Strengthening Flood Resilience in Coastal Cities: An Integrated Framework for Kakinada

A Thesis

Submitted in partial fulfilment of the requirements for the award of the degree

of

Master of Planning (Urban Planning)

in

Department of Architecture and Planning

by

NISHANT CHOURASIA
24209011107



MAULANA AZAD
NATIONAL INSTITUTE OF TECHNOLOGY,
BHOPAL- 462003(INDIA)
July, 2026

©MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY, BHOPAL– 462003

ALLRIGHTSRESERVED

MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY, BHOPAL

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the Thesis entitled " **Strengthening Flood Resilience in Coastal Cities: An Integrated Framework for Kakinada** "in partial fulfillment of the requirements for the award of the Master of Planning Urban Planning and submitted in the Department of Architecture and Planning .of the Maulana Azad National Institute of Technology, Bhopal is an authentic record of my own work carried out during the period from July 2025 to July 2026 under the supervision of Dr. Nakul Dhagat Professor, Department of Urban Planning, Maulana Azad National Institute of Technology, Bhopal.

The matter presented in this Thesis has not been submitted by me for the award of any other degree of this or any other Institution.

(Nishant Chourasia)

This is to certify that the above statementm added by the candidate is correct to the best of my knowledge.

Date: (Dr. Nakul Dhagat)

ACKNOWLEDGEMENT

It is my pleasure to acknowledge the contributions of all who have helped and supported me during the work reported in this Thesis.

I wish to express my gratitude to a number of people who became involved with this study, one way or another to all those who gave me the opportunity to complete it. I want to thank my college Department of Architecture and Planning, Maulana Azad National Institute of Technology Bhopal, Madhya Pradesh for giving me permission to commence this topic in first instance.

First and foremost, I want to express my heartfelt gratitude and thanks from my core of heart to my Thesis supervisor Dr. Nakul Dhagat, Professor, Maulana Azad National Institute of Technology Bhopal, Madhya Pradesh for his guidance, whole hearted cooperation, critical comments and motivation in carrying out this study. His encouragement throughout the study and painstaking effort in providing helpful suggestions in giving final establish to this text are gratefully acknowledged.

Unconditional love and blessings of my parents Mr. B.D. Chourasia and Mrs. Kavita Chourasia showered all through this journey was a great source of inspiration for me their values support, who has been a source if motivation and who always come to my help whenever needed.

Above all, I express my indebtedness to the ALMIGHTY for all his blessings and kindness.

Nishant Chourasia

24209011107

Masters of Planning (Urban Planning)

MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY, BHOPAL

CERTIFICATE OF PLAGIARISM

This is to certify that the thesis entitled "**Strengthening Flood Resilience in Coastal Cities: An Integrated Framework for Kakinada**" is a piece of research work carried out by **Nishant Chourasia**, Scholar No.**24209011107** under my guidance and supervision for the degree of Master of Planning (Urban Planning) from the Department of Architecture and Planning of Maulana Azad National Institute of Technology, Bhopal (M.P.) India

To the best of my knowledge and belief he is to certify that:
i. Prima facie this thesis can be considered for the award of the degree,
ii.Thesis does not contain any work which has been previously submitted for the award of any other degree.
iii.Percentage of plagiarism is %(max 8-12% as per clause 10.12). Please check report is enclosed for reference.
iv.This thesis work:
a.Has not been carried out in collaboration with any other organization.

Signature :

Name of the Candidate :

Signature :

Name of Guide :

Countersigned by

Signature :

Name :

HOD, Department:

ABSTRACT

Coastal cities in India are increasingly facing flood risks due to climate change, sea-level rise, extreme rainfall events, cyclones, and rapid urbanization. These challenges threaten infrastructure, livelihoods, ecosystems, and urban development, highlighting the need for effective flood resilience strategies. This study aims to develop an integrated framework for strengthening flood resilience in coastal cities, with Kakinada, Andhra Pradesh, selected as the case study. The research examines flood conditions, policies, and resilience approaches through literature review and case study analysis, followed by a GIS-based assessment of physical and socio-environmental factors such as elevation, slope, drainage, land use, population, rainfall, and historical flood events. Based on the assessment of flood risk, vulnerability, and existing resilience gaps, the study proposes an integrated framework that combines nature-based solutions, technological interventions, grey infrastructure, and participatory governance. The framework is intended to support informed planning and decision-making, reduce flood risks, and enhance the long-term resilience of coastal cities facing increasing climate-related challenges.

सारांश

भारत के तटीय शहर जलवायु परिवर्तन, समुद्र-स्तर में वृद्धि, अत्यधिक वर्षा की घटनाओं, चक्रवातों तथा तीव्र शहरीकरण के कारण बढ़ते हुए बाढ़ जोखिमों का सामना कर रहे हैं। ये चुनौतियाँ बुनियादी ढाँचे, आजीविका, पारिस्थितिक तंत्र तथा शहरी विकास के लिए गंभीर खतरा उत्पन्न करती हैं, जिससे प्रभावी बाढ़-लचीलापन रणनीतियों की आवश्यकता और अधिक महत्वपूर्ण हो जाती है। यह अध्ययन तटीय शहरों में बाढ़-लचीलापन को सुदृढ़ करने हेतु एक समेकित रूपरेखा विकसित करने पर केंद्रित है, जिसमें आंध्र प्रदेश के काकीनाडा शहर को अध्ययन क्षेत्र के रूप में चुना गया है। शोध के अंतर्गत साहित्य समीक्षा तथा विभिन्न केस स्टडी के माध्यम से बाढ़ की परिस्थितियों, नीतियों एवं लचीलापन संबंधी दृष्टिकोणों का अध्ययन किया गया है। इसके पश्चात GIS आधारित विश्लेषण के माध्यम से ऊँचाई, ढाल, जल निकासी तंत्र, भूमि उपयोग, जनसंख्या, वर्षा तथा ऐतिहासिक बाढ़ घटनाओं जैसे भौतिक एवं सामाजिक-पर्यावरणीय कारकों का मूल्यांकन किया गया है। बाढ़ जोखिम, संवेदनशीलता तथा वर्तमान लचीलापन संबंधी कमियों के आकलन के आधार पर यह अध्ययन एक समेकित रूपरेखा प्रस्तुत करता है, जिसमें प्रकृति-आधारित समाधान, तकनीकी हस्तक्षेप, ग्रे अवसंरचना तथा सहभागी शासन को सम्मिलित किया गया है। यह रूपरेखा बेहतर नियोजन एवं निर्णय-निर्माण को समर्थन प्रदान करने, बाढ़ जोखिमों को कम करने तथा बढ़ती जलवायु संबंधी चुनौतियों का सामना कर रहे तटीय शहरों की दीर्घकालिक लचीलापन क्षमता को सुदृढ़ करने के उद्देश्य से विकसित की गई है।

TABLE OF CONTENT

CANDIDATE'S DECLARATION ..... **ii**

ACKNOWLEDGEMENT ..... **iii**

CERTIFICATE OF PLAGIARISM ..... **iv**

ABSTRACT ..... **v**

सारांश. ..... **vi**

LIST OF FIGURES ..... **xiii**

LIST OF TABLES ..... **xv**

LIST OF ABBREVIATIONS ..... **xvv**

1. INTRODUCTION **1**

1.1 What is Flood? 1

1.2 Types of Floods 1

1.2.1 River (or fluvial) floods 1

1.2.2 Ponding (or pluvial) floods 2

1.2.3 Flash floods 2

1.2.4 Coastal floods 2

1.2.5 Urban floods 3

1.3 Impacts of Flooding 4

1.3.1 Loss of Life 4

1.3.2 Damage to property 5

1.3.3 Displacement of people 5

1.3.4 Environmental Degradation 5

1.3.5 Economic Losses 6

1.4 Need for the study 7

1.4.1 Contextual Background and Problem Identification 7

1.4.2 Knowledge Gaps and Research Requirements 8

1.4.3 Practical Relevance and Academic Contribution 8

1.4.4 Urgency and Consequences of Inaction 9

2 RESEARCH DESIGN **10**

2.1 Finalized Title 10

2.2 Aim 10

2.3 Objectives 10

2.4 Research Questions 10
3. LITERATURE REVIEW 11
3.1 Introduction 11
3.2 Adaptive Planning Frameworks and Nature-Based Solutions 11
3.2.1 Adaptive Planning Principles 11
3.2.2 Nature-Based and Hybrid Infrastructure Solutions 12
3.3 Grey Infrastructure and Advanced Geospatial technologies 14
3.3.1 Grey Infrastructure 15
3.3.2 Advanced Geospatial Technologies 16
3.4 Governance and Participatory Planning 16
3.4.1 Institutional Coordination 17
3.4.2 Climate Justice and Equitable Adaptation 20
3.5 Research Gaps, Implementation Challenges and Future Directions 20
3.5.1 Critical Research and Implementation Gaps 21
3.5.2 Implications for Indian Coastal Cities 23
3.6 Coastal towns 24
3.6.1 States 25
3.6.2 Union Territories 31
3.6.3 Change in length of Coastline of India 32
4. RESEARCH METHODOLOGY 34
4.1 Phase 1 Objectives 35
4.1.1 Objective 1 35
4.1.2 Objective 2: 35
4.1.3 Objective 3 35
4.1.4 Objective 4 36
4.2 Phase 2 Objectives 36
4.2.1 Objective 5 36
4.2.2 Objective 6 36
4.3 Scope of the Study 37
4.4 Limitations 37
5. CASE STUDIES 38
5.1 Chennai Floods (2015) 38
5.1.1 Introduction and Background 39
5.1.2 Factors and Impact 39
5.1.3 Response and Lessons Learned 41

5.2 Kerela Floods (2018) 42
5.2.1 Introduction and Background 43
5.2.2 Factors and Impact 43
5.2.3 Response and Lessons Learned 45
5.3 Gujrat Floods (2017) 46
5.3.1 Introduction and Background 47
5.3.2 Factors and Impact 47
5.3.3 Response and Lessons Learned 49
6. INFERENCE DRAWN 51
7. SELECTION OF CASE STUDY- KAKINADA 52
7.1 Identification of the Study Area 53
7.2 Physical and Climatic Profile 57
7.3 Socio-economic Profile and Recent Flood History 57
8. DATA COLLECTION, THEMATIC MAPPING AND ANALYSIS (KAKINADA) 58
8.1 Base Map 58
8.2 Ward Map 59
8.3 Population Map 60
8.4 Contour Map 61
8.5 Slope Map 62
8.6 Stream order map 63
8.7 Proposed Drains Map 64
8.8 Drainage Zone Map 65
8.9 Drainage Sub Zone Map 66
8.10 Kakinada Rainfall data (2016 – 2021) 67
8.11 Shoreline Changes in Kakinada District 68
8.12 Coastal Flood Events Affecting Kakinada (2021-2025) 69
9. CONCEPTUAL AND METHODOLOGICAL FRAMEWORK 71
9.1 Rationale for the framework 71
9.2 Conceptual Framework 71
9.3 Stage-wise methodology 72
9.3.1 Stage One: Existing Conditions Assessment 72
9.3.2 Stage Two: Flood Risk Assessment 74
9.3.3 Stage Three: Vulnerability Assessment 78
9.3.4 Stage Four: Gap Analysis 81

9.3.5 Stage Five: Planning Proposals and Strategies 83
9.4 Expected Outcomes 86
9.5 Summary of the Framework 86
9.6 Implementation Framework: Translating the Proposal into Ground-Level Action 87
9.6.1 Institutional and Governance Structure 88
9.6.2 Regulatory and Legal Instruments 89
9.6.3 Phased Implementation Roadmap 90
9.6.4 Financing Mechanisms 91
9.6.5 Participatory and Community Engagement Mechanism 92
9.6.6 Monitoring, Evaluation, and Feedback 93
9.6.7 Summary Implementation Matrix 93
9.6.8 Anticipated Barriers and Mitigation 94
10. CONCLUSION 95
REFERENCES 96
Annexure: ArcGIS Pro Geoprocessing Steps and Tool Settings **..... 100**

LIST OF FIGURES

Figure 1.1 Types of Floods ……3

Figure 1.2 direct and indirect impacts of flood ……...6

Figure 3.3 Coastal map of India ……24

Figure 4.1 Research Methodology Flowchart ……...34

Figure 5.1 Chennai district map ……38

Figure 7.1 Key location map ……52

Figure 7.2 Hazard proneness of coastal states ……54

Figure 7.3 Multi hazard Index across Coastal districts ……..…. 54

Figure 7.4 Andhra Pradesh district map ……. 56

Figure 8.1 Kakinada ward map ……..…. 58

Figure 8.2 Kakinada ward map ……..…. 59

Figure 8.3 Population map ……... 60

Figure 8.4 Contour map ……... 61

Figure 8.5 Slope map ……... 62

Figure 8.6 Stream order map ……... 63

Figure 8.7 Proposed drains map …….. 64

Figure 8.8 Drainage zone map ……. 65

Figure 8.9 Drainage sub zone map ……... 66

Figure 8.10 Monthly & annual rainfall data ...……...……..... 67

Figure 8.11 Shoreline change map ……...……..... 68

Figure 9.1 LULC map ……...……... 73

Figure 9.2 Flow Accumulation map ……...……. 75

Figure 9.3 Flood Risk Assessment map ……...……..... 77

Figure 9.4 Combined Vulnerability map ……...…….. 79

Figure 9.5 Composite Vulnerability map ……...…….. 80

Figure 9.6 Combined gap analysis map ……...…… 81

Figure 9.7 Flood resilience gap map ……...……. 82

Figure 9.8 Combined Proposal map ……..……..... 83

Figure 9.9 Integrated Flood Resilience Proposal map ……...……..... 85

Figure 9.10 Implementation framework linking the proposal to ground-level action……..……..... 88

LIST OF TABLES

Table 3.1 Key parts of Adaptive flood planning ……12

Table 3.2 Nature-Based Flood Defenses and Their Function ……12

Table 3.3 Types of Infrastructures for sea defense ……14

Table 3.4 Types of Grey Infrastructure 15

Table 3.5 Responsibilites of Departments & Authorities ……...18

Table 3.6 Gaps Identified ……...21

Table 3.7 Coastal towns in Gujrat ……25

Table3.8 Coastal towns in Maharashtra ……26

Table 3.9 Coastal towns in Karnataka ……26

Table 3.10 Coastal towns in Kerela ……..27

Table 3.11 Coastal towns in Goa ……..28

Table 3.12 Coastal towns in Tamil Nadu ……..29

Table 3.13 Coastal towns in Andhra Pradesh ……30

Table 3.14 Coastal towns in Odisha ……...30

Table 3.15 Coastal towns in West Bengal ……31

Table 3.16 Daman & Diu ……...32

Table 3.17 Pondicherry ……..32

Table 3.18 The state wise/UT wise 'Length of Coastline of India' ……33

Table 7.1 States that are more vulnerable to Hazards ……55

Table 7.2 Coastal towns of Andhra Pradesh ……..… 56

Table 8.1 Capacities of STPs ……..…… 66

Table 8.2 Annual Rainfall Statistics, Kakinada 2016–2021 ……68

Table 8.3 Flood events summary ……..70

Table 9.1 Datas used ……..……... 71

Table 9.2 Slope classification ……..…… 74

Table 9.3 Flood risk factor weights ……..……. 76

Table 9.4 Flood risk classification result ……..…… 77

Table 9.5 Composite vulnerability classification results ……..…… 79

Table 9.6 Proposed policy zoning framework ……. 84

Table 9.7 Ward level flood risk & intervention priority ……. 84

Table 9.8 Summary of stage wise findings ……. 86

Table 9.9 Three-tier institutional structure for implementation ……. 89

Table 9.10 Phased implementation roadmap ……. 90

Table 9.11 Summary implementation matrix ……. 93

LIST OF ABBREVIATIONS

- **AAI**: Airports Authority of India
- **ADB** : Asian Development Bank
- **AEE** : Assistant Executive Engineer
- **AMC** : Antecedent Moisture Condition
- **AMRUT** : Atal Mission for Rejuvenation and Urban Transformation
- **ATIS** : Administrative Training Institutes
- **BIS** : Bureau of Indian Standards
- **BMTPC** : Building Materials and Technology Promotion Council
- **CAPF** : Central Armed Police Forces
- **CBRI** : Central Building Research Institute
- **CDEF** : Civil Defence
- **CII** : Confederation of Indian Industries
- **CMA** : Chennai Metropolitan Area
- **CMDA** : Chennai Metropolitan Development Authority
- **CMWSSB** : Chennai Metro Water Supply and Sewage Board
- **CPHEEO** : Central Public Health and Environmental Engineering Organisation
- **CRRI** : Central Road Research Institute
- **CSIR** : Council of Scientific and Industrial Research
- **CWC** : Central Water Commission
- **DCR** : Development Control Regulations
- **DDMA** : District Disaster Management Authority
- **DFIN** : Finance Department
- **DMD** : Disaster Management Department
- **DOS** : Department of Space
- **DRD** : Department of Rural Development
- **EFD** : Forest and Environment Department
- **F&ES** : Fire and Emergency Services

- **FIHD** : Department of Fisheries
- **GLOFS** : Glacial Lake Outburst Floods
- **GoI** : Government of India
- **HTL** : High Tide Level
- **IAS** : Indian Administrative Services
- **IE (I)** : Institution of Engineers (India)
- **IMD** : India Meteorological Department
- **INR** : Indian National Rupee
- **IPCC** : Intergovernmental Panel on Climate Change
- **IRD** : Irrigation Department
- **ISDR** : International Strategy for Disaster Reduction
- **IT** : Information Technology
- **JICA** : Japan International Co-operating Agency
- **LLOFS** : Landslide Lake Outburst Floods
- **lpcd** : Litres per capita per day
- **MAFW** : Ministry of Agriculture and Farmers' Welfare
- **MCA** : Ministry of Corporate Affairs
- **MCF** : Ministry of Chemicals and Fertilizers
- **MEITY** : Ministry of Electronics and Information Technology
- **MFIN** : Ministry of Finance
- **MHA** : Ministry of Home Affairs
- **MHIPE** : Ministry of Heavy Industries and Public Enterprises
- **MHUA** : Ministry of Housing and Urban Affairs
- **MOCI** : Ministry of Commerce and Industry
- **MOEFCC** : Ministry of Environment, Forest and Climate Change
- **MOES** : Ministry of Earth Sciences
- **MOJS** : Ministry of Jal Shakti
- **MORD** : Ministry of Rural Development
- **MOSPI** : Ministry of Statistics and Programme Implementation

- **MOST** : Ministry of Science and Technology
- **MPFI** : Ministry of Food Processing Industries
- **MSJE** : Ministry of Social Justice and Empowerment
- **MWCD** : Ministry of Women and Child Development
- **NBCC** : National Buildings Construction Corporation
- **NCC** : National Cadet Corps
- **NDMA** : National Disaster Management Authority
- **NDRF** : National Disaster Response Force
- **NGOS** : Non-Governmental Organisations
- **NIDM** : National Institute of Disaster Management
- **NLC** : Neyveli Lignite Corporation Ltd
- **NLRTI** : National Level Research and Technical Institutions
- **NRSC** : National Remote Sensing Centre
- **NSS** : National Service Scheme
- **OMR** : Old Mahabalipuram Road
- **PRIS** : Panchayati Raj Institutions
- **PWD** : Public Works Department
- **RWH** : Rain Water Harvesting
- **SDMA** : State Disaster Management Authority
- **SDRF** : State Disaster Response Force
- **SERC** : Structural Engineering Research Committee
- **SIDM** : State Institute of Disaster Management
- **SLRTI** : State Level Research and Technical Institutions
- **SoI** : Survey of India
- **SRSAC** : State Remote Sensing Application Centre
- **SWD** : Storm Water Drains
- **TNCP** : Town and Country Planning Department
- **TNHB** : Tamil Nadu Housing Board
- **TNSCB** : Tamil Nadu Slum Clearance Board

- **TNSDMA** : Tamil Nadu State Disaster Management Authority
- **UDD** : Urban Development Departments
- **ULBS** : Urban Local Bodies
- **UNDP** : United Nations Development Programme
- **URDPFI** : Urban and Regional Development Plan Formulation and Implementation
- **USD** : United States Dollar
- **WMO** : World Meteorological Organisation
- **WRD** : Water Resources Department
- **WSD** : Water and Sanitation Department

1. INTRODUCTION

1.1 What is Flood?

A flood represents a type of natural disaster characterized by the land area that is conventionally dry being covered by water, leading to the potential for huge damages to property, infrastructure, agriculture, and ecosystems. Flooding occurs when water from any source, such as rivers, lakes, ocean tides, or heavy rain, becomes more than the ground or drainage systems can handle. Common causes include long or heavy rainfall, rapid melting of snow and ice, overflow from a river, breaching of dam and/or levee failures, coastal storm surges from cyclones or tsunamis, and human activities such as urbanization or deforestation (Aziz et al., 2024). Flooding can be further divided into several types as depicted in (figure 1.1); namely, river floods, flash flooding, that occurs quickly following heavy rainfall; coastal floods; pluvial (or rainfall) flooding; and groundwater flooding. The impact of flooding can be from minimal short-term inconveniences to catastrophic long-term damage to the loss of life, spread of disease, and water contamination. This is why the management of flooding is an important activity in mitigating risk and safeguarding communities.

1.2 Types of Floods

There are different types of floods, depending on their origin and speed of onset. There are mainly three types: river flooding, which occurs when rivers or streams overflow their banks as a result of long periods of rain or snowmelt; coastal flooding, caused by seawater flooding the land along the coast during high tides, storms, or cyclones; and pluvial flooding, resulting from heavy rainfall that overwhelms drainage systems and causes standing water even away from rivers or coasts.

1.2.1 River (or fluvial) floods

Prolonged rain over extensive areas may cause major rivers to overflow, flooding entire regions with floodwater. Even areas downstream that experience little or no rain may be flooded, since the water fills the river system slowly. Rain enters rivers directly and by runoff from saturated or impervious surfaces; most runoff moves from smaller tributaries into larger ones. This cumulative process takes some time, which may allow river levels to rise gradually and, from time to time, unexpectedly. Flooding may isolate

communities, obstruct highways, and destroy communications because officials must often relocate people before the rivers break over their banks. The flooded areas can be very large, although they are usually narrow, and often pose a disaster to local economies.

1.2.2 Ponding (or pluvial) floods

Ponding, or pluvial flooding, occurs in relatively flat areas when heavy rainfall exceeds the capacity of the ground, canals, or lakes to absorb or drain water. Instead of water coming from rivers, rainwater collects on the surface, forming puddles and ponds; it may also overflow canals or ditches. This process is gradual, giving people time to go indoors or evacuate.

Consequently, the water layer is generally shallow-only a few centimeters to decimeters-and rarely causes an immediate threat to life. On the other hand, economic damages can become serious, especially if large areas or critical activities are affected by such flooding. Ponding resembles urban flooding but generally occurs in rural regions without complex sewage systems. It points out the importance of efficient drainage systems to avoid surface water accumulation and minimize losses from extreme rainfall.

1.2.3 Flash floods

Heavy rainfall in areas with steep slopes can very rapidly turn a dry riverbed into a torrent of swiftly running water called flash floods. Rainwater falls on the slopes, rushes down, and raises the water levels in the channel to as much as several meters above normal in a very short period, overflowing riverbanks. In contrast with the slower riverine floods, flash floods occur with astonishing swiftness and provide little time for warning or evacuation. The powerful flow can transport rocks, trees, cars, and other large debris, making these events extremely dangerous and destructive.

The abrupt onset and force of flash floods endanger lives, especially in hilly and mountainous regions like those affected by the 2013 Uttarakhand and 2018 Kerala floods. Even if water levels do not seem very high, flowing water can sweep away vehicles or people, so never attempt to cross flooded roads.

1.2.4 Coastal floods

A coastal flood happens when seawater inundates low-lying coastal areas, typically due to storm surges caused by severe storms or cyclones. Strong winds associated with these storms push water toward the coast, forming high waves and elevated sea levels, especially where atmospheric pressure drops. With increases in sea level, a combination

of waves could overtop natural or artificial barriers, such as dunes or dikes that protect the shoreline from erosion and possible breaches in the defenses. Coastal flooding is a dynamic process; tides change with high tide rising or low tide receding.

1.2.5 Urban floods

Urban flooding is a unique type of flooding induced by inability or failure to drain rainfall resulting from a high density of buildings. It differs from flash, coastal, or river flooding in that the primary causes are heavy rainfall falling within a very short period and exceeding city drainage and sewer capacity, partly because there is less open soil to absorb the water. This results in runoff and accumulation of water on streets at a very rapid rate, especially when drains are silted up or blocked by solid wastes or illegal encroachments. Water may enter the sewage system in one location and emerge elsewhere, creating flooded roads and incidents like displaced drain covers. Urban floods can seriously disrupt daily life, blocking roads, halting work and schooling, and causing costly economic damage; however, the number of casualties is typically lower since water rises gradually and rarely reaches life-threatening levels.

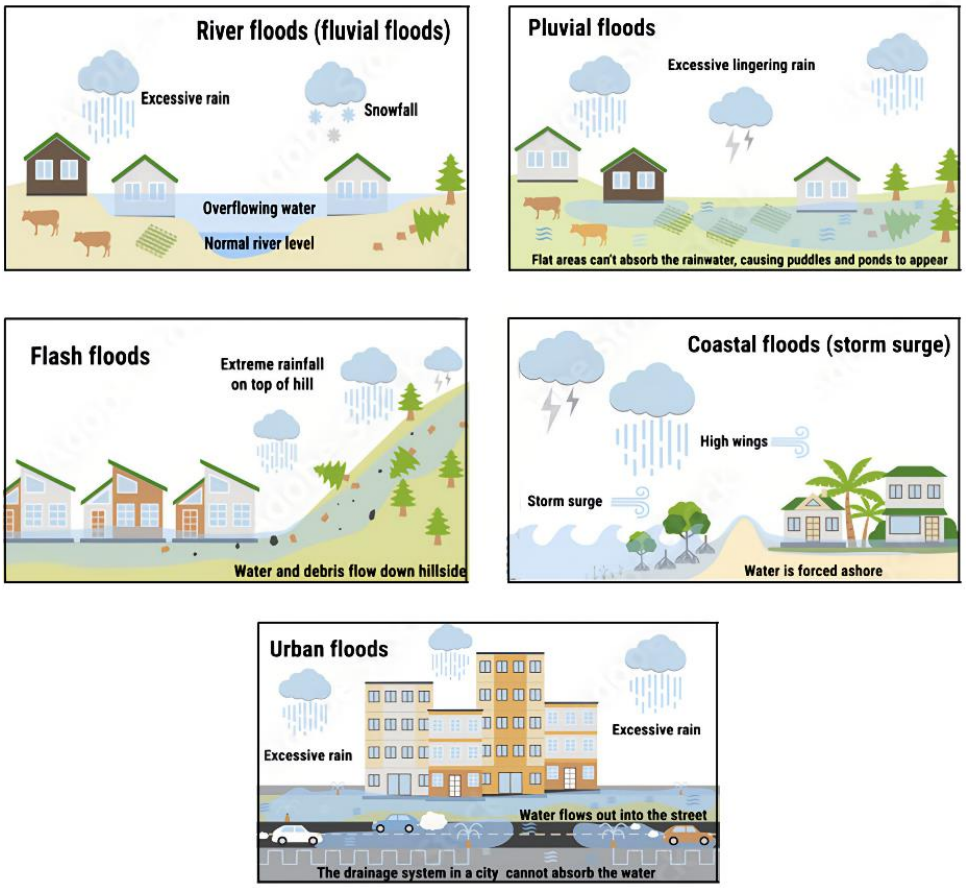


Figure 1.1: Types of Floods, Source: https://waterportal.ca/what-is-flooding/

1.3 Impacts of Flooding

India is highly vulnerable to floods. Out of the total geographical area of 329 million hectares (mha), more than 40 mha is flood prone (Monckeberg & Gómez, 2025). Floods are a recurrent phenomenon, which cause huge loss of lives and damage to livelihood systems, property, infrastructure and public utilities. It is a cause for concern that flood related damages show an increasing trend. The average annual flood damage in the last 10 years period from 1996 to 2005 was Rs. 4745 crores as compared to Rs. 1805 crore, the corresponding average for the previous 53 years. This can be attributed to many reasons including a steep increase in population, rapid urbanization growing developmental and economic activities in flood plains coupled with global warming. The direct and indirect impacts are shown in (figure 1.2).

