# ASSESSING THE INFLUENCE OF VULNERABILITY ON FLOOD DISASTER GOVERNANCE: A STUDY OF INFORMAL SETTLEMENTS IN CHENNAI, INDIA

Total word count: 4191
Number of figures: 6

# Vulnerability and Flood Disaster Governance in Chennai, India

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# 1 Abstract:

Chennai, a city with a 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 populations. 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

# 2 Introduction:

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 (Shivakumar, 2023). This unplanned growth, combined with the increasing impacts of climate change, has intensified the vulnerability of informal settlements to natural hazards, particularly floods (Williams, 2019). 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 (Dangol, 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. 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.

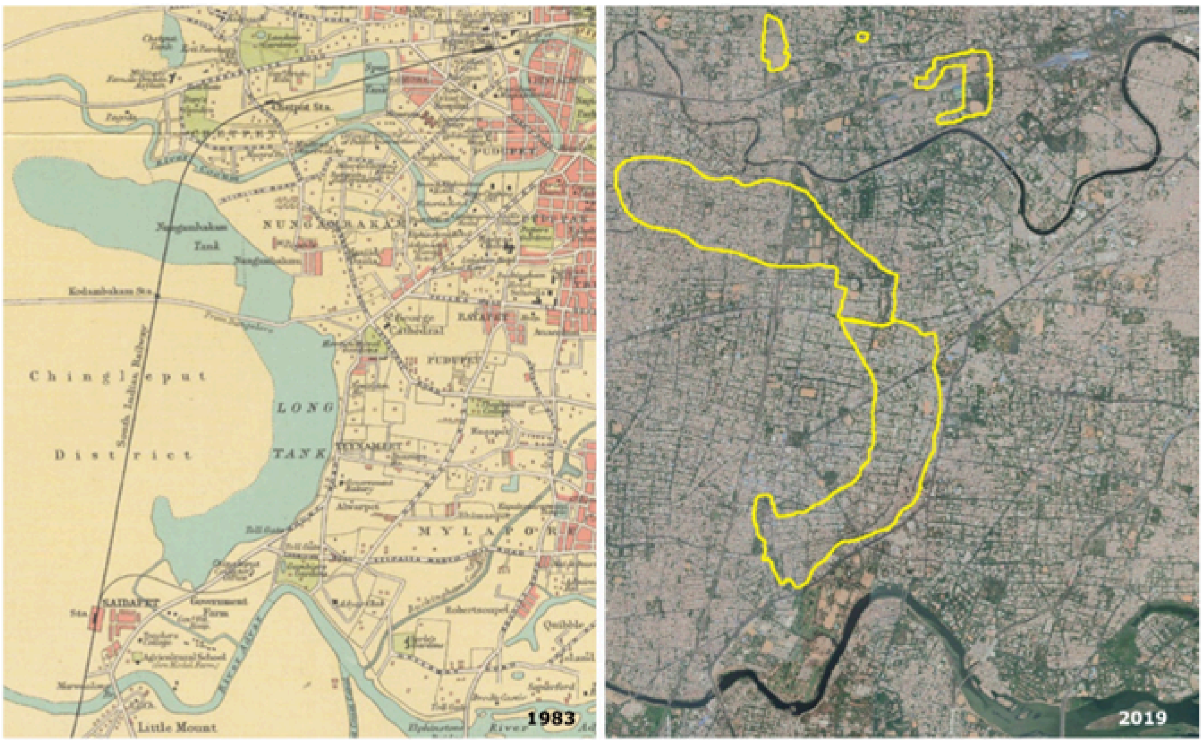


Figure 2-1 Encroachment of Long Tank from 1983 to 2019

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 (Wu, 2020). 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, 2018). 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. 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.

The objectives of this study are centered on understanding and addressing the vulnerability of informal settlements in Chennai, particularly in the context of flood risk and disaster governance. This study analyzes the spatial distribution of vulnerability in informal settlements across the city. This will be achieved by mapping the socio economic and physical factors that contribute to vulnerability. Geospatial techniques, such as GIS analysis, will be employed to assess the extent and patterns of vulnerability across different wards in Chennai. The study will utilize the Multi- Criteria Decision Making (MCDM) method; specifically the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), to develop a vulnerability index. This method will provide a comprehensive and quantitative assessment of vulnerability across different areas. The study also examines the relationship between governance expenditure and vulnerability, with a focus on capital expenditure dedicated to flood prevention and mitigation. By analyzing budgetary allocations and the distribution of financial resources across different wards, this study seeks to determine whether government spending is aligned with the areas of greatest vulnerability. This will involve a detailed analysis of the capital expenditure data from the Greater Chennai Corporation, correlating it with vulnerability maps to assess whether the expenditure is sufficient and targeted effectively.

