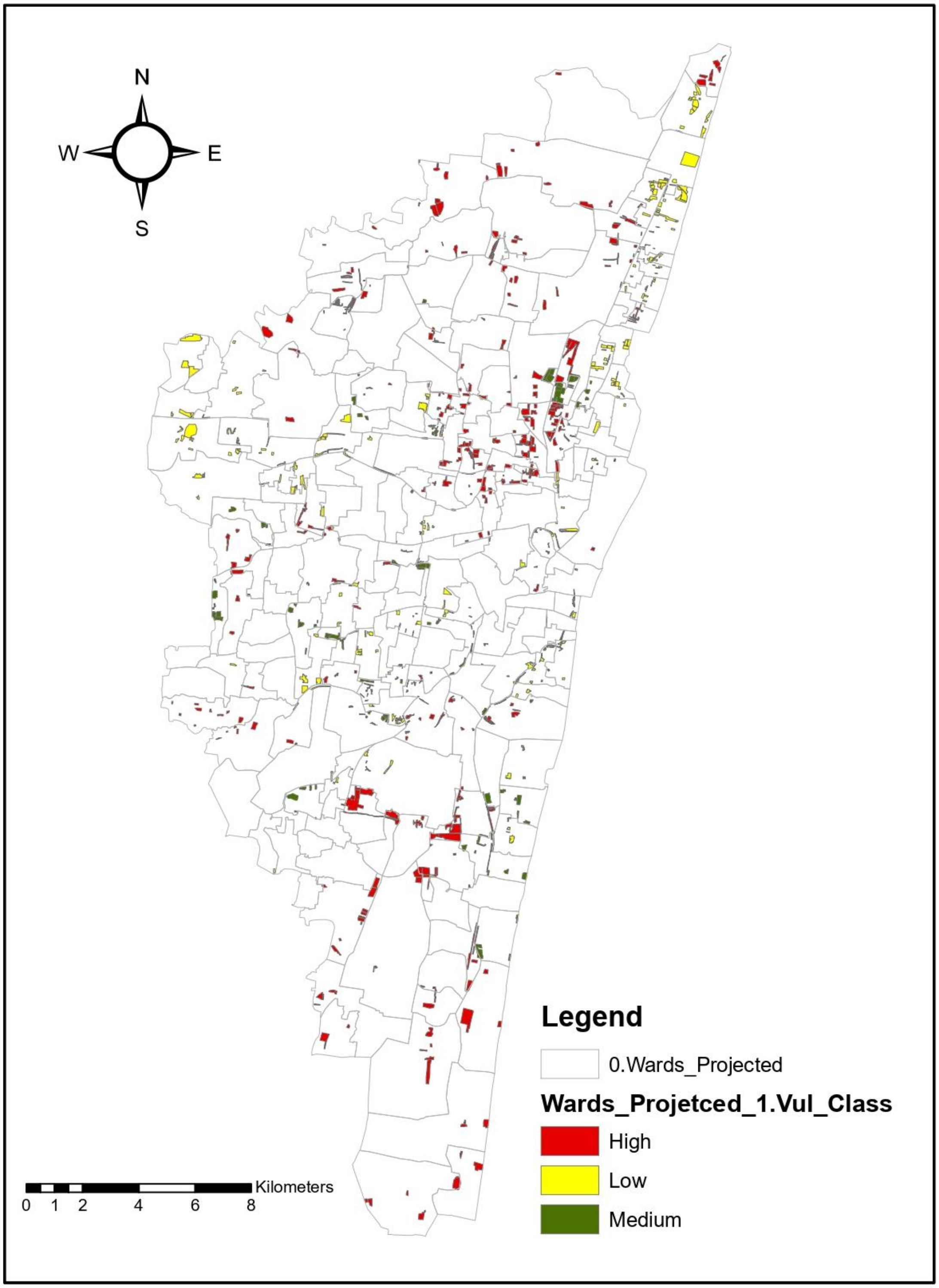


Figure 6-13 Physical Vulnerability in the Informal Settlements

6.2.2 SOCIO ECONOMIC VULNERABILITY

The socio-economic vulnerability assessment was conducted using a robust quantitative framework to evaluate disparities across different wards in Chennai. The analysis incorporated 40 individual indicators, grouped into 18 broad variables, capturing various dimensions such as income, education, housing conditions, employment, access to basic services, health, and social vulnerability (e.g., SC/ST and BPL population ratios).

Table 6-2 Listing of Socio economic variables

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1						Tenability				BPL and SC/ST		Housing Condition		
2	Wards	Number of Slums	Population of Slums	Number of households of Slums	Area of Slums (in sq.m)	Tenable number of slums	Tenable number of households	Untenable number of slums	Untenable number of households	Number of households - BPL	Number of households - SC/ST	Number of pucca houses	Number of semi pucca houses	Number of kutcha houses
3	1	15	12259	3402	62640	13	2889	2	513	204	2450	1554	1236	612
4	2	22	18314	5082	93581	20	4315	2	767	305	3660	2322	1847	914
5	3	24	19471	5403	99494	21	4588	3	815	324	3891	2469	1964	972
6	4	18	15031	4171	76803	16	3542	2	629	250	3004	1906	1516	750
7	5	21	17716	4916	90526	19	4175	2	742	295	3540	2246	1787	885
8	6	11	9487	2633	48474	10	2235	1	397	158	1896	1203	957	474
9	7	12	9982	2770	51006	11	2352	1	418	166	1995	1266	1007	498
10	8	5	3747	1040	19146	4	883	1	157	62	749	475	378	187
11	9	3	2432	675	12429	3	573	0	102	41	486	308	245	121
12	10	2	1300	361	6644	1	306	0	54	22	260	165	131	65
13	11	4	3657	1015	18685	4	862	0	153	61	731	464	369	183
14	12	1	619	172	3162	1	146	0	26	10	124	78	62	31
15	13	0	0	0	0	0	0	0	0	0	0	0	0	0
16	14	4	3407	945	17408	4	803	0	143	57	681	432	344	170
17														
18	15	1	6372	103	13862	1	89	0	14	6	51	42	39	22
19	16	13	6753	1712	229806	11	1484	3	229	108	843	694	652	366
20	17	14	4936	1815	243535	12	1572	3	242	114	894	735	691	388
21	18	10	1290	1326	177997	8	1149	2	177	83	653	537	505	283
22	19	3	2698	347	46530	2	300	1	46	22	171	140	132	74
23	20	6	304	725	97310	5	628	1	97	46	357	294	276	155
24	21	1	0	82	10960	1	71	0	11	5	40	33	31	17

6.2.2.1 VARIABLE WEIGHTING USING SHANNON ENTROPY

To assign objective weights to the selected indicators, the **Shannon Entropy method** was used. This method measures the uncertainty or disorder in the data distribution, with the premise that indicators with greater variability across spatial units contain more information and should be assigned higher weights. The entropy value for each indicator Ej was computed using the formula:

$$E_j = -k \sum_{i=1}^{m} p_{i,j} \ln p_{i,j} \qquad p_{i,j} = \frac{r_{i,j}}{\sum_{i=1}^{m} r_{i,j}} \qquad k = (\ln m)^{-1}$$

Here, xij represents the value of the j th indicator for the i th ward, pij is the normalized value, and n is the total number of wards. Based on the calculated entropy values, weights were derived inversely—indicators with lower entropy (greater variation) were assigned higher weights.

Table 6-3 Assigning weights using Shannon Entropy

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1						Tenability				BPL and SC/ST		Housing Condition		
2	Wards	Number of Slums	Population of Slums	Number of households of Slums	Area of Slums (in sq.m)	Tenable number of slums	Tenable number of households	Untenable number of slums	Untenable number of households	Number of households - BPL	Number of households - SC/ST	Number of pucca houses	Number of semi pucca houses	Number of kutcha houses
3		-4.84337	-4.79033	-4.75832	-4.64182	-4.81682	-4.73743	-4.83275	-4.79227	-4.61014	-4.74956	-4.59367	-4.80409	-4.85047
4	Entropy	0.914134	0.904123	0.898081	0.876093	0.909123	0.894138	0.912129	0.90449	0.870114	0.896428	0.867006	0.906719	0.915473
5	Degree of Diversification	0.085866	0.095877	0.101919	0.123907	0.090877	0.105862	0.087871	0.09551	0.129886	0.103572	0.132994	0.093281	0.084527
6	**Weights**	**0.022733**	**0.025384**	**0.026984**	**0.032805**	**0.02406**	**0.028027**	**0.023264**	**0.025287**	**0.034388**	**0.027421**	**0.035211**	**0.024696**	**0.022379**

6.2.2.2 VULNERABILITY RANKING USING TOPSIS

Following the entropy-based weighting, the **Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)**—a Multi-Criteria Decision-Making (MCDM) method—was applied. This technique ranks alternatives (in this case, wards) by calculating their relative closeness to the ideal (least vulnerable) and negative-ideal (most vulnerable) solutions.

The normalized decision matrix (NDM) denotes the normalized values which represent the relative performance of the alternatives.

$$NDM = L_{lm} = \frac{c_{lm}}{\sqrt{\sum_{l=1}^{q} c_{lm}^2}}$$

By multiplying every element of each column of normalized decision matrix got a weighted decision matrix.

$$\boldsymbol{V = V_{lm} = W_m \ x \ L_{lm}}$$

The PIS (I^+) and the NIS (I^-) are defined with respect to the weighted decision matrix as follows.

$$\mathrm{NIS} = I^- = \{V_1^-, V_2^-, \ldots, V_q^-\}, \text{ where:}$$

$$V_m^- = \{(\mathrm{mini}(V_{lm}) \text{ if } m \in J);(\mathrm{maxi} \ V_{lm} \text{ if } m \in J')\}$$

Where J' is associated with the non-beneficial attributes and J is associated with beneficial attributes.

$$S_l^+ = \sqrt{\sum_{m=1}^{p} (V_m^+ - V_{lm})^2} \;;\; l = 1, 2, \; \dots, \; q$$

$$S_l^- = \sqrt{\sum_{m=1}^{p} (V_m^- - V_{lm})^2} \;;\; l = 1, 2, \; \dots, \; q$$

Where, l = Alternative index,
m = Criteria index.
The relative closeness of the ideal solution is computed as

$$C_l = \frac{S_l^-}{(S_l^+ + S_l^-)} \;,\; 0 \le C_l \le 1$$

Ranking is done based on the values of l C the higher value of the relative closeness has a high rank and hence the better performance of the alternative. Rank the preference in descending order to compare the better performances of alternatives".

6.2.2.3 ADDRESSING DATA DISTRIBUTION: LOG TRANSFORMATION

The distribution of the resulting TOPSIS scores was observed to be right-skewed**,** indicating that a few wards had exceptionally low vulnerability while most had higher vulnerability. To normalize the distribution and improve categorization, a **log** transformation was applied. This transformation helped compress the scale and enhance interpretability.

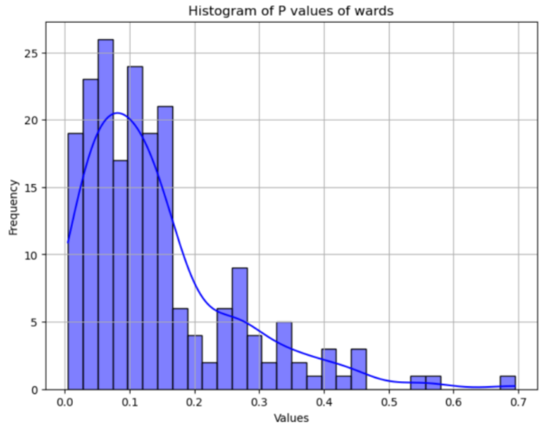


Figure 6-14 Right skewed P value distribution

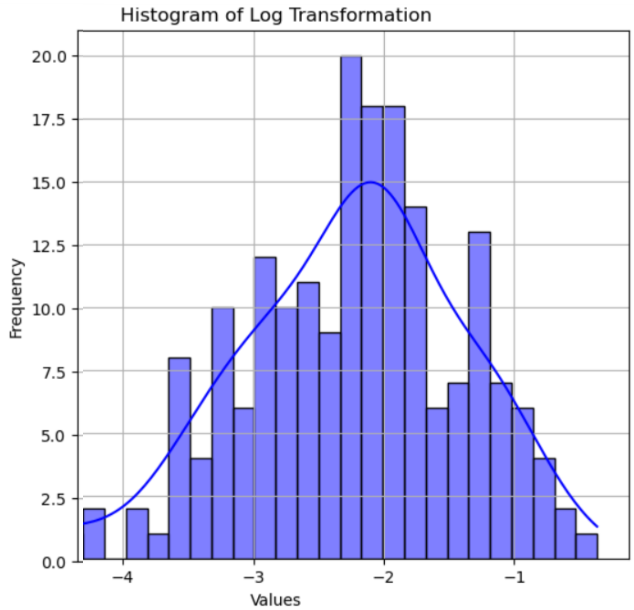


Figure 6-15 Normal P value distribution after Log transformation

6.2.2.4 CLASSIFICATION OF VULNERABILITY LEVELS

Post-transformation, the scores were standardized, and standard deviation-based classification was used to categorize wards into three vulnerability levels:

High Vulnerability: Scores greater than one standard deviation above the mean

Medium Vulnerability: Scores within one standard deviation of the mean

Low Vulnerability: Scores lower than one standard deviation below the mean

This method provided a statistically grounded classification system, allowing for a more meaningful comparison across spatial units.

The final vulnerability map shows a clustering of high socio-economic vulnerability in wards with high proportions of SC/ST and BPL populations, poorly built housing, lower literacy rates, and limited access to health and basic services. Many of these coincide with informal settlements, validating spatial overlap with physically vulnerable zones. The combined approach of entropy-based weighting and TOPSIS ranking ensures an objective, replicable method for vulnerability assessment.

Table 6-4 Categorization of wards based on the P values acquired

	A	B	C	D	E	F	G
1	P values of wards	Categories	X values	Y values		Log Transformation	Categories
2	0.292591824	High	-0.33015	0.001137		-1.228976735	High
3	0.413121606	High	-0.32015	0.001591		-0.884013284	High
4	0.430132182	High	-0.31015	0.002211		-0.843662718	High
5	0.345299568	High	-0.30015	0.003049		-1.063342927	High
6	0.396746489	High	-0.29015	0.004176		-0.924457768	High
7	0.227822932	Medium	-0.28015	0.005679		-1.479186566	Medium
8	0.240532843	Medium	-0.27015	0.007666		-1.424898639	Medium
9	0.096436469	Medium	-0.26015	0.010275		-2.338870837	Medium
10	0.071674399	Medium	-0.25015	0.013672		-2.635621653	Medium
11	0.043479991	Medium	-0.24015	0.018061		-3.135454419	Medium
12	0.098218461	Medium	-0.23015	0.023688		-2.320561088	Medium
13	0.031797953	Medium	-0.22015	0.030845		-3.448353353	Low
14	0.007127616	Low	-0.21015	0.039876		-4.943778502	Low
15	0.084237875	Medium	-0.20015	0.051179		-2.474110636	Medium
16	0.043547443	Medium	-0.19015	0.065215		-3.133904299	Medium
17	0.266713487	High	-0.18015	0.082503		-1.32158028	High
18	0.272402289	High	-0.17015	0.103624		-1.300475303	High
19	0.199598859	Medium	-0.16015	0.129216		-1.611445632	Medium
20	0.097791861	Medium	-0.15015	0.159969		-2.324913929	Medium

An in-depth examination of the ward-wise socio-economic vulnerability revealed that certain areas consistently exhibited higher levels of vulnerability due to a combination of structural and systemic disadvantages. Wards located in North Chennai, particularly in zones such as Tondiarpet, Royapuram, and parts of Thiru. Vi. Ka Nagar, ranked among the most socio-economically vulnerable. These areas showed high concentrations of Scheduled Caste and Below Poverty Line populations, overcrowded housing, limited access to sanitation, and low female literacy rates. In contrast, wards in South Chennai exhibited lower vulnerability levels, supported by better infrastructure, higher income levels, and broader access to education and healthcare. This spatial disparity highlights the urgent need for targeted policy interventions and welfare programs that prioritize resource allocation to the most vulnerable communities.