An average every year, 75 lakh hectares of land is affected, 1600 lives are lost and the damage caused to crops, houses and public utilities is Rs.1805 crores due to floods. The maximum number of lives (11,316) was lost in the year 1977. The frequency of major floods is more than once in five years (Pramod & Chadchan, 2023).

Impacts of floods in India –

1.3.1 Loss of Life

1.3.2 Damage to property

1.3.3 Displacement of people

1.3.4 Environmental Degradation

1.3.5 Economic Losses

1.3.1 Loss of Life

Of all the natural disasters that hit India in the last decade, floods caused the maximum harm, accounting for 67.2 per cent of the total deaths. This proportion has significantly increased in the last few decades as deaths caused by floods used to be 20-35 per cent of all deaths caused by natural disasters.

On an average, over 1,500 Indians have lost their lives to floods every year between 2011 and 2020. In the previous decade, the average was a little over 1,200, according to “the international disasters database: EM-DAT”.

Four states in northern India (Assam, Bihar, Uttar Pradesh, and West Bengal) have been extensively impacted by flooding, affecting over 18 million people, including 7.5 million children. (UNICF)

1.3.2 Damage to property

Floods can damage houses, buildings, roads, bridges, crops, livestock, vehicles, and other infrastructure and assets. According to the NDMA, floods affect about 75 lakh hectares of land and inflict damage worth Rs 1,805 crore to crops, houses and public utilities every year in India.

For instance, India experienced 85 floods between 2009 and 2020 that affected over 10 crore people and resulted in 17,540 fatalities along with estimated damages of approximately $58 billion.

Such fatalities and economic losses are likely to increase with the projected severity and frequency of climate disasters in India, particularly heat waves and heavy precipitation in urban areas as per the IPCC ARC 6 report. While the country is expected to spend $1.4 trillion on infrastructure development by 2024-25, the emphasis on building climate resilience to safeguard investments cannot be greater.

1.3.3 Displacement of people

Floods in India cause widespread displacement of people, forcing families to leave their homes and seek temporary shelter. In just the first half of 2025, over 160,000 people were displaced nationwide, with states like West Bengal, Assam, and Tripura especially affected.

Major floods, including in Bihar and Punjab, have resulted in mass evacuations and several thousands living in relief camps. On average, India sees millions of internal displacements each year due to floods.The family usually loses everything when it gets displaced: a home, and frequently a source of livelihood. Long-term problems include poverty, lack of basic services, and interrupted education.

1.3.4 Environmental Degradation

The consequences of floods in India include severe environmental degradation due to soil erosion, sedimentation, and loss of natural habitats. Floodwaters wash away the fertile topsoil, deposit sands and silts in croplands, and destroy the habitats of plants and

animals, thus threatening the existence of species such as the Gangetic dolphin and gharial.

Floodwaters often carry with them untreated sewage, industrial chemicals, and even solid waste, and this contaminated water may enter rivers, ponds, or groundwater, making it hazardous to biodiversity and public health due to the increased risk of waterborne diseases and long-term contamination of soil and water resources.

1.3.5 Economic Losses

Flooding in India leads to massive economic loss each year by severely affecting agriculture, infrastructure, and industry.

Recent data indicates that the average annual direct flood losses are around $14 billion (₹115,000 crore), with many years well above this figure. For example, North India floods in 2023 caused losses of ₹10,000–₹15,000 crore. In 2021 alone, India suffered $3.2 billion in damages from flooding, while urban flooding alone costs $4 billion per year today and could rise to $30 billion by 2070 if climate risks continue to worsen.

The floods destroy crops-75 lakh hectares are affected every year-and damage building, roads, and bridges, causing disruption in business and supply chains.

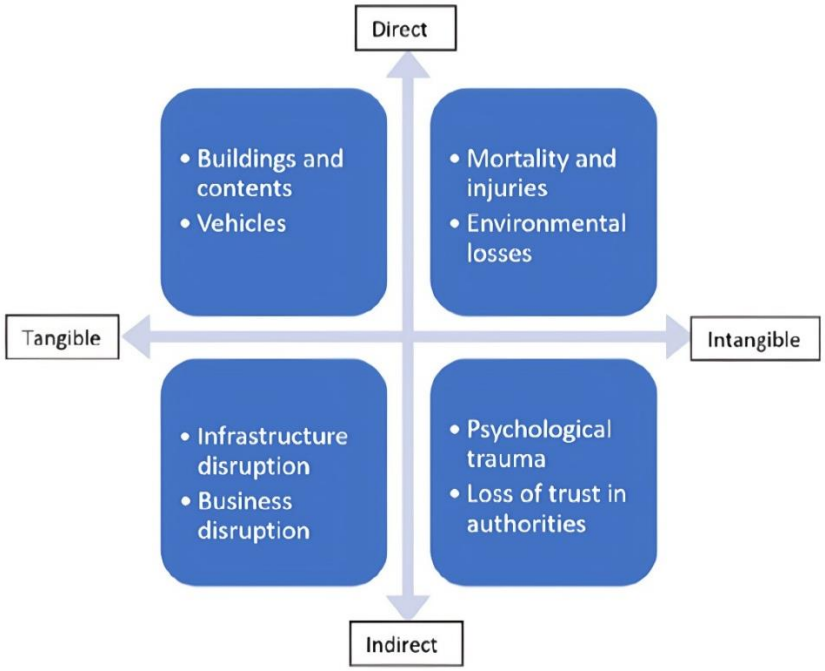


Figure 1.2: direct and indirect impacts of flood, Source: https://www.researchgate.net/publication/353238154_Economic_Evaluation_of_Mental_Health_Effects_of_Flooding_Using_Bayesian_Networks

1.4 Need for the study

Floods continue to be one of the most important natural hazards affecting both urban and rural settings. This trend is increasing in frequency and severity due to rapid urbanization, climate change, and changes in land use. The importance of undertaking specific flood studies cannot be gainsaid; after all, such studies help identify the most vulnerable areas by determining the level of risk and informing the design of adequate flood mitigation measures. Knowledge of the behavior of floods ensures evidence-based urban planning, integrates resilience into the infrastructure, and enhances the stormwater management system for long-term sustainability. Against the backdrop of increasing instances of extreme weather, it further underpins the development of a mechanism that instills emergency preparedness, public safety, and adaptation to climate change, thereby protecting the citizens, property, and urban economies. Information is thus useful for policymakers and planners, among other stakeholders, as they strive for resilient and sustainable development in flood-prone areas.

1.4.1 Contextual Background and Problem Identification

Urbanization pressure and the vagaries of climate change have combined to create an unprecedented situation for India's coastal regions, where more than 250 million people inhabit a stretch of 11,098.81 kilometers of coastline.. The recent IPCC assessments have indicated that by the end of this century, twelve major Indian coastal cities-Mumbai, Chennai, Kochi, and Visakhapatnam-will almost be submerged three feet underwater (India Today, 2021). Presently, this shows from global rankings, in which Mumbai stands as the second most flood-vulnerable city in the world, while Kolkata holds the 3rd, Chennai the 13th, and Surat the 14th position in UNDP assessment reports (Anand et al., n.d., 2024).

That this challenge is very serious is reflected by the growing economic impacts of repeated disasters. While the Mumbai floods in 2005 led to losses amounting to USD 2 billion, those in Chennai in 2015 led to losses worth USD 3 billion. Reports suggest that extreme rainfall events throughout central India have tripled since 1950. Chennai received 1,218.6mm rainfall in November 2015, which was the highest in more than a hundred years. According to the National Disaster Management Authority, the annual loss due to floods has increased significantly, with an average loss of Rs. 4,745 crores from 1996-2005 compared to Rs. 1,805 crore for the previous 53 years (NDMA, 2024).

Rapid urbanization multiplies these risks, with the city of Bengaluru losing 79% of its water bodies and over 64% of Indian sub-districts showing increased heavy rainfall days. The Indian National Centre for Ocean Information Services estimates that Mumbai has a 51% inundation risk because of coastal flooding, a scenario shared with Alappuzha at 54% inundation and in large swaths of Odisha's coastal districts.

1.4.2 Knowledge Gaps and Research Requirements

Despite increased awareness of risks from coastal floods, there are three key knowledge gaps: the lack of extensive empirical data regarding the effectiveness of integrated flood resilience interventions within different Indian urban coastal contexts; while a number of studies have shown that nature-based solutions can reduce wave energy by as much as 72% (Daro Justine & Seenath, 2025), and integrated methods show great promise (Daro Justine & Seenath, 2025), evidence remains fragmented about their effectiveness when used as part of combined systems rather than as single interventions.

Most of the existing literature focuses on partial aspects like hydrological modeling or infrastructure assessment, with a serious lack in terms of comprehensive evaluation tools which would simultaneously assess physical, social, economic, and institutional dimensions (Ambily et al., 2024; Prashar et al., 2023). Provide developments in this direction, but these are narrow and essentially call for broader validation across different contexts (Ambily et al., 2024).

Present methods tend to see technological solution, nature-based intervention, and social strategy as separate domains, which do not necessarily leverage their collective strength. The Framework developed for coastal vulnerability mapping for Maharashtra informs but falls short on comprehensive integration necessary for effective flood resilience planning, especially with respect to (Krishnan et al., 2019).

1.4.3 Practical Relevance and Academic Contribution

These findings have immediate practical implications for urban planners, policymakers, and at-risk coastal communities. Given the fact that sea-level rise is occurring at a rate well above the global average around Asia, and extreme sea-level events that occurred once in 100 years are projected to strike annually by mid-century, decision-makers need evidence-based frameworks to guide investment priorities (Times of India, 2019). Employing inundation maps for 15 Indian coastal cities, the Centre for Science, Technology and Policy demonstrates that land subsidence will surpass 10% by

2100 in Mumbai, Yanam, and Thoothukudi, thereby underlining the requirement for site-specific resilience strategies (CSTEP, 2024).

This work has direct relevance to the needs identified in India's Integrated Coastal Risk Mitigation and Resilience Programme, focusing on community capacity building and sustainable development planning. In particular, approaches for participatory inclusion of local communities, especially within informal settlements, play a key role in resilience planning while addressing social equity and environmental justice.

Theoretically, this research will move the concept of resilience forward by showing how technological, ecological, and social systems can be reinforcing rather than parallel. Methodologically, it will provide standardized assessment tools that can be applied across contrasting coastal urban contexts, allowing for systematic comparison of resilience interventions and thus facilitating knowledge transfer across cities and regions.

1.4.4 Urgency and Consequences of Inaction

The urgency is underscored by accelerating climate impacts and rapid urbanization, creating unprecedented flood risks. According to the IPCC, extreme sea-level events will occur annually by mid-century in many regions, while marine heatwaves have doubled in frequency between 1982 and 2016, (Times of India, 2019). The adaptation window is rapidly closing, making immediate resilience action critical.

These consequences of inaction are severe and far-reaching. Economic analysis suggests that without adequate adaptation, coastal flooding is likely to result in damages exceeding billions of dollars annually across Indian coastal cities. Equally distressing is the human cost: the 2015 Chennai floods led to 1.8 million people being displaced, over 500 deaths, and economic damage over $3 billion (Times of India, 2019).

Delayed action will see adaptation costs rise considerably and effectiveness of intervention decline. Early application of integrated resilience strategies can halt maladaptive development patterns and ensure that the adaptation measures undertaken are cost-effective and socially equitable. Without this research, decision-makers will continue to adopt approaches piecemeal, which may further exacerbate vulnerability through inability to address the systemic interaction of various risk factors. This is why evidence-based, integrated frameworks must be developed to help ensure safety, sustainability, and prosperity for India's coastal urban populations in an era of accelerating climate change.

2 RESEARCH DESIGN

2.1 Finalized Title

Strengthening Flood Resilience in Coastal Cities: An Integrated Framework for a Coatal town in India

2.2 Aim

To strengthen flood resilience in an Indian coastal city by developing an integrated framework that combines nature-based solutions, technology, and participatory governance.

2.3 Objectives

1. To Identify different flood conditions experienced across India and their Impact on cities with special focus on coastal cities.
2. To understand various government policies and framework related to flood resilience and control.
3. To understand various methods and approaches employed for flood control and resilience with special reference to Indian context.
4. To identify Indian cities and regions that are particularly vulnerable to coastal floods.
5. To Identify a case city and conduct a systematic assessment of flood risk.
6. To develop an integrated framework for flood resilience using nature based, technological solutions and participatory governance for the case city.

2.4 Research Questions

1. What gaps exist in current flood resilience strategies and assessment methods for Indian coastal cities?
2. What methods (traditional and nature-based) are being used in Indian cities to control floods and increase resilience?
3. Which Indian coastal cities are most vulnerable to severe flooding, and why?
4. How can nature-based solutions, digital technologies and participatory governance be effectively integrated into a unified flood resilience framework?

3. LITERATURE REVIEW

3.1 Introduction

Coastal cities around the world face big problems with flooding. Rising seas, heavier rains (from climate change), fast city growth, and the loss of natural areas like wetlands and mangroves are making floods worse. In India and other developing countries, this problem is even harder because cities have limited budgets, weak coordination between departments, and many poor people living in areas that flood easily (Daro Justine & Seenath, 2025).

Our perspective on combating floods has evolved significantly during the past ten years. We are moving away from just building concrete barriers. Instead, we now combine nature-based solutions, smart planning, technology, and community involvement to make cities more resilient-meaning being better able to handle, survive, and recover from floods. This review discusses what is known from research on the prevention and management of coastal floods, focusing on solutions that work practically, what still needs learning, and particularly drawing on experiences related to coastal cities in India.

3.2 Adaptive Planning Frameworks and Nature-Based Solutions

3.2.1 Adaptive Planning Principles

Flood risks are changing, so most experts now advise "adaptive planning." That means cities should plan for a variety of possible futures, not just the risks they know today. Adaptive planning includes envisioning various futures based on alternative scenarios; determining "triggers," or specific warning signs that might require action; developing plans that can be adapted as needed; monitoring risk factors; and updating plans on a regular schedule.

Because of these constraints, it is essential to inject flexibility into the city flood policies; they also add that most cities face challenges with this form of planning. The probable reasons include insufficient funds, little coordination, or even lack of dependable information. (Table 3.1) presents some of the components of Adaptive flood planning (Valente & Pinho, 2025). Scarcity of data and cumbersome bureaucracies are some of the stumbling blocks in India, for instance, where the planners often come with aspirations of applying these concepts.

Table 3.1: Key parts of Adaptive flood planning *Source: Author*

Planning Element	What It Means
Multiple scenarios	Prepare for various future flood possibilities.
Triggers/thresholds	Clearly indicate points where new actions are required
Flexible solutions	Options that can be changed or expanded over time
Monitoring	Continuously monitoring rainfall, sea level, etc.
Updates	Revising plans periodically as conditions change

3.2.2 Nature-Based and Hybrid Infrastructure Solutions

Nature-based solutions, such as those listed in (Table 3.2) (including mangrove restoration, saltmarsh creation, urban wetland rehabilitation, riparian buffer establishment, and permeable green infrastructure), are demonstrating substantial documented efficacy in flood attenuation, wave energy dissipation, and cascading ecological and social co-benefits. Global empirical evidence on vegetative NBS effectiveness, reporting wave energy reduction ranging from 66% for established mangrove stands to 72% for mature saltmarsh systems (Daro Justine & Seenath, 2025).

In the Indian coastal southwest, in Kochi, for example (Ambily et al., 2024) and (Aloscious et al., 2025) assessed portfolios of integrated NBS that bring together restored urban wetlands, mangrove protection, permeable pavements, and riparian buffers. Their Ecological Flood Resilience Index (EFRI) analysis indicated that 37% of Kochi presents very low flood resilience, mainly concentrated in the central areas of the urban environment with very high impervious surface cover and degraded hydrological connectivity.

Table 3.2: Nature-Based Flood Defenses and Their Function *Source: Author*

Nature-Based Solution	Type	Primary Function	Application Area
Wetlands	Ecosystem Restoration	Absorb and store excess water, reduce flood peaks	Coastal, riverine, urban
Mangroves	Ecosystem Restoration	Trap sediments, slow water flow, protect from storm surges	Coastal (tropical/subtropical)

Salt Marshes	Ecosystem Restoration	Absorb wave energy, reduce coastal erosion	Coastal
Nature-Based Solution	**Type**	**Primary Function**	**Application Area**
Floodplains	Ecosystem Restoration	Act as natural buffer, store overflow water	Riverine
Forests and Reforestation	Ecosystem Restoration	Increase soil infiltration, reduce runoff, stabilize slopes	Watershed, hillsides, urban
Rain Gardens	Green Infrastructure	Absorb stormwater runoff from urban surfaces	Urban, residential
Bioswales	Green Infrastructure	Slow and filter stormwater along roads and streets	Urban streets, parking lots
Green Roofs	Green Infrastructure	Capture and retain rainwater on rooftops	buildings
Permeable Pavements	Green Infrastructure	Allow water to infiltrate into soil, reduce surface runoff	Urban streets, parking, walkways
Living Shorelines	Hybrid/Green Infrastructure	Stabilize shorelines, reduce erosion using vegetation	Coastal shorelines
Sand Dunes	Coastal Protection	Act as natural buffer against waves and erosion	Beaches on coast
Riparian Buffers	Ecosystem Restoration	Stabilize riverbanks, slow water flow	Rivers and streams
Urban Parks/Sponge Spaces	Green Infrastructure	Temporarily store and absorb excess rainwater	Neighborhoods
Oyster/Coral Reefs	Living Infrastructure	Absorb wave energy, reduce storm surge impact	Coastal
Peatlands	Ecosystem Restoration	Store carbon and water, reduce runoff	Upland areas
Natural Drainage Paths	Natural Flood Management	Restore natural water flow pathways	Urban, peri-urban
Vegetated Embankments	Hybrid Infrastructure	Stabilize banks with vegetation, prevent erosion	Rivers, embankments
Beach Nourishment	Coastal Protection	Restore natural coastal defense, reduce wave energy	Coastal beaches

(Table 3.2) below shows a more detailed list from the literature of nature-based solutions, which have been identified as the main approaches taken in improving coastal flood resilience via sustainable, ecological, and adaptive interventions.

Emerging scholars increasingly emphasizes hybrid infrastructure strategies, as shown in (Table 3.3), that strategically integrate engineered ("gray") elements with ecological ("green" and "blue") components. (Xu et al., 2025) conducted systematic review of hybrid sea defense configurations, concluding that engineered structures supplemented with vegetated components deliver superior performance across multiple evaluation criteria: enhanced flood attenuation, increased biodiversity value, improved landscape qualities, and generation of diverse socio-economic co-benefits compared to gray-infrastructure-only alternatives. (Du et al., 2020), evaluating Shanghai's future flood vulnerability, demonstrated that hybrid adaptation strategies yielded substantially lower residual risk and superior cost-benefit ratios relative to either gray or green approaches independently.

Table 3.3: Types of Infrastructures for sea defense *Source: Author*

Infrastructure Type	Flood Mitigation Capacity	Key Co-benefits	Implementation Barriers
Gray infrastructure	High; predictable	Limited	High cost; inflexible
Green infrastructure	Moderate; absorptive	Biodiversity; cooling; recreation	Space; maintenance
Blue infrastructure	Water retention; moderate	Biodiversity; water quality	Complex interdependencies
Hybrid integration	High with co-benefits	Multiple; synergistic	Coordination; expertise gaps

3.3 Grey Infrastructure and Advanced Geospatial technologies

Grey infrastructure refers to human-made, engineered systems like levees, dams, concrete barriers, drainage pipes, culverts, stormwater retention ponds, and wastewater treatment plants. The solution for managing excess water, preventing flooding, and solving urban water management often relies on rapidly conveying the stormwater away from the built-up areas. Grey infrastructure, while effective for large-scale flood protection and conveyance of water, often serves single purposes, can be quite rigid or inflexible, and may have increased surface runoff due to greater impervious surface cover in cities.

Advanced geospatial technologies include GIS, remote sensing, and spatial modeling that have enormous potential to facilitate planning, monitoring, and optimizing the performance of grey infrastructure. These technologies help pinpoint with high resolution

the locations of flood-prone zones, assess drainage capacity, and simulate flood events for different eventualities. Integrating real-time data with spatial analysis enables urban planners and engineers to determine vulnerabilities, assign priorities for upgrading infrastructure, and build more resilient flood management systems. A combination of strong grey infrastructure together with advanced geospatial tools will increase the resilience of cities through evidence-based decision-making and adaptive planning for future flood risks.

3.3.1 Grey Infrastructure

According to (Table 3.4) grey infrastructural systems have conventionally been applied for the purpose of flood protection in urban and coastal areas. They are designed to physically control, divert, or retain excess water during rainfall or tidal events. Engineering solutions of this nature are particularly crucial in safeguarding very densely populated cities and key infrastructure from the very real possibility of flooding, not to mention in places where the need for immediate removal and retention of floodwaters requires urgency due to the scarcity of space and high concentrations of assets. However, recent studies have highlighted that while grey infrastructure offers solid and predictable protection, it requires substantial investment and continuous maintenance and might lack long-term ecological or social resilience. This has stimulated growing interest in the integration of grey systems with nature-based systems for more sustainable urban flood management.

Table 3.4: Types of Grey Infrastructure *Source: Author*

Type	Primary Function	Application Area
Levees & Embankments	Block and direct overland floodwaters	Riversides, coastal zones
Floodwalls	Physically prevent water from entering an area	Urban riverbanks, city edges
Dams & Reservoirs	Store or delay excess upstream water	River basins, reservoirs
Stormwater Drains & Sewers	Rapidly convey runoff away from surfaces	Urban streets, neighborhoods
Pumping Stations	Remove accumulated water from low areas	Below sea level basins, cities
Tide Gates	Block tidal surges and high tides	Estuaries, river mouths

Retaining Walls	Support slopes, control localized water flow	Slopes, riverbanks, canals
Channelization	Increase speed, control river course	Engineered river sections
Check Dams	Slow water, reduce erosion in smaller streams	Upland streams, rural areas
Flood Diversion Channels	Redirect excess floodwater intentionally	Urban peripheries, floodplains

The above table lists the key types of grey infrastructure commonly used for flood defense, highlighting their primary functions and application areas in managing and controlling urban and coastal flooding.

3.3.2 Advanced Geospatial Technologies

Recent advances in geospatial science - high-resolution remote sensing, machine learning algorithms, and hydrodynamic modelling have substantially enhanced flood risk assessment precision and computational efficiency. (Ambily et al., 2024) employed machine learning-integrated sea-level rise projections across eight major Indian coastal cities (Mumbai, Kolkata, Chennai, Visakhapatnam, Surat, Kochi, Thiruvananthapuram, Mangaluru), finding that Mumbai and Kolkata face disproportionately elevated inundation risks under high-emissions scenarios. Such city-level, scenario-specific projections enable targeted, contextually informed adaptation planning rather than generic national strategies.

(Ambily et al., 2024) integrated Synthetic Aperture Radar (SAR) satellite imagery with machine learning algorithms, achieving 75% classification accuracy using Support Vector Machine techniques for near-real-time flood mapping during cyclonic events. These technological advances promise operational-scale flood detection and early warning; however, critical implementation gaps persist: a lack of high-resolution historical datasets to train algorithms, limited capacity of municipalities to operationalize sophisticated remote-sensing systems, a lack of integration with social vulnerability data, and prohibitive financial and technical barriers in resource-constrained settings (Ren et al., 2025).

3.4 Governance and Participatory Planning

Governance and participatory planning lie at the very core of developing resilient flood management systems through a paradigm shift away from top-down directives to

more inclusive, community-driven processes. Over the past two decades, this paradigm shift has revealed the value of involving a broad array of stakeholders-not just government and technical experts but also local communities, NGOs, private sector actors, and others-in the planning and implementation cycle at every stage. Participatory approaches can facilitate the processes whereby communities articulate their lived experiences, indigenous knowledge, and coping strategies, allowing flood risk reduction strategies that are grounded in local realities and priorities.

Various techniques like participatory appraisals, PRA, and participatory diagramming let the stakeholders themselves identify the root causes of floods, appraise the consequences, and collectively design relevant interventions. A bottom-up process leading to more ownership and legitimacy among the people, with reduced dependence on outside agencies, has been shown to bring down costs by mobilizing contributions and resources from the local level. Participation brings the added value of making decisions more context-sensitive, with the involvement of the most 'affected' stakeholders. As has been illustrated from different case studies, both at the global and local levels.

3.4.1 Institutional Coordination

Resilience to urban flooding cannot be achieved solely through technical or engineering solutions. Recent research underlines the imperative of close collaboration among various governmental departments with local level participation. (Carvalho & Spataru, 2023) assessed flood governance arrangements in the UK and concluded that even in countries where the legislation is strong, there are significant issues, such as coordination among different agencies, lack of mechanisms for equity and inclusion, and limited consideration given to pre-disaster risk reduction.

(Prashar et al., 2023) conducted a systematic review of urban flood resilience assessment-related literature over the period 1996–2022. A synthesis review of 235 studies on urban flood resilience found the majority of research focused on early warnings, emergency responses, and basic preparedness. Less attention is given to helping communities recover after floods and to building long-term adaptive capacity. Also, important factors like social connections and the environment often get overlooked.

Table (Table 3.5) showing different departments and authorities for urban flood management in India.