The central research question guiding this study is: ‘Is disaster governance driven by the vulnerability of the exposed population?’ By exploring this question, the study aims to provide valuable insights into the effectiveness of disaster governance in addressing the needs of vulnerable populations, particularly in informal settlements. The findings will contribute to a better understanding of how governance expenditure and vulnerability are interconnected, ultimately helping to propose strategies for more effective flood risk management and disaster prevention in Chennai.

# 3 Literature Review

Chennai, among the vulnerable cities of the Global South, presents a compelling case where the convergence of climatic extremes, infrastructure inadequacies, and socio-political neglect has compounded flood risks – especially for informal settlements. While much of the existing literature emphasizes engineering-based mitigation measures, a more nuanced body of scholarship has emerged in recent years that interrogates the social and governance dimensions of flood risk. This literature review critically examines such perspectives, especially focusing on informal settlements and marginalized communities in Chennai.

## 3.1 Vulnerability and Informality

Vulnerability in informal settlements is not a natural condition but a result of structural exclusion and spatial marginalization. Dilip Diwakar discusses how resettlement policies in post-disaster Chennai pushed slum dwellers to the urban peripheries – areas often lacking basic infrastructure and more prone to flooding. This displacement under the guise of rehabilitation increased both physical exposure and social vulnerability (G., 2016). Similarly, Christopher analyzes how informal settlements are often located in ecologically sensitive zones such as floodplains and marshlands, not by choice, but due to governance failures in ensuring affordable and safe housing (L.Atkinson, 2024). These studies highlight that vulnerability is produced through systemic neglect and policy decisions that fail to account for lived realities.

### 3.1.1 Governance and Planning Processes:

Governance frameworks in Chennai have played a central role in both generating and managing flood risk. Subramanian critiques the fragmented nature of urban governance in Indian cities, pointing to poor coordination among agencies and the top-down implementation of flood mitigation projects. In Chennai, infrastructural interventions like storm water drains are often executed without local consultation, bypassing the needs of vulnerable communities (Subramanian, 2018). Researchers further argue that flood risk is exacerbated by the failure to integrate traditional water systems and ecological landscapes into formal urban planning. These studies collectively call for governance reforms that prioritize inclusivity and ecological sensitivity.

### 3.1.2 Democratic Governance and Climate Policy Outcomes:

Recent studies have explored the complex relationship between democratic institutions and climate action. While democracies often adopt more climate-related policies and regulations, actual reductions and improved adaptation outcomes are not guaranteed. Structural factors such as unequal wealth distribution, corruption, etc. can weaken the impact of these policies. In the context of urban flood governance, this implies that democratic structures alone are insufficient unless coupled with equity—focused reforms (Lindvall, 2024). For cities like Chennai, democratic decentralization needs to be complemented by inclusive decision-making and redistributive investments to truly build resilience in informal and vulnerable communities.

### 3.1.3 Climate Finance and the Limits of Private Sector Engagement:

The growing reliance on private finance for climate adaptation – especially in the Global South – has been critiqued for undermining principles like local ownership, transparency, and equity. Studies on the Green Climate Fund reveal that private-sector-led projects often prioritize large-scale, mitigation focused investments with limited involvement of local stakeholders (Kalinowski, 2024). This dynamic is relevant to Chennai's flood governance, where flood control projects are often planned from the top without including the most affected communities. Such an approach can leave out the needs of vulnerable groups. This calls for reorienting climate finance towards more accountable, locally embedded mechanisms that address both infrastructural and socio political dimensions of risk.

The literature review makes it clear that flood vulnerability in Chennai is a socio-political phenomenon shaped by governance failures, planning practices, and systemic marginalization of informal settlements.

## 4 Materials and Methods

This study adopts an integrated spatial and statistical approach to evaluate flood vulnerability and capital investment in Chennai. The methodology is structured around the creation of physical and socio-economic vulnerability indices, followed by a comparative analysis with municipal expenditure data related to flood management.