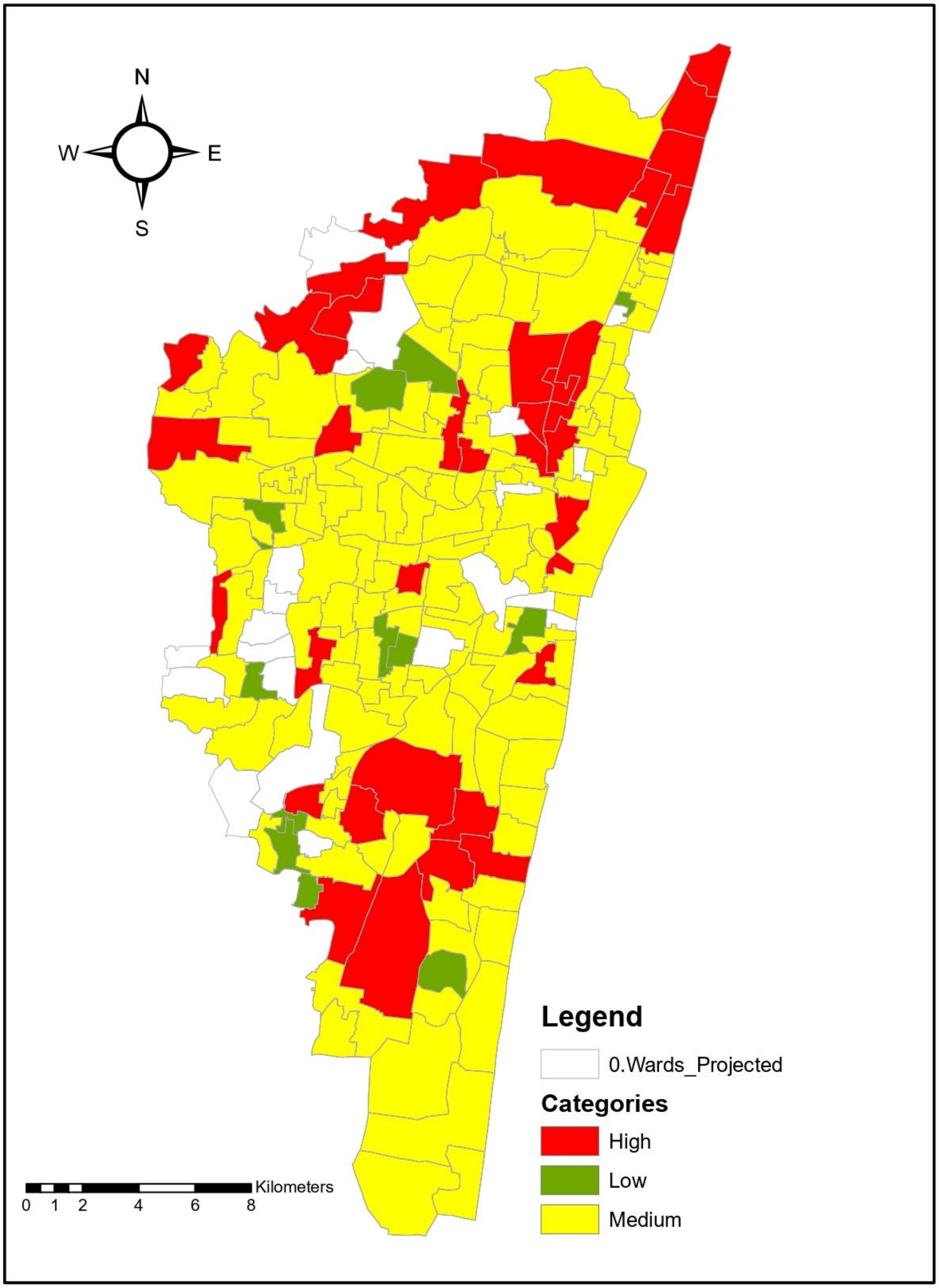


Figure 6-16 Ward Wise Socio Economic vulnerability map

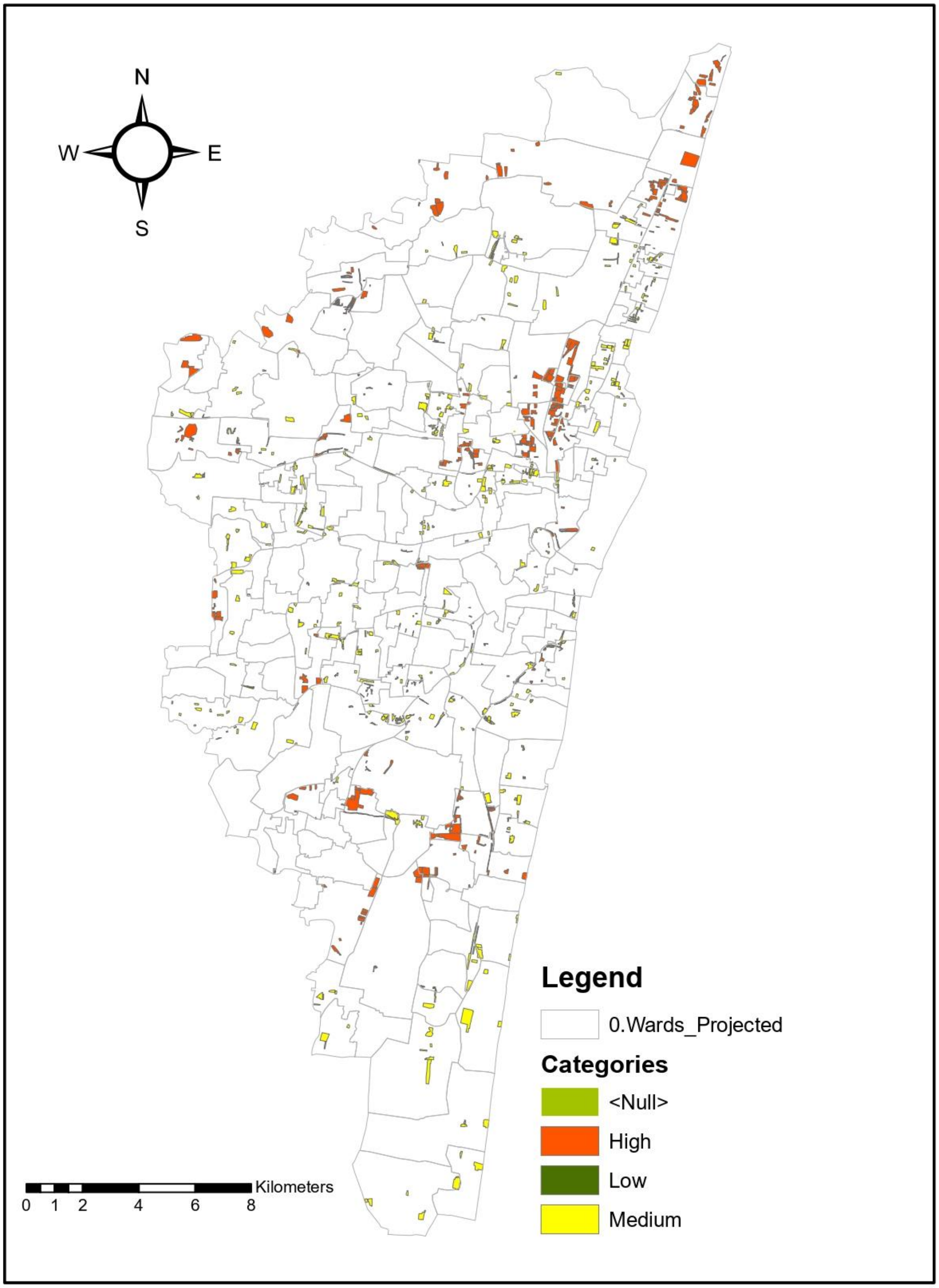


Figure 6-17 Socio Economic vulnerability in the Informal Settlements of Chennai

6.2.3 COMBINED VULNERABILITY MAPPING

To derive a more holistic understanding of flood risk exposure, a Combined Vulnerability Index was calculated by integrating both physical and socio-economic vulnerability components. Each component was assigned an equal weight of 0.5, reflecting the dual importance of environmental and human dimensions in determining overall risk. The formula used was:

Combined Vulnerability Index = (0.5 × Physical Vulnerability) + (0.5 × Socio-Economic Vulnerability)

This approach allowed for the synthesis of spatial data layers capturing terrain-based risks—such as elevation, slope, and drainage density—with ward-level socio-economic indicators like housing quality, literacy, and income. The result was a composite map that clearly highlights wards with high cumulative vulnerability, enabling more targeted disaster risk reduction strategies. This integrated mapping underscores that areas with moderate physical risk but high socio-economic fragility may still require prioritized attention, and vice versa.

Table 6-5 Combined Vulnerability Index

	A	B	C
1	**Physical_Index**	**Socio_Index**	**Combined_Index**
2	0.260437376	0.292591824	0.27604682
3	0.112610054	0.413121606	0.215688772
4	0.141153082	0.430132182	0.24640309
5	0.14612326	0.345299568	0.224624795
6	0.091167282	0.396746489	0.190184908
7	0.111900028	0.227822932	0.159666504
8	0.140159046	0.240532843	0.183610603
9	0.533939222	0.096436469	0.226916754
10	0.017040613	0.071674399	0.034948186
11	0.017608634	0.043479991	0.027669898
12	0.01221244	0.098218461	0.034633611
13	0.045015621	0.031797953	0.037833908
14	0.007526271	0.084237875	0.025179298
15	0.044589605	0.043547443	0.044065443
16	0.550411815	0.266713487	0.383147823
17	0.767537631	0.272402289	0.45725158
18	0.479125249	0.199598859	0.309245619
19	0.600113604	0.097791861	0.242252401
20	0.317807441	0.110684403	0.187553531