Table 3.5: Responsibilites of Departments and Authorities for Urban Flood Management Source: NDMA (2019)

Responsibilities		National Authorities	State Authorities
Understanding Urban Flood Risks	Mapping/Zonning, Estimation levels, Monitoring networks	MHUA, MO ES, MOJS, DOS	DMD, SDMA, RD, SRSAC, DDMA, PRIS (for peri - urban areas), ULBs
	Information Systems, Monitoring, Forcasting, Early Warning	MOES, MOJS	
	Hazard Risk Vulnerability and Capacity Assesment (HRVCA)	NDMA, NIDM, MSJE	
	Disaster Data Collection and Management	MHA (Nodal Body), MOSPI, all ministries/departments.	DMD, SDM A, all departments.
Inter-Agency Coordination	Overall disaster governance	MHUA	DMD, SDMA, RD, SRSAC, DDMA, PRIS (for peri - urban areas)
	Response	MHUA	DMD, SDMA, RD, SRSAC, DDMA, PRIS (for peri - urban areas), ULBs
	Warnings, Information, Data	MOES (IMD) Nodal Body, MOJS, MOES, NDMA, MEITY	DMD, SDMA, RD, DDMA, ULBS, PRIS (for peri - urban areas)
	Non-structural Measures	MHUA, BIS, NDMA	DMD, SDMA, RD, DDMA, ULBS, PRIs (for peri - urban areas)
Structural DRR Measures	Civil Works	MHUA (Nodal Body), NBCC, BMTPC, CBRI, SERC, IE(1), CRRI	DMD, UDD, ULBS, PRIs (for peri-urban areas)
	Establishment/Strengthening of Emergency Operation Centres	Relevant Central Ministries, MHA	DMD, SDMA, ULBS, PRIs (for peri-urban areas)
	Hazard resistant construction, strengthening, and retrofitting of all lifeline structures and critical infrastructure	NDMA, NBCC, BMTPC, CBRI, SERC, IE(I)	SDMA, DDMA, ULBS, PRIs (for peri-urban areas)
Non - Structural DRR Measures	Preparation of comprehensive Urban Storm Drainage Design Manual (USDDM)	MHUA	DMD, SDMA, DDMA, UDD
	Preparation of Storm Water Drainage System Inventory	MHUA	DMD, SDMA, ULBS, PRIS (for peri-urban areas)
	Operation and Maintenance of Drainage Systems	MHUA	DMD, SDMA, ULBS, PRIs (for peri-urban areas)
	Environmental Impact Assessment	MOEFCC (Nodal Body), MHUA	DMD, SDMA, ULBS, EFD, PRIS (for peri-urban area)

	• Techno-Legal Regime • Land use planning City/Town Planning	MHUA, MFIN	DMD, SDMA, ULBS, EFD, PRIs (for peri-urban area)
	Constitution of Urban Flooding Cell for Integrated UFDM	MHUA	DMD, SDMA, UDD
	Public-Private Partnerships	NDMA, MHUA MCA (Nodal Body), MCF, MOCI, MPFI, MHIPE, MFIN	UDD, SDMA, DOMA
Capacity Development	Risk Transfer	MFIN (Nodal Body), NDMA, MHA, MAFW	DFIN (Nodal Body), DMD, SDMA, State Department of Agriculture
	Education and Training	MHUA (Nodal Body), MHRD, MHFW, NDRF NIDM, CBSE, MYAS	ULB, PRIS (for peri-urban areas), SDRF
	Awareness Generation	MHUA (Nodal Body), NDMA, NDRF, CAPF, NIDM	DMD, SDMA, RD, DDMA, SDRF, FILES. CDEF, Police, ULB, PRIS (for peri-urban areas)
	Documentation	NIDM	DMD, SDMA, RD, DDMA, ULB, State ATI
	Empowering women, marginalised, and persons with disabilities	MWCD (Nodal Body), MSJE, NOMA, NIDM	DMD, SDMA, DDMA, RD, SIDM, ATI, and other state -level institutions
	Community-Based Disaster Management	MHUA (Nodal Body), MORD (Nodal Agency), NDMA, NIDM	DMD, SDMA, SDRF, RD, DDMA, ULB, SIDM
	Mock Drills/ Exercises	MHUA, NDMA, All Govt. Ministries/ Agencies, NDRF, Armed Forces, CAPF	DMD, SDMA, RD, DDMA, ULB, SDRF. F&ES, CDEF, Police
Climate Change Risk Management	Research, Forecasting / Early Warning, Data Management, Zoning, Mapping	MHUA, NDMA, All Govt. Ministries/ Agencies, NDRF, Armed Forces, CAPF	DMD, IRD, WSD (Nodal Body), EFD, SDMA, Agricultural Department, FIHD, DDMA, ULBS, PRIS (for peri areas)
	Hazard Risk Vulnerability and Capacity Assessment (HRVCA)	MOES, MOJS (Nodal Body), MAFW, MOEFCC, DOS, NLRTI	DMD, SDMA, RD, IRD, WRD, SLRTI
	Climate Change Adaptation (CCA)	NIDM, MOJS (Nodal Body), MOST, MOST, CSIR, DOS, NLRTI MOES & MOEFCC (Nodal Body), MOST, DOS, MOJS.	DMD, SDMA, IRD, WSD (Nodal Body), EFD, DRD, DDMA, ULBS, PRIs (for peri-urban areas)

3.4.2 Climate Justice and Equitable Adaptation

Recent studies show that to protect coastal cities from floods in a lasting way, we need strategies that focus on including everyone especially vulnerable communities and making sure their voices are heard in planning and decision making. This means climate policies should be fair and give people equal chances to use blue spaces like rivers and wetlands. This involves everyone, not only experts and officials, as iterated by (Carvalho & Spataru, 2023).

Study after study has shown that as floods continue to arrive, property values decrease and richer families leave. This leads to less well-off people staying in the most flood-prone areas-a dynamic some refer to as "climate gentrification." That's of particular concern in places like India, where informal settlements are often situated on precarious land. Any flood planning that doesn't take such inequities into consideration is likely to exacerbate the problem (Ndille & Belle, 2014).

Other studies indicate that the building of defenses-walls and drains-can help a city cope with floods, but they do not necessarily help people prepare for future risks and make communities capable of taking action. Local involvement in mapping and planning flood risk is crucial since solutions must fit real needs. Where many experts agree, the evidence on how effective community-led flood mapping is in engaging residents in formal decision-making remains limited.

3.5 Research Gaps, Implementation Challenges and Future Directions

Despite the continuing advances, there are still significant research gaps and practical barriers to flood disaster management in India. The major deficiencies are related to the absence of detailed contour maps and digital elevation models for flood-prone regions, the lack of comprehensive flood forecasting and warning systems, and the minimal usage of advanced technologies for real-time monitoring and hazard communication. Fragmented decision-making, insufficient enforcement of flood plain zoning regulations, and poor coordination between agencies further bedevils the effective reduction of risk. In addition, there are other issues: low inflow forecasting of reservoirs and low levels of public awareness and capacity building reduce practical effectiveness at the ground level in terms of scientific and policy advances. The particular gaps mentioned above need improved investment in research, integrated hazard, vulnerability and risk assessment, improved inter-agency collaboration, and focused development of disaster-resilient

technology and participatory approaches. In the future, building comprehensive data systems, using technology-driven solutions, and promoting good governance will be extremely important in creating climate-resilient communities and reducing the gap between research, policy, and implementation.

3.5.1 Critical Research and Implementation Gaps

There are still many important issues that need more attention in future flood planning and studies, as shown in (Table 3.6). Recently, a review of climate adaptation efforts was conducted in coastal cities across 33 countries and found most changes being made comprise small, slow, and limited impacts. There is little real proof actually that such actions reduce flood risks. The way cities adapt is usually uncoordinated, and big changes are few and far between. With sea-level rise from climate change accelerating and floods getting more dangerous, steps taken today are just not enough to keep up with the growth in risks (Wannewitz et al., 2024).

The following table presents research gaps by gap area; it then describes what, from the current knowledge or practice, is missing and why the addressing of each gap is important to flood resilience.

Table 3.6: Gaps Identified *Source: Author*

Gap Area	What Is Missing	Why It Matters
Long-term Data	Studies only track 2-5 years; no data on 20–30-year performance of solutions.	Cities can't invest confidently without knowing if solutions last.
Maintenance Costs	Research doesn't track yearly upkeep costs for green infrastructure.	Hidden costs cause projects to fail and stop working.
Standardized Monitoring	Different studies use different measurement methods; no common standards.	Cities can't compare results or learn from each other.
Multiple Solutions Together	Most studies test one solution alone, not combinations working together.	Real cities need integrated approaches; we need system-level understanding.
Community Participation	Vulnerable people rarely involved in actual decision-making on solutions.	Poor and informal settlements suffer most but aren't asked for input.

Social Equity	Research focuses on building infrastructure, not fairness for poor people.	Plans often help rich areas first; poor people stay vulnerable.
Holistic Frameworks	Studies focus on one aspect (engineering OR ecology OR social), not all together.	Real problems need multiple perspectives combined.
Local Context	Most success stories from wealthy countries; few tests in developing nations.	India and other developing countries need locally adapted solutions.
Vulnerability Assessment	Only measured exposure (proximity); ignored sensitivity and recovery ability.	Real vulnerability is complex; simple proximity isn't enough for planning.
Technology Usage	Advanced satellite and AI tools exist but rarely used operationally in cities.	Technology means nothing if cities can't afford or operate it.
Governance Coordination	Different departments (drainage, parks, planning, emergency) work separately.	Silos waste money and create protection gaps.
Participatory Decision-Making	Community mapping exists but rarely leads to real community participation in decisions.	Local knowledge is collected then ignored; communities should help decide.
Budget-Friendly Tools	Decision-making tools assume lots of data; developing countries don't have these.	Current tools don't work for India's limited budgets and capacity.
BGI Standards	No standard methods to measure green infrastructure performance; no agreed designs.	Without standards, results vary widely; scaling up is difficult.
Financing Models	Research documents costs but not how developing countries actually pay for adaptation.	India's coastal cities need clear financing options and mechanisms.
Recovery Planning	Research emphasizes preparation; few study how communities recover after floods.	Recovery takes months/years; planning this is as important as prevention.
Climate Variability	Old weather patterns don't predict future; climate change creates unprecedented events.	Plans based on old data give false confidence; new approaches needed.

3.5.2 Implications for Indian Coastal Cities

Cities like Mumbai, Kolkata, and Chennai showcase the critical and multi-dimensional issue that flooding has become in India. Sea-level rise, heavy monsoons, and rapid city growth create huge challenges for urban areas. In most instances, the poorest families experience the worst of these phenomena in low-lying and flood-prone urban pockets. We must consider using city-specific strategies that integrate the use of advanced technology with government support and proactive participation by citizens in terms of their adoption. Take Kochi and Sindhudurg as examples: we need city-specific strategies that put a mix of advanced technologies into place along with government support and active participation from the public (Prashar et al., 2023).

Recently, research has brought forward new knowledge and better approaches for hybrid infrastructure, climate modeling, and giving communities a stronger hand in planning. Most success stories showcased come from small and short-term projects, or from more developed countries. There is still considerable uncertainty regarding the performance of nature-based solutions over the long term and too often equity and social needs are incompletely integrated into planning.

Thus, to really protect our coastal cities, much more is needed in terms of local research, innovative ways of linking technical, social, and environmental understandings, and a sharper focus on equity and community participation. More funds and reforms are also required so the solutions for flood defense can actually make a difference for all. Future research should pay special attention to needs and realities in developing countries, to long-term results, and to plans that combine all these dimensions for better, practical flood resilience.

3.6 Coastal towns

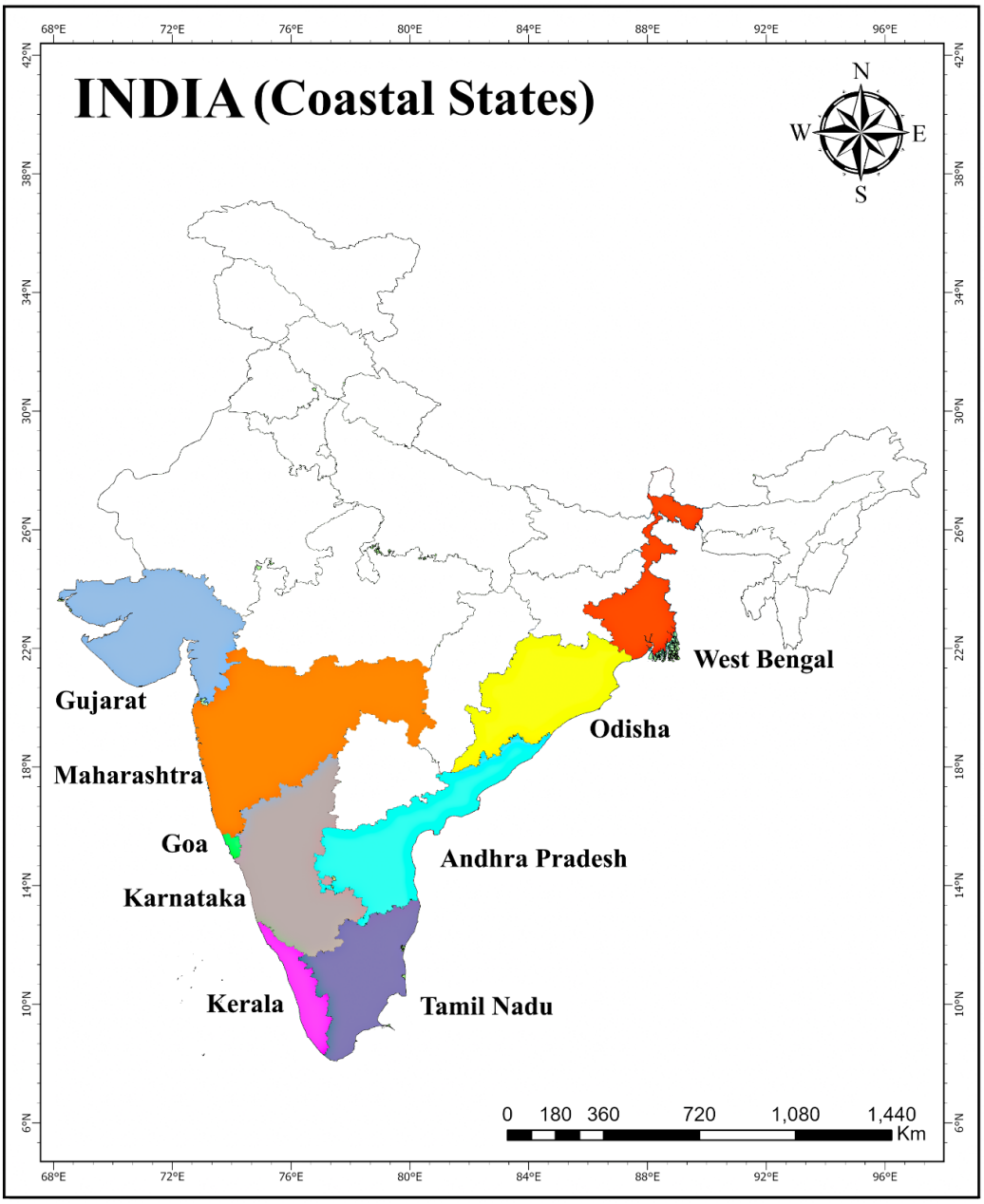


Figure 3.3: Coastal map of India, Source: GIS Pro

The coastline of India extends for about 11,098.81 km, which is among the longest in the world, and accounts for almost 13% of the land area of the country. This coastline is along the mainland and the islands housing a variety of ecosystems and activities such as fishing, trade, and tourism. The nine states (Figure 3.3), namely Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Odisha, West Bengal and Union Territories of Daman & Diu, Puducherry, Andaman & Nicobar, and Lakshadweep, that have coasts have towns with culture, history, and economy attributed to their location. The table below shows in detail the list of coastal towns in each state –

3.6.1 States

The following are the major coastal states in India that are badly hit by floods due to their areas affected with seasonal monsoon rains and cyclonic storms, leading to flooding of rivers. Their long coastlines and low-lying areas make them more vulnerable to water-related disasters, needing better ways of coastal management and preparedness.

1. Gujrat

The coastline of Gujarat, officially revised to 2,340.62 km is the longest among Indian states, features intricate bays, islands, gulfs, and estuaries. This diverse stretch supports rich ecosystems, prominent ports, vibrant fishing and trade hubs and major coastal industries that link communities to the Arabian Sea. (Table 3.7) shows all the coastal towns in Gujrat.

Table 3.7: Coastal towns in Gujrat *Source: Author*

Towns	Population	District
Bhavnagar	593368	Bhavnagar
Porbandar	151770	Porbandar
Veraval	154636	Junagadh
Dwarka	38873	Jamnagar
Jamnagar	479920	Jamnagar
Okha	62052	Jamnagar
Surat	4467797	Surat
Valsad	114636	Valsad
Mandvi	51376	Kachchh
Mundra	20338	Kachchh
Mangrol	63794	Junagadh
Sutrapada	26132	Junagadh
Mahuva	82772	Bhavnagar
Khambhat	83715	Anand
Bhat	6823	Gandhinagar

2. Maharashtra

The coastline of Maharashtra has been officially revised to 877.97 km as per 2025, extending along the Arabian Sea. It boasts Mumbai as a major global port and commercial hub, significant fisheries, popular beaches, and various coastal communities along the picturesque Konkan belt. (Table 3.8) shows all the coastal towns in Maharashtra.

Table 3.8: Coastal towns in Maharashtra *Source: Author*

Towns	Population	District
Navi Mumbai	1120547	Thane
Vasai-Virar	1222390	Thane
Alibag	20743	Raigarh
Uran	30439	Raigarh
Ratnagiri	76229	Ratnagiri
Vengurla	12392	Sindhudurg
Dahanu	50287	Thane
Mira-Bhayandar	809378	Thane
Chinchani	13646	Thane
Tarapur	6962	Thane
Nandgaon	23604	Nashik
Shirgaon	5971	Thane
Borli	6952	Raigarh
Murud	12216	Raigarh
Dabhol	7038	Ratnagiri

3. Karnataka

Karnataka's coastline extends for 343.30 km as of 2025 along the Arabian Sea. It encompasses main estuaries, 86 offshore islands, and 12 onshore islands. Coastal districts like Uttara Kannada, Udupi, and Dakshina Kannada depend on fisheries, ports, tourism, and a unique marine biodiversity. (Table 3.9) lists all the coastal towns in Karnataka..

Table 3.9: Coastal towns of Karnataka *Source: Author*

Towns	Population	District
Mangalore	488968	Dakshina Kannada
Udupi	125306	Udupi
Kundapura	30444	Udupi
Karwar	63755	Uttara Kannada
Bhatkal	32000	Uttara Kannada
Ankola	15309	Uttara Kannada
Kumta	29266	Uttara Kannada
Honavar	19109	Uttara Kannada
Varamballi	6809	Udupi
Nadsal	11611	Udupi
Mulki	17274	Dakshina Kannada
Ullal	53773	Dakshina Kannada

4. Kerela

Starting from 2025, the officially revised coastline of Kerala is 600.15 km in length along the Arabian Sea, featuring a continuum of backwaters, lagoons, and dynamic fishing villages lining its shores. It is immensely important for Kerala's economy, ecology, and culture and connects different coastal towns and ecosystems. (Table 3.10) List of all coastal towns in Kerela.

Table 3.10: Coastal towns of Kerela *Source: Author*

Towns	Population	District
Kasaragod	54172	Kasaragod
Kannur	56823	Kannur
Thalassery	92558	Kannur
Kozhikode	431560	Kozhikode
Feroke	32122	Kozhikode
Kochi	336048	Ernakulam
Alappuzha	174176	Alappuzha
Kollam	348657	Kollam
Varkala	40048	Thiruvananthapuram
Thiruvananthapuram	743691	Thiruvananthapuram
Manjeshwar	8742	Kasaragod
Uppala	11542	Kasaragod
Mangalpady	12790	Kasaragod
Shiriya	5277	Kasaragod
Mogral	8912	Kasaragod
Kudlu	26235	Kasaragod
Chemnad	14323	Kasaragod
Udma	8115	Kasaragod
Kanhangad	73342	Kasaragod
Kannapuram	18459	Kannur
Pappinisseri	35134	Kannur
Azhikode (south)	25195	Kannur
Azhikode (North)	22128	Kannur
Muzhappilangad	23709	Kannur
New Mahe	10986	Kannur
Azhiyur	30023	Kozhikode
Iringal	25894	Kozhikode
Chemancheri	34819	Kozhikode
Beypore	69752	Kozhikode
Ariyallur	22558	Malappuram
Tirur	56058	Malappuram
Ponnani	90491	Malappuram

Punnayur	19387	Thrissur
Chavakkad	39098	Thrissur
Perinjanam	21012	Thrissur
Pallippuram	22512	Thiruvananthapuram
Kodamthuruth	21295	Alappuzha
Kandalloor	19925	Alappuzha
Puthuppally	20390	Alappuzha
Ayanivelikulangara	24268	Kollam
Chavara Kollam	42655 348657	Kollam Kollam
Mayyanad	40039	Kollam
Paravur	31503	Ernakulam
Vakkom	19267	Thiruvananthapuram

5. Goa

The officially revised coastline of Goa, as of 2025, is 193.95 km and is India's shortest. The coastline runs along the Arabian Sea and supports beautiful beaches, important fishing villages, bustling tourism, and historic ports and rich ecological and cultural diversity. (Table 3.11) shows all the coastal towns in Goa.

Table 3.11: Coastal towns of Goa *Source: Author*

Towns	**Population**	**District**
Panaji	40017	North Goa
Vasco-da-Gama	94,393	South Goa
Mormugao	94393	South Goa
Canacona	12434	South Goa
Pernem	5021	North Goa
Arambol	5322	North Goa
Mandrem	8336	North Goa
Morjim	6760	North Goa
Siolim	10936	North Goa
Anjuna	9636	North Goa
Calangute	13810	North Goa
Candolim	8500	North Goa
Nerul	5042	North Goa
Bambolim	6885	North Goa
Chicalim	6933	South Goa
Sancoale	21923	South Goa
Benaulim	11919	South Goa
Varca	5439	South Goa
Canacona	12434	South Goa

6. Tamil Nadu

Tamil Nadu's coastline officially revised to 1,068.69 km is India's second longest, supports major marine fish production, vibrant fishing communities, prominent ports, pilgrimage tourism, seafood processing, shipbuilding, and coastal economic zones that are vital for the growth of the state and its blue economy aspirations. (Table 3.12) gives details of all the coastal towns in Tamil Nadu.

Table 3.12: Coastal towns of Tamil Nadu *Source: Author*

Towns	Population	District
Chennai	4646732	Chennai
Mahabalipuram	15172	Kancheepuram
Cuddalore	173636	Cuddalore
Nagapattinam	102905	Nagapattinam
Velankanni	11108	Nagapattinam
Rameswaram	44856	Ramanathapuram
Tiruchendur	32171	Thoothukkudi
Thoothukkudi	237830	Thoothukkudi
Kanyakumari	22453	Kanniyakumari
Colachel	23227	Kanniyakumari
Keelakarai	38355	Ramanathapuram
Mandapam	18427	Ramanathapuram
Devipattinam	11599	Ramanathapuram
Thondi	18465	Ramanathapuram
Ammapattinam	6652	Pudukkottai
Vedaranyam	34266	Nagapattinam
Tharangambadi	23191	Nagapattinam
Parangipettai	25541	Cuddalore
Kovalam	8124	Kancheepuram

7. Andhra Pradesh

Andhra Pradesh has the third longest coastline among Indian states, revised to 1,053.07 km in 2025. Its coast borders the Bay of Bengal and contains important ports and sandy beaches. There are many tourist beaches, such as Rishikonda, Bheemunipatnam, and Vodarevu, which attract visitors throughout the year. That longer shoreline also makes Andhra Pradesh more vulnerable to cyclones, erosion, and flooding, thus underscoring the need for thoughtful coastline planning and robust disaster management. (Table 3.13) lists all the coastal towns in Andhra Pradesh.

Table 3.13: Coastal towns of Andhra Pradesh *Source: Author*

Towns	Population	District
Nellore	499575	Sri Potti Sriramulu Nellore
Kakinada	312538	East Godavari
Machilipatnam	169892	Krishna
Narsapur	6647	Medak
Chirala	87200	Prakasam
Bapatla	70777	Guntur
Kanuru	49006	Krishna
Bheemunipatnam	52110	Visakhapatnam
Srikakulam	125939	Srikakulam

8. Odisha

The coastline of Odisha is officially put at 574.71 km in 2025, along the Bay of Bengal. It features major river deltas, important fishing grounds, and active ports. The state is rapidly developing, with growing port infrastructure and a mix of ecological and economic activities that support vibrant communities. For details, see (Table 3.14) showing all coastal towns in Odisha.

Table 3.14: Coatal towns of Odisha *Source: Author*

Towns	Population	District
Brahmapur	356598	Ganjam
Gopalpur	7221	Ganjam
Puri	200564	Puri
Konark	16779	Puri
Paradip	68585	Jagatsinghapur
Kendrapara	47006	Kendrapara
Ganjam	11747	Ganjam
Rambha	12111	Ganjam
Dungamal	6271	Khordha
Balugaon	17645	Khordha

9. West Bengal

West Bengal's coastline, officially revised to 721.02 km in 2025, borders the Bay of Bengal and has seen the highest percentage increase (357%) among Indian states. Its coast features the ecologically vital Sundarbans delta, key ports, and diverse, vibrant fishing communities. (Table 3.15) Shows all the coastal towns in West Bengal.

Table 3.15: Coastal towns of West Bengal *Source: Author*

Towns	Population	District
Digha	8159	North Twenty-Four Parganas
Haldia	200827	Purba Medinipur
Diamond Harbour	41802	South Twenty-Four Parganas
Tajpur	7035	Hugli
Silampur	12664	Maldah
Tamluk	65306	Purba Medinipur
Kolaghat	25191	Purba Medinipur
Kaijuri	5932	Haora
Naupala	7856	Haora
Gopinathpur	4688	Barddhaman
Chaulia	6186	Paschim Medinipur
Shashati	6914	Haora
Anantapur	5532	Purba Medinipur
Dihimandalghat	7910	Haora
Deuli	9007	Paschim Medinipur
Kamalpur	6664	Medinipur
Dinga Khola	5271	Haora
Ramnagar	5446	Barddhaman
Kalinagar	11282	Pilibhit
Haripur	5910	Barddhaman

These are the coastal towns of each state in India, as identified and listed in this chapter. By compiling them systematically, this overview provides a clear reference to the distribution and diversity of coastal settlements across the country.

3.6.2 Union Territories

As of 2025, India has eight Union Territories, including Delhi, Puducherry, Chandigarh, Andaman and Nicobar Islands, Lakshadweep, Ladakh, Jammu & Kashmir, and Dadra and Nagar Haveli and Daman & Diu. Unlike states, these regions are administered directly by the central government through appointed Administrators or Lieutenant Governors. Some Union Territories, such as Delhi and Puducherry, have their own legislatures and a degree of self-governance, while others are managed solely by central authorities. The Union Territories are also singularly different in their administrative and geographic profiles, from highly bustling megacities like Delhi to the far-flung and ecologically fragile Lakshadweep and the Andaman and Nicobar Islands. Their governance structure enables closer central oversight and often addresses strategic, cultural, or geographic considerations.

1. Daman & Diu

Table 3.16: Daman and Diu *Source: Author*

Towns	Population	District
Daman	44282	Daman
Diu	23991	Diu

2. Pondicherry

Table 3.17: Pondicherry *Source: Author*

Towns	Population	District
Puducherry	244377	Puducherry

The six Union Territories with a coastal boundary line are Daman and Diu, Puducherry, Lakshadweep, and the Andaman and Nicobar Islands. As per the Census of India classification, towns in Daman and Diu and Puducherry are listed while settlements in Lakshadweep and the Andaman and Nicobar Islands do not meet the official definition of a town. These islands are primarily composed of small villages and dispersed habitations, many of which have limited population size and administrative structure. Therefore, no separate table has been prepared for these regions. However, their geographical and ecological significance remains vital, as they play an important role in India's coastal environment, marine biodiversity, and national security. (Table 3.16) and (Table 3.17) Shows all the coastal towns in Daman & Diu and Punducherry.

3.6.3 Change in length of Coastline of India

The length of India's coastline was officially updated to 11,098.81 km in April 2025 as shown in (Table 3.18), reflecting a new standardized methodology and more detailed mapping. Previous estimates, such as the widely cited 7,516.6 km, were based on older, less precise measurements and did not fully account for offshore islands and coastal intricacies. The revised figure was determined through collaborative efforts by central government agencies and coastal states, using high-resolution electronic charts and updated terms of reference. The table below presents the state-wise and union territory-wise distribution of the re-verified coastline length of India as accepted by stakeholders in 2025.