The physical vulnerability indicators were primarily derived from remotely sensed satellite imagery and topographic data. Land Use Land Cover (LULC), slope, elevation, drainage density, and distance from water bodies, stream power index, and topographic wetness index were generated using Landsat 9 satellite imagery sourced from the United States Geological Survey (USGS) Earth Explorer platform. Stream networks were acquired in vector format from the Greater Chennai Corporation (GCC) open data repository. The data were further refined using hydrological tools in ArcGIS to enhance the accuracy of the stream alignment with topography. Groundwater level data was obtained through secondary sources published in government reports.

Each of these factors was spatially processed in ArcGIS. Raster layers were reclassified and normalized, and weights were assigned based on their relative contribution to flood risk, informed by existing literature. A weighted overlay analysis was conducted to generate a composite physical vulnerability index. Outputs were created for both administrative wards and informal settlements to capture intra-urban differentiation. The final vulnerability scores were classified into three categories: high, medium, and low.

To evaluate social sensitivity and adaptive capacity, forty socio-economic indicators were selected and grouped under 18 thematic variables such as population size and density, housing quality, household size, access to water and sanitation, literacy, employment type, caste and income-based marginalization, and tenure status. Informal settlement data was sourced from the Rajiv Awas Yojana (RAY) slum database for Chennai city, which includes spatial delineations and basic demographic details of notified and non-notified slums. Demographic and housing-related data were extracted from the Census of India 2011.

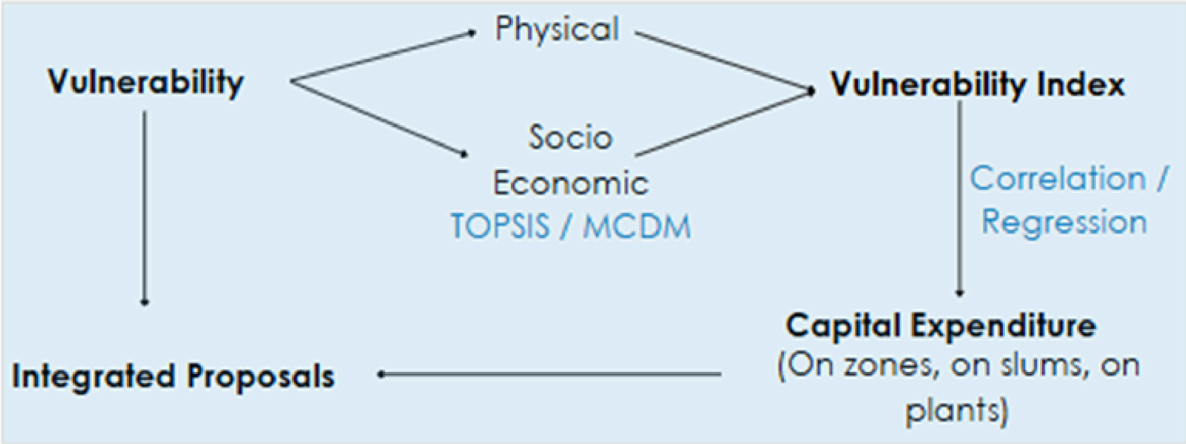


Figure 4-1 Methodology

A Multi-Criteria Decision-Making (MCDM) technique, TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), was used to develop the socio-economic vulnerability index. The method involves normalization of indicators, assignment of weights based on Shannon entropy, and calculation of an index that ranks spatial units based on proximity to an ideal (low vulnerability) and anti-ideal (high vulnerability) condition. The index was spatially visualized at both ward and slum levels and categorized into high, medium, and low socio-economic vulnerability zones.

Recognizing the multidimensionality of flood risk, a composite vulnerability index was constructed by combining the physical and socio-economic indices with equal weighting (50:50). This integration reflects the balance between environmental exposure and social capacity to respond to or recover from flooding events. The composite index was mapped across the city to identify overall vulnerable zones, enabling targeted governance analysis.

To assess whether flood-related investments correspond with spatial vulnerability, data on capital expenditure at the ward level were analyzed. Municipal capital expenditure data were compiled from the Chennai Corporation's published budget documents and annual reports, with a focus on flood-related expenditure heads, including storm water infrastructure, water body maintenance, tools and equipment, and other climate adaptation measures.

To analyze the relationship between public investment and spatial vulnerability, correlation and regression analyses were conducted. A non-parametric rank correlation method was applied to understand the monotonic relationship between vulnerability and expenditure. Further, a spatial regression model was developed using the composite vulnerability index as the dependent variable and capital expenditure as the independent predictor. This helped account for spatial dependencies and understand the extent to which governance investment aligns with actual vulnerability on the ground.