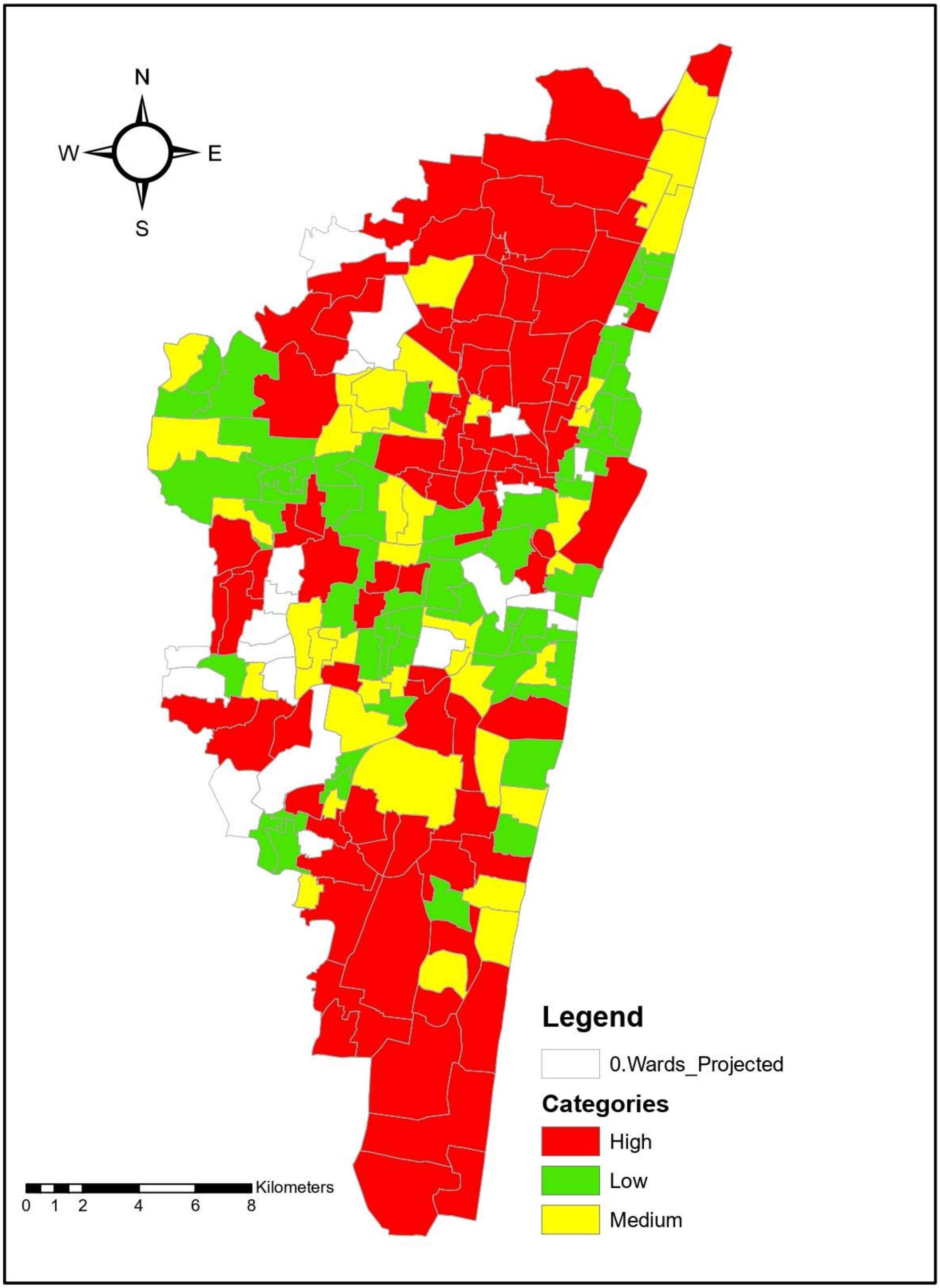


Figure 6-18 Ward wise Combined Vulnerability Index

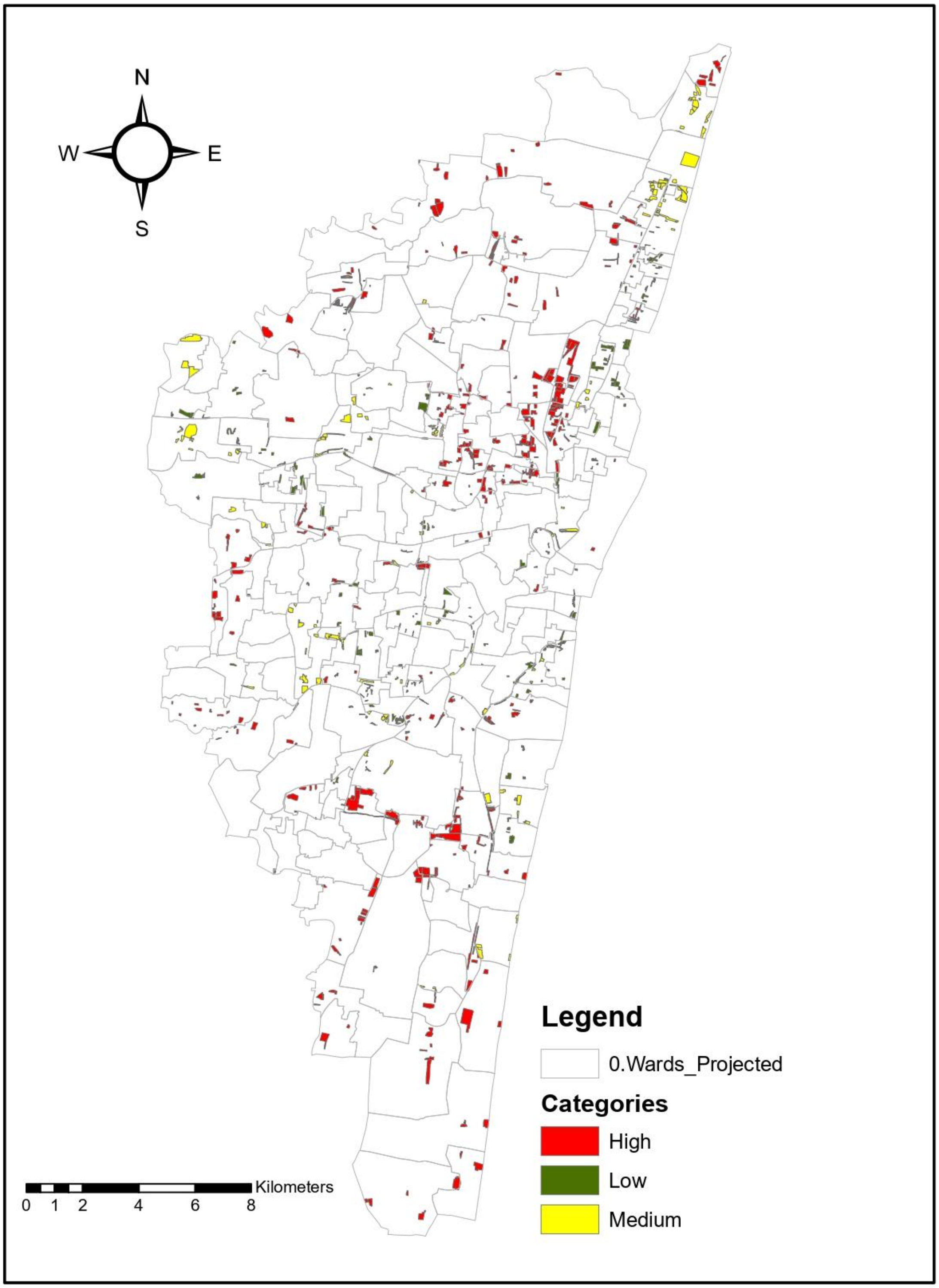


Figure 6-19 Combined Vulnerability Index of Informal Settlements in Chenn

6.2.4 INFERENCE FROM COMBINED VULNERABILITY INDEX:

The Combined Vulnerability Index, calculated as an equal-weighted composite of physical and socio-economic vulnerability, provides a holistic picture of flood risk across Chennai's wards. This integrated approach captures the multidimensional nature of vulnerability by considering not just the environmental and locational exposure to flooding, but also the social and economic capacity of residents to cope with and recover from disasters. The results reveal that the highest levels of combined vulnerability are concentrated in wards located predominantly in the northern and central parts of the city—areas such as Zones 5, 6, and parts of Zone 9—where informal settlements are widespread.

These high-vulnerability wards face compounded risks. Physically, they lie in low-lying zones with poor natural drainage; high stream power, shallow slopes, and is in close proximity to rivers and canals, which makes them more prone to waterlogging and inundation. Simultaneously, socio-economic indicators in these areas—such as high concentrations of SC/ST populations, low household incomes, poor housing typologies (kutcha and semi-pucca), and lack of access to sanitation and water supply, and low educational attainment—reflect structural disadvantages that reduce community resilience.

Interestingly, some wards with moderate physical risk show high overall vulnerability due to poor socio-economic performance. For example, certain interior wards with better elevation and drainage infrastructure still exhibit high vulnerability scores due to dense slum populations, informal housing, and weak service delivery. Conversely, wards with high physical exposure but better socio-economic indicators—such as improved infrastructure, better housing conditions, and higher literacy—show lower combined vulnerability. This divergence underlines the importance of addressing social fragility along with infrastructural deficits in disaster risk planning.

The Combined Vulnerability Index also helps in distinguishing between wards that require urgent multi-sectorial intervention and those where targeted improvements in either physical or social infrastructure might suffice. It enables a more balanced allocation of resources by highlighting where governance actions can achieve the greatest impact. For instance, flood mitigation projects in highly vulnerable wards must be coupled with livelihood enhancement programs, community-based disaster preparedness, and infrastructure upgrades. Moreover, the findings validate the relevance of integrating spatial GIS-based analysis with socio-economic data and multi-criteria decision-making methods like Shannon Entropy and TOPSIS.

This layered understanding of vulnerability not only strengthens the empirical basis for disaster risk reduction but also offers critical input for the Greater Chennai Corporation's planning and budgeting processes. It provides the foundation for developing localized, equity-based climate adaptation strategies and serves as a compelling argument for embedding resilience into both urban planning and welfare governance.

6.3 CAPITAL EXPENDITURE ANALYSIS

To assess the financial prioritization of flood management across Chennai, the capital expenditure data allocated for flood-related projects was extracted zone-wise from Greater Chennai Corporation's budget documents. As the primary financial data was available only at the zone level, a disaggregation technique was adopted to convert this data to the ward level. This was achieved by proportionally distributing the capital expenditure based on each ward's share of residential and commercial property tax contribution within its respective zone. Property tax serves as a proxy indicator of both population density and economic activity, allowing for a more realistic estimation of resource distribution. This method enabled the creation of a spatially disaggregated ward-wise capital expenditure map focused solely on flood management interventions such as storm water drain improvements, de silting, pumping infrastructure, and canal rehabilitation. The resultant dataset supports a comparative analysis of fiscal investment against physical and socio-economic vulnerabilities, helping to highlight mismatches between flood-prone areas and public investment. It also lays the groundwork for identifying underfunded high-risk wards, which can inform future budget allocations and improve equity in disaster preparedness spending.

Table 6-6 Capital Expenditure in each ward

Wards	CE Actuals in Thousands (21 - 22)	SWM (in Thousands)	SWD (in Thousands)	Public Convinence	Miscellaneous works	Expenditure total for flood	% of expenditure used for flood	2017-18 - Property Tax Collection (in crores) - Residential	2017-18 - Property Tax Collection (in crores) - Commercial	Total Property Tax		% (weights)	Ward wise Capital Expenditure	Total Capital Expenditure
1								0.1985228	0.0216886	0.220211		1.625375	453.8210888	577342.1128
2								2.0465437	0.163712	2.210256		16.31385	4554.989653	5794766.736
3								1.2407698	0.0063519	1.247122		9.204978	2570.121837	3269657.598
4								0.3748149	0.0812266	0.456042		3.366032	939.8298639	1195632.756
5								1.948412698	1.718697	3.66711		27.06686	7557.336796	9614292.725
6								0.4064667	0.2067476	0.613214		4.526121	1263.738305	1607702.597
7	127218.000	7806	0	0	20115	27921.000	21.94736594	0.9037638	0.3587159	1.26248		9.318335	2601.772261	3309922.635
8								0.3107744	0.155977	0.466751		3.445082	961.9012847	1223711.576
9								0.2890711	0.0997267	0.388798		2.869708	801.2511656	1019335.708
10								0.3585903	0.1149173	0.473508		3.494949	975.8247512	1241424.732
11								0.4645467	0.0934557	0.558002		4.118603	1149.955255	1462950.077
12								0.482442197	0.1086098	0.591052		4.362542	1218.065281	1549598.289
13								0.5094881	0.1796625	0.689151		5.086605	1420.231086	1806789.582
14								0.3600102	0.3446342	0.704644	13.54834	5.200965	1452.161372	1847410.655
15								0.164029898	0.168696	0.332726		5.181624	769.6266081	952559.1566
16								0.211517097	0.514588356	0.726105		11.30782	1679.550886	2078763.337
17								0.08932502	0.3985436	0.487869		7.597701	1128.486461	1396716.408
18	123769.000	0	0	0	14853	14853	12.00058173	2.713180965	0.9099242	3.623105		56.42353	8380.586409	10372567.99
19								0.50963636	0.368022483	0.877659		13.668	2030.108274	2512644.709
20								0.144249153	0.0425853	0.186834		2.90962	432.1658374	534887.3353
21								0.135960457	0.05100788	0.186968	6.421267	2.911705	432.4755238	535270.6311
22								0.574461295	0.72147647	1.295938		7.227054	2109.143514	2163453.959
23								0.436413609	1.1929222	1.629336		9.086315	2651.750065	2720032.629
24								0.915228189	1.72854654	2.643775		14.74353	4302.753166	4413549.06

6.4 CORRELATION AND REGRESSION BETWEEN VULNERABILITY AND EXPENDITURE

6.4.1 CORRELATION ANALYSIS: ASSESSING THE DIRECTION AND STRENGTH OF RELATIONSHIP

To understand the association between capital expenditure and ward-level vulnerability, a non-parametric Spearman rank correlation was employed. This method was chosen due to the non-linear relationship observed between the two variables. The calculated Spearman rank correlation coefficient was -0.49, suggesting a moderate negative correlation. This implies that as capital expenditure increases, vulnerability tends to decrease — but not in a perfectly linear manner. The sum of squared differences between the ranks was 1,987,851. While Spearman's correlation is effective in understanding the direction and strength of the relationship, it does not capture the actual magnitude of change or account for spatial context.

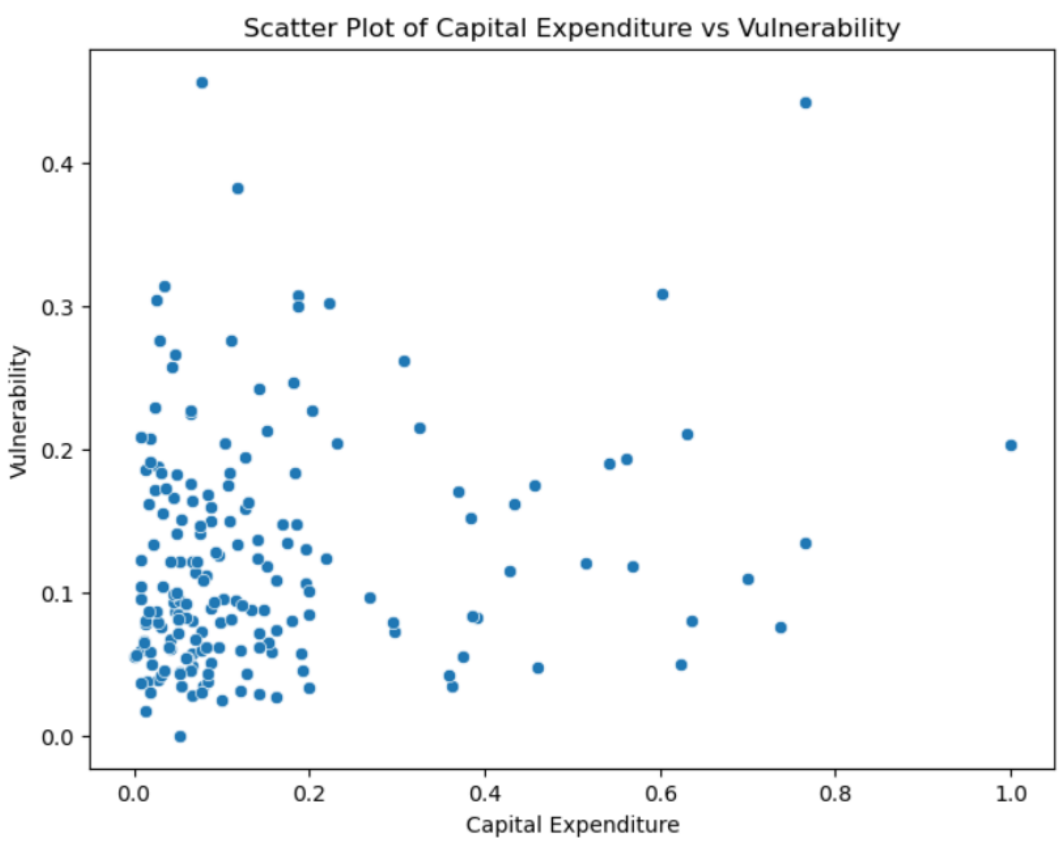


Figure 6-20 Scatter Plot of Capital Expenditure vs. Vulnerability

Sum of square of difference	Spearman's rank correaltion coeffiecint
1987851	-0.490925523

Vulnerability ↓ Expenditure ↑	Vulnerability ↑ Expenditure ↓

The moderate negative correlation suggests that when there is an increase in the expenditure, there is a decrease in the vulnerability and vice versa.