Table 3.18: The state wise/UT wise 'Length of Coastline of India'

S.no	State/Union Territory	Coastline length (in Km)
1	Gujarat	2,340.62
2	Maharashtra	877.97
3	Goa	193.95
4	Karnataka	343.30
5	Kerela	600.15
6	Tamil Nadu	1,068.69
7	Andhra Pradesh	1,053.07
8	Odisha	574.71
9	West Bengal	721.02
10	Daman & Diu	54.38
11	Pondicherry	42.65
12	Lakshadweep Islands	144.80
13	Andaman & Nicobar Islands	3,083.50
Total length of Coastline of India		**11,098.81**

Source: Ministry of Ports, Shipping and waterways Transport Research Wing

4. RESEARCH METHODOLOGY

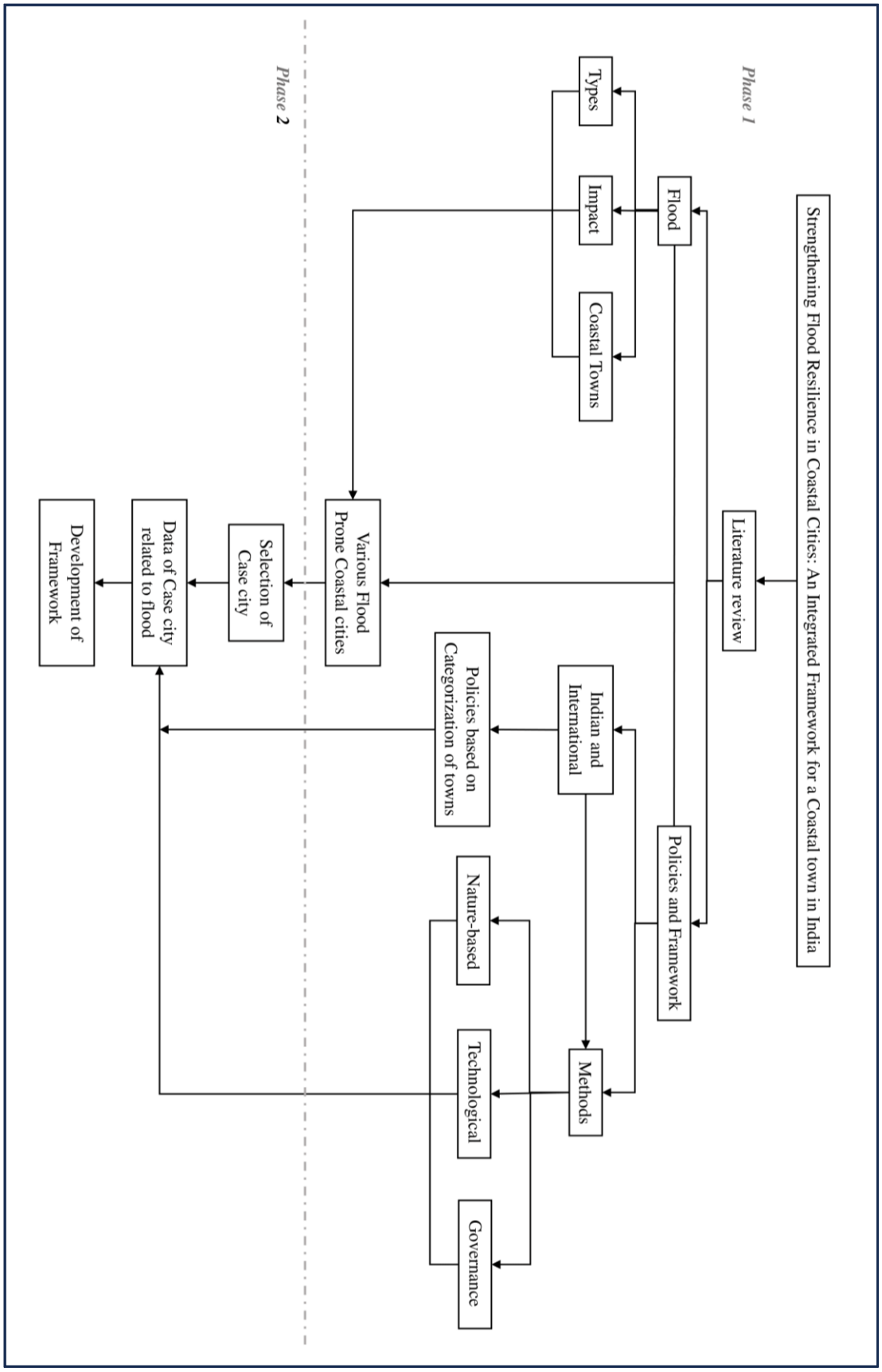


Figure 4.1: Research Methodology Flowchart

4.1 Phase 1 Objectives

4.1.1 Objective 1: To Identify different flood conditions experienced across India and their Impact on cities with special focus on coastal cities.

1. Review and analyze existing data and literature on various types of floods in India, including riverine, coastal, urban and flash floods.
2. Map flood-prone regions based on geographic, climatic, and hydrological factors using satellite data and government reports.
3. Focus on case studies of coastal cities vulnerable to storm surges, cyclones, sea-level rise, and urban flooding to understand specific impacts on infrastructure and communities.

4.1.2 Objective 2: To understand various government policies and framework related to flood resilience and control.

1. Collect and review official government documents and guidelines on flood resilience and control.
2. Analyze key policies and frameworks by summarizing main strategies.
3. Compare the focus and effectiveness of these policies for different flood-prone regions, with attention to special schemes for coastal cities.
4. Map existing government efforts to understand strengths and gaps, focusing on how these governments support or limit real urban flood resilience.

4.1.3 Objective 3: To understand various methods and approaches employed for flood control and resilience with special reference to Indian context.

1. Obtain information on grey infrastructure engineered solutions to handle flood risk for flood control and resilience.
2. Discuss nature-based and ecosystem-based approaches that rely on natural processes and ecosystem services to provide flood risk management while enhancing long-term resilience.
3. Consider non-structural strategies that enhance urban flood preparedness and response through planning, regulation, risk assessment, and public involvement.

4.1.4 Objective 4: To identify Indian cities and regions that are particularly vulnerable to coastal floods.

1. Collect information from government agencies and reports regarding how coastal floods pose a threat to Indian cities and regions.
2. Look at recent studies on sea-level rise, storm surges, and flood events in coastal areas and identify which cities have witnessed major floods.
3. Synthesize these findings through mapping to highlight the most susceptible urban regions for urgent resilience measures.

4.2 Phase 2 Objectives

4.2.1 Objective 5: To Identify a case city and conduct a systematic assessment of flood risk.

1. Based on flood risk maps and recent events, select a coastal city of India that is very prone to flooding.
2. Collect data on rainfall records, sea level trends, land use maps, and flood history of that city from official reports and scientific sources.
3. Use mapping tools to analyze and visually identify flood-prone zones with consideration for elevation, drainage, population density, and exposure.
4. Assess flood risk, combining information on the likelihood of floods with information on the number of people and assets in harm's way and the city's vulnerability based on housing type, infrastructure, and preparedness.

4.2.2 Objective 6: To develop an integrated framework for flood resilience using nature based, technological solutions and participatory governance for the case city.

1. Study nature-based solutions that naturally absorb and slow down floodwater in the case city.
2. Find technological solutions that help predict, prepare for, and control flood risks.
3. Best participatory practices that integrate governance, local communities, stakeholders, and city authorities in the planning, decision-making, and implementation of flood resilience measures.

4. Integrate all three approaches into one single, easy-to-use framework for the case city, through which nature-based, technology-driven, and community-led actions work together in the interest of better flood resilience.

4.3 Scope of the Study

The scope of this research is to develop an integrated framework with the aim of enhancing flood resilience specifically for Indian coastal cities. While all Indian coastal cities are unique, their different people, places, and environments create a different set of challenges. This research will identify flood hazard-prone areas throughout the cities and will select one area for a more detailed case study to examine the particularized flood risk and gaps in resilience. This study will look at integrating conventional infrastructure with nature-based solutions and high-end technology, such as remote sensing and geographic information systems, to provide actionable recommendations for flood management, community preparedness, and policy planning.This integrated framework shall enable Indian coastal cities to better cope with growing flood risks caused by climate change and urban growth, thereby strengthening their capacity to protect people, property, and ecosystems now and in the future.

4.4 Limitations

Several limitations and challenges may arise during the research. Data collection might be incomplete, inconsistent, inaccessible at different government agencies with regard to flood events and socio-economic information. The digital elevation model and remote sensing data used for mapping flood hazard and vulnerability will vary in quality and resolution. Short observation periods and uncertainties in climate projections make it challenging to estimate the performance and benefits of proposed resilience measures fully over time.

5. CASE STUDIES

5.1 Chennai Floods (2015)

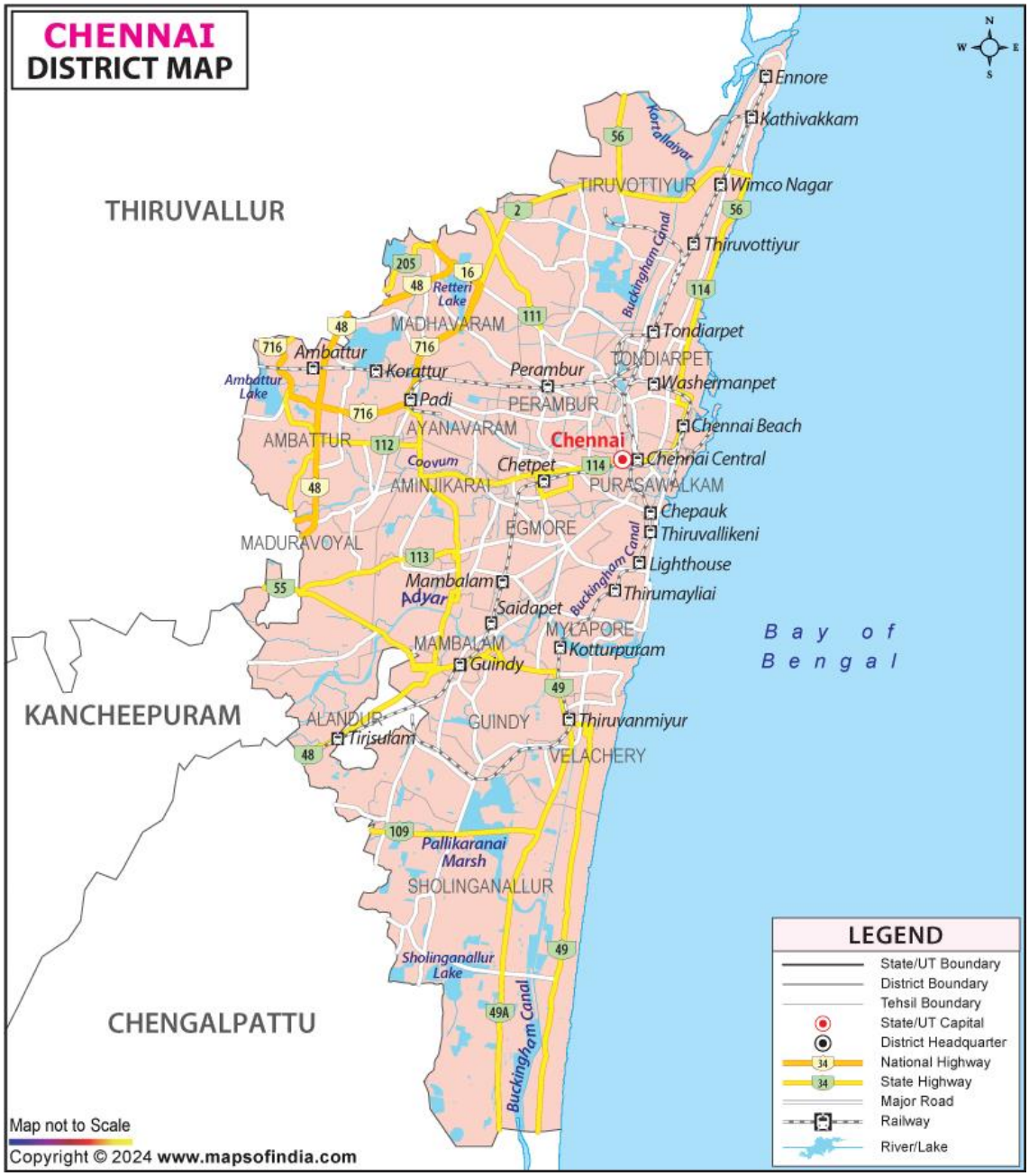


Figure 5.1: Chennai district map, Source: https://www.mapsofindia.com/maps/tamilnadu/districts/chennai-district-map.html

5.1.1 Introduction and Background

The Chennai floods of 2015 were among the most disastrous urban floods in South Asia. The coastal city of Chennai received unprecedented rainfall from late November to early December 2015, causing massive inundation and crumbling of infrastructure. Chennai (Figure 5.1) is situated on the Coromandel Coast with low-lying topography, with large parts of the city lying below mean sea level. The Northeast monsoon contributes around 60 percent of the annual rainfall in the city (*ChennailFlood_NIDM2021.Pdf*, n.d.).

Before the 2015 floods, it became evident that Chennai had several structural vulnerabilities. Over 90% of its natural wetlands were converted into urban development- a process that had destroyed natural flood buffers. The Pallikaranai wetland was reduced from its original 5,500 hectares to around 550 hectares. The encroachment of the river floodplains in the city by urbanization along the Adyar and Cooum rivers drastically reduced the natural flood conveyance capacity. Its drainage system exhibited chronic maintenance gaps, insufficiency in desilting, and woefully inadequate capacity to move stormwater away.

5.1.2 Factors and Impact

The 2015 Chennai floods were triggered by an extremely heavy northeast monsoon rain, further exacerbated by El Niño and warmer Bay of Bengal waters. The magnitude of the flood, however, was enhanced through unplanned urban growth, rampant wetland and water-body encroachment, blocked natural drainage paths, and ill-maintained stormwater networks. Incorrect releases from city reservoirs, particularly Chembarambakkam, contributed to the sudden flooding in low-lying areas. These factors together led to widespread flooding and major disruption in transport and essential services, along with extensive property damage and mass displacement, highlighting the vulnerabilities created by rapid urbanization and inadequate flood preparedness.

Meteorological and Anthropogenic Causes

The main trigger was rainfall intensity that had never been witnessed before during the Northeast monsoon. Chennai recorded an average of 290 mm of rain in 24 hours from December 1–2, 2015, against the previous single-day record of 261.6 mm in 1901. Still, the India Comptroller and Auditor General termed the floods as mainly "man-made." Other underlying human-induced causes included:

1. A 90% loss of wetlands eliminated natural stormwater absorption capacity.
2. River encroachment through urbanization.
3. According to this, the three major causes were poor drainage, solid waste accumulation, and failure of the drainage system due to inadequate maintenance.
4. expansion of impervious surfaces reducing groundwater infiltration.
5. lack of inter-departmental coordination at the time of reservoir discharge.

Scale of Impacts

The floods in Chennai caused more than 500 deaths throughout Tamil Nadu, with about 1.8 million people directly affected. Relief operations included the formation of 6,605 relief camps that temporarily housed about 1.7 million displaced persons. Effects were felt disproportionately in informal settlements built on lands previously considered wetlands. Economic damage has been estimated at around $2 billion to $3 billion, making the 2015 Chennai floods one of the costliest natural disasters in the world that year (Seenirajan et al., 2017).

Infrastructure damages were widespread: more than 25 lakh (2.5 million) houses were damaged, of which about 57,000 buildings were damaged; 6,964 homes were completely destroyed in Chennai district alone. More than 3.82 lakh hectares of agricultural land were submerged with crop loss across the state. Transport services and Chennai airport were flooded; airport services shut down for 3 days. The extended blackout halted municipal services, cut off the water supply, and crippled healthcare delivery.

The impact on health was severe: disrupted operations in hospitals, partial flooding in several facilities, and around 51 patients had to be urgently evacuated. The SMEs suffered disproportionately: commercial establishments suffered water ingress up to 2 meters high, destroying their inventory, equipment, and business records. The recovery period for many SMEs was 3-6 months (Seenirajan et al., 2017). Agriculture workers and informal sector workers remained out of work for a longer period during recovery. As many as 30% of households in Chennai suffered losses ranging from ₹200,000 to ₹2 million.

5.1.3 Response and Lessons Learned

NDRF deployed 50 teams comprising 1,715 personnel and 194 boats with 94 deep-sea divers for rescue operations. More than 600 boats were mobilized for rescue in informal settlements and low-lying areas. Around 12.29 million food packets were distributed across relief camps. Stormwater pumping operations were deployed to drain water from 787 waterlogged neighbourhoods. More than 100,000 tonnes of flood debris were cleared from Chennai city. Twenty-six thousand, 270 medical camps were organized, treating around 2.56 million people. The State government disbursed ₹67.47 crore as initial ex-gratia relief to 1,11,278 affected households.

Community-based organizations were immensely resilient. Tamil Nadu Thowheed Jamath mobilized more than 700 volunteers for rescue, relief, and rehabilitation. Restaurants and commercial establishments provided volunteer labor and material support; Kolapasi restaurant distributed around 1.7 lakh boxes of food. Online platforms allowed for real-time information sharing and helped coordinate volunteers.

Key Lessons for Urban Flood Resilience

The Chennai floods brought to the fore a number of important lessons: first, on infrastructure and drainage-the stormwater networks simply couldn't cope with record rainfall, and years of inadequate desilting and aging pipes made drainage inefficient; the messy mix of responsibilities across so many agencies meant that decisions about reservoir discharges were often stalled or conflicted and widened the gaps in action. Second, wetland conservation: wetlands are important natural hydrological buffers, and neighborhoods built atop filled wetlands received the full fury of the floodwaters. The area had lost one of its critical lines of defense against flooding with about 90 percent of the original wetlands gone. Drainage, environment management, and emergency response are ground responsibilities split under different budgetary and administrative arrangements that resulted in coordination gaps; planning should be participatory, involving civil society and vulnerable populations. Assessment post-disaster showed that access to relief resources remained unequal; informal settlements received late and inadequate attention; building back better essentially calls for resilience measures like elevated electrical systems and flood-proof barriers.

5.2 Kerela Floods (2018)

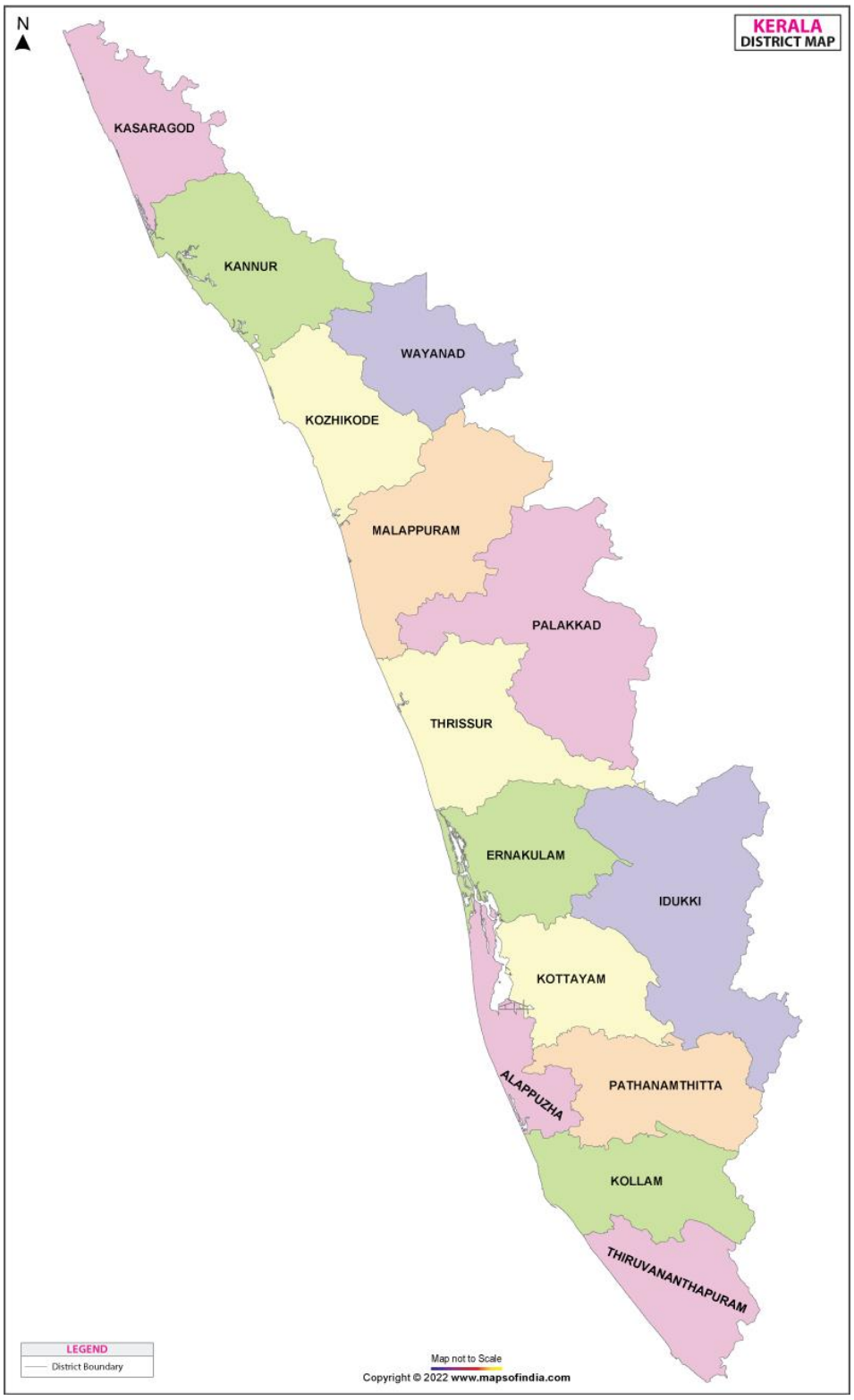


Figure 5.2: District map of Kerela, Source: https://www.mapsofindia.com/maps/kerala/kerala.htm

5.2.1 Introduction and Background

The Kerala floods of August 2018 were the state's most severe natural disaster in nearly a century. (Figure 5.2) shows the district map of Kerela, from June to August, Kerala experienced extraordinary monsoon rainfall, causing catastrophic flooding and landslides in all 14 districts. The floods resulted in 483 deaths, displaced over 1.5 million people, and led to economic losses of around ₹40,000 crore (about $5.4 billion USD), marking it among the most destructive flood events in recent South Asian history (Memorandum, 2018) . Kerala's inherent vulnerabilities including a 600-kilometer coastline along the Arabian Sea, 41 major rivers, extensive backwaters, and steep terrain of the Western Ghats contribute to severe flood and landslide risks during heavy rains.

Years of development had reduced Kerala's natural flood resilience. Widespread deforestation, vested interest-driven constructions in ecologically sensitive areas, loss of wetlands, unbridled mining of sand, and destruction of traditional paddy fields had weakened the natural water-retention mechanisms. Complicating the picture further is the presence of 80 dams scattered all over Kerala. Between the ecological erosion and the web of infrastructure, the stage was set for disaster when unusually heavy rains hit.

5.2.2 Factors and Impact

In 2018, Kerala suffered some of the worst floods in a hundred years. The culprit was extraordinary rainfall, with August delivering rainfall nearly twice the average. That rainfall filled 35 of the state's 54 dams to their limits, prompting a wave of dam releases. The sudden surge of water, already pressing reservoirs to capacity, hit just as a rare confluence of weather patterns rolled in: low-lying areas disappeared under water in a matter of hours. Human activities made matters worse: forests cleared, towns sprawled without planning, wetlands invaded, and reservoir operations mismanaged. Each of these reduced the land's natural ability to soak up runoff. The floods wrecked homes, damaged infrastructure and farms, upended livelihoods, forced more than a million people from their homes, and left vast losses in life and property in its wake. The disaster underlined Kerala's fragility in the face of climate extremes and brought into sharp focus an urgent need for flood-ready planning that protects ecological health.

Meteorological and Anthropogenic Causes

The 2018 Southwest monsoon brought rainfall in Kerala that was 23% above the long-

term average, with August rainfall alone nearly double the norm at 96% above average.. During August 8-10, 2018, Kerala received 310 mm of rainfall in 48 hours. Nevertheless, a study conducted by the Rajiv Gandhi Institute of Development Studies found severe governance failures and anthropogenic factors significantly enhanced the gravity of the disaster, well beyond what was contributed by the meteorological anomalies themselves (Ali & George, 2022). Dam authorities opted to treat hydroelectric power generation as their priority, rather than flood control functions. Critical anthropogenic factors included:

1. 35 of 54 dams were opened simultaneously for the first time in history with no co-ordination or community warnings
2. All five spillway shutters of the Idukki Dam and five gates of Malampuzha Dam opened simultaneously
3. Absence of comprehensive flood mapping prevented authorities from understanding the potential inundation extent
4. Inadequate dam Emergency Action Plans; rejection of the 2011 Western Ghats Ecology Expert Panel recommendations on land-use restrictions
5. Lack of coordinated communication between dam authorities and district administrations

Scale of Impacts

It is estimated that about 5.4 million people, one-sixth of Kerala's total population, were affected across 775 villages in all districts. Deaths concentrated in August, with disproportionate impacts on low-lying informal settlements and riverbank communities. More than 1.5 million people were displaced, and 12,300 relief camps were opened to shelter about 1.7 million people. Estimates of economic damage ranged between ₹27,000 crore and ₹40,000 crore, which positioned the 2018 Kerala floods as among the costliest natural disasters globally for the year (Singh et al., 2025).

The infrastructure damage was immense: 10,319 homes were entirely destroyed, while over 100,000 were partially destroyed, rendering approximately 220,000 people homeless. Over 10,000 kilometers of roads were destroyed-about a third of the road network-and required around ₹1 billion to rebuild. Agriculture suffered losses of over 16,000 hectares of cultivated land. Transport systems on the road, rail, and even in Kerala's aviation infrastructure suffered heavy disruption. Electrical installations, including generation and distribution facilities, were also severely affected. Migrant

workers, who form significant portions of Kerala's unskilled and semi-skilled labor and who lived in low-lying flood-prone areas, suffered from discrimination in the distribution of relief camps and linguistic barriers to official warnings; this precipitated mass migrations of around 500,000 workers using railway networks, complicating post-disaster reconstruction efforts. Health sector impacts were severe, with partial inundation of several hospitals and the need for emergency evacuation of about 51 patients.

5.2.3 Response and Lessons Learned

The mobilization of emergency operations involved more than 600 boats for rescue, and vital rescue support was provided by fishermen and civil society volunteers. Large contingents of the National Disaster Response Force were deployed along with helicopters for aerial rescue and supply operations in isolated hilly areas. More than 12,000 people were rescued on active rescue days through synchronized operations using boats. Medical Interventions Medical camps were set up, establishing 26,270 health camps that treated around 2.56 million people for trauma and health emergencies. Around 12.29 million food packets were distributed across relief camps. Storm water pumping operations were deployed to drain water from waterlogged neighborhoods. Over 100,000 tonnes of flood debris were cleared from affected areas. The state government short-armed relief at ₹600 crore, far too small for the scale of needs pegged at ₹40,000 crore. (Memorandum, 2018).

Yet, on the ground, the response flashed with resilience and a volunteer spirit. Young people, civil-society groups, religious organizations, and fishermen organized rescues and relief efforts with remarkable coordination. Schools doubled as emergency shelters, while panchayats, or local self-government bodies, steered relief work in a decentralized and efficient way. Digital platforms kept information flowing in real time and helped volunteers stay coordinated.

Key Lessons for Urban Flood Resilience

The Kerala floods gave the following lessons:

1. Dam Management: Water resource councils must create a thoughtful balance between generating power and preventing floods. Each large dam must have a Mandatory Emergency Action Plan, coupled with clear coordinated communication rules for releases from the dam. Detailed flood maps are necessary

to prevent inundation downstream.

2. Ecological Sustainability: Stringently enforce land-use regulations in environmentally sensitive areas; no building on river floodplains. Systematically recover and protect wetlands; interweave consideration for ecology in every development plan.
3. Disaster Preparedness: Participatory disaster management plans at the district and local levels ensure relevance and feasibility. Improved meteorological communication protocols must effectively convey warning severity. Social audit systems must ensure accountability in response.
4. Equity: Multilingual warning systems prevent the exclusion of non-Malayalam-speaking residents; explicit inclusion of migrant workers in preparedness planning, and transparent, nondiscriminatory relief allocation.