Finally, a bivariate classification matrix was generated by intersecting vulnerability levels (high, medium, low) with expenditure levels (high, medium, low), resulting in six typologies. This classification aids in identifying areas with effective investment, underfunding, and potential inefficiencies in resource distribution.

## 5 Results and Discussion:

The findings from this study underscore the layered nature of flood vulnerability in Chennai, highlighting not only the physical and socio-economic characteristics that contribute to risk but also the governance response in terms of capital investment. The results demonstrate stark spatial inequalities, both in the distribution of vulnerability and in the allocation of municipal resources meant to address it.

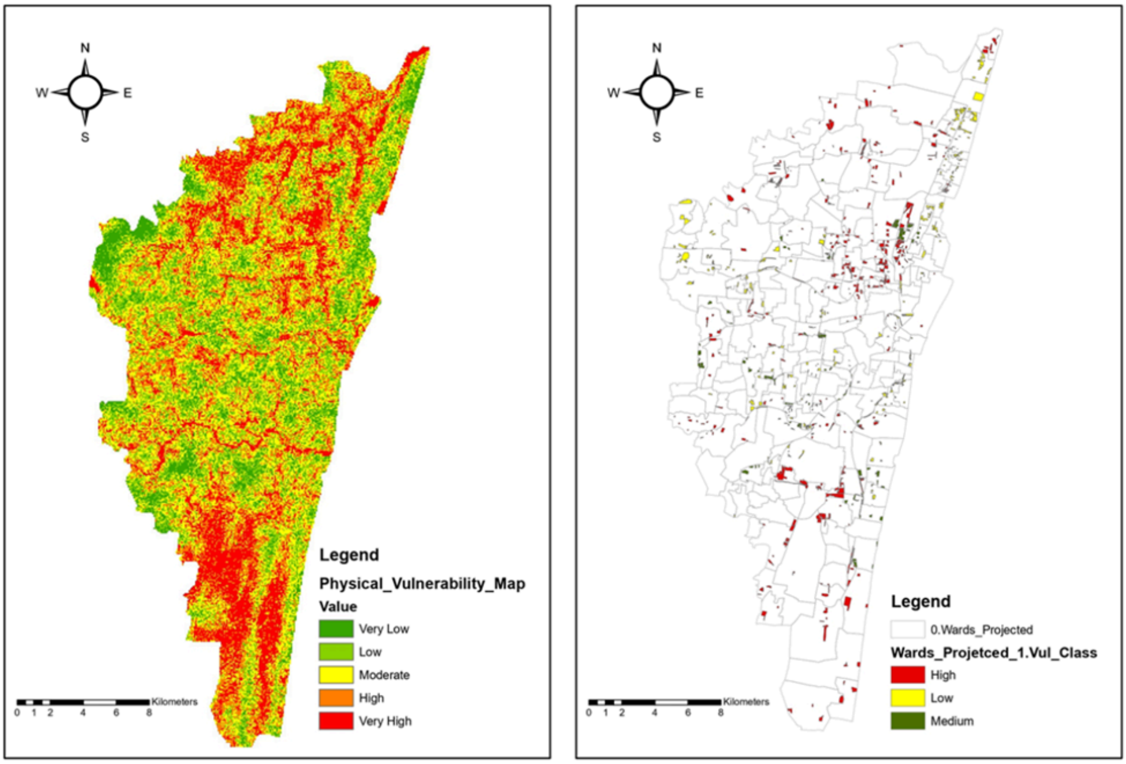


Figure 5-1 Physical Vulnerability

The composite physical vulnerability index reveals a distinct clustering of high-risk zones in the northern and southwestern parts of the city. These areas are marked by low elevation, high drainage density, steep slopes in localized areas, and proximity to natural waterways—conditions that collectively increase susceptibility to urban flooding. Further, high values of the Stream Power Index (SPI) and Topographic Wetness Index (TWI) indicate zones of potential runoff concentration and soil saturation. These high physical vulnerability zones align with known flood-prone neighborhoods historically impacted during heavy monsoon events, reflecting the realism of the index in capturing flood exposure.

In contrast, the central and coastal wards—many of which have benefitted from earlier investments in storm water infrastructure—exhibit relatively low physical vulnerability, owing to favorable topography, planned development, and greater elevation. However, even within these wards, micro-level variations persist, as informal settlements situated along canals or on reclaimed wetlands continue to face localized physical risk.