6.4.2 REGRESSION ANALYSIS: QUANTIFYING THE IMPACT OF CAPITAL EXPENDITURE

To further analyze the effect of capital expenditure on vulnerability, a logarithmic regression model was applied, as the relationship between the variables was found to be non-linear. In this model, vulnerability was considered the dependent variable, and capital expenditure was the independent variable. The regression output showed an R-squared value of 0.031, indicating that only 3.1% of the variation in vulnerability is explained by capital expenditure. However, the p-value was 0.016, which is below the 0.05 threshold, suggesting the relationship is statistically significant despite its weak explanatory power. The AIC value of -405.3 supports the model's statistical validity, albeit indicating limited predictive strength. These results highlight the complexity of public expenditure impact, where the amount spent may not directly translate into reduced vulnerability unless implemented efficiently.

```
                            OLS Regression Results
==============================================================================
Dep. Variable:          Vulnerability   R-squared:                       0.031
Model:                            OLS   Adj. R-squared:                  0.026
Method:                 Least Squares   F-statistic:                     5.876
Date:                Sat, 08 Feb 2025   Prob (F-statistic):             0.0163
Time:                        11:50:43   Log-Likelihood:                 204.66
No. Observations:                 183   AIC:                            -405.3
Df Residuals:                     181   BIC:                            -398.9
Df Model:                           1
Covariance Type:            nonrobust
==================================================================================
                     coef    std err          t      P>|t|      [0.025      0.975]
----------------------------------------------------------------------------------
const              0.1089      0.008     13.330      0.000       0.093       0.125
Log_Capital_Ex     0.1059      0.044      2.424      0.016       0.020       0.192
==============================================================================
Omnibus:                       48.805   Durbin-Watson:                   0.979
Prob(Omnibus):                  0.000   Jarque-Bera (JB):               87.911
Skew:                           1.323   Prob(JB):                     8.14e-20
Kurtosis:                       5.128   Cond. No.                         7.56
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
```

Figure 6-21 Logarithmic regression results

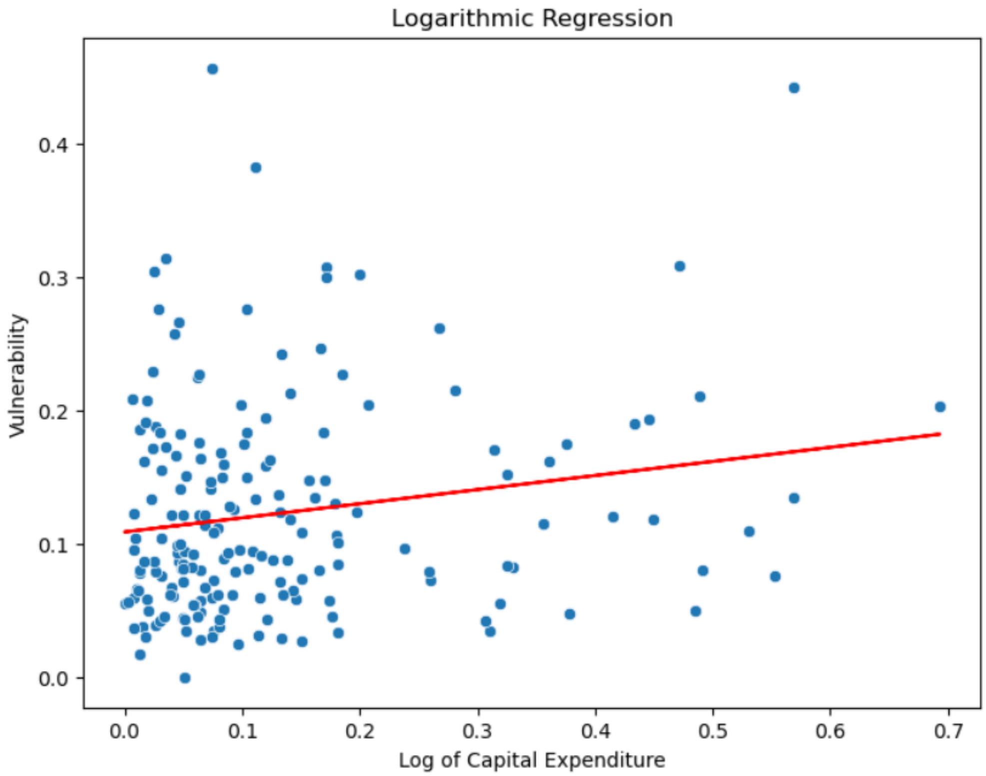


Figure 6-22 Scatter plot after logarithmic regression between the variables

6.4.3 SPATIAL REGRESSION: ACCOUNTING FOR GEOGRAPHIC DEPENDENCE

Given the spatial nature of both capital expenditure and vulnerability, traditional regression techniques like OLS may overlook crucial spatial interdependencies. Hence, a Spatial Lag Model (SLM) was applied. This model assumes that the vulnerability of a ward is influenced not only by its own characteristics but also by those of its neighboring wards. The model demonstrated a significant spatial lag coefficient, indicating spatial dependence — where high vulnerability in one ward tends to coincide with high vulnerability in adjacent wards.

$$Y = \rho W_Y + X\beta + \epsilon$$

Y = Dependent Variable (Vulnerability)
ρW_Y = Spatial Lag (Weighted sum of neighboring values)
$X\beta$ = Independent variable (Capital Expenditure)
ϵ = Error Term

In the SLM, the R-squared value improved markedly to 0.3181, showing that 31.8% of the variation in vulnerability can be explained when spatial dependence is accounted for. The p-value of 0.02389 confirms statistical significance, and the AIC dropped to -449.885, signifying a better model fit compared to both OLS and non-spatial logarithmic regression. These results suggest that vulnerability is not only a function of direct investment but also spatially contagious, emphasizing the importance of regionally coordinated investments in flood risk mitigation.

```
• OLS Regression Results:
REGRESSION RESULTS
-----------------

SUMMARY OF OUTPUT: ORDINARY LEAST SQUARES
-----------------------------------------
Data set            :     unknown
Weights matrix      :        None
Dependent Variable  :Vulnerability              Number of Observations:       184
Mean dependent var  :      0.1220              Number of Variables   :         2
S.D. dependent var  :      0.0809              Degrees of Freedom    :       182
R-squared           :      0.0344
Adjusted R-squared  :      0.0291
Sum squared residual:     1.15529              F-statistic           :    6.4874
Sigma-square        :       0.006              Prob(F-statistic)     :   0.01169
S.E. of regression  :       0.080              Log likelihood        :   205.409
Sigma-square ML     :       0.006              Akaike info criterion :  -406.818
S.E of regression ML:      0.0792              Schwarz criterion     :  -400.388

------------------------------------------------------------------------------------
            Variable     Coefficient       Std.Error     t-Statistic     Probability
------------------------------------------------------------------------------------
            CONSTANT         0.10928         0.00770        14.19115         0.00000
      Capital_Ex_Norm         0.08505         0.03339         2.54704         0.01169
------------------------------------------------------------------------------------
Warning: Variable(s) ['Constant'] removed for being constant.

REGRESSION DIAGNOSTICS
MULTICOLLINEARITY CONDITION NUMBER           2.159

TEST ON NORMALITY OF ERRORS
TEST                             DF        VALUE           PROB
Jarque-Bera                       2       85.495         0.0000

DIAGNOSTICS FOR HETEROSKEDASTICITY
RANDOM COEFFICIENTS
TEST                             DF        VALUE           PROB
Breusch-Pagan test                1        3.248         0.0715
Koenker-Bassett test              1        1.593         0.2069
================================ END OF REPORT =====================================

• Spatial Lag Regression Results:
REGRESSION RESULTS
-----------------

SUMMARY OF OUTPUT: MAXIMUM LIKELIHOOD SPATIAL LAG (METHOD = FULL)
-----------------------------------------------------------------
Data set            :     unknown
Weights matrix      :     unknown
Dependent Variable  :Vulnerability              Number of Observations:       184
Mean dependent var  :      0.1220              Number of Variables   :         3
S.D. dependent var  :      0.0809              Degrees of Freedom    :       181
Pseudo R-squared    :      0.3181
Spatial Pseudo R-squared:  0.0353
Log likelihood      :    227.9424
Sigma-square ML     :      0.0046              Akaike info criterion :  -449.885
S.E of regression   :      0.0676              Schwarz criterion     :  -440.240

------------------------------------------------------------------------------------
            Variable     Coefficient       Std.Error     z-Statistic     Probability
------------------------------------------------------------------------------------
            CONSTANT         0.04349         0.01073         4.05217         0.00005
      Capital_Ex_Norm         0.06435         0.02849         2.25882         0.02389
      W_Vulnerability         0.54451         0.07617         7.14871         0.00000
------------------------------------------------------------------------------------
Warning: Variable(s) ['Constant'] removed for being constant.
```

Figure 6-23 Spatial Regression results

6.4.4 INFERENCE AND IMPLICATIONS

The comparative analysis reveals that while capital expenditure does influence vulnerability, its effects are complex and spatially dependent. The negative correlation suggests that targeted investments can reduce vulnerability, but the weak explanatory power of traditional regression indicates that effectiveness matters more than expenditure volume. Spatial regression strengthens this insight by showing how vulnerability in one ward can influence its neighbors, underlining the need for strategic, well-coordinated urban planning. These findings advocate for policies that consider both spatial dynamics and implementation efficiency to address urban flood vulnerability more effectively.

6.5 FINAL CLASSIFICATION OF WARDS AND INFORMAL SETTLEMENTS

To gain deeper insights into the relationship between flood vulnerability and capital expenditure, wards were categorized into four distinct typologies based on their combined vulnerability index and ward-level capital expenditure. This typology helps assess not just the adequacy but also the efficiency of investment in flood risk management across Chennai's urban landscape.

Table 6-7 Final Classification of wards based on Vulnerability and capital expenditure

	A	B	C	D
1	**Ward_No**	**Vulnerability**	**Capital_Ex**	**Category**
2	1	0.27604682	0.0286495	High Vulnerability, Low CapEx
3	2	0.215688772	0.325058	High Vulnerability, High CapEx
4	3	0.24640309	0.181604	High Vulnerability, High CapEx
5	4	0.224624795	0.0637754	High Vulnerability, Low CapEx
6	5	0.190184908	0.542051	High Vulnerability, High CapEx
7	6	0.159666504	0.0871857	High Vulnerability, High CapEx
8	7	0.183610603	0.183891	High Vulnerability, High CapEx
9	8	0.226916754	0.0653706	High Vulnerability, Low CapEx
10	9	0.034948186	0.0537598	Low Vulnerability, Low CapEx
11	10	0.027669898	0.0663769	Low Vulnerability, Low CapEx
12	11	0.034633611	0.0789621	Low Vulnerability, High CapEx
13	12	0.037833908	0.0838847	Low Vulnerability, High CapEx
14	13	0.000000005	0	Low Vulnerability, Low CapEx
15	14	0.025179298	0.100804	Low Vulnerability, High CapEx
16	15	0.044065443	0.0514741	Low Vulnerability, Low CapEx
17	16	0.383147823	0.117238	High Vulnerability, High CapEx
18	17	0.45725158	0.0774104	High Vulnerability, High CapEx
19	18	0.309245619	0.60155	High Vulnerability, High CapEx
20	19	0.242252401	0.142574	High Vulnerability, High CapEx
21	20	0.187553531	0.0270844	High Vulnerability, Low CapEx
22	21	0.03857449	0.0271068	Low Vulnerability, Low CapEx
23	22	0.087868563	0.148287	Low Vulnerability, High CapEx

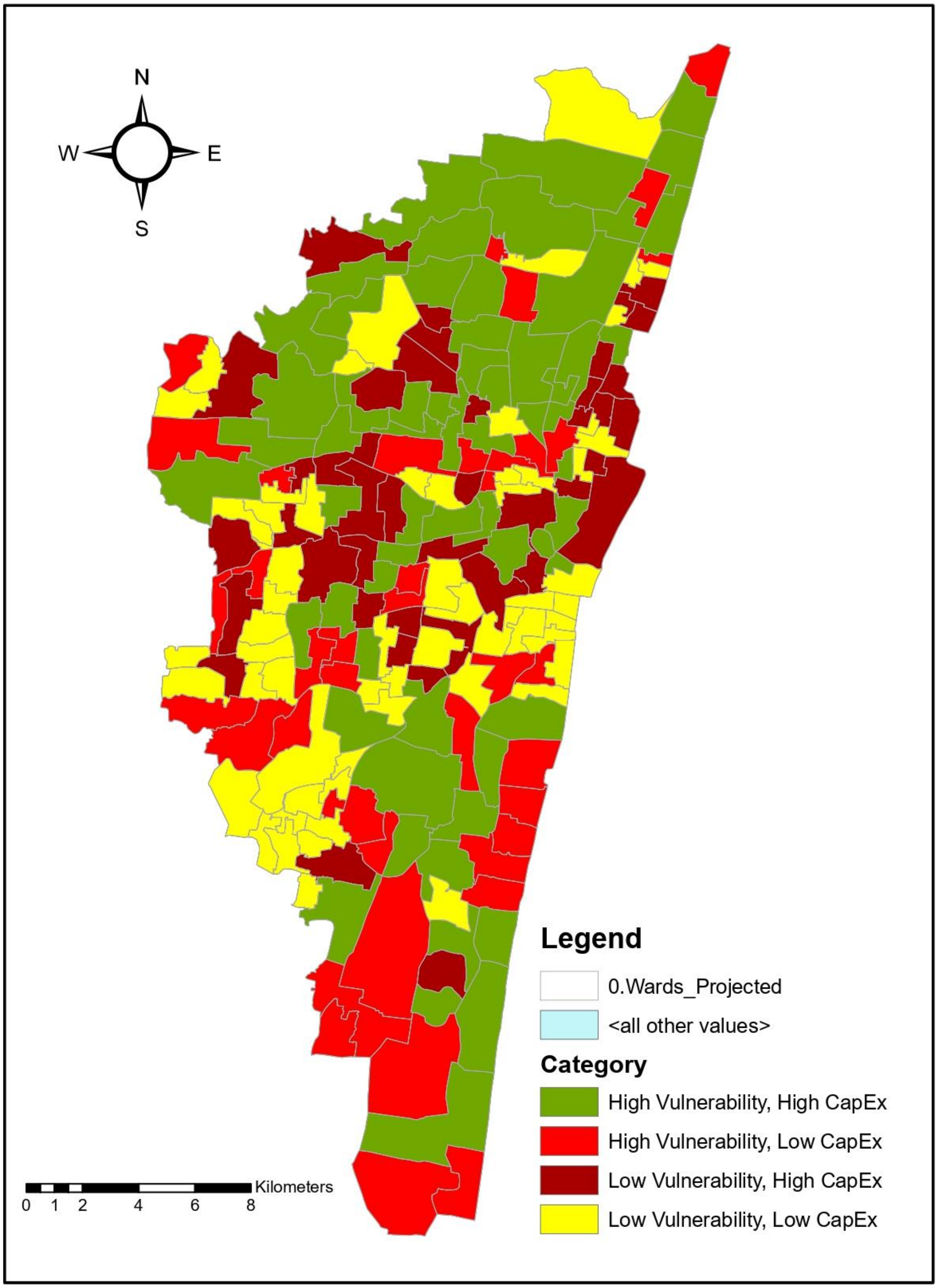


Figure 6-24 Classification of wards based on vulnerability and capital expenditure