5.3 Gujrat Floods (2017)

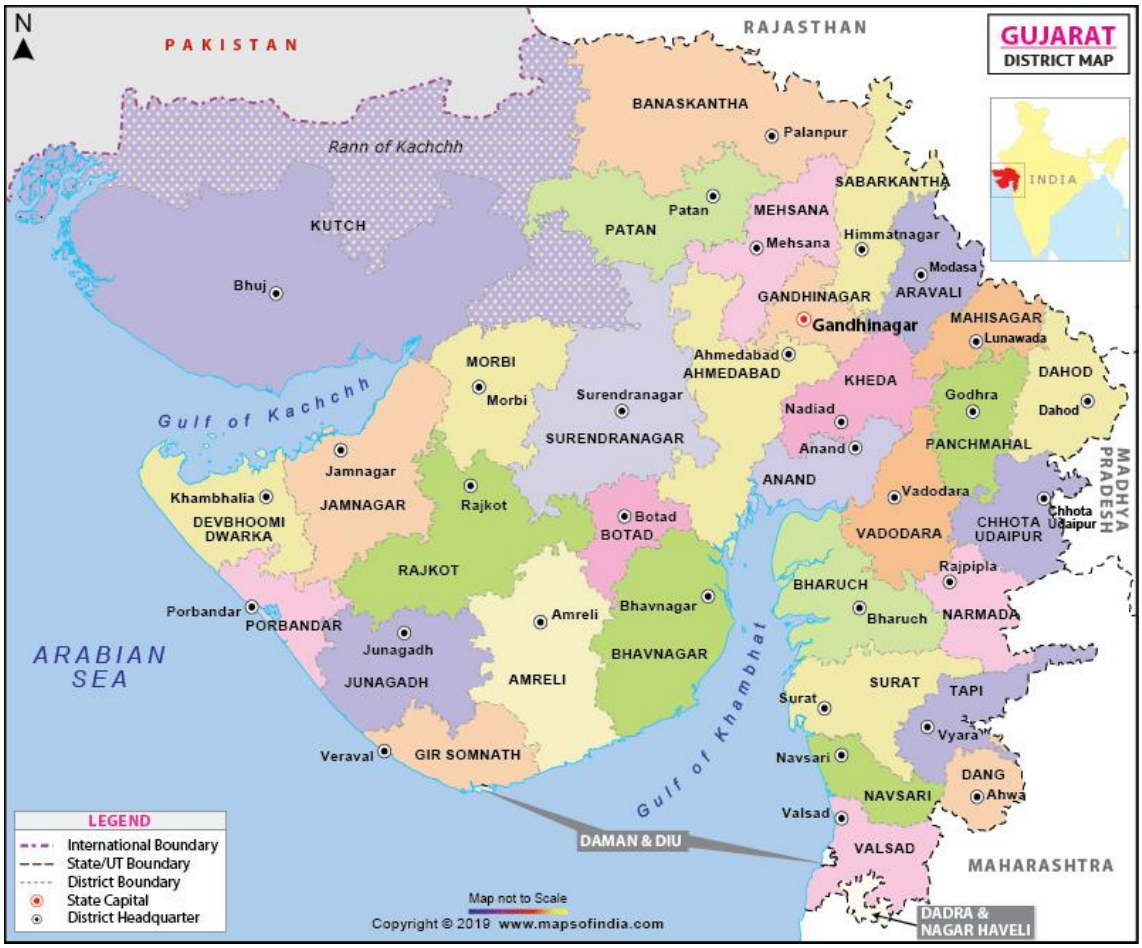


Figure 5.3: District map of Gujrat, Source: https://www.mapsofindia.com/maps/gujarat/gujarat.htm

5.3.1 Introduction and Background

The Gujarat floods in July 2017 ranked among the most destructive monsoon disasters to have taken place recently in the state. Heavy rainfall pounded the districts throughout the month of July. This caused massive flooding in several districts (Figure 5.3) and subsequently caused 224 deaths, displaced almost 450,000 people, and damaged a lot of infrastructure. The flood had been severe in Banaskantha, Patan, Morbi, Sabarkantha, Gandhinagar, Mehsana, and Ahmedabad, with Banaskantha accounting for 61 fatalities and over 4,000 cattle lost. Economically speaking, agricultural regions reported massive losses of crops (Disaster & Authority, n.d.).

Gujarat's vulnerability thus emanates from both natural and artificial factors. Its topography, being naturally flat and crossed by major rivers like the Banas, Sipu, Narmada, and Sabarmati, is flooded during heavy monsoons. However, with decades of rapid urban growth, insufficient drainage infrastructure, and shrinkage in wetlands and forests, its land lost much of its capacity to absorb excess water. This was exacerbated by the poor management of dams, especially at central locations such as Dantiwada and Sipu; there was also slack maintenance and no coordination. When heavy rain finally occurred, the combination of environmental destruction and poor planning resulted in one of Gujarat's worst flood catastrophes.

5.3.2 Factors and Impact

The July 2017 floods in Gujarat happened mainly because an extraordinary amount of rain dumped over a very short period. Districts such as Banaskantha, Patan, Aravalli, Surendranagar, and Morbi saw rainfall pegged at up to 158% of the long-term average. With rivers and dams already brim-full and a heavy upstream downpour in Rajasthan, big releases from reservoirs such as Sipu and Dantiwada sent water rushing into villages, towns, and farms far faster than the land could handle. Add to those breaches in embankments and poor drainage in low-lying areas, and you have a storm that arrived with brutal speed. The impact was severe: more than 200 people died, thousands were displaced, infrastructure for roads, rail, and electricity suffered extensive damage, and crops-especially cotton and millet-in northern Gujarat took a hard hit. This disaster underlined how this region is especially vulnerable to the mercurial monsoon, highlighting with urgency the need for better flood management, early warning systems, and a coordinated rapid-action program.

Meteorological and Anthropogenic Causes

Heavy rain lashed Gujarat during the 2017 Southwest monsoon. Precipitation recorded between July 1 and 28 reached 559.4 mm, against an average of 339.6 mm for that period-about a 65% surplus. Certain districts recorded extraordinary rainfall: Banaskantha witnessed 267%, Patan 208%, Gandhinagar 189%, and Morbi 174%. During the last week of July, particularly on July 24-25, Northern Gujarat was choked by over 200 mm in just 24 hours, whereas Dhanera soaked up 235 mm in just six hours on July 24-nearly the heaviest in these 112 years of record (Parkash et al., 2022). However, severe governance failures magnified the ferocity of this disaster. The primary anthropogenic causes were:

1. Uncoordinated water release by Dantiwada and Sipu dams: heavy rainfall over dam catchment areas simultaneously
2. Delayed opening of dam gates in some locations damaged critical outlet channels
3. Release of water from Daroi dam into Sabarmati River, which had already received excess water from Narmada
4. Lack of a well-coordinated inter-departmental communication between dam authorities and district administrations
5. Inadequate systems of early warning and public notification concerning dam releases.

Scale of Impacts

The 2017 Gujarat floods hit around 4.5 lakh people across several districts; the maximum losses accrued to rural agricultural areas and urban slum settlements. The death toll, by early August 2017, rose to 224, with the maximum causalities of 61 deaths in Banaskantha, Patan, Ahmedabad, Surendranagar, and Chhota Udaipur districts. The combined rescue operations by the Army, Air Force, NDRF, and the State Disaster Response Forces transferred more than 39,000 people to safer places. Relief works opened 29 camps, sheltering around 18,000 shifted people (Disaster & Authority, n.d.).

Extensive damage to infrastructure included more than 370 roads-submerged or closed-including six National Highways, 153 State Highways, and 674 Panchayat roads that severely disrupted connectivity. The flood season hit hard, cutting power to 753

villages and leaving people without basic services. More than 3,000 homes were damaged, of which over 700 belonged to Dalit families in Dhanera taluka. Agriculture was badly hit: topsoil washout along the Banas River in Dhanera, Vav, and Tharad destroyed crops, and most villages could not estimate the actual extent of crop loss (Jodhani et al., 2024). Homes, land, and wells of Dalit and OBC families bore a large part of this destruction, communities standing on the margins. In Ahmedabad, slum areas faced brutal waterlogging that washed homes and all valued belongings away, particularly in Ladhapura's Dalit Basti, where roughly half the families lost everything.

5.3.3 Response and Lessons Learned

The 2017 Gujarat floods saw the mobilization of rapid, large-scale relief efforts. The effects of this included: over 113,000 persons relocated, thousands rescued through the coordinated effort of the Indian Army, Air Force, NDRF, and SDRF. The state government ran 90 relief camps, gave away more than two million food packets, and restored essential services including electricity to 700 villages. They also deployed 1,500 sanitation workers to check the spread of diseases.

Response Operations

The 2017 Gujarat floods saw a rapid multi-group response. The National Disaster Response Force deployed 18 teams, while the Army and Air Force conducted rescues and relief work, including airlifting people to safety. On July 27 alone, 17 people were rescued by air. The cumulative number of people rescued surpassed 36,800-about 6,000 families. Medical relief teams opened 153 camps for treating the injured and preventing disease outbreaks. Prime Minister Narendra Modi's aerial survey on July 25 underlined the gravity of the disaster and catalyzed tight federal coordination.

Community groups and residents demonstrated remarkable resilience, taking matters into their hands by undertaking local evacuations and providing relief on their own. As in many disasters, schools were converted into relief camps, and even the response and rehabilitation were overseen directly by local officers up to the Chief Minister level. The relief operations focused on food distribution, public health maintenance, and restoration of basic services such as electricity and water. In spite of the state government's elaborate relief packages, many homes encountered long-term recovery difficulties.

Key Lessons for Resilience in Urban and Rural Floods

1. Active management of dams involves coordination across agencies, with standardized gate-opening procedures and advanced flood mapping to provide timely warnings and safer releases.
2. The outlets of dams need routine maintenance to prevent infrastructure failure during a flood.
3. Further, the Dalits, who are also included among the lowest-income groups, should be clearly mentioned in disaster planning and recovery, prioritizing livelihood restoration.
4. Urban slums are in special need for: improved drainage, prevention of waterlogging, and robust networks of transport.
5. Real-time coordination across departments and regular joint drills of water, disaster, and local authorities are essential in their response to emergencies.

6. INFERENCE DRAWN

1. The Necessity of Integrated and Context-Specific Resilience Frameworks

This Thesis establishes that fragmented measures or isolated interventions cannot achieve effective flood resilience in Indian coastal cities. Analyses of Chennai, Kerala, and Gujarat revealed that the combination of rapid urbanization, loss of natural buffers such as wetlands and floodplains, and gaps in institutional coordination increase flood vulnerability significantly. Evidence presented here supports the urgent need for integrated frameworks that synthesize nature-based solutions, technological innovations, and multi-level governance. The results show that restoring natural drainage, strengthening infrastructural systems, and managing various agencies in a coordinated manner can effectively lessen the immediate impacts of floods and longer-term, climate-related risks to urban areas. Second, successful flood resilience strategies will necessarily need to be situated within the socio-ecological contexts of individual coastal cities, based on local vulnerabilities and capacities.

2. Centrality of Equity, Social Inclusion, and Community Engagement

The study further argues that increasing flood resilience requires the incorporation of needs and voices of the most marginalized populations—those most susceptible to disasters—into policy formulation. In all selected cases, informal settlements and economically vulnerable groups suffered from the highest impacts and demonstrated protracted recovery, showing that social equity remains poorly addressed by existing policies. Equitable resilience is best pursued through truly participatory planning processes, culturally informed communication-including multilingual early warning systems-and equitable resource distribution in the wake of relief and rehabilitation work. Sustainable flood resilience is not based on either engineering or policy measures but requires an empowered civil society that can mobilize and maintain adaptive solutions. Thus, continuous community involvement, systematic data collection, and adaptive management are the necessary elements to construct robust, future-oriented flood resilience in Indian coastal urban cities.

7. SELECTION OF CASE STUDY- KAKINADA

This chapter establishes Kakinada (Figure 7.1) as the case-study city and provides the context needed for the thesis chapters on data collection, modelling, framework formulation and proposals. The selection is justified using national-scale evidence on coastal vulnerability and city-specific physical, socio-economic, infrastructural and institutional characteristics that make Kakinada a useful setting to study integrated flood resilience. The chapter has five subsections: rationale for selection, study-area definition, physical and climatic profile, socio-economic profile, and recent flood and cyclone history with response gaps. The presentation balances geospatial-technical analysis with governance and planning considerations, reflecting the integrated approach of the thesis.

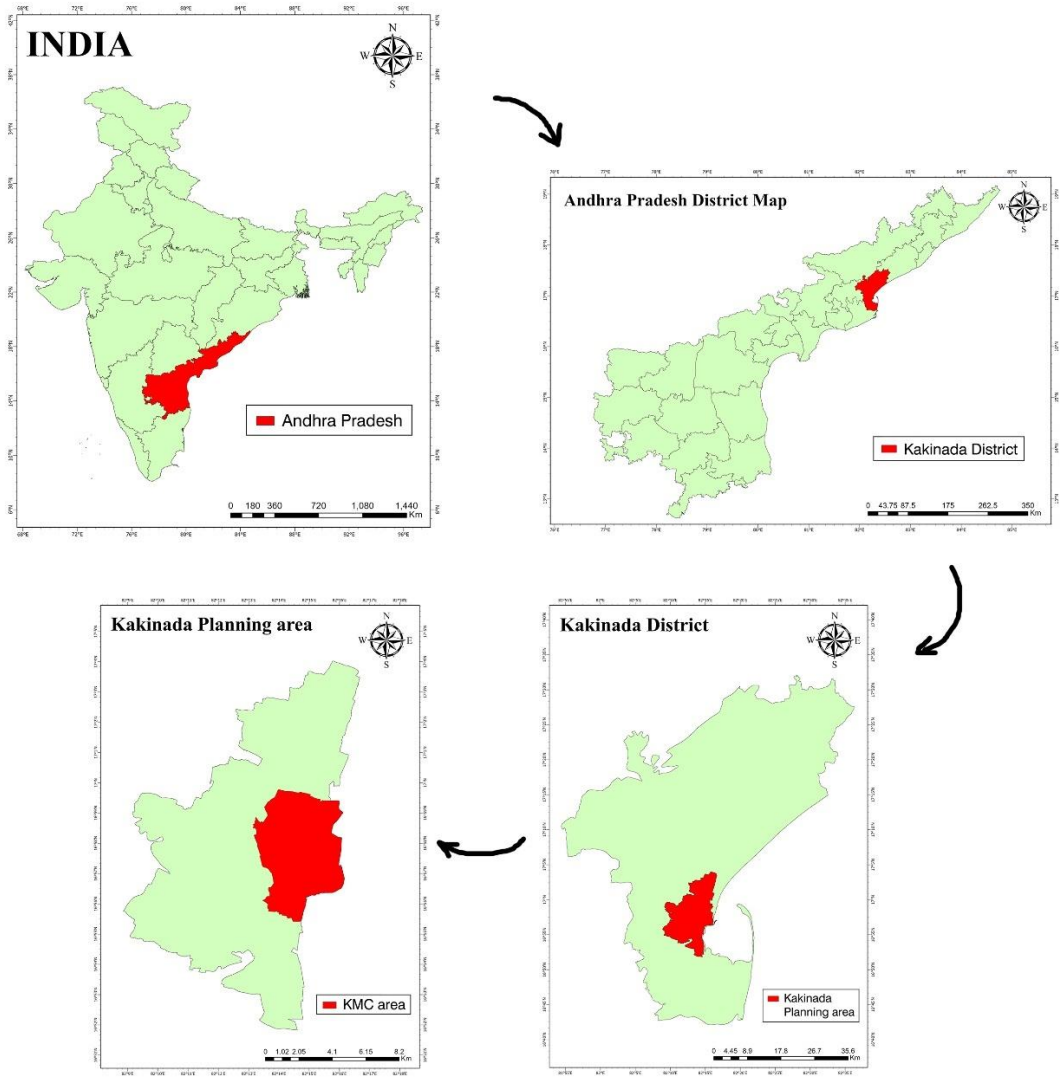


Figure 7.1: Key location map, Source: GIS Pro

7.1 Identification of the Study Area

The Marine Fisheries Information Service, Technical & Extension Series (MFIS), a quarterly publication of the ICAR-Central Marine Fisheries Research Institute, presented a detailed assessment of Climatic Impact-Drivers (CIDs) in the Indian coastal context. The study systematically analyzed multiple climate-related hazards using the CID framework to evaluate regional vulnerability along India's coastline.

Climatic Impact-Drivers (CIDs)

Climatic Impact-Drivers (CIDs), as defined in the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, refer to physical climate conditions that influence human and natural systems. These drivers may produce harmful, beneficial, or neutral effects depending on the context and the vulnerability of the affected system. CIDs include changes in temperature, rainfall patterns, drought conditions, extreme heat events, cyclones, and sea-level rise.

CIDs and Coastal Hazards in India

The study focused on India's coastal areas and selected 5 major hazards:

1. Sea level rise
2. Floods
3. Shoreline change (erosion or land gain)
4. Heatwaves
5. Cyclones

These were studied using data from agencies like:

- India Meteorological Department
- Ministry of Earth Sciences
- Copernicus Climate Change Service

Scientists created separate hazard indices for each risk and then combined them into one Multi-Hazard Index (MHI) to see which areas are most vulnerable.

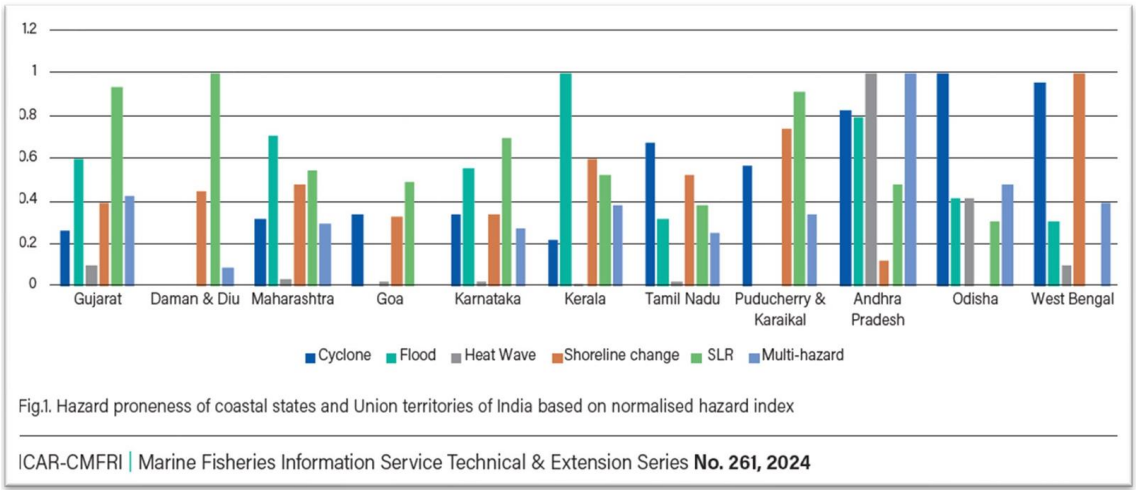


Figure 7.2: Hazard Proneness of coastal states and union territories of India based on normalised hazard index, Source: ICAR-CMFRI

Multi-hazard index across the coastal districts

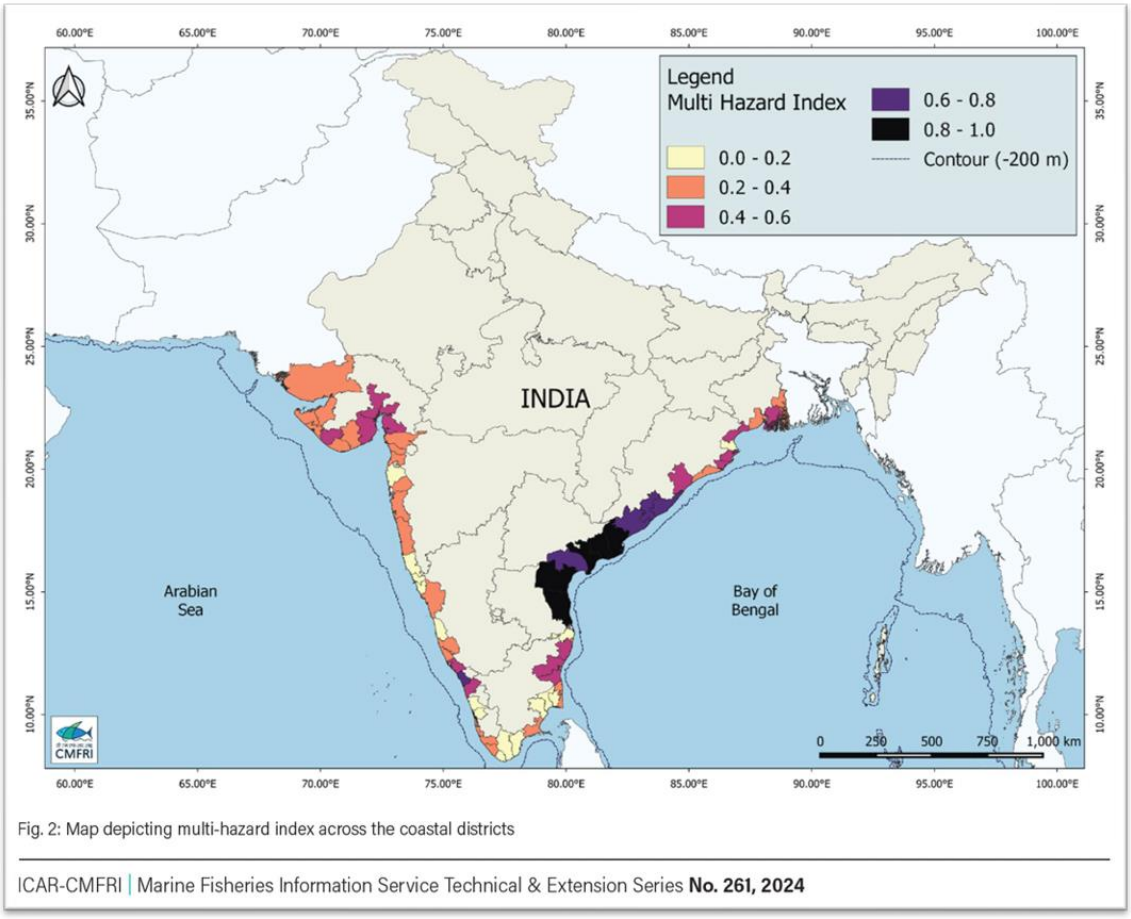


Figure 7.3: Multi-Hazard index across coastal distrcits, Source: ICAR-CMFRI

The map presents the Multi-Hazard Index for India's coastal districts, highlighting varying levels of vulnerability to climate-related hazards such as cyclones, floods, and storm surges. Andhra Pradesh shows (Table 7.1) the highest hazard category, indicating severe exposure along the Bay of Bengal coast.

Table 7.1: States that are more vulnerable to Hazards *Source: Author*

State	Major Risks	Overall Vulnerability
Andhra Pradesh	Cyclones, Heatwaves, Floods	🔴 Highest
Odisha	Cyclones, Floods	🔴 Very High
West Bengal	Cyclones, Shoreline Erosion	🔴 Very High
Gujarat	Sea Level Rise	🟠 Moderate–High
Kerala	Floods	🟠 Moderate
Maharashtra	Floods, Shoreline Change	🟠 Moderate
Goa	Minor risks	🟢 Low

The selection of Andhra Pradesh as the study area is justified due to its high flood vulnerability within a multi-hazard coastal environment. Its exposure to recurrent flooding, combined with rapid urban and coastal development, provides a suitable context for examining and strengthening flood resilience in coastal cities.

Coastal towns in Andhra Pradesh

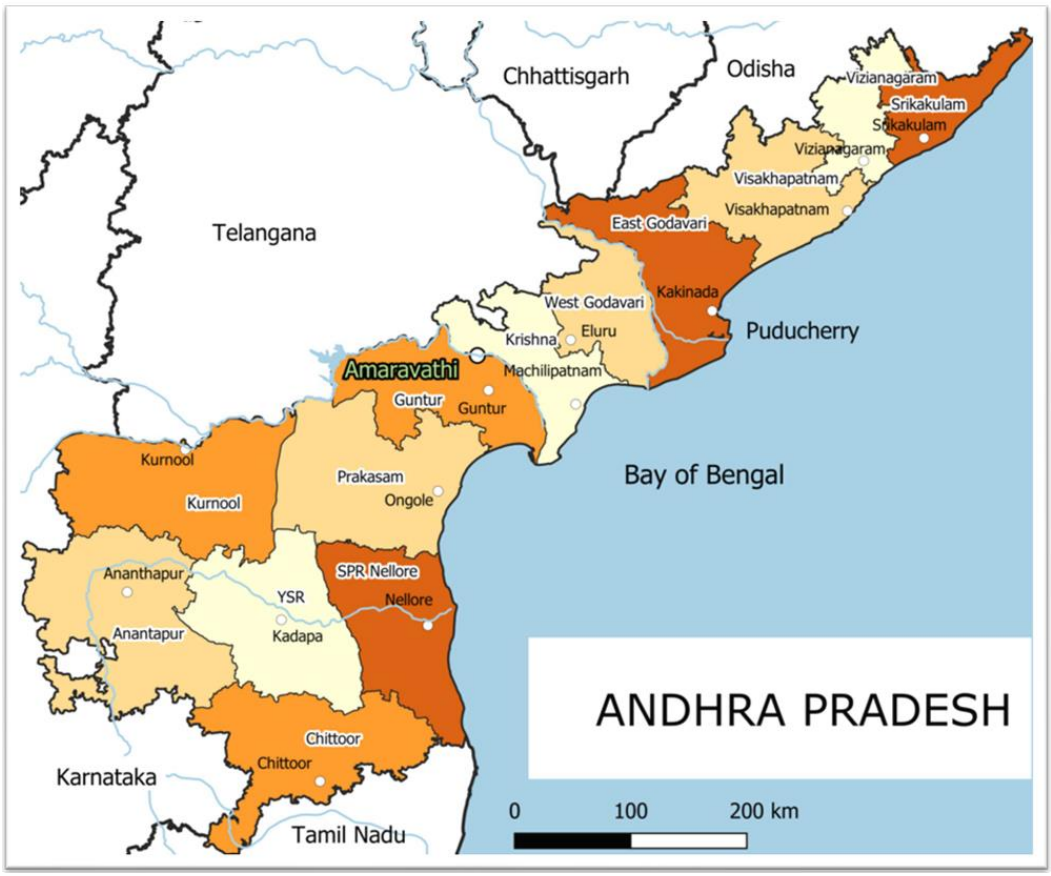


Figure 7.4: Andhra Pradesh district map, Source: ICAR-CMFRI

Coastal towns identified in Andhra Pradesh -

Table 7.2: Coatal towns of Andhra Pradesh *Source: Author*

Towns	Population	District
Nellore	499575	Sri Potti Sriramulu Nellore
Kakinada	312538	East Godavari
Machilipatnam	169892	Krishna
Narsapur	6647	Medak
Chirala	87200	Prakasam
Bapatla	70777	Guntur
Kanuru	49006	Krishna
Bheemunipatnam	52110	Visakhapatnam
Srikakulam	125939	Srikakulam

7.2 Physical and Climatic Profile

Kakinada is located on a flat, low-relief deltaic plain only a few metres above mean sea level, making it highly vulnerable to flooding. Even small rises in rainfall, river discharge, tides, or storm surges can cause widespread inundation and slow drainage. Kakinada Bay, protected by Hope Island, supports port operations but is sensitive to sediment movement and dredging. The Coringa mangrove forests in the south-east act as a natural buffer against storm surges and also support fisheries and coastal ecosystems.

Flooding in Kakinada is caused by the combined effects of intense rainfall, high discharges from Godavari distributaries, and coastal conditions such as tides, storm surges, and sea-level rise. These risks become more severe during monsoon seasons and Bay of Bengal cyclones, often producing compound flood events across the city.

7.3 Socio-economic Profile and Recent Flood History

Kakinada functions as a regional hub for administration, commerce and education, with a population that has grown beyond the 2011 census baseline. Density is highest in the older core and around the port, while new growth follows main roads and coastal areas. Many informal settlements occupy low-lying zones along drains, tanks and port edges, combining high exposure with low adaptive capacity.

Livelihoods include fisheries, port-related services, SEZ-based industry, hydrocarbon support, agriculture, aquaculture and a growing services sector. The diversity supports some economic resilience, but informal and primary-sector workers absorb much of the human cost of floods. Critical infrastructure hospitals, schools, utilities, ports and industrial plants has both local and wider impacts when disrupted. Governance is shared among many agencies, which is an advantage for implementation but a challenge for coordination.