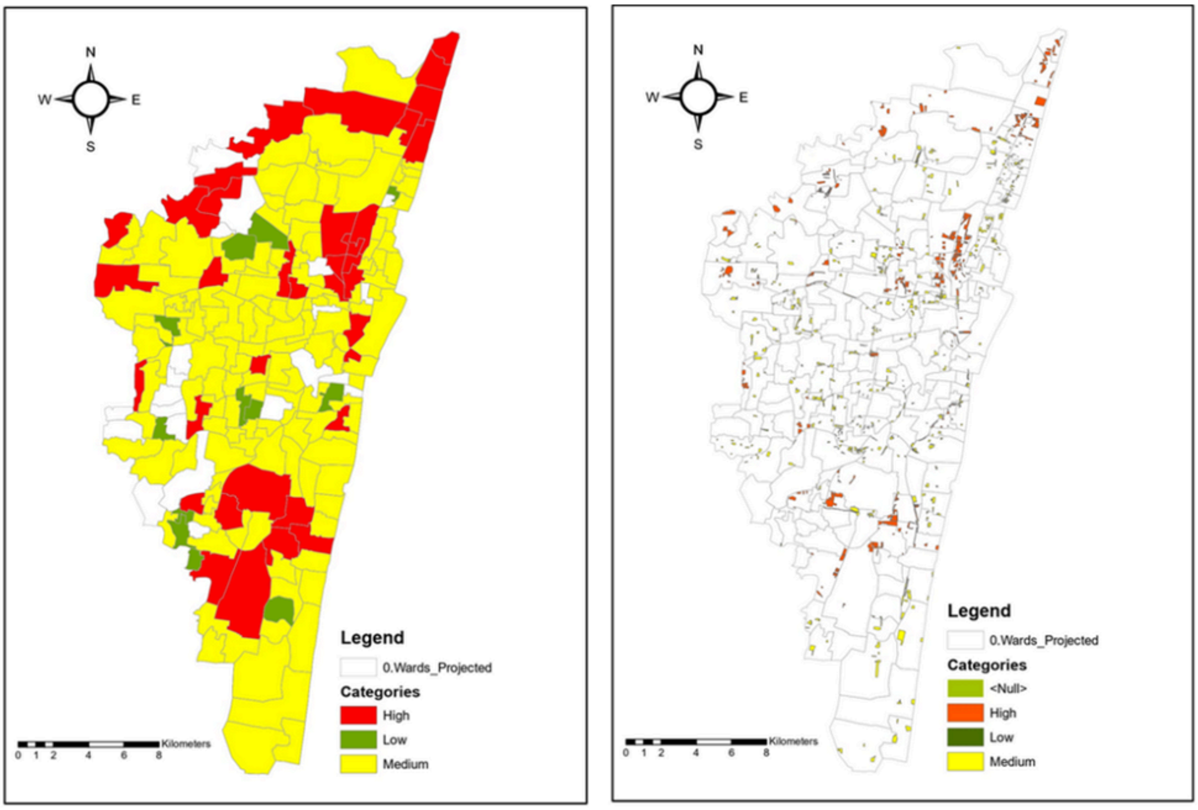


Figure 5-2 Socio Economic Vulnerability

The socio-economic vulnerability index displays a different but overlapping geography. Wards with high vulnerability scores are primarily located in north Chennai, and the western periphery, where large concentrations of informal settlements exist. These areas are characterized by high population density, poor housing conditions, limited access to sanitation and water, and marginalized caste and income groups.

Notably, while some physically vulnerable areas show low socio-economic vulnerability—often better planned or resourced neighborhoods—there are also zones where both vulnerabilities intersect. These compounded risk areas are of particular concern, as residents in such zones have both high exposure to floods and limited adaptive capacity. The spatial visualization of these patterns offers an important lens into the urban inequality embedded in disaster risk.