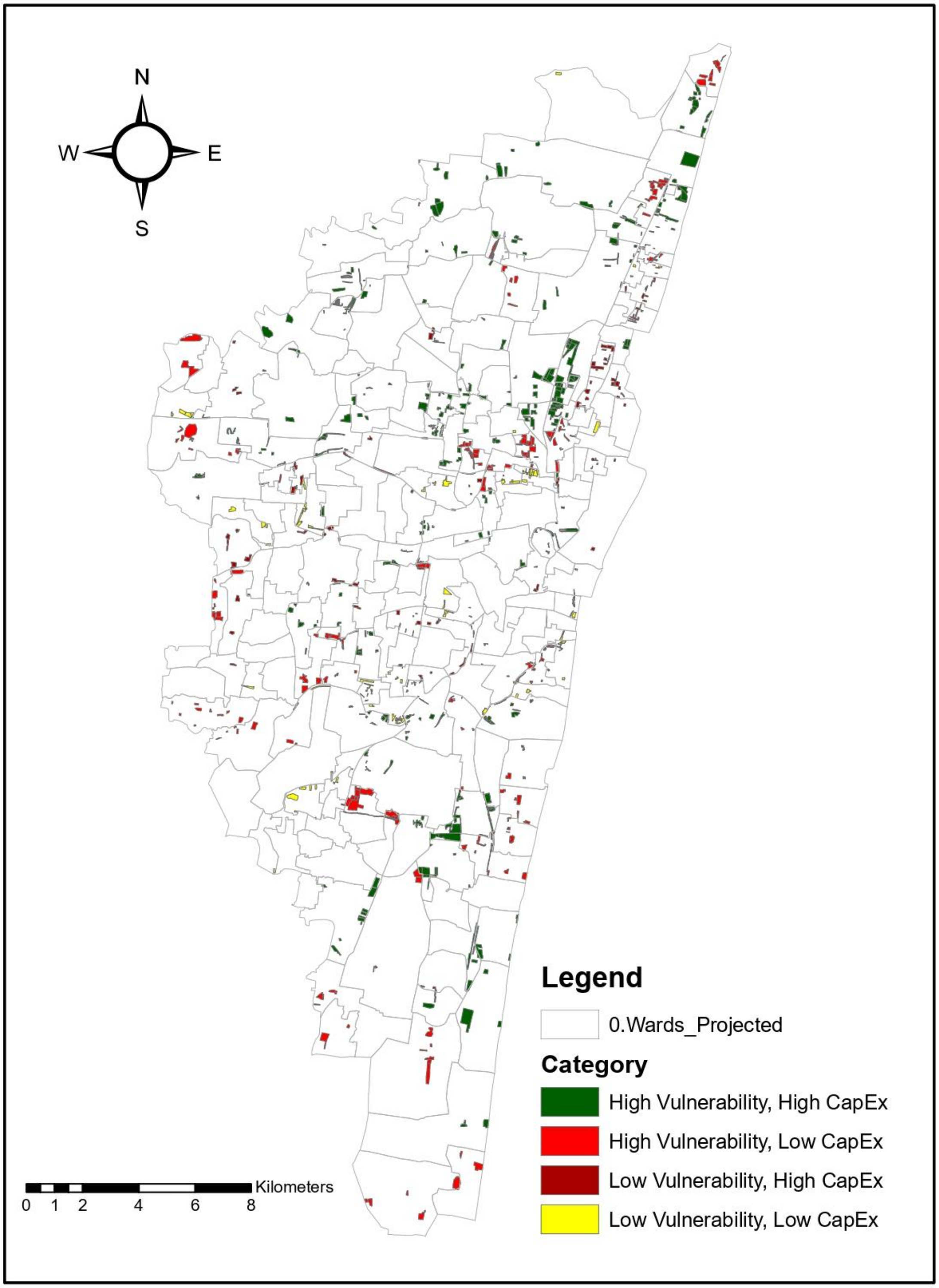


Figure 6-25 Classification of informal settlements based on vulnerability and capital expenditure

1. Underfunded Risk Zones (High Vulnerability, Low Capital Expenditure): These wards experience high flood vulnerability but receive relatively low capital investment. This mismatch indicates areas of policy neglect, institutional oversight, or budgetary constraints. The lack of investment in high-risk zones represents a serious governance gap that can exacerbate the impact of flooding on vulnerable populations.

2. Ineffective Investment Zones (High Vulnerability, High Capital Expenditure): In these wards, despite significant financial input, high vulnerability persists. This paradox points towards issues in the quality and targeting of infrastructure projects. Ineffective planning, delayed implementation, or the absence of community-centric solutions may undermine the intended outcomes of such expenditures, leading to sustained or even increased vulnerability.

3. Naturally Resilient Zones (Low Vulnerability, Low Capital Expenditure): These areas exhibit low flood vulnerability without major capital input. This can be attributed to naturally advantageous geographic features such as higher elevation, permeable soil, or well-functioning natural drainage systems. These zones highlight areas where nature provides a buffer against flooding, requiring only minimal infrastructure support.

4. Efficient Investment Zones (Low Vulnerability, High Capital Expenditure): Wards in this category reflect the ideal planning-investment outcome, where adequate and well-targeted capital expenditure corresponds to low levels of flood vulnerability. This indicates effective governance, proactive planning, and successful implementation of flood mitigation strategies. These areas serve as models of good practice for future urban flood resilience planning.

By classifying the wards using this framework, the analysis not only highlights spatial disparities in risk and resource allocation but also reveals areas for policy intervention, replication of successful models, and the need for equitable, evidence-based planning in flood disaster governance.

6.6 CONCLUSION: SYNTHESIZING VULNERABILITY AND GOVERNANCE INSIGHTS

The analytical framework combining physical and socio-economic vulnerability with capital expenditure has revealed critical patterns in Chennai’s flood risk landscape. The integration of multiple variables through advanced spatial and statistical methods—such as weighted overlays, TOPSIS, Spearman correlation, and spatial regression—allowed for a nuanced understanding of how vulnerability manifests and persists across wards. The identification of four zone typologies further emphasized the role of governance, highlighting gaps in resource allocation, implementation efficiency, and natural resilience. These insights offer a strong evidence base for informed policy-making, ensuring that future investments are both equitable and strategically targeted to build urban flood resilience, particularly for the most vulnerable communities.

CHAPTER 7 – PROPOSAL

- Introduction and Focus Area
- Vulnerability and degradation of Adyar River
- Urban River Management Framework (URMF) by NIUA

7 PROPOSAL

7.1 INTRODUCTION AND FOCUS AREA

This proposal focuses on the restoration and flood resilience of the Adyar River corridor, one of the three principal rivers running through Chennai. As the analysis of flood vulnerability and capital expenditure revealed, the Adyar region exhibits high vulnerability due to a combination of ecological degradation and unregulated development.

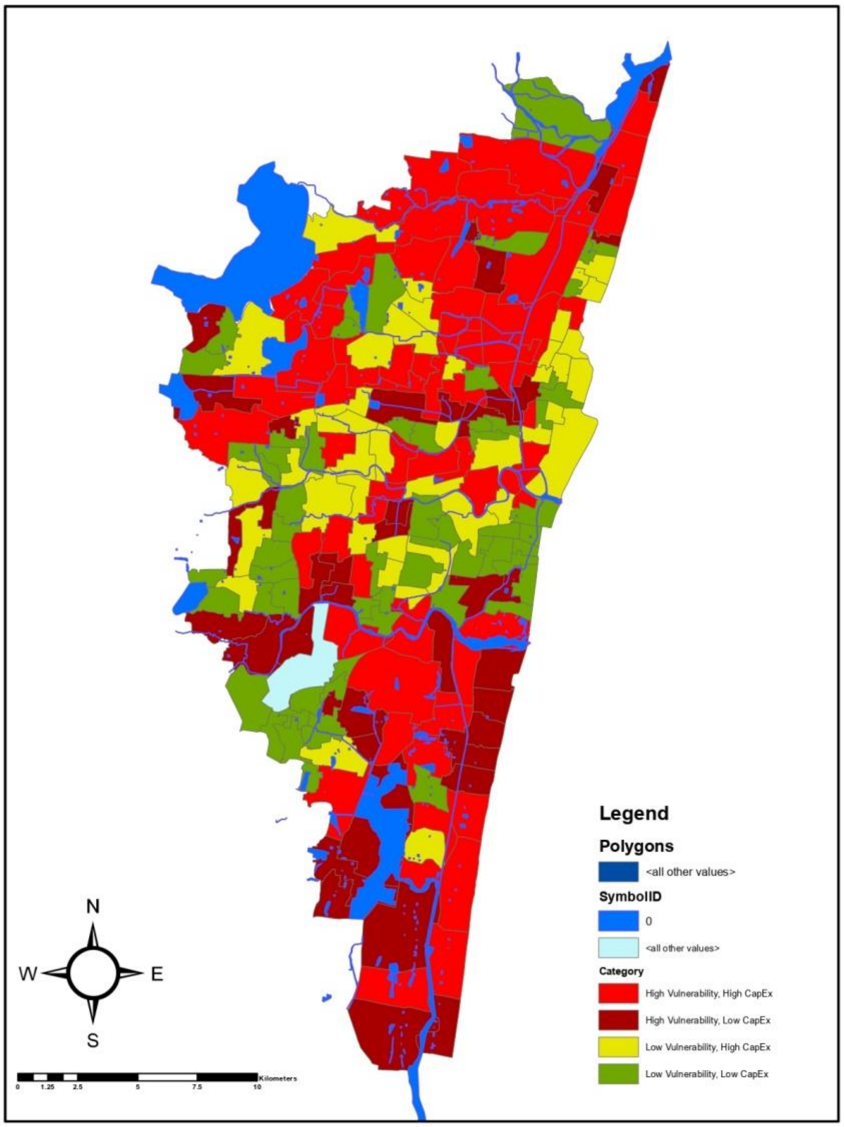


Figure 7-1 Categorization of wards of Chennai City based on vulnerability and capital expenditure

The strategy prioritizes the Adyar River stretch for intervention, with an aim to showcase a replicable model of integrated river restoration and informal settlement upgrading. The selected site encompasses both informal and elite encroachments, enabling a comprehensive approach to urban flood governance.

Based on the analysis, the study categorized regions into four capital expenditure–vulnerability types:

- Underfunded Risk Zone
- Ineffective Investment Zone
- Naturally Resilient Zone
- Effective Investment Zone

The Adyar region falls under the Underfunded Risk Zone, characterized by high flood vulnerability and inadequate capital expenditure. This proposal, therefore, targets improved planning, ecological restoration, and community engagement in this critical stretch.

7.2 VULNERABILITY AND DEGRADATION OF THE ADYAR RIVER

The **Adyar River**, originating from **Chembarambakkam Lake**, spans 29 km through Chennai. Its ecological degradation is attributed to:

- Unregulated sand mining
- Rapid industrialization and effluent discharge
- Waste and sewage dumping
- Mosquito breeding in stagnant waters
- Encroachments (informal and elite)
- Loss of traditional livelihoods

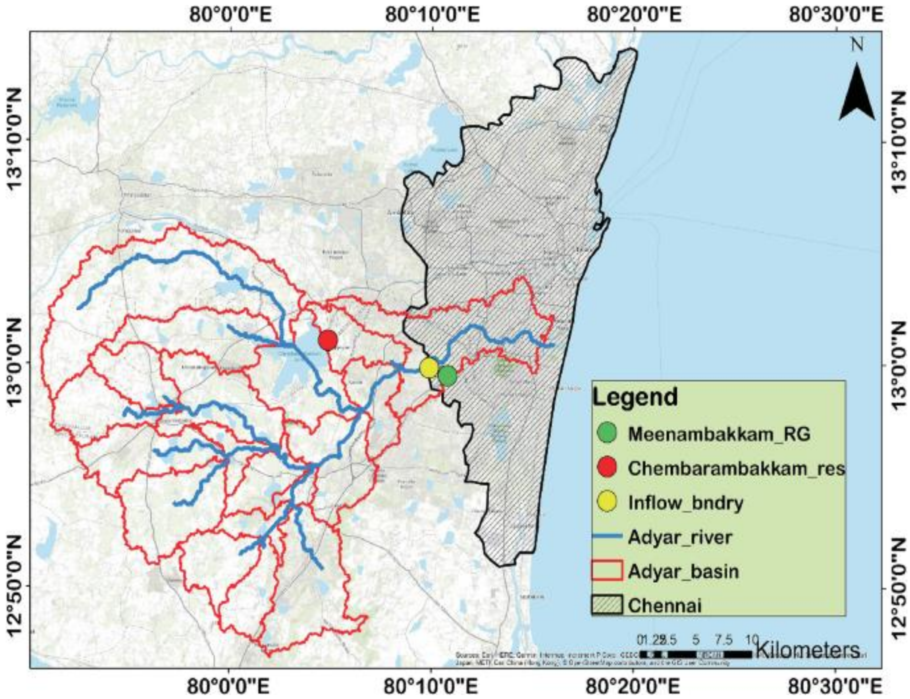


Figure 7-2 Adyar River Basin

Figure 7-3 Adyar river pollution

These issues directly contribute to urban flooding and deteriorate public health and ecosystem services. Current government strategies focus on encroachment removal**,** yet disproportionately target informal settlements. Elite encroachments, often camouflaged under real estate "restoration" projects, remain unaddressed, revealing a governance gap.

7.3 URBAN RIVER MANAGEMENT FRAMEWORK (URMF) BY NIUA

The NIUA's Urban River Management Framework (URMF) outlines a vision for a 'River-City Connect', bridging ecological integrity and urban integration.

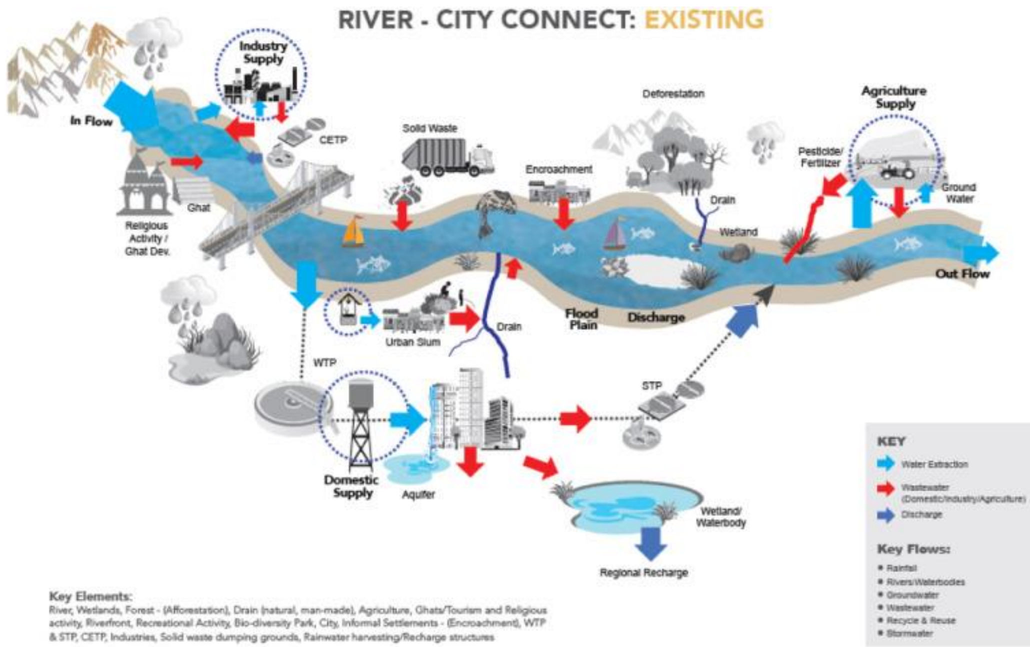


Figure 7-4 Existing situation of the river and city interaction

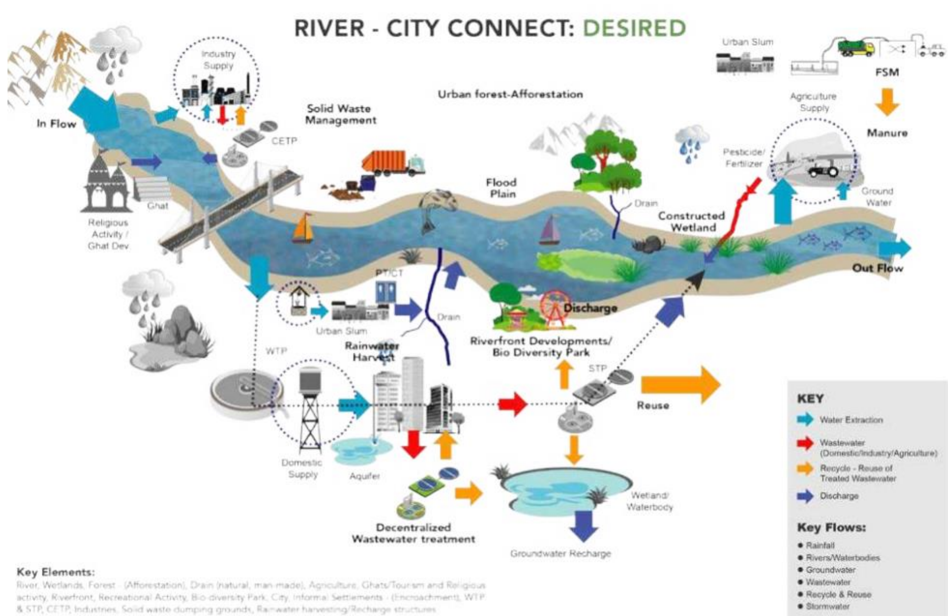


Figure 7-5 Desired situation of the river and city interaction

Among its ten objectives, we focus on three critical areas:

7.3.1 OBJECTIVE 1: REGULATING FLOODPLAIN ACTIVITIES

- No Development Zone: Demarcating a 100m buffer zone on either side of the river (CRZ standards) and integrating it with the city's Master Plan.
- Polluter Pays Principle: Levying heavy penalties on violators, with incentives like 'River Awards' and 'Green Certifications' for compliant stakeholders.
- Riparian Buffers: Establishing vegetated buffer zones to prevent runoff pollution, improve habitat, and reduce erosion.