In recent years, cyclones such as Phailin (2013), Hudhud (2014), Titli (2018), Pethai (2018), Asani (2022) and Michaung (2023) have caused evacuations, infrastructure damage and livelihood losses. Monsoon and post-monsoon urban flooding are also chronic, with heavy rainfall coinciding with high water levels in distributaries or the bay, leading to backwater effects and surface flooding. Encroachment on drains, blocked channels and an outdated stormwater master plan amplify the problem.

8. DATA COLLECTION, THEMATIC MAPPING AND ANALYSIS (KAKINADA)

8.1 Base Map

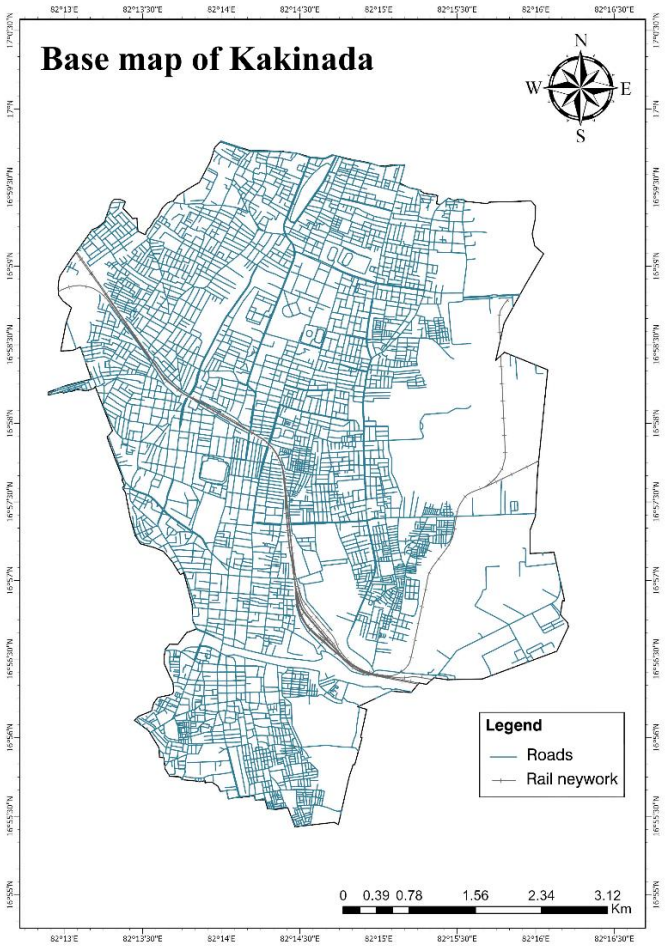


Figure 8.1: Kakinada base map, Source: GIS Pro

This map of Kakinada (Figure 8.1) shows the distribution of roads and railway networks across the city. The dense road pattern reflects strong urban connectivity, while the railway line passing through the area plays an important role in transportation and regional accessibility.

8.2 Ward Map

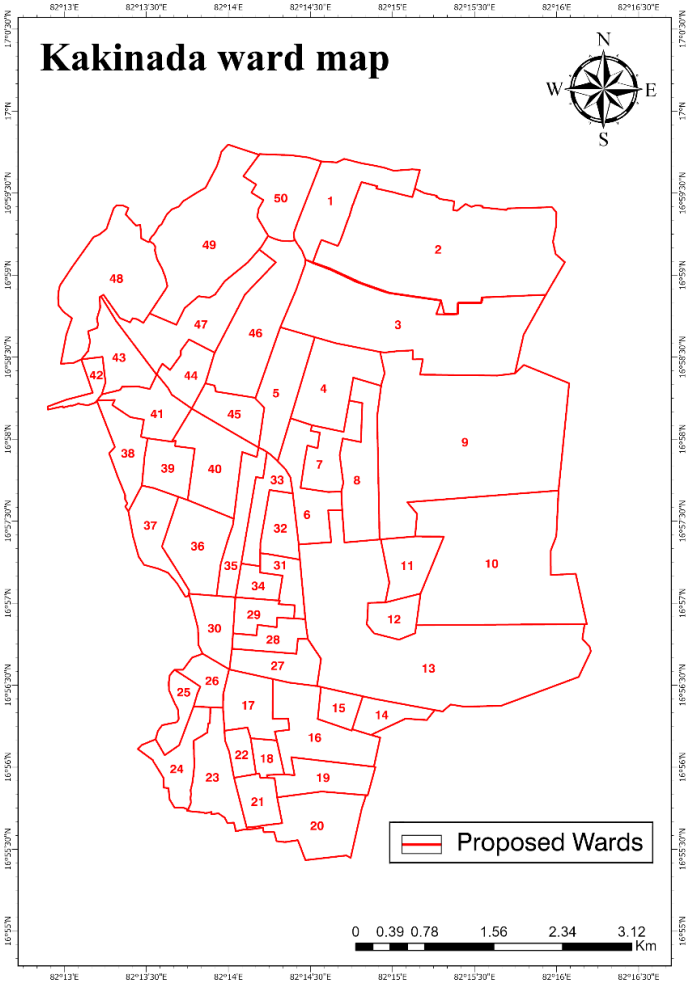


Figure 8.2: Kakinada ward map, Source: GIS Pro

The ward map (Figure 8.2) shows the fifty proposed wards of the Kakinada Municipal Corporation as polygons, numbered from 1 to 50. Wards on the northern and eastern edges, such as 1, 2, 3, 9, 10, 13, 49 and 50, are larger and contain more undeveloped land, while the older core and western and southern wards are smaller and denser. This layer serves as the main unit for vulnerability analysis, service delivery and resilience planning.

8.3 Population Map

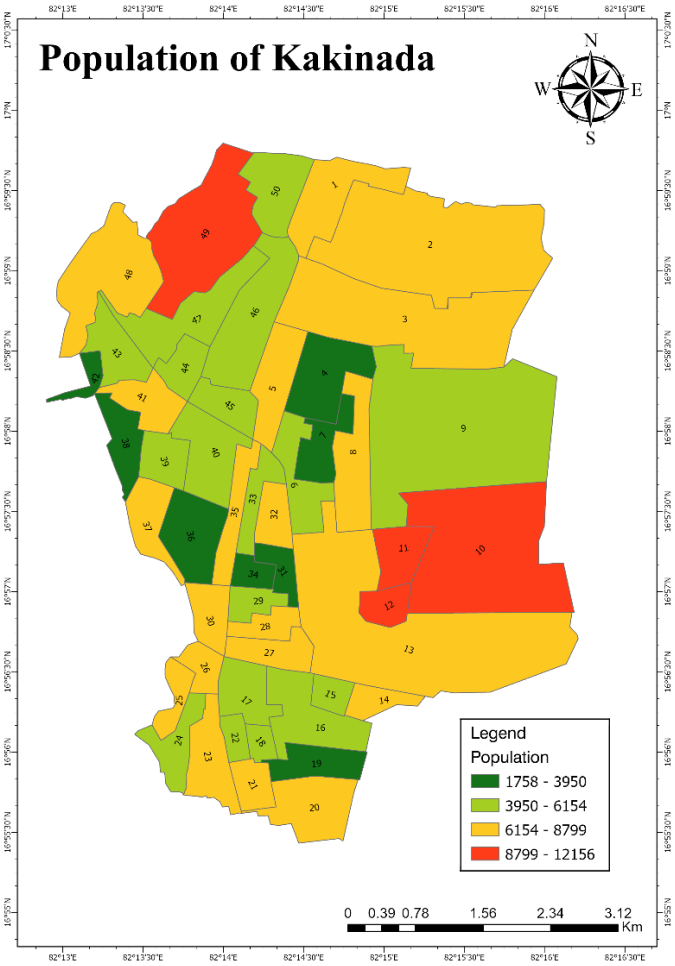


Figure 8.3: Population map, Source: GIS Pro

The population map (Figure 8.3) distributes Kakinada's population across fifty proposed wards and groups them into four population categories. The highest-population wards are concentrated mainly in the northern and eastern parts of the city, particularly around wards 49, 10, 11, and 12. These areas represent recently densified zones and bay-facing urban sections near the industrial-port fringe.

Moderately populated wards surround these clusters, while lower-population wards occur mainly in the central-west and south-west.

However, lower total population does not always mean lower density because some of these wards are physically smaller. The eastern high-population wards are especially vulnerable due to their proximity to major drainage channels and the bay edge.

8.4 Contour Map

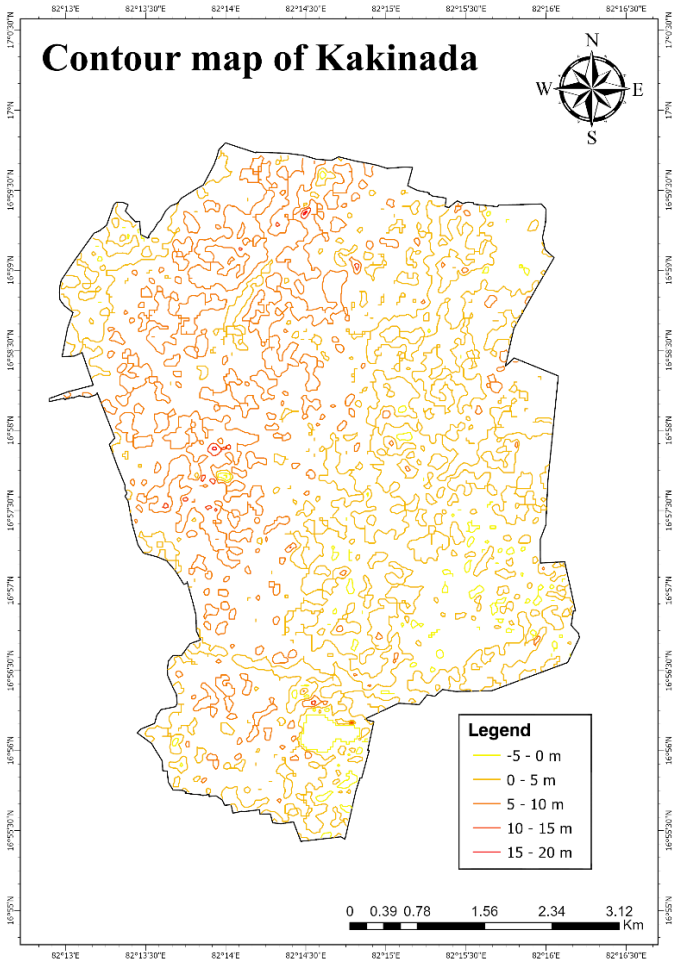


Figure 8.4: Contour map, Source: GIS Pro

The contour map (Figure 8.4) classifies elevation into five bands from minus five to twenty metres and confirms Kakinada's extremely low-relief, near-sea-level deltaic setting. Most of the city falls within the zero-to-five and five-to-ten metre ranges, while areas above fifteen metres are almost absent.

Depressions at or below mean sea level occur mainly along the western and south-western margins near the delta back-swamp. Consequently, natural drainage gradients are minimal, making the city heavily dependent on engineered drainage systems that can fail during high tides and storm surges.

8.5 Slope Map

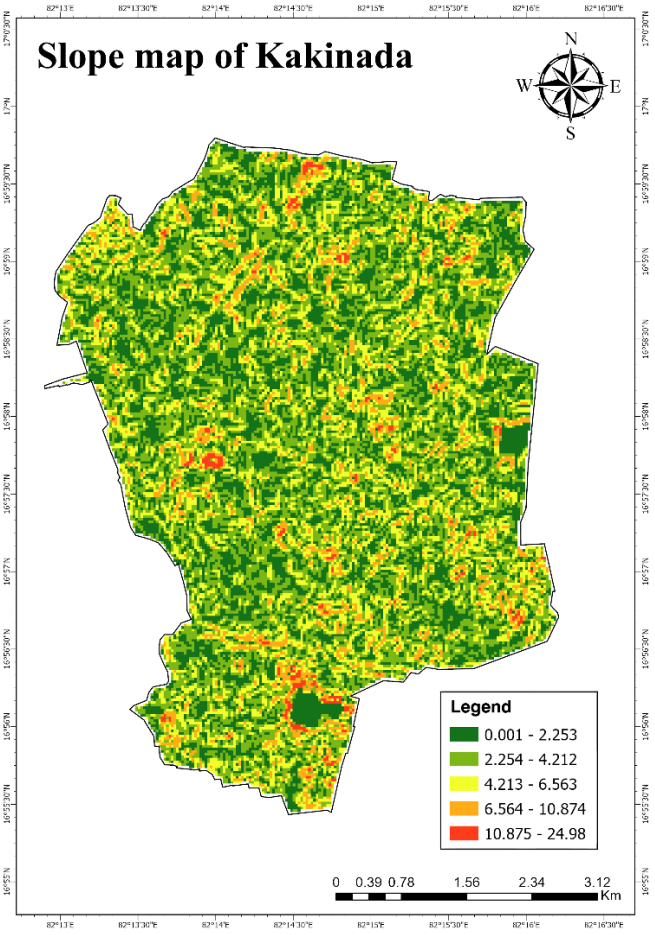


Figure 8.5: Slope map, Source: GIS Pro

The slope map (Figure 8.5) classifies terrain gradients into five categories ranging from nearly flat surfaces to slopes of about twenty-five degrees. Most parts of Kakinada fall within the lowest slope classes, supporting earlier evidence that the city is an extremely flat deltaic plain. The few isolated patches with steeper slopes are small and scattered and are likely associated with human-made features such as embankments, roads, railway lines, raised building platforms, and port infrastructure rather than natural topography.

This means that no area of the city can be considered naturally safe from flooding. It also suggests that small engineering measures, such as raising plinth levels and improving drainage systems, can greatly reduce flood risk.

8.6 Stream order map

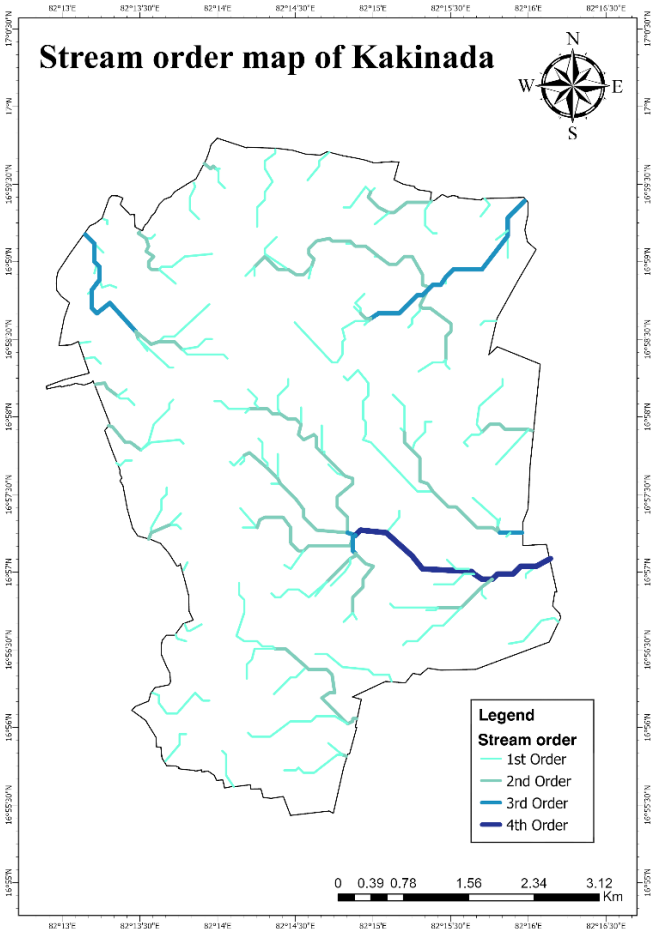


Figure 8.6: Stream order map, Source: GIS Pro

The stream-order map (Figure 8.6), classified into four Strahler orders, highlights the natural drainage structure of Kakinada. Numerous first-order streams join to form second-order channels, which then connect to two major third-and-fourth-order trunk channels flowing toward Kakinada Bay. One major trunk passes through the central and southern parts of the city, while another crosses the northern area.

These channels form the base of the city's drainage network and strongly influence flood behaviour. Convergence points of smaller streams can become flooding hotspots if blocked by waste or encroachment. Since the outlets discharge into the bay, tidal conditions and storm surges greatly affect how efficiently rainfall drains from the city.

8.7 Proposed Drains Map

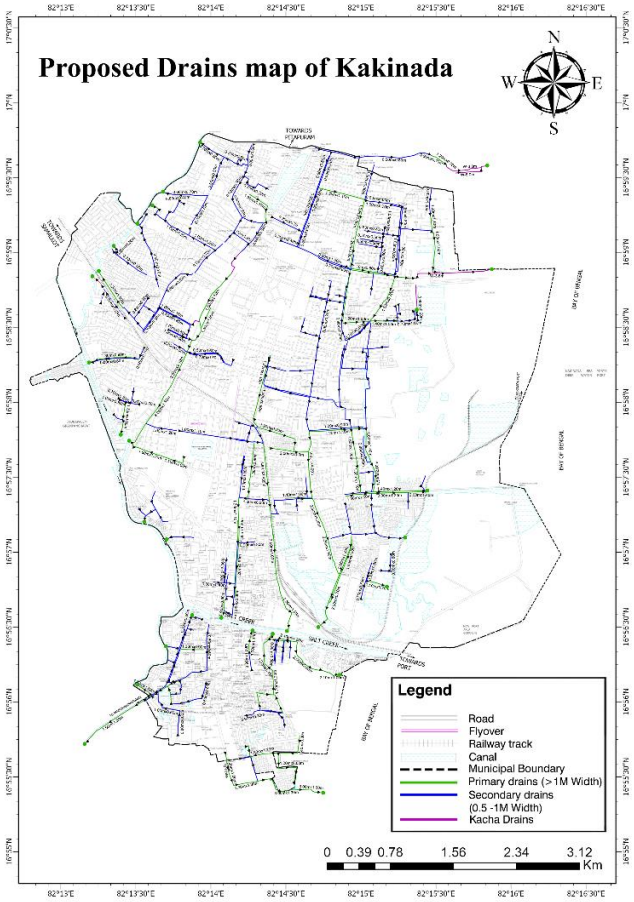


Figure 8.7: Proposed Drains map, Source: Municipal Corporation

The map (Figure 8.7) illustrates the proposed drainage network of Kakinada and highlights the arrangement of primary, secondary, and kacha drains throughout the urban area. Primary drains, shown in green, are wider than 1 m and function as the main stormwater conveyance channels, directing runoff toward canals, creeks, and coastal outlets. Secondary drains, represented in blue, collect water from roads and residential neighborhoods before joining the primary network. Kacha drains, marked in purple, are unlined or temporary drains that assist local surface runoff movement, especially in peripheral and low-developed regions of the city.

8.8 Drainage Zone Map

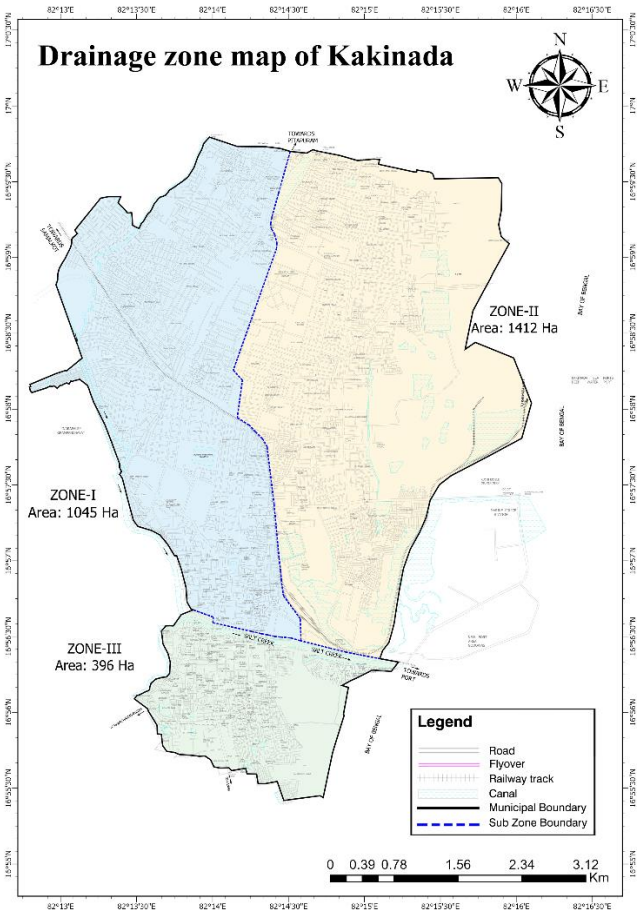


Figure 8.8: Drainage Zone map, Source: Municipal Corporation

The map (Figure 8.8) shows that Zoning has been done as per catchments area of the town into 3 zones based on topography, natural slopes and contour levels. Figure 4 shows the storm water zoning map of the Kakinada city into 3 zones and figure 5 shows the sub zone map.

8.9 Drainage Sub Zone Map

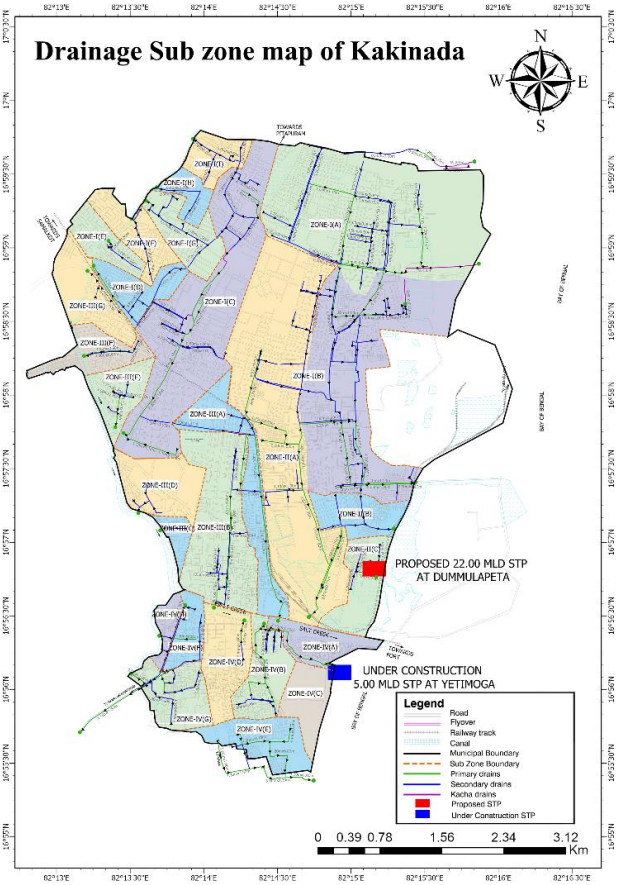


Figure 8.9: Drainage Sub zone map, Source: Municipal Corporation

The STPs are proposed to be in such a way so that in future when sewerage scheme materializes the STPs will be utilized for sewerage scheme also. (Figure 8.9) shows the location of Proposed STPs in Kakinada Municipal Corporation.

Capacities of STPs

Table 8.1: Capacities of STPs *Source: Municipal Corporation*

S.No	Name of Zone	Wards Covered	Population			Sewage Flows (MLD)			STP Capacity (mld)			Location of Proposed STP
			2026	2041	2056	2026	2041	2056	Under Construction	Proposed	Required	
1	Zone I	1 to 4, 5(P),6(P),7(P), 8(P),9(P),10(P), 11(P),44 to 50	119527	137933	156345	14.05	16.13	18.36		22.00		Dummulapeta
2	Zone II	5(P),6(P),7(P), 8(P),10(P), 11(P),12,13(P)	41773	48204	54637	4.90	5.66	6.41				
		Total	**161300**	**186137**	**210982**	**18.95**	**21.79**	**24.77**				
3	Zone III	27 to 43	117103	135137	153166	13.73	15.84	17.96			16.00	
4	Zone IV	14 to 26	87301	100743	114187	10.28	11.81	13.45	5.00		7.00	Yetimoga
		Total	**365704**	**422017**	**478335**	**42.96**	**49.44**	**56.18**	**5.00**	**22.00**	**23.00**	

8.10 Kakinada Rainfall data (2016 – 2021)

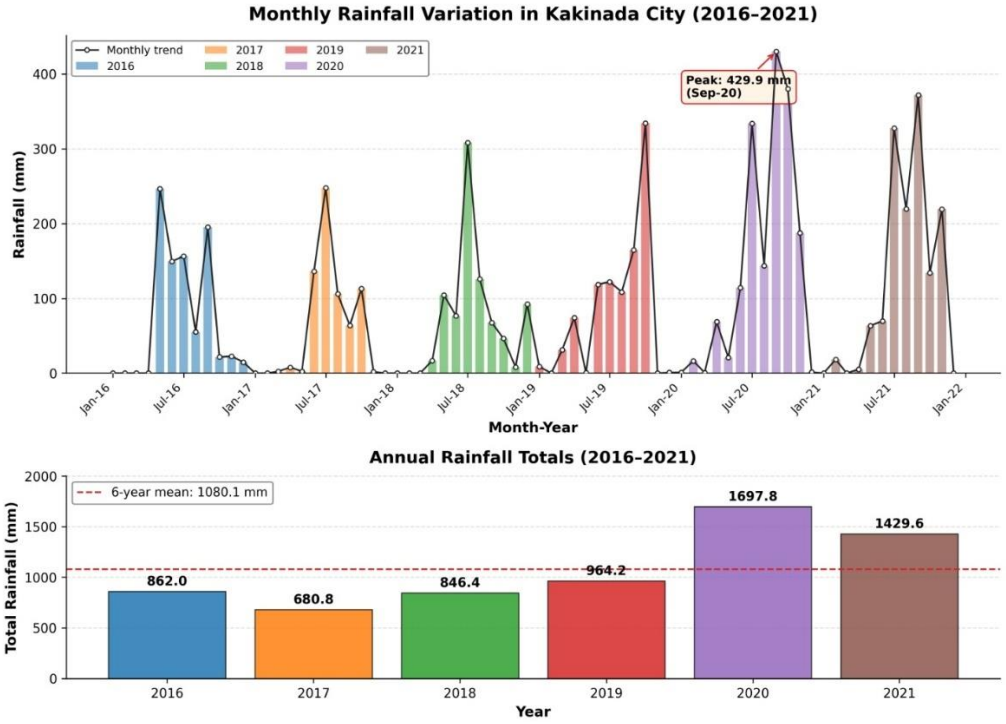


Figure 8.10: Monthly & Anual Rainfall data, Source: data.gov.in

Rainfall in Kakinada City over the six-year period from 2016 to 2021 (Figure 8.10) exhibits a pronounced monsoonal pattern, with precipitation concentrated between June and October and minimal activity during the winter and pre-monsoon months. The annual rainfall averaged approximately 1080.1 mm, but showed considerable interannual variability, ranging from a low of 680.8 mm in 2017 to a peak of 1697.8 mm in 2020. The single highest monthly rainfall was recorded in September 2020 at 429.9 mm, coinciding with the southwest monsoon's withdrawal phase.

A discernible upward shift is evident in the latter half of the study period, with both 2020 (1697.8 mm) and 2021 (1429.6 mm) substantially exceeding the six-year mean, while 2016-2019 remained below it. This intensification suggests increasing rainfall variability and potential climatic shifts, which may have implications for urban drainage, flood management, and water resource planning in the coastal city of Kakinada.

(Table 8.2) summarises the annual rainfall statistics for Kakinada for the six-year period from 2016 to 2021.