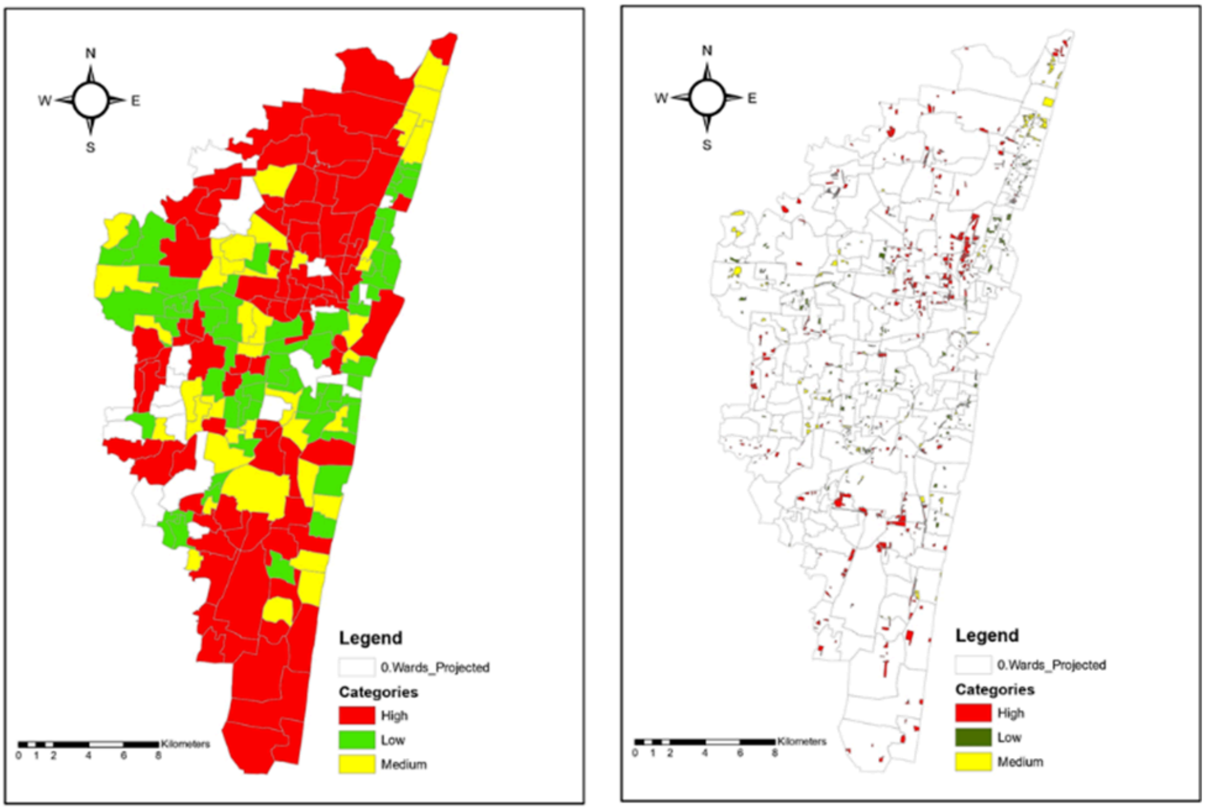


Figure 5-3 Combined Vulnerability Index

The overall vulnerability index, created by integrating physical and socio-economic indices with equal weighting, reveals that around one-third of the city's wards fall into the 'high overall vulnerability' category. These zones typically lie in the northwestern and southern parts of the city, encompassing both peri-urban expansion areas and older informal localities.

Medium vulnerability zones are more spatially dispersed, often found in transition zones between the core and periphery, where urban development is rapidly evolving. Low vulnerability areas are generally associated with planned neighborhoods, stronger infrastructure systems, and relatively lower population densities.

This composite mapping facilitates a nuanced understanding of where both exposure and social sensitivity converge, providing a strategic starting point for resilience interventions.

The comparison of vulnerability with ward-wise capital expenditure on flood-related infrastructure unveils a significant governance challenge. A Spearman rank correlation coefficient of -0.49 indicates a moderate negative correlation—in simple terms, areas with higher vulnerability often receive less investment, while better-protected zones continue to attract higher funding.

This mismatch is particularly stark in several north Chennai wards, where chronic flooding and dense informal settlements coexist with relatively low per capita capital expenditure. These findings suggest the presence of systemic underinvestment in high-need areas, potentially due to political marginality, institutional biases, or limited fiscal capacity of local governance structures.

The spatial regression model, which accounts for spatial autocorrelation, further reinforces these findings. With an $R^2$ value of 0.3181 and a p-value of 0.023, the regression confirms a statistically significant but weak explanatory relationship between capital expenditure and vulnerability. While some targeted investments appear to align with need, the overall pattern lacks coherence and strategic prioritization.