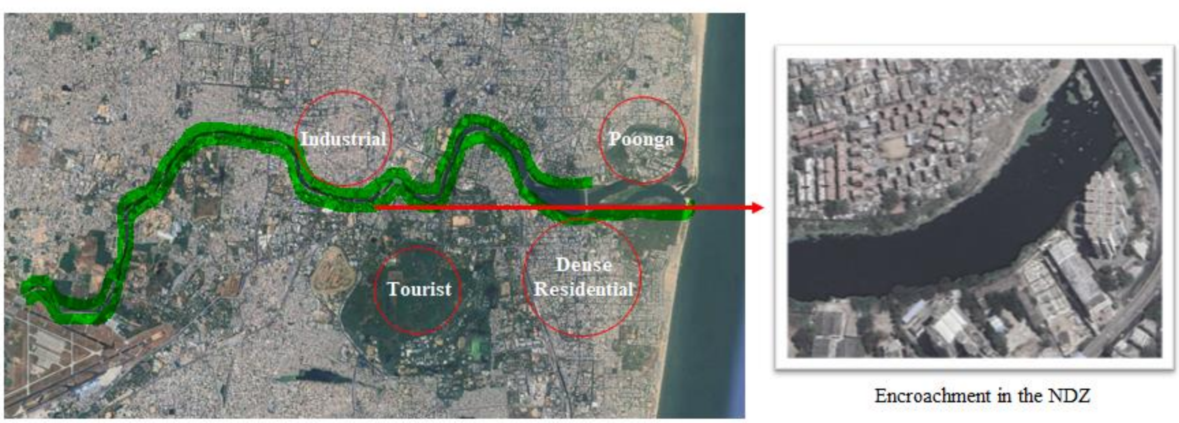


Figure 7-6 No Development Zone along the Adyar river

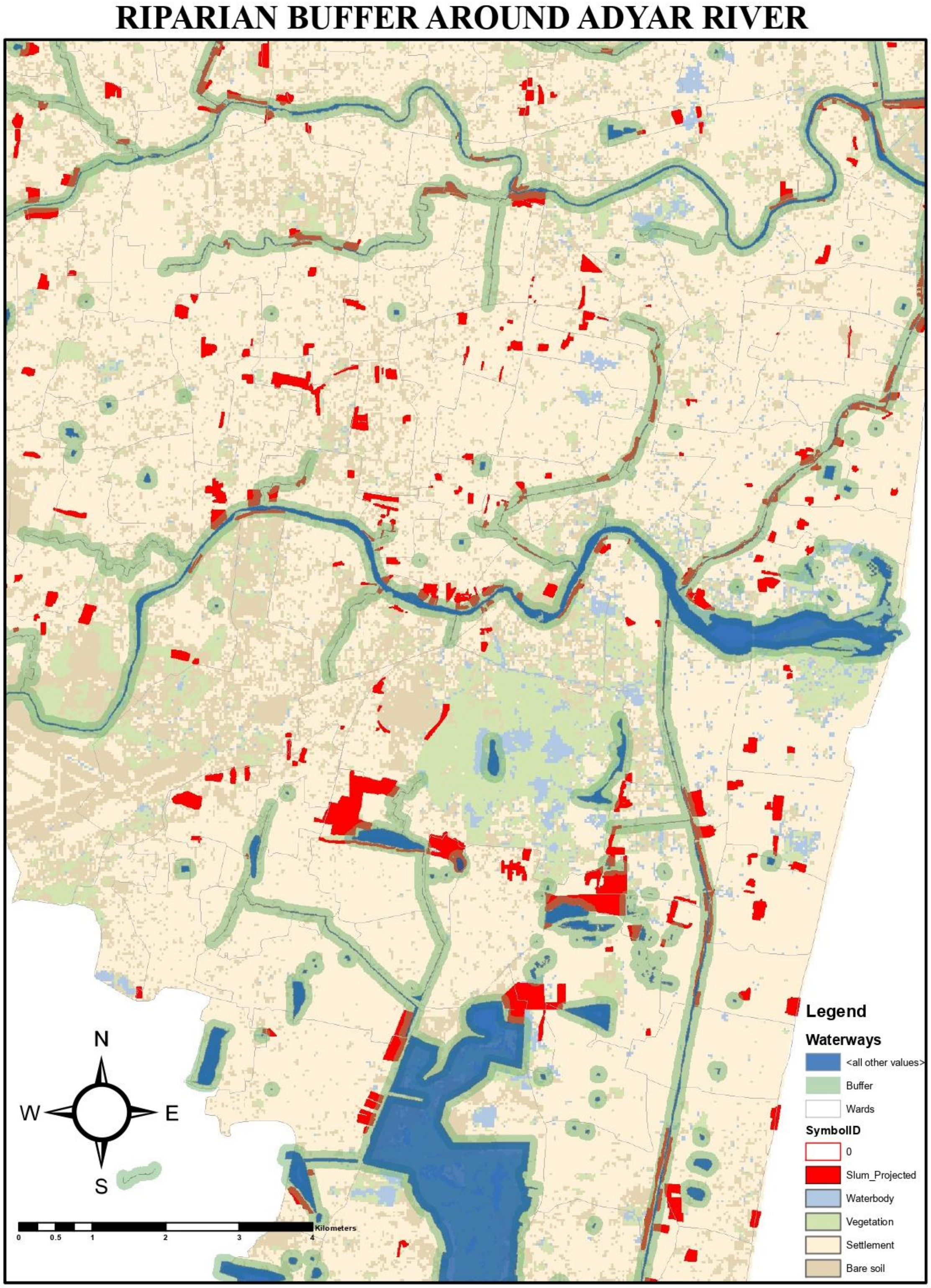


Figure 7-7 Riparian Buffer of 100 m around the Adyar river

Table 7-1 Listing of wards on the buffer region and its corresponding area.

1	Ward no.	Area (sq.m)	Area (sq.km)
2	94	507568.1663	
3	173	141531.295	
4	172	372223.2306	
5	174	229897.5575	
6	150	428596.2599	
7	12	1463000.661	
8	151	385559.6199	
9	139	951267.2355	
10	140	1051006.764	
11	143	537852.8414	
12	138	2035153.014	
13	3	754021.9238	
14	141	572229.3972	
15	137	221192.8693	
16	144	584984.5253	
17	145	513629.6405	
18	134	219389.8609	
19	142	849342.1203	
20	136	30221.34763	
21	135	97468.93034	
22			
23	**Total area**	**11946137.26**	**11.94613726**

The delineation of a 100-meter riparian buffer zone along both banks of the Adyar River results in a total area of approximately 11.94 square kilometers being demarcated as a No Development Zone (NDZ). This zone, as per the objectives outlined in the Urban River Management Framework (URMF) by NIUA, is essential for restoring the ecological health of the river, mitigating flood risks, and preventing further encroachment and pollution. However, this buffer also intersects with several residential pockets, both formal and informal, necessitating the relocation of existing populations residing within this sensitive zone. The clearance and rehabilitation of these settlements are critical not only from an environmental perspective but also to ensure public safety in the face of recurrent urban flooding events. A clear demarcation of this area allows for strategic planning of resettlement and compensation mechanisms**,** while simultaneously prioritizing the restoration of the riverbank as a functional ecological corridor that can enhance urban resilience and biodiversity.

7.3.2 OBJECTIVE 2: POLLUTION-FREE RIVER

To achieve the goal of a pollution-free Adyar River, a combination of structural and non-structural measures is essential, rooted in the holistic understanding of the urban water cycle. The urban water cycle involves the continuous movement of water through various interconnected stages—rainfall, runoff, water supply, wastewater generation, and eventual discharge into natural water bodies. When not properly managed, this cycle is disrupted, leading to severe water quality degradation and urban flooding. Structural measures such as Decentralized Wastewater Treatment Systems (DEWATS) play a crucial role in treating wastewater at the source, particularly in areas where centralized sewerage is either inefficient or absent. These systems reduce the volume of untreated effluents entering the river, thus mitigating direct pollution loads. Controlled outfalls help regulate discharge points and avoid peak flow dumping, while silt traps and trash barriers prevent sediment and solid waste from entering the water stream. Additionally, planting riparian vegetation along the riverbanks helps in natural filtration of pollutants, erosion control, and improving the riverine habitat.

On the other hand, non-structural measures focus on behavioral, institutional, and policy-level changes. Polluter tracking and regulation ensures that industries and residential users are held accountable for their effluent outputs, with strict enforcement of discharge standards. Formation of community monitoring groups empowers local stakeholders to participate in safeguarding the river's health through regular surveillance and awareness campaigns. Incentive programs for wastewater reuse, such as subsidies for grey water recycling or recognition for low-discharge industries, can promote sustainable water practices and reduce dependence on freshwater sources. Together, these measures foster a circular and resilient urban water system, reducing environmental stress on the river while reinforcing the city's commitment to sustainable water governance.

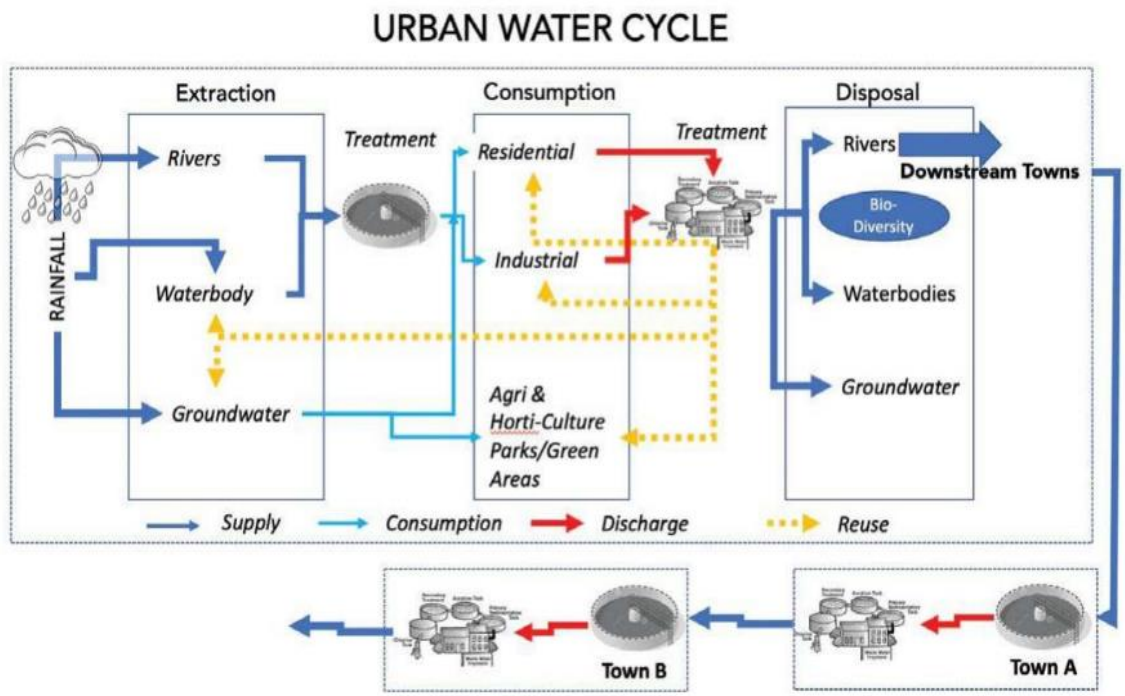


Figure 7-8 Urban Water Cycle

7.3.2.1 NATURE BASED SOLUTION – PHYTORID TECHNOLOGY

1. THEORY:

Phytorid is a constructed wetland technology developed by NEERI, designed to treat wastewater using specific wetland plants. The system consists of:

- A sedimentation zone
- A gravel-based filtration bed planted with species like *Canna indica*, *Typha*, etc.
- Anaerobic and aerobic treatment zones

Benefits:

- No electricity needed
- Low maintenance
- Suited for decentralized, low-income areas
- Produces reusable water for gardening/groundwater recharge

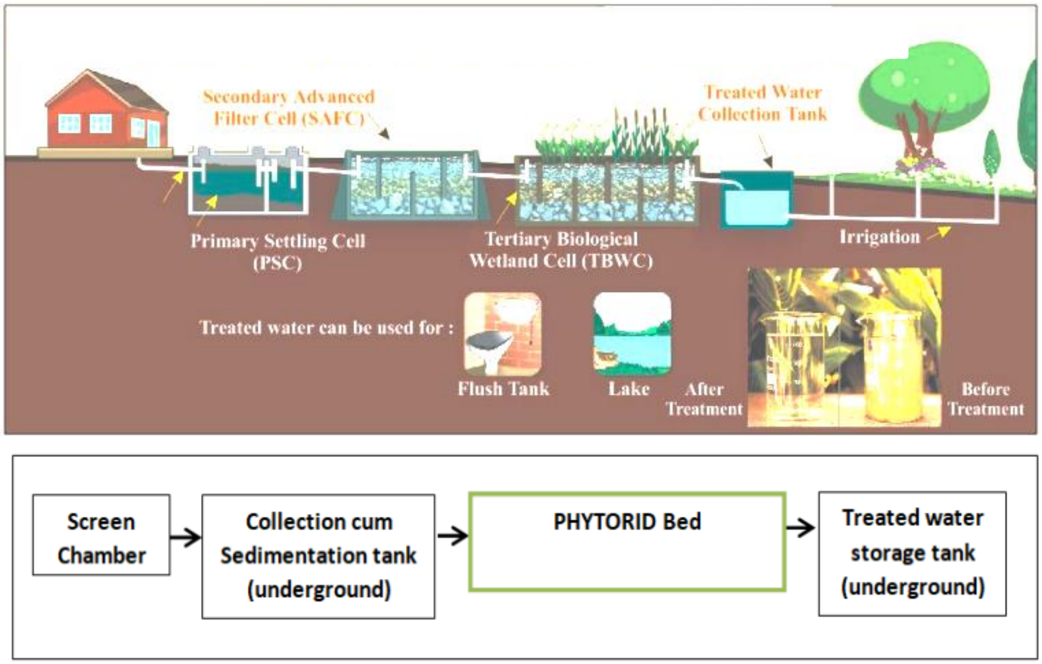


Figure 7-9 Components of Phytorid Technology

2. PROPOSAL AREA DELINEATION:

The site for the proposed Phytorid-based decentralized wastewater treatment system was meticulously selected through a multi-criteria spatial analysis incorporating key environmental and physical parameters. The selection process considered the inundation map of the Adyar River, identifying low-lying areas frequently affected by flooding, thereby prioritizing zones where wastewater accumulation and overflow are critical concerns. This was further refined using Land Use Land Cover (LULC) data to avoid ecologically sensitive zones and prioritize degraded or built-up areas that can be repurposed. Elevation data was utilized to ensure gravitational flow and efficient functioning of the treatment system, avoiding areas at extreme altitudes or with complex topography. Finally, the classification of vulnerable zones helped align the intervention with areas of high need, especially in informal settlements lacking access to sanitation infrastructure. The convergence of these spatial layers ensured that the selected site is not only technically viable but also socially and ecologically strategic, contributing significantly to the rejuvenation of the Adyar River corridor.