Table 8.2: Annual Rainfall Statistics, Kakinada 2016–2021 *Source: data.gov.in*

Year	Annual Rainfall (mm)	Peak Month	Peak Rainfall (mm)
2016	862.0	May	246.7
2017	680.8	September	196.6
2018	846.4	July	264.0
2019	964.2	October	299.0
2020	1,697.8	September	429.9
2021	1,429.6	September	372.0
Mean	**1,080.1**	—	—

8.11 Shoreline Changes in Kakinada District

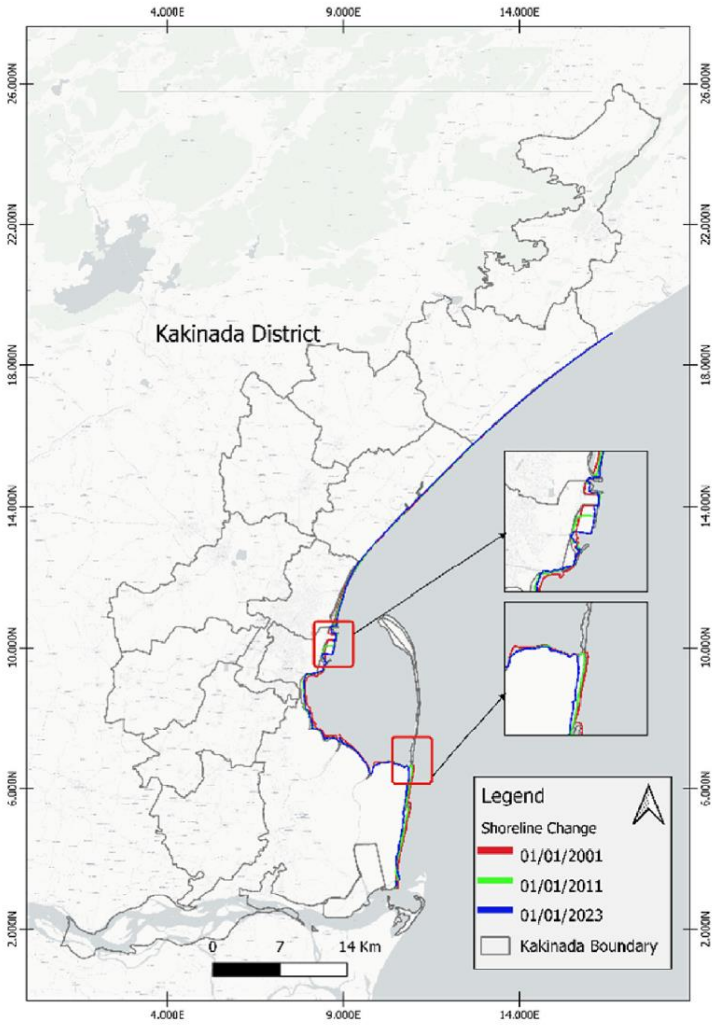


Figure 8.11: Shoreline change map, Source: Assessing dynamic coastal vulnerability to climate hazards: A geospatial approach in Kakinada District, Andhra Pradesh, India

Between 2001 and 2021, the study area's shoreline receded significantly, indicating severe coastal erosion. The greatest shoreline changes, ranging from 604.35 to 1016.25 m, occurred along the southern coastal sections as shown in (Figure 8.11).

The southern study area experienced severe erosion, while northern coasts showed moderate-to-severe erosion. Central regions underwent accretion, consistent with findings by Pal and Rao (2008), reporting over 600 acres lost since 1970.

8.12 Coastal Flood Events Affecting Kakinada (2021-2025)

2021 - Heavy Monsoon Flooding

Annual rainfall: 1429.6 mm (well above 6-year mean of 1080.1 mm — from your dataset). Peak month: September 2021 with 372 mm, followed by 219.4 mm in November.

Kakinada experienced waterlogging in low-lying wards and flooding in Godavari delta villages from sustained monsoon rainfall and depression-induced spells.

2022 - Cyclones Asani & Mandous

Cyclone Asani (May 2022) weakened into a deep depression near Machilipatnam, causing heavy rains and crop damage, with Kakinada and the East Godavari coast receiving heavy rainfall and rough seas. Deccan Chronicle.

Cyclone Mandous (December 2022) affected coastal districts of Andhra Pradesh, bringing heavy rain to most parts, including the Kakinada belt. Deccan Chronicle.

2023 - Cyclone Michaung (Indirect Impact)

Cyclone Michaung crossed the coast near Bapatla with wind speeds reaching 90–100 kmph, causing heavy rainfall, infrastructure damage and flooding several nearby districts. Deccan Chronicle

Although landfall was south of Kakinada, the system's outer rainbands and storm-surge effects produced heavy rainfall, rough sea conditions, and coastal inundation along the East Godavari coast.

2024 - Monsoon Depressions

No direct major cyclone landfall at Kakinada in 2024, but multiple Bay of Bengal depressions during the southwest and northeast monsoons produced heavy rainfall events and tidal flooding episodes along the Godavari delta and Kakinada coastline.

2025 - Cyclone Montha (Direct Landfall)

This is the most significant recent event for your thesis:

Severe Cyclonic Storm Montha crossed the Andhra Pradesh and Yanam coasts between Machilipatnam and Kalingapatnam, south of Kakinada, during midnight hours of October 28–29, 2025. Karmactive

Wind speeds were recorded at 52 km/h in Kakinada during landfall, with extremely heavy rainfall (≥21 cm) at isolated places over Coastal Andhra Pradesh and Yanam on October 28. KarmactiveKarmactive

Storm surge of about 1 metre above astronomical tide affected low-lying coastal zones at landfall, with wave heights of 2 to 4.7 metres along Andhra Pradesh coast. Over 10,000 people were evacuated from Kakinada and Konaseema hours before the system crossed the coast. Deccan Chronicle.The cyclone caused major damage and flooding across coastal districts of Andhra Pradesh.

(Table 8.3) Shows the flood events summary:

Table 8.3: Flood events summary *Source: Compiled by Author*

Year	Event	Landfall/Impact Zone	Peak Winds	Storm Surge	Kakinada Impact
2021	Monsoon flooding	Kakinada delta	—	—	Heavy waterlogging
2022	Cyclones Asani & Mandous	AP coast	~65–75 km/h	<1 m	Heavy rain, rough seas
2023	Cyclone Michaung	Bapatla (S of Kakinada)	90–100 km/h	~1.1 m	Indirect flooding
2024	Multiple depressions	AP coast	<60 km/h	—	Tidal flooding episodes
2025	**Cyclone Montha**	**Near Kakinada (S)**	**~110 km/h (gusts)**	**~1 m**	**Direct landfall, evacuations, ≥21 cm rain**

9. CONCEPTUAL AND METHODOLOGICAL FRAMEWORK

9.1 Rationale for the framework

Coastal cities such as Kakinada are increasingly exposed to compound flood hazards arising from the interaction of high-intensity rainfall events, inadequate stormwater drainage capacity, tidal influence, and the progressive loss of natural buffers such as wetlands, mangroves, and canal systems. Addressing this challenge requires a planning response that moves beyond isolated engineering interventions toward an integrated framework capable of linking hazard assessment, vulnerability analysis, and spatial planning proposals within a single coherent structure.

This chapter presents the conceptual and methodological framework adopted for the present study. The framework is structured as a five-stage sequential process beginning with an assessment of existing urban conditions and concluding with a set of integrated planning proposals aimed at strengthening flood resilience in Kakinada. Each stage builds upon the findings of the preceding one, ensuring that the final proposals are grounded in empirical spatial analysis rather than generic design assumptions. All spatial analysis was carried out using ArcGIS Pro.

9.2 Conceptual Framework

The conceptual framework adopted for this study follows a linear, stage-wise logic in which each level of analysis informs the next. It begins with the documentation of existing physical conditions, proceeds through flood risk and vulnerability assessment, identifies critical gaps between current conditions and desired resilience outcomes, and culminates in a set of spatial and policy proposals oriented toward a flood-resilient Kakinada. (Table 9.1) shows the data used.

Table 9.1: Data used *Source: Compiled by Author*

Data	Source	Format
SRTM 1-Arc-Second Digital Elevation Model (30m)	USGS EarthExplorer	GeoTIFF
Roads, canals, buildings, wetlands, coastline	OpenStreetMap	GeoPackage

Ward boundaries - 50 wards	Kakinada Municipal Corporation	Shapefile
Ward population - 2,94,219 total	Kakinada Municipal Corporation	Attribute table
Land Use Land Cover / CRZ Zoning	Kakinada Master Plan	Shapefile

9.3 Stage-wise methodology

9.3.1 Stage One: Existing Conditions Assessment

The first stage establishes a baseline spatial record of the existing urban, environmental, and land use conditions of Kakinada. The Land Use Land Cover (LULC) map (Figure 9.1), sourced from the Kakinada Master Plan, documents the distribution of residential, commercial, industrial, agricultural, and coastal regulation zones across the city. This baseline serves as the spatial reference against which all subsequent risk and vulnerability layers are overlaid, and provides critical context for understanding the relationship between land use patterns and flood exposure.

The LULC map also captures the Coastal Regulation Zone (CRZ) classifications IA, IB, II, III, and IVB which are of particular relevance to flood risk in Kakinada given the city's direct exposure to the Bay of Bengal. These zones define the regulatory framework governing development along the coastline and inform the planning proposals developed in Stage Five.

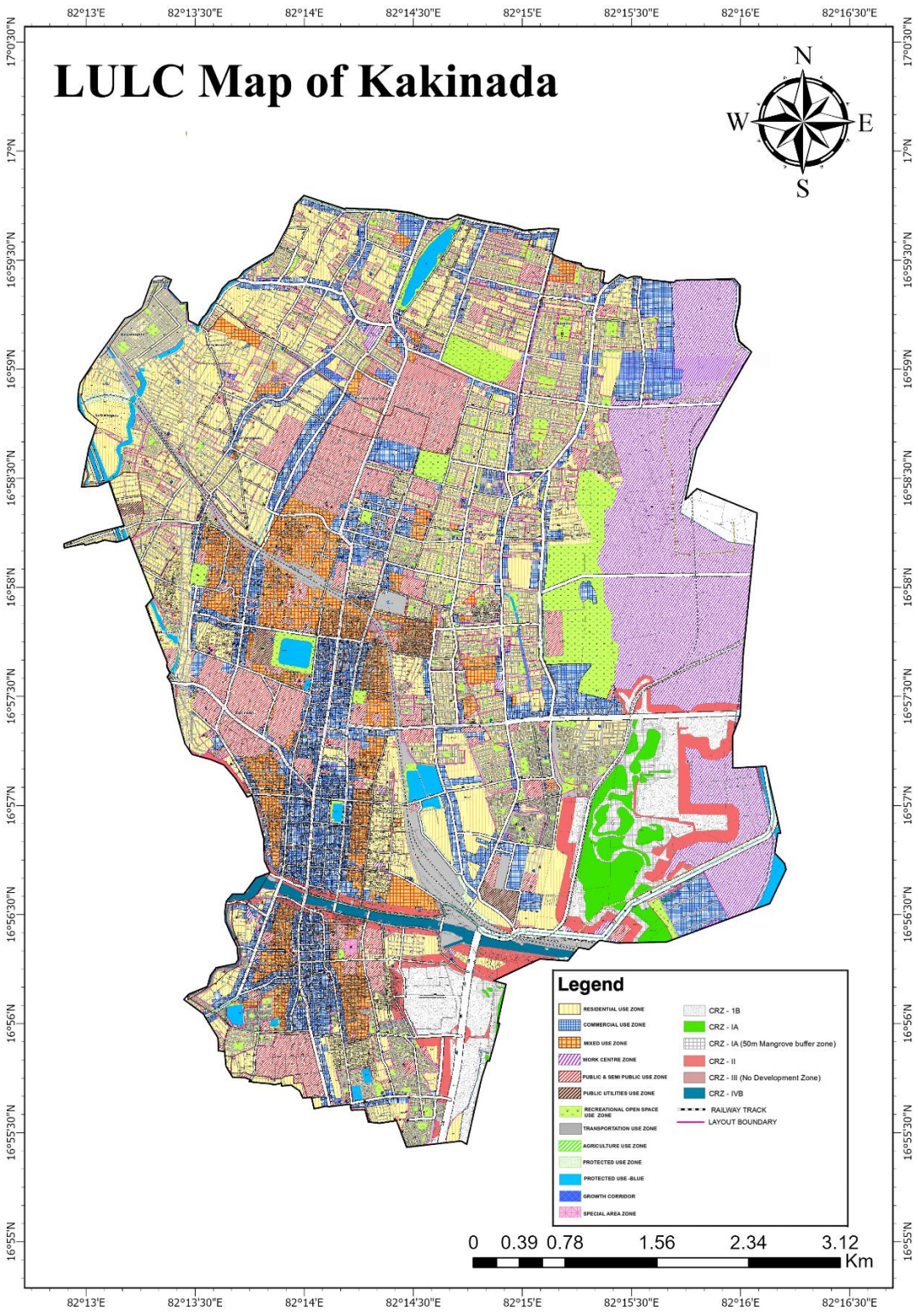


Figure 9.1: LULC map, Source: Kakinada Urban Development Authority (KUDA)

9.3.2 Stage Two: Flood Risk Assessment

The second stage constitutes the core hazard analysis of the framework. Flood risk is assessed through a Multi-Criteria Evaluation (MCE) approach in which four terrain and proximity factors are individually scored, normalised to a common 0-1 scale, and combined through a weighted overlay. The result is classified into three risk categories High, Medium, and Low forming the primary flood risk map of Kakinada.

1) Supporting Maps - Terrain Analysis

Three supporting rasters were prepared from the SRTM DEM prior to the weighted overlay: the Digital Elevation Model clipped to the ward boundary, a slope map, and a flow accumulation map. Together these characterise the terrain conditions that determine flood behaviour across the study area.

Elevation is the primary determinant of flood depth with a range of -6 to +22 metres and a mean of 6.5 metres, Kakinada's extremely low-lying terrain confirms high flood susceptibility across the majority of the city. Slope confirms this a mean of 2.18 degrees and maximum of 15.4 degrees indicates effectively flat terrain where gravity drainage is severely limited. Flow accumulation identifies drainage convergence zones where runoff from large upstream areas concentrates, classified into five categories from Very Low to Very High.

The slope raster was derived from the SRTM 30m DEM using the Slope tool in ArcGIS Pro (output in degrees) and classified as follows in (Table 9.2):

Table 9.2: Slope classification *Source: Compiled by Author*

Slope Class	**Range (degrees)**
Very Low	0 – 2
Low	2 – 4
Moderate	4 – 7
High	7 – 11
Very High	> 11

2)Flow AccumulationFlow Accumulation

Flow accumulation analysis (Figure 9.2) identifies where surface water converges across the terrain by calculating, for each pixel, the total number of upstream pixels draining into it. The DEM was first processed through a sink-filling operation to remove spurious depressions, followed by the application of a D8 flow direction algorithm that routes water from each pixel toward its steepest downslope neighbour. The resulting surface was classified into five categories - Very Low, Low, Moderate, High, and Very High, using Natural Breaks classification. High and Very High accumulation values are concentrated in the eastern and southern portions of the study area, corresponding to the low-lying coastal zone and existing canal alignments, where runoff from the wider urban catchment converges during monsoon rainfall events.

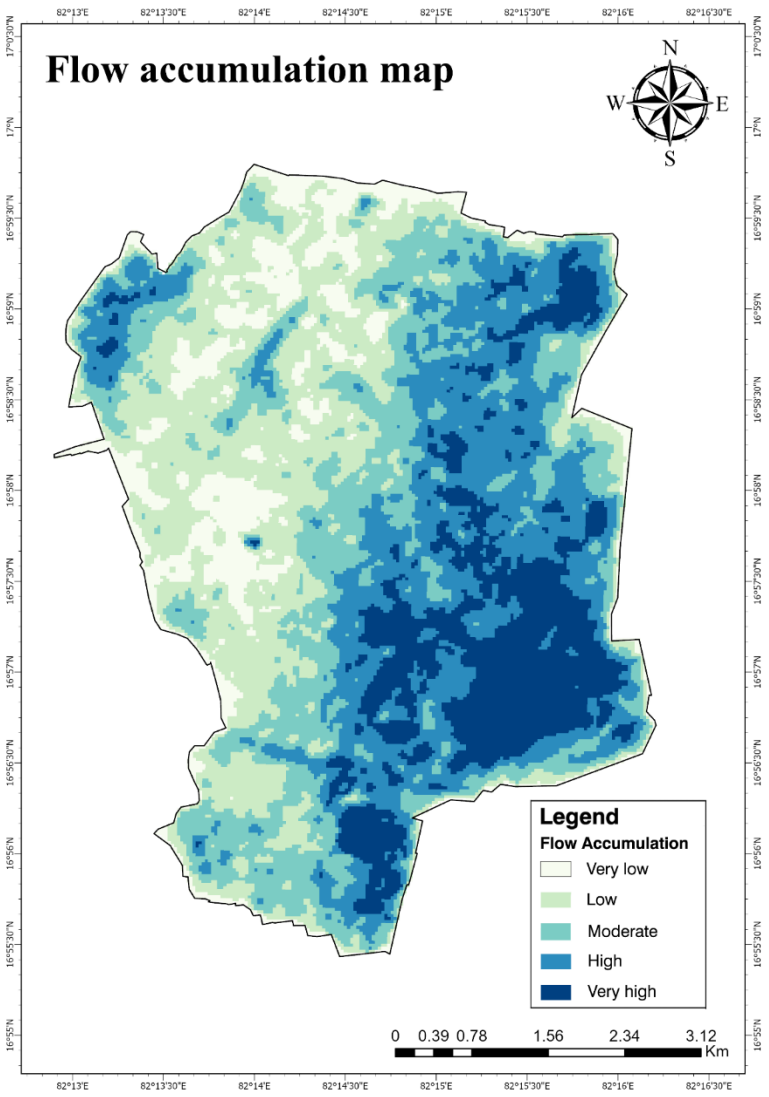


Figure 9.2: Flow accumulation map, Source: GIS Pro

3) Flood Risk Assessment

The four flood risk factors (Table 9.3) were combined using a weighted overlay. Elevation received the highest weight (40%) as the primary determinant of waterlogging. Coastal proximity (25%) was included due to direct tidal and storm surge exposure from the Bay of Bengal. Slope (20%) captures the terrain's ability to drain water. Canal proximity (15%) reflects the overflow and backflow risk associated with the existing canal network.

Table 9.3: Flood risk factor weights *Source: Compiled by Author*

Factor	**Weight**	**Rationale**
Elevation (inverted)	40%	Primary determinant of flood depth and waterlogging
Coastal proximity	25%	Direct exposure to tidal flooding and storm surge from Bay of Bengal
Slope (inverted)	20%	Flat terrain retains water; steep areas drain rapidly
Canal proximity	15%	Areas near canals face overflow and backflow risk during monsoon

The weights were assigned based on the physical characteristics of Kakinada's coastal delta setting and are consistent with the multi-criteria Evaluation approach used in flood risk literature for low-lying coastal cities (Seenirajan et al., 2017; Jodhani et al., 2024). Each factor was normalised to a 0-1 scale prior to the overlay. The combined Flood Risk Index is derived using the following weighted overlay formula:

$$\textit{Flood Risk Index} = (0.40 \times \textit{Elevation Score}) + (0.25 \times \textit{Coastal Proximity Score}) + (0.20 \times \textit{Slope Score}) + (0.15 \times \textit{Canal Proximity Score})$$

The resulting classified map (Figure 9.3) shows that 34 per cent of the study area falls within the High-risk category, concentrated primarily in the eastern coastal zone and low-lying southern wards. Medium risk accounts for 33 per cent, covering the transitional urban core. Low risk accounts for the remaining 33 per cent in the relatively higher-elevation western portions of the city as shown in (Table 9.4).

Table 9.4: Flood risk Classification result *Source: Compiled by Author*

Risk Class	Pixel Count	Area (%)	Colour
Low Risk	11,106	33.0%	Yellow
Medium Risk	11,105	33.0%	Orange
High Risk	11,443	34.0%	Dark Red

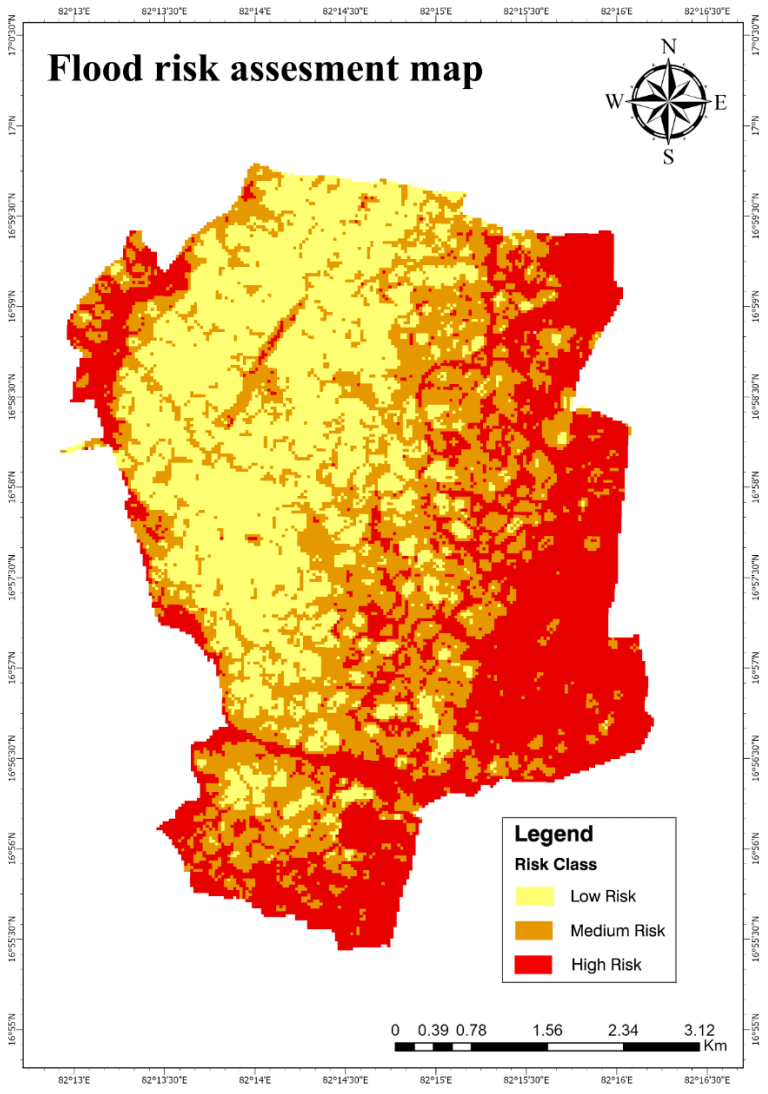


Figure 9.3: Flood risk assesment map, Source: GIS Pro

9.3.3 Stage Three: Vulnerability Assessment

While flood risk identifies where flooding is most likely to occur, vulnerability assessment identifies where the consequences of flooding are likely to be most severe. Three dimensions of vulnerability - physical, social, and environmental were assessed independently and then combined into a composite classification (Figure 9.4).

1) Supporting Maps - Three Vulnerability Dimensions

Physical vulnerability was assessed by combining building density (derived from OSM building footprints) with drainage stress (elevation and slope combined). Areas that are simultaneously densely built and low-lying with flat terrain face the greatest physical flood damage risk. The densely built central and western wards record the highest scores.

Social vulnerability was assessed using actual ward-level population data (2,94,219 people across 50 wards) and road accessibility. Wards with high population density and poor access to major roads particularly Wards 10, 11, 12, and 49 with populations of 9,800 to 10,500 face the greatest difficulty in evacuation and emergency response.

Environmental vulnerability was assessed using distance from wetlands, proximity to canals, and distance from the coastline. The eastern coastal zone encompassing Wards 2, 3, 9, and 10 records the highest environmental vulnerability owing to direct coastal exposure and the absence of wetland buffers.

The three vulnerability dimensions were scored using the following formulas:

$$\textit{Physical Vulnerability} = (0.50 \times \textit{Building Density Score}) + (0.50 \times \textit{Drainage Stress Score})$$

$$\textit{Social Vulnerability} = (0.70 \times \textit{Population Density Score}) + (0.30 \times \textit{Road Inaccessibility Score})$$

$$\textit{Environmental Vulnerability} = (0.40 \times \textit{Wetland Loss Score}) + (0.30 \times \textit{Canal Encroachment Score}) + (0.30 \times \textit{Coastal Exposure Score})$$

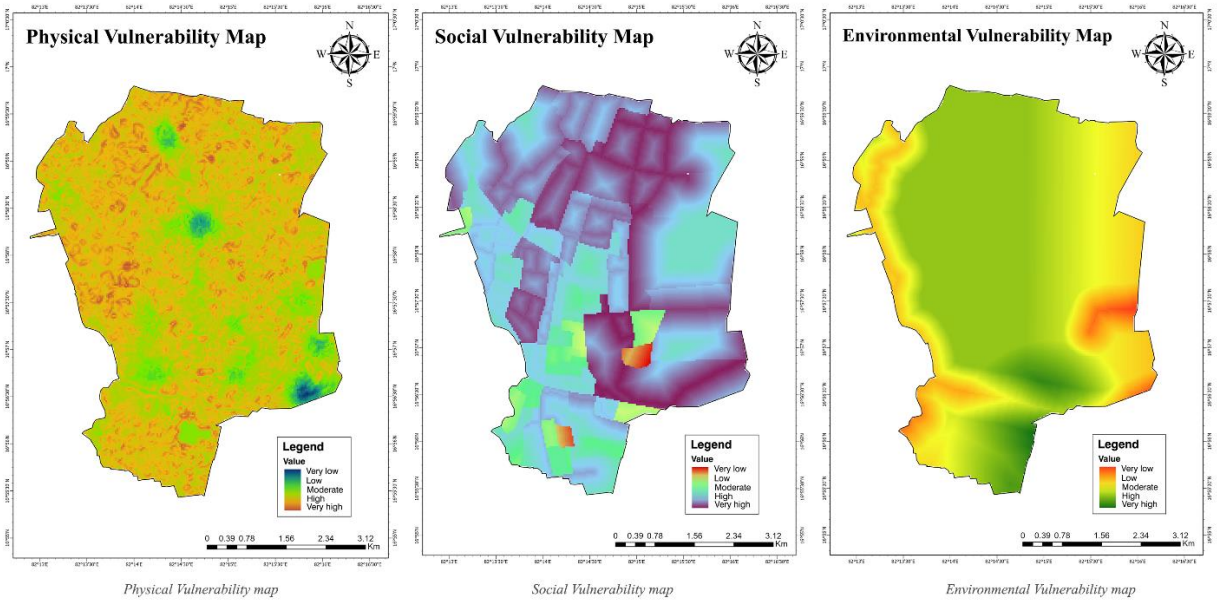


Figure 9.4: Combined Vulnerability map, Source: GIS Pro

2) Composite Vulnerability

The three dimensions were combined using a dimension-counting method (Table 9.5). Each dimension was independently divided into terciles, and pixels scoring in the top third were identified as being in the high vulnerability tier. A pixel scoring high across all three dimensions was classified as High composite vulnerability; high in two dimensions as Moderate; and high in one or none as Low (Figure 9.5). This method was preferred over a weighted average as it preserves the significance of co-occurring vulnerabilities.