This result suggests that current expenditure decisions are not systematically guided by vulnerability data. Rather, they may reflect other administrative or political considerations—emphasizing the need for more data-driven, equity-oriented planning processes.

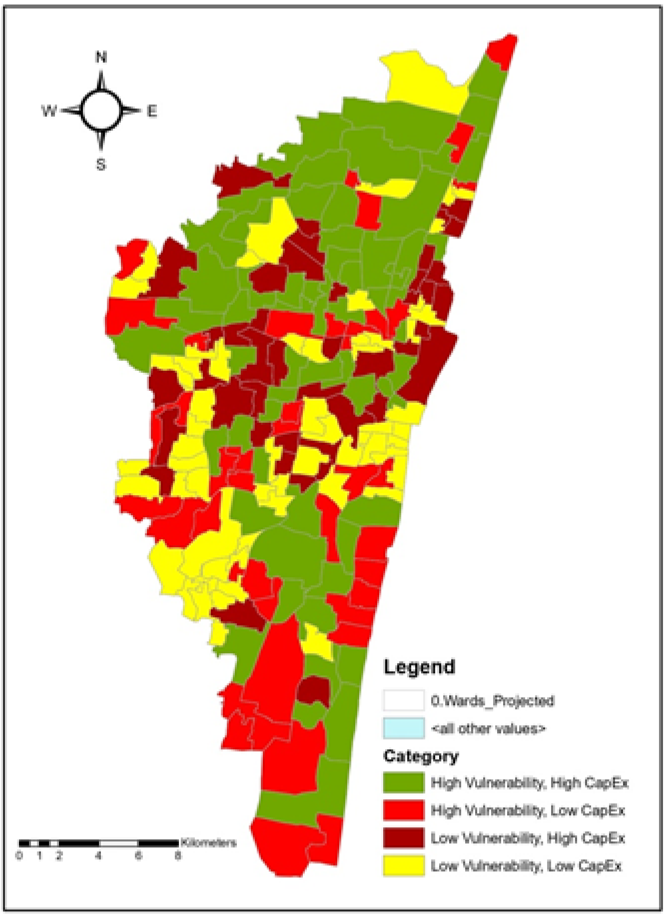


Figure 5-4 Ward wise classification in terms of vulnerability and capital expenditure

To further interpret this misalignment, a bivariate classification was developed by intersecting the three vulnerability categories with the three expenditure categories. This six-class typology uncovers four especially noteworthy types:

High Vulnerability – Low Expenditure: These are the most concerning zones, representing governance blind spots. Despite high needs, these areas remain under funded; exacerbating risks to already vulnerable populations.

High Vulnerability – High Expenditure: While investment exists, persistent vulnerability here may signal inefficiencies in implementation or misalignment of interventions with actual drivers of risk.

Low Vulnerability – High Expenditure: This pattern could indicate overinvestment or political prioritization in low-risk areas, raising equity concerns.

Low Vulnerability – Low Expenditure: These zones may not currently require significant investment, but ongoing monitoring is essential, particularly in the context of climate change.

The typology provides a decision-making framework for policymakers, allowing for targeted interventions that prioritize both need and impact potential. It also raises important questions about the efficiency of public spending and the degree to which vulnerability data informs policy.

# 6 Proposal

This study proposes an integrated strategy for restoring the Adyar River corridor in Chennai, with a particular focus on enhancing flood resilience through ecological and socially inclusive interventions. The Adyar River, which flows through some of the most densely populated and ecologically stressed zones in the city, has been identified as a highly vulnerable stretch that suffers from both chronic flooding and environmental degradation. The river corridor also exemplifies a spatial mismatch in public investment, falling under what the study categorizes as an Underfunded Risk Zone—a region with high flood vulnerability and inadequate capital expenditure on flood mitigation infrastructure.

The proposed intervention seeks to address this imbalance by designing a comprehensive river restoration plan that targets pollution control, informal settlement upgrading, flood mitigation, and public engagement. A key component of the proposal involves the demarcation of a 100-meter buffer on both sides of the Adyar River, totaling an area of approximately 11.94 square kilometers. This riparian buffer is designated as a No Development Zone (NDZ), aimed at ecological restoration and the prevention of further encroachments and flood-related hazards. However, since this buffer overlaps with multiple residential pockets—including both formal and informal settlements—the proposal also outlines a structured approach to rehabilitation and relocation that is socially sensitive and environmentally necessary. By establishing vegetated riparian buffers, the intervention seeks to reduce surface runoff pollution, improve riverbank stability, and restore habitat connectivity along the river.