25 Year return period from 1991 to 2015

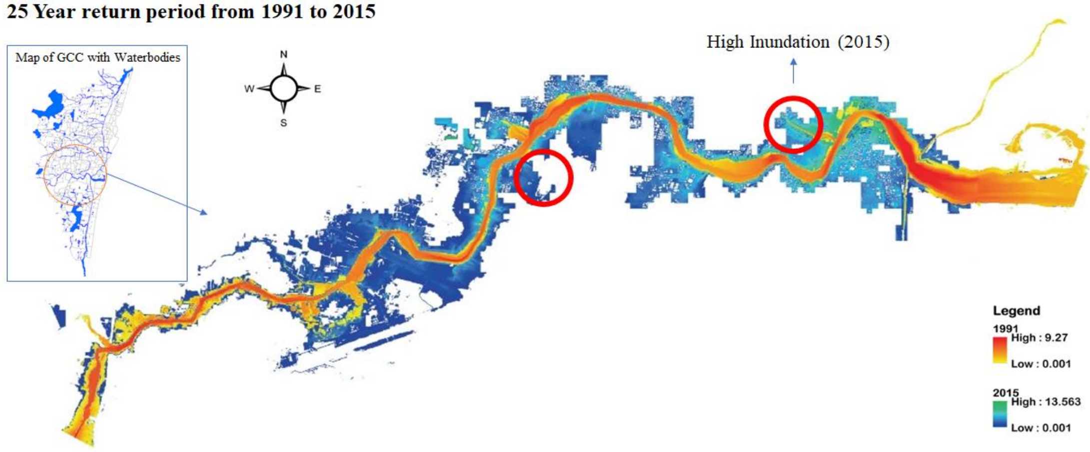


Figure 7-10 Pockets in the flood inundation map to propose constructed wetland

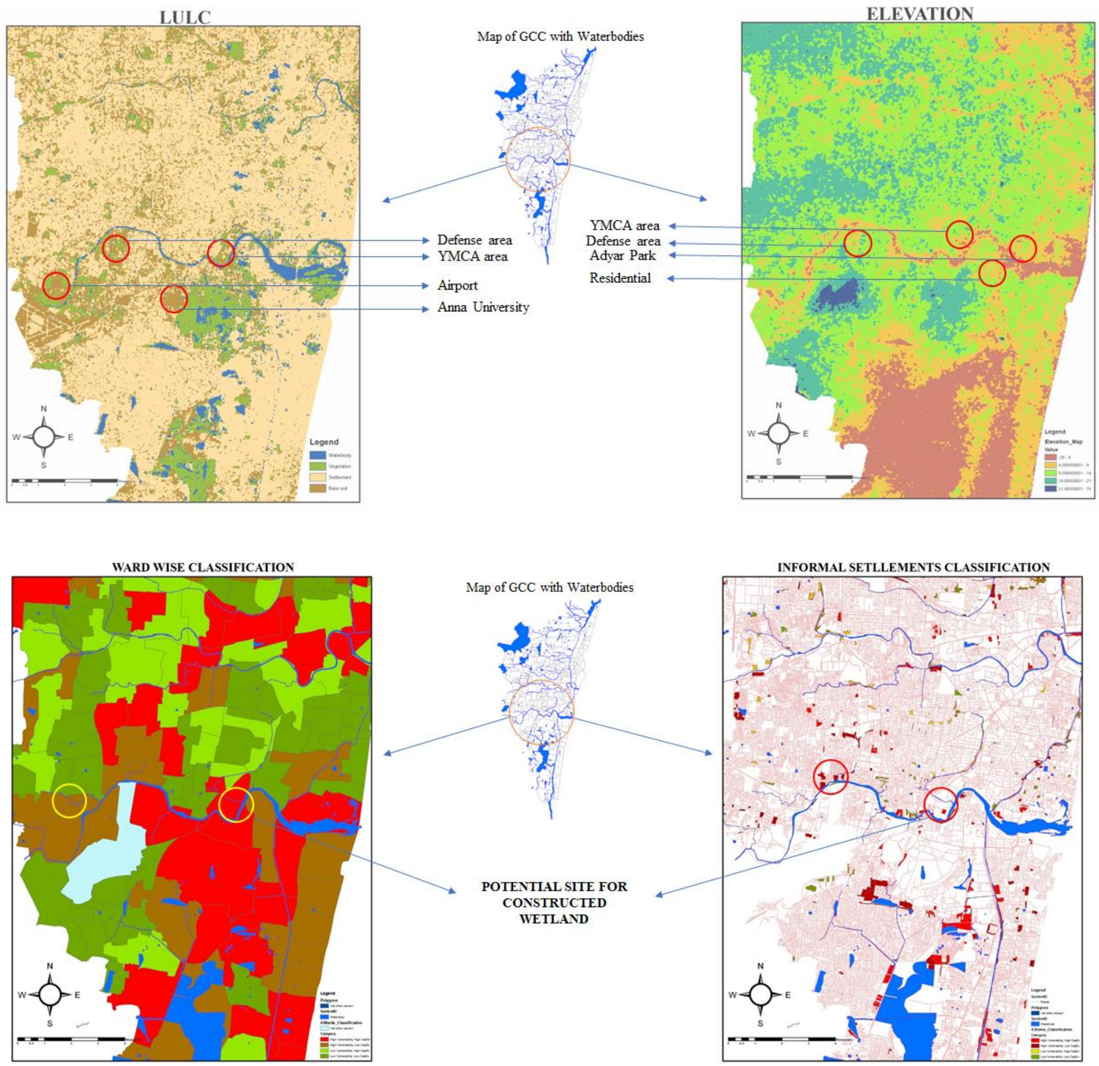


Figure 7-11 Pockets in the LULC, Elevation and classification maps to propose constructed wetland

3. SITE AREA AND ITS CHARACTERISTICS

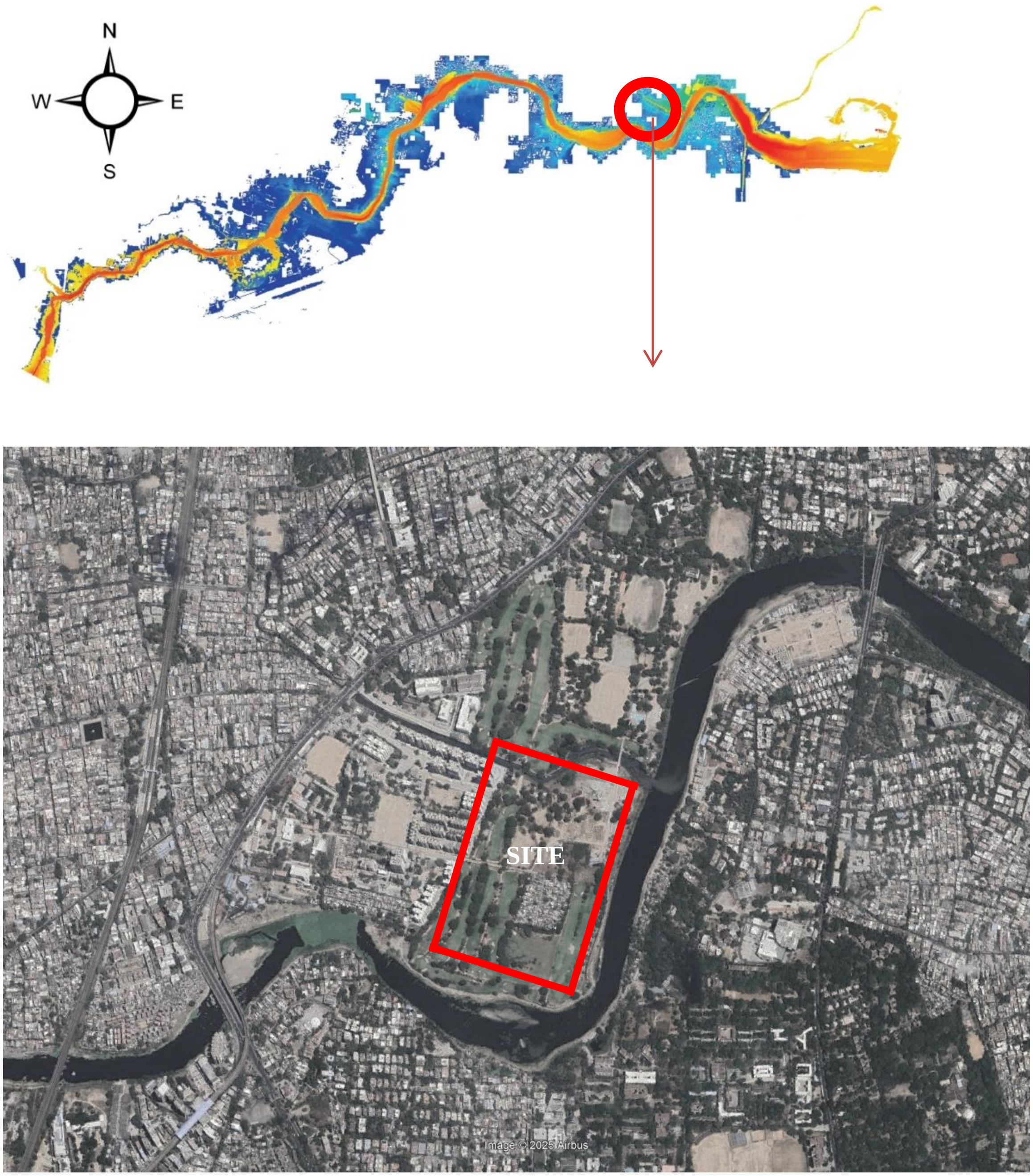


Figure 7-12 Selected site for Phytorid construction

The selected site for the Phytorid treatment system is strategically located along the Nandanam–Adyar Creek, an ecologically sensitive stretch that plays a crucial role in the drainage and flood regulation of the Adyar River basin. The existing land use at the site comprises a mix of public and semi-public functions, including the TNA Infra

Nandanam Plant**,** the expansive YMCA grounds**,** and adjacent community settlements that are primarily residential in nature. This land use pattern offers a viable opportunity for the integration of nature-based wastewater treatment infrastructure without significantly disrupting existing functions. The surrounding land uses include important public assets such as the PWD Government Quarters, the YMCA College**,** and established residential layouts, indicating a dense and diverse urban fabric. The presence of institutional and residential clusters underscores the urgent need for decentralized wastewater management solutions in this zone, and the site's location at the confluence of multiple land uses enhances the feasibility of demonstrating the Phytorid system as a community-shared ecological infrastructure that serves both environmental and public health objectives.

4. SITE AREA CALCULATION

Per capita water supply = 135 LPCD *(MoHUA)*

Per capita wastewater generation = 80% of 135 = 108 LPCD

Population of the surrounding wards = 1000

Total wastewater generated = 108 * 1000 = 1.08 MLD = 1 MLD

Total wastewater generated in the zone = 1 MLD

Area = (Wastewater flow * Hydraulic retention time) / (Design depth * porosity factor)

Wastewater flow = 1 MLD = 1000 m3/day

Hydraulic retention time = 3-5 days

Design depth = 0.5 – 0.7 m *(UN Habitat Constructed Wetlands Manual)*

Porosity factor = 0.4 (40%)

Area = (1000 * 4) / (0.6 * 0.4) = 1.66 hectares = 2 hectares

Total Area required for the Phytorid treatment is 2 hectares

Components and its corresponding area of the phytorid wetland system:

1. **Inlet chamber + Pretreatment zone** = 5% of 2 ha = 1000 m2 – removal of grit, reducing suspended solids, BOD, oil and grease.
2. **Treatment cells (gravel beds with plants) =** 35% of 2 ha = 7000 m2 – Filtration through plant roots
3. **Phytorid plants (macrophytes)** = 40% of 2 ha = 8000 m2 – Absorb nutrients, removal of heavy metals
4. **Outlet chamber =** 20% of 2 ha = 4000 m2 – Collects treated water before discharge and send it for reuse.

Figure 7-13 Components of Phytorid technology in the selected site area

5. COST AND IMPACT ANALYSIS

Capital expenditure per KLD = INR 15 Lakh

For 1 MLD (1000 KLD) = 1000 * 15 = INR 15,000 Lakh = INR 150 Crores

Capital expenditure required for the phytorid based wastewater treatment plant = INR 150 crores

Operation & Maintenance cost per KLD per year = INR 1.83 Lakh

For 1 MLD (1000 KLD) = 1000 * 1.83 = INR 1,830 Lakh = INR 18.3 Crores/year

Operation & Maintenance cost required for the phytorid based wastewater treatment plant = INR 18.3 Crores/year

The identified site for the Phytorid treatment system is situated within Ward No. 171**,** a zone that falls under the High Vulnerability and High Capital Expenditure category based on the integrated vulnerability and expenditure classification. This ward is particularly significant due to its exposure to recurrent flooding and the socio-economic fragility of its residential population. Moreover, it is surrounded by wards categorized as High Vulnerability but Low Capital Expenditure**,** highlighting the spatial disparity in resource allocation for flood resilience and environmental management. The implementation of a Phytorid-based decentralized wastewater treatment system in this location is projected to require an investment of approximately ₹150 crores**,** which accounts for around 10% of the total Capital Expenditure allocated for flood-related infrastructure in the region. This targeted expenditure is both justified and strategic, as it addresses a critical urban water management gap while simultaneously promoting nature-based solutions that can deliver long-term environmental and public health benefits across multiple vulnerable neighborhoods.