To tackle the severe issue of untreated wastewater discharge into the river, the proposal introduces a nature-based wastewater treatment solution using Phytorid technology. This system is a decentralized constructed wetland that requires no electricity and minimal maintenance, making it especially suitable for low-income and flood-prone areas. The proposed site for the Phytorid system is located along the Nandanam–Adyar Creek stretch, a zone characterized by mixed public and residential land use, ecological sensitivity, and infrastructural gaps. Based on multi-criteria spatial analysis incorporating land use, elevation, flood inundation, and vulnerability data, the site was selected for its technical feasibility and strategic relevance. The system is designed to treat 1 million liters of wastewater per day, generated by an estimated population of 1,000 residents. The total area required for this facility is two hectares, subdivided into sedimentation, filtration, vegetation, and collection zones. The estimated capital cost of the Phytorid system is ₹150 crores, with an annual operation and maintenance cost of ₹18.3 crores. This investment addresses a critical gap in urban sanitation infrastructure while contributing to public health, groundwater recharge, and biodiversity enhancement.

In addition to wastewater treatment, the proposal emphasizes the need for effective storm water management to reduce the risk of urban flooding. To achieve this, a network of decentralized detention basins is proposed across low-lying and hydrologically vulnerable pockets within the Adyar basin. These basins are designed to temporarily store excess surface runoff during peak rainfall events, allowing for controlled release and natural infiltration. Based on hydrological calculations, the peak storm water flow in the Adyar River is estimated at 1699 cubic meters per second. To accommodate this volume over a twelve-hour detention period, a total storage capacity of 73.4 million cubic meters is required. Considering the impracticality of creating a single centralized basin in a densely built urban environment, the study proposes a distributed system of basins across approximately 1,027 hectares, taking advantage of existing depressions and underutilized spaces. These basins are expected to significantly lower flood peaks, reduce sedimentation, improve water quality through natural filtration, and offer opportunities for community recreation and biodiversity conservation.

Lastly, the success of river restoration efforts depends not only on physical infrastructure but also on community involvement. The proposal therefore incorporates a robust strategy for building citizen awareness and promoting participatory governance. Public education initiatives such as river literacy campaigns, community workshops, and interpretive signage are proposed to foster a deeper understanding of the river's ecological importance and the implications of human actions. Beyond awareness, mechanisms for active engagement—such as neighborhood river committees, citizen monitoring groups, and participatory planning forums—are also recommended. These efforts aim to embed environmental stewardship in local culture and decision-making, ensuring that the interventions are maintained and supported over the long term.

Taken together, this proposal presents a replicable and context-sensitive model for urban river restoration that bridges ecological restoration, infrastructure planning, and social inclusion. By focusing on a neglected yet critical stretch of the Adyar River, the strategy not only mitigates immediate flood risks but also contributes to broader goals of urban resilience, public health, and environmental justice in rapidly growing cities like Chennai.

# 7 Conclusion:

This study demonstrates the critical value of integrating spatial and statistical approaches to understand flood vulnerability in Chennai, particularly within the context of rapid urbanization and growing climate risks. By constructing both physical and socio-economic vulnerability indices and analyzing their alignment with municipal capital expenditure, the research highlights significant spatial disparities and systemic mismatches in flood governance.

The results reveal that areas most vulnerable to flooding—characterized by environmental exposure and socio-economic marginalization—often receive inadequate public investment. Conversely, better-served regions with lower risk profiles continue to attract higher capital spending, underscoring governance inefficiencies and equity concerns.

The use of composite indices, spatial analysis, and regression modeling has enabled a nuanced understanding of vulnerability patterns across wards and informal settlements. The six-category typology developed in this study provides a strategic tool for prioritizing interventions, identifying underfunded risk zones, and evaluating the effectiveness of existing expenditure.

Moving forward, the findings call for a paradigm shift in urban flood management—one that is rooted in data-driven planning, equitable resource allocation, and inclusive governance. Integrating vulnerability assessments into budgetary frameworks, strengthening institutional accountability, and empowering local communities must become central pillars of Chennai's climate resilience strategy.

By aligning investment with actual need, urban authorities can not only enhance infrastructure performance but also safeguard the most vulnerable populations, ensuring that flood resilience is both effective and just.

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