Table 7-2 Environmental Impact of Phytorid constructed wetlands

Environmental Impact
1. Improvement in Water Quality – Reduction in pollutants such as BOD, COD, nutrients and suspended solids. Controls eutrophication.
2. Groundwater recharge – Reused water for irrigation or infiltration into the groundwater.
3. Reduction in urban flood risks – wetland acting as buffer, slows down water flow and sediment deposition in the river & **Enhancement of biodiversity & ecological restoration**

Table 7-3 Social Impact of Phytorid constructed wetlands

Social Impact
1. **Improved Public Health –** Reducing the risk of waterborne diseases, reducing mosquito breeding
2. Community Benefits & Awareness – Can be designed as an eco – park or public space engaging local communities
3. Enhancement of riverfront aesthetics – Converting polluted drainage areas into green spaces, improving landscape quality

Table 7-4 Economic Impact of Phytorid constructed wetlands

Economic Impact
1. Cost savings on sewage treatment – decentralized treatment reduces load on STPs, cutting operational costs for the city. Low maintenance and energy – free operation
2. Revenue generation – Treated water can be used for irrigation, landscaping or industrial cooling.
3. Job creation – Provides employment opportunities in construction, maintenance and environmental monitoring.

7.3.2.2 NATURE BASED SOLUTION – DETENTION BASIN

1. THEORY:

A detention basin is an integral component of storm water management infrastructure, designed to temporarily capture and store excess rainwater and surface runoff**,** thereby reducing peak flow volumes and mitigating the risk of urban flooding. In the context of the Adyar River, such basins serve multiple critical functions. Primarily, they contribute to flood mitigation by lowering the peak flood levels during intense rainfall events, which is essential for protecting vulnerable communities along the riverbanks. Secondly, they enhance storm water management by slowing down runoff, allowing for its controlled release into natural drainage channels or treatment systems. Another significant benefit is the promotion of groundwater recharge, as these basins allow for percolation, helping replenish diminishing aquifers. Furthermore, detention basins aid in water quality improvement, as the process of sedimentation within the basin naturally removes suspended solids and pollutants before the water is discharged. When designed thoughtfully, these basins can also support urban biodiversity and recreation, functioning as constructed wetlands or green public spaces that enhance both ecological value and community well-being.

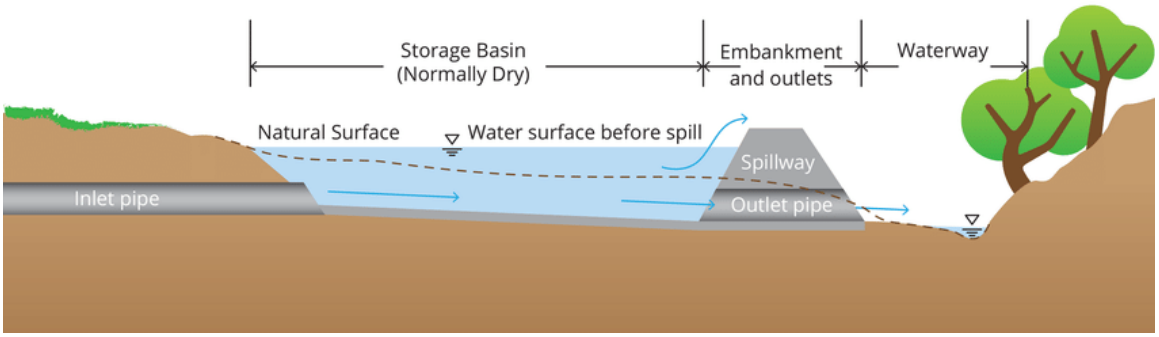


Figure 7-14 Cross Section of a Detention Basin

2. SITE AREA CALCULATION

Peak storm water flow in the Adyar river (Q) = 1699 m3/s

Detention time = 12 hours

Depth of the basin = 5 m

Required storage volume = Q * T = 1699 * 12 * 3600 = 73.4 million m3

Required storage volume for the detention basin is 73.4 million m3

Basin area requirement = v/d = 73.4 / 5 = 1468 hectares

Basin area required is 1468 hectares

Since it is a huge area, and will be impractical to be located in a densely populated city, the site can be located in a naturally depressed region where 30% of storm water will already be absorbed by permeable spaces in the waterway.

Therefore the revised basin area requirement is 1027 hectares

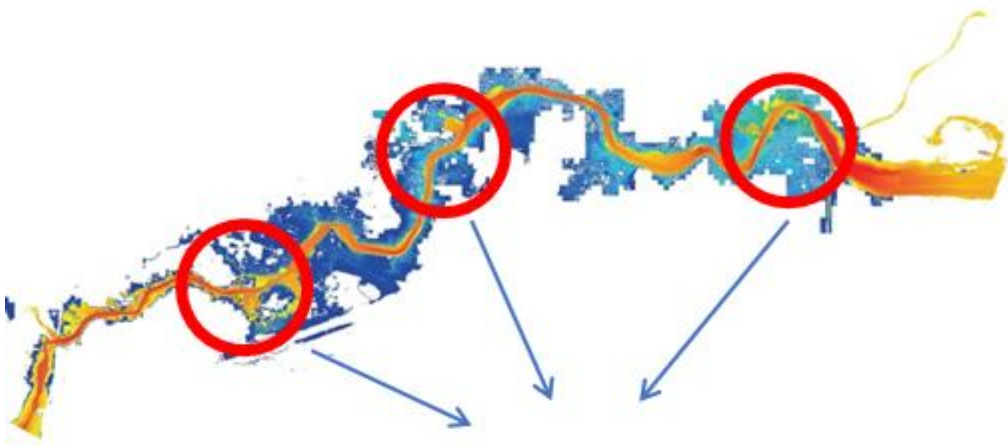


Figure 7-15 Pocket proposals of the detention basin around Adyar river

Given the expansive area of 1027 hectares that falls within the vulnerable flood-prone zones along the Adyar River, it is neither feasible nor practical to accommodate a single, centralized detention basin to manage storm water runoff across the entire stretch. Instead, a decentralized approach will be adopted, wherein multiple detention basins will be strategically located across different micro-catchments. Each basin will be designed to cater specifically to its immediate surrounding watershed, ensuring efficient storm water capture, storage, and delayed release. This distributed system will enhance local flood resilience, prevent overloading of the main river channel, and provide tailored responses to the unique hydrological and topographical characteristics of each catchment.

The cost of implementing these detention basins will be significantly influenced by the excavation requirements, which form the major component of capital expenditure. The depth, area, and slope of excavation will be guided by the Public Works Department (PWD) standards, which ensure structural stability, optimal water holding capacity, and integration with existing drainage systems. Despite the initial investment, detention basins offer a cost-effective long-term solution, particularly due to their low operation and maintenance requirements. Unlike conventional storm water pumping systems or engineered concrete storage tanks, these nature-based solutions rely on gravity and vegetation for performance, thus reducing the need for energy inputs and specialized maintenance.

7.3.3 OBJECTIVE 9: CITIZEN AWARENESS

Building citizen awareness is a critical component in restoring the Adyar River and enhancing resilience to urban flooding. Communities living along the river—particularly those in informal settlements—are often the first to face the consequences of environmental degradation, yet they are rarely involved in its restoration. This objective seeks to create an informed citizenry that understands the value of the river, the importance of floodplain regulations, and the ecological and public health consequences of actions like waste disposal and encroachment. Awareness campaigns should not only target behavioral change, but also promote a sense of collective ownership over the river and its ecosystems. These campaigns can include community workshops, school-based river literacy programs, interactive signage, and river walks that convey historical, ecological, and cultural narratives of the Adyar. By embedding river stewardship into the everyday knowledge systems of the community, this objective transforms passive residents into active custodians of urban water ecosystems.

7.3.4 OBJECTIVE 10: CITIZEN ENGAGEMENT

Beyond awareness, active citizen engagement is essential to the long-term success of urban river management. This objective emphasizes co-creation and participatory governance by involving local residents, civil society groups, and stakeholders in planning, monitoring, and maintaining interventions along the Adyar River. Participatory tools such as citizen science programs, neighborhood river committees, and public feedback mechanisms can enable residents to report pollution sources, monitor water quality, and advocate for their rights—especially in the context of informal settlement rehabilitation or relocation. Engagement strategies must be inclusive, transparent, and sensitive to the socio-economic dynamics of the area, ensuring that marginalized voices are heard and represented. By transforming river restoration from a top-down government initiative to a shared civic mission, this objective nurtures a stronger river-city relationship, cultivates accountability, and builds a foundation for sustainable, community-led environmental stewardship.

CHAPTER 8 – CONCLUSION

8 CONCLUSION

A key contribution of this study lies in its emphasis on the intersectionality of vulnerability, where physical exposure intersects with social and economic marginalization. Informal settlements, often situated in environmentally sensitive zones due to lack of secure tenure and affordable housing, are doubly disadvantaged—exposed not only to the physical risks of flooding but also to systemic neglect in governance and infrastructure provision. The spatial disaggregation of vulnerability factors, coupled with stakeholder interviews and secondary data analysis, reveals how urban development patterns, informal housing growth, and insufficient public services converge to exacerbate disaster risks. The findings call attention to the urgent need for context-specific planning that considers both environmental thresholds and socio-economic equity while designing flood mitigation infrastructure and urban redevelopment schemes.

Moreover, the research illustrates that flood governance cannot be addressed through technocratic solutions alone. Instead, it calls for adaptive and inclusive governance frameworks that recognize informal communities as legitimate stakeholders in the urban fabric. By integrating tools such as citizen mapping, participatory planning, and decentralized infrastructure like phytorid-based wastewater treatment and detention basins, the study highlights scalable, low-impact interventions that serve both ecological and human needs. The alignment with national frameworks like the NIUA's Urban River Management Plan ensures that these proposals are not only grounded in local context but also linked to broader policy aspirations. Ultimately, this thesis advocates for a paradigm shift in urban planning—one that transitions from reactive, infrastructure-heavy flood responses to proactive, ecosystem-based governance rooted in resilience, justice, and long-term sustainability.

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NANDHINI P | 23AR60R17

CITY PLANNING

EDUCATION

Year	Degree/Exam	Institute	CGPA/Marks
2025	Master of City Planning (PG)	Indian Institute of Technology (IIT), Kharagpur	8.86/10
2022	Bachelor of Architecture (UG)	Mohamed Sathak AJ Academy of Architecture, Siruseri	8.57/10
2017	Senior School Certificate Examination (10+2)	Prince Mat. Hr. Sec. School, Nanganallur, Chennai	95.3%
2015	Secondary School Examination (10)	SV Vivekananda Vidyalaya, Chitlapakkam, Chennai	9.4/10

COURSEWORK INFORMATION

Core Subjects: Planning Legislation | Planning Informatics | Development Management and Finance | Urban Design | Transportation Planning | Remote Sensing and GIS | Quantitative methods in Planning | Housing

Electives: Environmental Planning | Financing Infrastructure Projects | Water Resources Assessment and Management | Regional Analysis and Programming

SKILLS AND EXPERTISE

- **Technical Skills :** GIS and Spatial Analysis | Data Analysis and Statistics | Environmental Planning | Urban Design
- **Knowledge Areas :** Urban Governance | Urban Economics | Disaster Management
- **Software Skills :** ArcGIS | SPSS | QGIS | SQL and Python Basics | MS Office | Photoshop | AutoCAD | Google Sketchup
- **Analytical and Communication Skills :** Public Speaking | Community Engagement | Problem - Solving | Scenario Planning
- **Languages:** Proficient in English, Tamil, Hindi and Sourashtra.

INTERNSHIPS AND PROJECTS

- Student Thesis Project **| Master of City Planning | IIT Kharagpur** **[July 2024 – Present]**
  - **Assessing the Influence of Vulnerability on Flood Disaster Governance: A Study of Informal Settlements in Chennai**
  - Analysis of **vulnerability** of informal settlements and **examining the capital expenditure** on flood management.
  - Utilizing **spatial data analysis** to identify high risk areas and **propose strategies** for improving flood mitigation.
- Planning Intern **| Biome Environmental Trust | Wipro Earthian | Bengaluru** **[May 2024 – July 2024]**
  - **Led water management initiatives** for Bangalore City, focusing on the **rejuvenation of open wells** and proposing **recharge wells** to improve groundwater sustainability.
  - Conducted **comprehensive water balance assessments** to forecast future water demands and developed **rainwater harvesting strategies** to optimize resource utilization.
- Academic Project **| City Development Plan | Masters of City Planning | IIT Kharagpur** **[Jan 2024 – May 2024]**
  - **Conducted a comprehensive analysis of social infrastructure** in Nashik city, with a focus on **healthcare facilities**.
  - **Proposed strategies** for healthcare development as part of the **Nashik City Development Plan 2044**, ensuring alignment with long term urban growth and sustainability goals.
- Other Academic Projects
  - Worked on a number of term papers and report documentation as part of academic projects.

POSITIONS OF RESPONSIBILITY

- **Class Representative I Master of City Planning I IIT Kharagpur** **[July 2023 – Present]**
- **Teaching Assistant I Master of City Planning I IIT Kharagpur** **[August 2024 – Present]**

Served as the Teaching Assistant for Bachelors of Architecture 1st year students for the subject "Descriptive Geometry" and serving as the TA for the 2nd year students for the "Architectural Design Studio" under Prof. Arup Das.

- **Host I Guru Vandana I IIT Kharagpur**

Hosted the Teachers day event "Guru Vandana" organized by RS – PG of Department of ARP on September 5, 2023.

AWARDS, CERTIFICATIONS AND CONFERENCES

- Abstract selected to present in the **2025 EWRI Conference** as a part of 2025 World Environmental & Water Resources Congress **conducted by American Society of Civil Engineers during May 19-May21, 2025 in Anchorage, Alaska.**
- Shortlisted for **NIUA Student Thesis Competition (STC S-5) on Re-imagining Urban Rivers** organized by NIUA in collaboration with **National Mission for Clean Ganga (NMCG)**
- **Google Earth Engine for Hydrological Applications: A Hands – on Introduction** by NPTEL, IIT Workshop
- **Best Thesis Award** - First place in 'Architectural Design competition – Thesis category' held at VIT, Vellore for the topic 'Heritage Interpretation Centre in Hampi, a project proposal for HWHAMA'.
- **Rank Holder** - Anna university Rank holder (33rd rank) for B.Arch. batch 2017 - 2022.
- **NPTEL Certification** - Certification in 'Structure, form and architecture : the synergy' with a consolidated score of 73%.

EXTRA-CURRICULAR ACTIVITES AND HOBBIES

- Photography I Badminton I Event Organization I Reading Fiction.