Table 9.5: Composite vulnerability classification results Source: Compiled by Author

Composite Class	Criteria	Pixel Count	Area (%)
Low	High tier in 0 or 1 dimension	23,580	70.1%
Moderate	High tier in 2 dimensions	8,443	25.1%
High	High tier in all 3 dimensions	1,631	4.8%

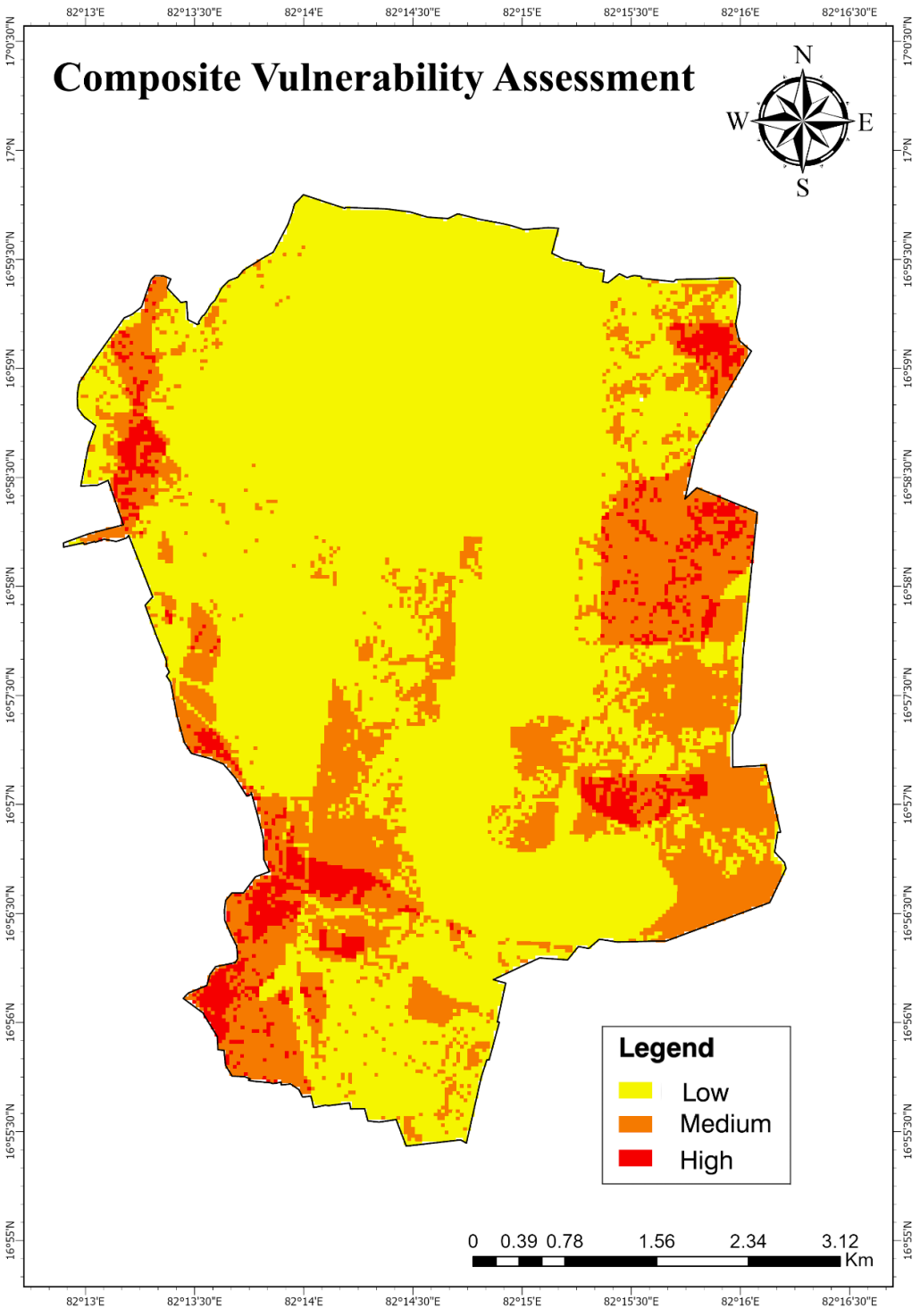


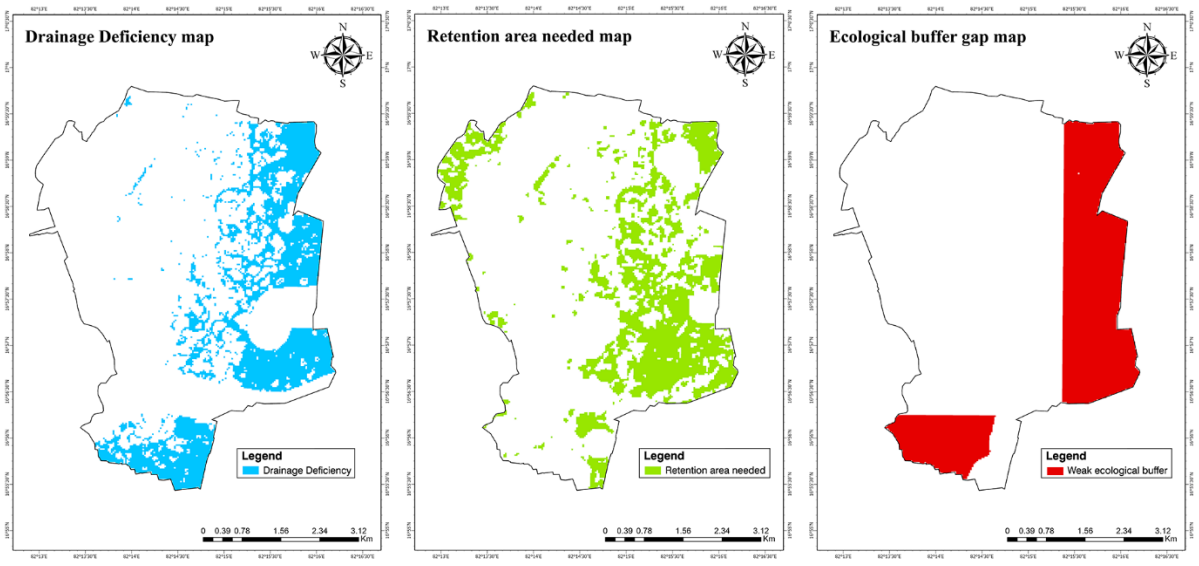
Figure 9.5: Composite Vulnerability map, Source: GIS Pro

9.3.4 Stage Four: Gap Analysis

The gap analysis identifies specific locations where current infrastructure and natural systems are failing to protect Kakinada from flooding. Four spatial gaps were identified, each representing a distinct category of deficiency and forming the direct link between assessment and the planning proposals that follow.

1) Supporting Maps - Individual Gap Layers

Drainage deficiency areas (7,704 pixels, approximately 7.1 km²) are locations at High flood risk with no canal or drain within 400 metres areas with no means of conveying stormwater away during heavy rainfall. Retention area gaps (8,045 pixels, approximately 7.4 km²) are low-lying areas below 5 metres elevation with no water body within 300 metres, indicating an absence of stormwater storage capacity. Ecological buffer gaps (8,805 pixels, approximately 8.1 km²) are coastal areas within 1,500 metres of the shoreline lacking wetland or mangrove cover within 500 metres, leaving the coastline directly exposed to wave energy and storm surge. Canal encroachment was identified at locations where built structures occupy the immediate buffer zone of canals, reducing their conveyance capacity as shown in (Figure 9.6).



Drainage deficiency map *Retention area needed map* *Ecological buffer gap map*

Figure 9.6: Combined Gap Analysis map, Source: GIS Pro

2) Composite Gap Analysis

The three gap layers are presented together in a composite map (Figure 9.7) by stacking them as transparent layers, allowing areas of overlapping deficiencies to be identified. Locations where multiple gap types coincide particularly in eastern Wards 9, 10, 14, and 20 represent the highest priority zones for intervention, facing simultaneous drainage, retention, and ecological deficiencies.

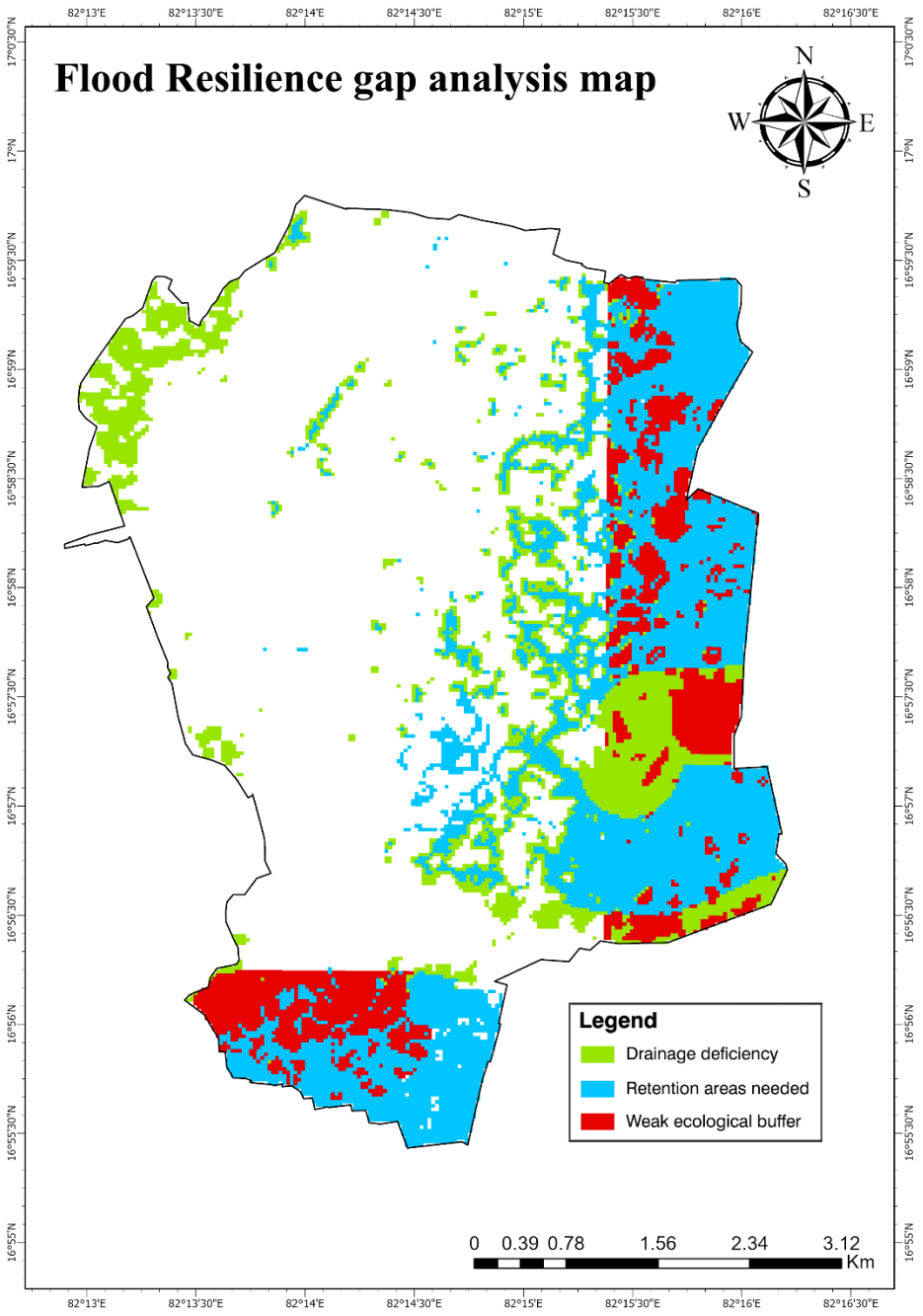


Figure 9.7: Flood Resilience gap analysis map, Source: GIS Pro

9.3.5 Stage Five: Planning Proposals and Strategies

The fifth stage develops planning responses to the gaps identified in Stage Four. Three categories of intervention are proposed policy-based zoning, blue-green infrastructure, and drainage improvements spatially layered and presented as a single integrated proposals map.

1) Supporting Maps — Individual Proposal Layers

Policy zones were derived directly from the flood risk classification (Table 9.6). Zone A (High risk, 34% of area) imposes a development moratorium with flood-proofing required for existing structures. Zone B (Medium risk, 33%) permits development subject to conditions including raised plinths, permeable surfaces, and mandatory drainage connection. Zone C (Low risk, 33%) is designated for normal urban growth.

Blue-green infrastructure proposals identify two types of nature-based intervention: retention pond sites in low-lying areas below 5 metres lacking nearby water bodies, and wetland restoration zones along the coastal fringe below 3 metres elevation where ecological buffer gaps are present.

Drainage improvement proposals differentiate three types of engineered intervention: canal widening where drainage gaps fall within 800 metres of an existing canal; new stormwater drains where gaps are more than 800 metres from any canal; and pump station installations at the lowest-lying points within High-risk zones where gravity drainage is insufficient as shown in (Figure 9.8).

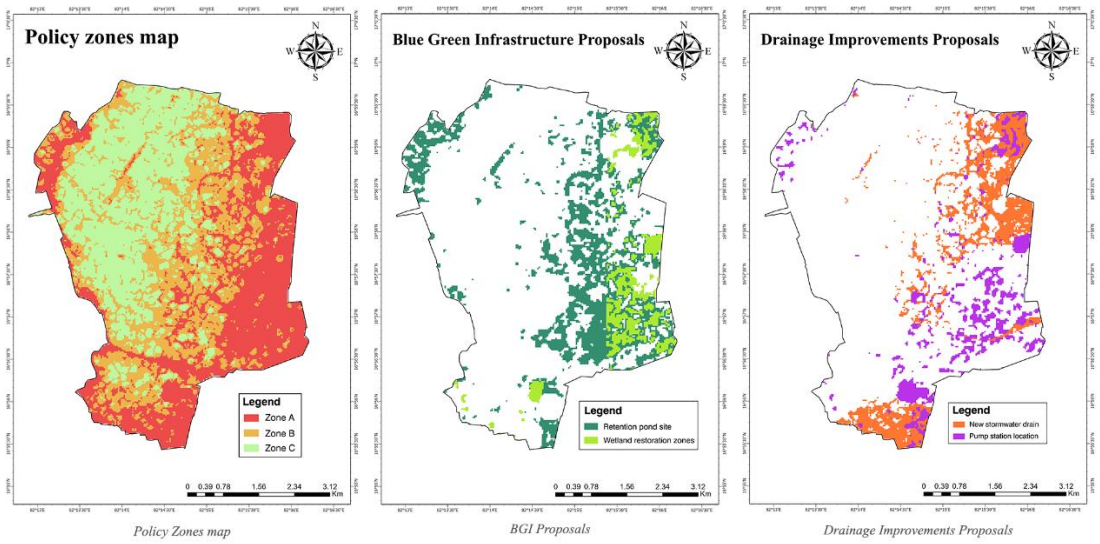


Figure 9.8: Combined Proposal Maps, Source: GIS Pro

Integrated Proposals Map

The three proposal layers are presented together in a single integrated map (Figure 9.9), spatially layered to show the full range of interventions across the study area. Ward-level intervention priority was determined by combining the proportion of each ward at High flood risk with ward population (Table 9.7). Wards combining high risk percentage with large populations are identified as Critical priority.

Table 9.6: Proposed policy zoning framework *Source: Compiled by Author*

Zone	Risk Basis	Area	Development Approach
Zone A	High Risk	34%	No new major development. Flood-proofing required.
Zone B	Medium Risk	33%	Development with conditions: raised plinths, permeable surfaces, drainage connection.
Zone C	Low Risk	33%	Normal development. Preferred zone for urban growth.

Table 9.7: Ward level flood risk & intervention priority *Source: Compiled by Author*

Ward	Locality	Population	% High Risk	Priority
Ward 10	Dummula Peta	10,056	88%	**Critical**
Ward 20	Mutha Nagar / Port Colony	7,259	95%	**Critical**
Ward 14	Yetimoga	7,647	78%	**Critical**
Ward 9	Kotha Kakinada	7,536	50%	**Critical**
Ward 11	Rajiv Gruhakalpa	10,541	42%	**Medium**
Ward 12	Sanjay Nagar and Parlovpeta	9,879	38%	**Medium**
Ward 49	Gaigolupadu Main Road	10,092	31%	**Medium**

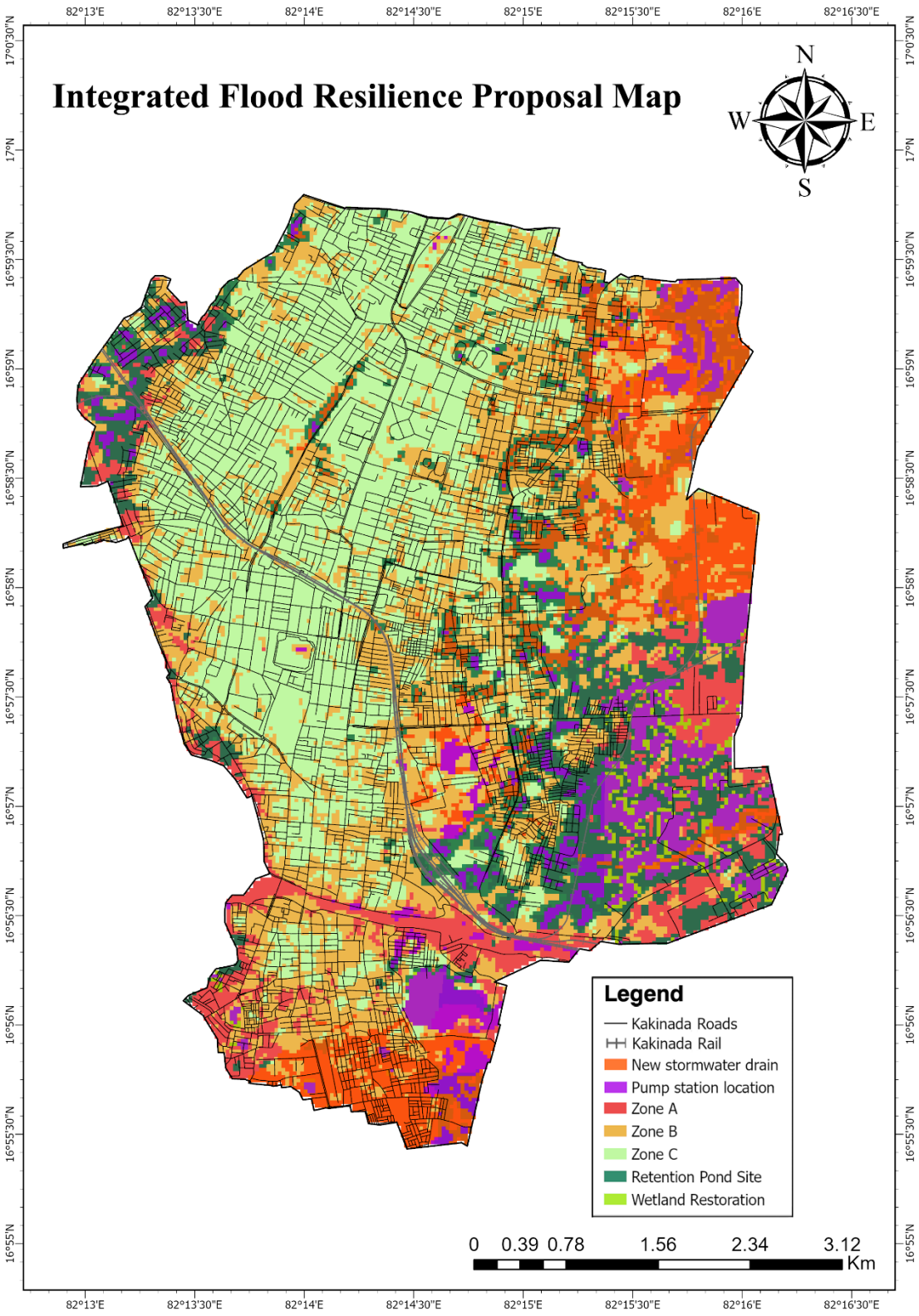


Figure 9.9: Integrated flood resilience proposal map, Source: GIS Pro

9.4 Expected Outcomes

The application of this integrated framework is expected to yield the following outcomes for Kakinada:

- Reduced flood exposure across High-risk zones through drainage improvement, stormwater retention, and coastal buffer restoration
- Improved stormwater drainage efficiency through canal widening and new drain construction in currently unserved areas
- Enhanced coastal protection through the restoration of mangrove and wetland buffers along the eastern shoreline
- More equitable flood resilience outcomes, with priority investment directed toward wards with the highest combination of flood risk and population exposure
- A regulatory framework through the three-zone policy structure that prevents further intensification of development in High-risk areas while directing growth toward safer zones

9.5 Summary of the Framework

Taken together, the five stages constitute an integrated methodological framework that moves systematically from the documentation of existing conditions to the formulation of spatially specific, evidence-based proposals (Table 9.8). The framework's emphasis on linking gap analysis directly to proposed interventions ensures that the resulting strategies for Kakinada are analytically grounded and practically actionable.

Table 9.8: Summary of stage wise findings *Source: Compiled by Author*

Stage	**Key Finding**
Stage 1- Existing Conditions	LULC map establishes the baseline land use and CRZ zoning context. Residential, commercial, industrial, agricultural and coastal regulation zones documented across 50 wards.
Stage 2- Flood Risk	34% of the study area is at High flood risk. Coastal eastern wards are most exposed. Mean elevation 6.5m

	and mean slope 2.18 degrees confirm extreme flood susceptibility.
Stage 3- Vulnerability	4.8% of the area exhibits High composite vulnerability. Social vulnerability concentrated in Wards 10, 11, 12, and 49. Environmental vulnerability highest in eastern coastal zone.
Stage 4- Gap Analysis	7,704 pixels drainage deficient. 8,045 pixels need retention provision. 8,805 pixels lack ecological buffers. Eastern wards 9, 10, 14 and 20 show overlap of all gap types.
Stage 5- Proposals	Zone A (34%) development moratorium. Zone B (33%) controlled development. Zone C (33%) designated for growth. Wards 10, 14 and 20 identified as critical priority zones.

9.6 Implementation Framework: Translating the Proposal into Ground-Level Action

The five-stage analytical framework presented in Sections 9.1 to 9.5 establishes what needs to be done in Kakinada - the policy zones, the blue-green interventions, and the drainage improvements required to reduce flood risk. On its own, however, an analytical and spatial framework does not guarantee that these proposals will be executed on the ground. Experience from Indian coastal cities shows that even well-designed flood resilience plans frequently stall at the stage of implementation, owing to fragmented institutional mandates, absent financing pathways, weak regulatory backing, and limited community ownership (Carvalho & Spataru, 2023; Prashar et al., 2023). This section therefore extends the proposal into an implementation framework: a structured, sequenced, and institutionally grounded pathway that specifies who acts, in what order, under what regulatory authority, with what financing, and how progress is verified.

The framework is organised around four mutually reinforcing pillars - institutional and governance structure, regulatory and legal instruments, phased roadmap and financing, and participation with monitoring and feedback - all converging on the ward-level

prioritisation established in Table 9.7. Figure 9.10 presents the overall logic of the framework, and the sub-sections that follow detail each pillar.

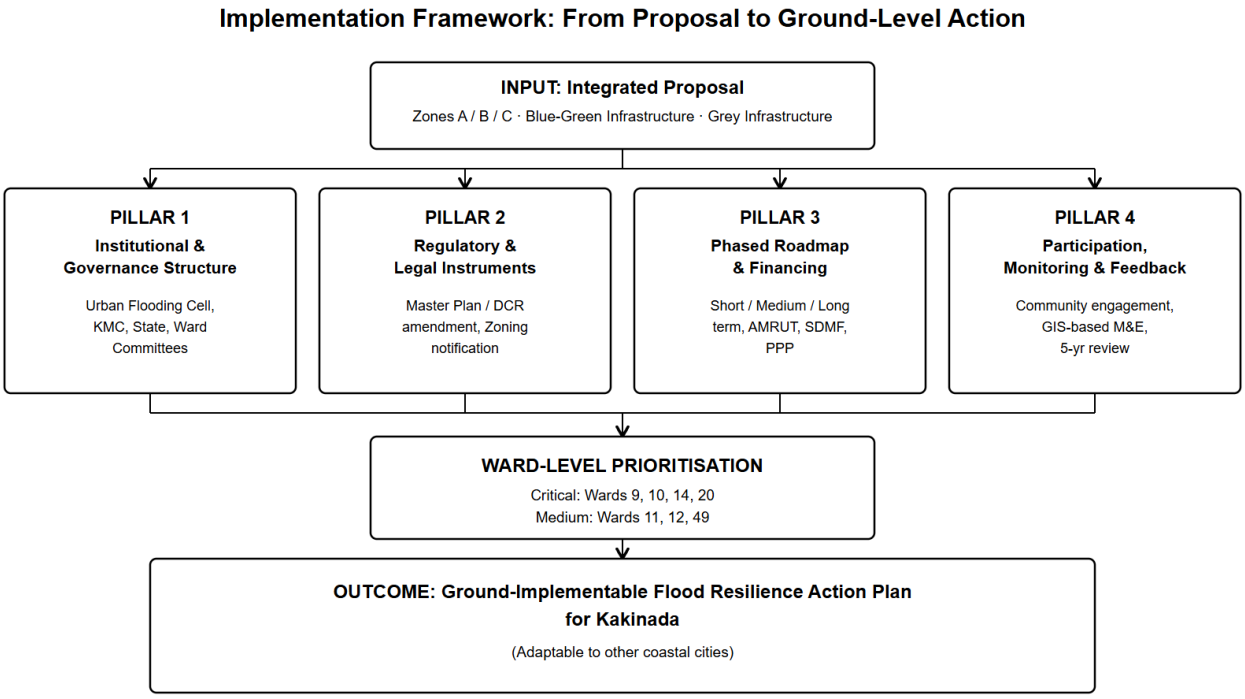


Figure 9.10: Implementation framework linking the proposal to ground-level action, Source: Compiled by Author

9.6.1 Institutional and Governance Structure

Table 3.5 already establishes that flood management responsibility in India is distributed across national ministries, state departments, and urban local bodies, with weak horizontal coordination identified in Table 3.6 as one of the most persistent implementation gaps ("Governance Coordination" and "Techno-Legal Regime"). Rather than proposing an entirely new bureaucracy, the implementation framework recommends anchoring delivery within a single dedicated coordinating body at the city level, supported by clearly assigned vertical linkages upward to the state and downward to the ward.

- Urban Flooding Cell (UFC), Kakinada - proposed as the nodal coordinating unit, consistent with the Constitution of an Urban Flooding Cell already recommended under national guidance (Table 3.5). Housed within the Kakinada Municipal Corporation (KMC), the UFC would be chaired by the Municipal Commissioner and include representatives of the Irrigation Department, the Public Health

Engineering / Water and Sanitation Department, the Town and Country Planning Department, and the District Disaster Management Authority (DDMA).

- State-level linkage - the Andhra Pradesh State Disaster Management Authority (SDMA) and the Water Resources Department provide technical sanction, inter-departmental arbitration, and access to state disaster mitigation funds.
- Ward-level linkage - a Ward Flood Resilience Committee in each of the priority wards (9, 10, 14, and 20; see Table 9.7), comprising the ward councillor, local officials, resident welfare associations, and community volunteers, to feed local knowledge upward and to oversee last-mile execution.

This three-tier structure directly addresses the coordination and participation gaps identified in Table 3.6 by giving each proposal component - policy zoning, blue-green infrastructure, and drainage works - a single accountable institutional home, while preserving the technical role of existing departments.

Table 9.9: Three-tier institutional structure for implementation *Source: Author*

Tier	Responsible Body	Primary Function
City (nodal)	Urban Flooding Cell, Kakinada Municipal Corporation	Coordinates all three proposal layers; single point of accountability
State	Andhra Pradesh SDMA, Water Resources Dept.	Technical sanction, inter-agency arbitration, mitigation fund access
Ward (local)	Ward Flood Resilience Committees (Wards 9, 10, 14, 20 priority)	Local monitoring, grievance redress, community mobilisation

9.6.2 Regulatory and Legal Instruments

For the policy zoning proposal (Table 9.6) to have practical effect, it must be given statutory backing rather than remaining an advisory GIS output. The framework proposes the following sequence of regulatory action:

- Notification of the three flood risk zones (A, B, and C) as an overlay in the Kakinada Master Plan / Development Control Regulations, so that building

permission processes automatically apply the restrictions and conditions defined in Table 9.6.

- Amendment of building bye-laws in Zone B to make raised plinth levels, permeable paving, and mandatory drainage connection a condition of building permission rather than a voluntary guideline.
- Coordination with the Coastal Regulation Zone (CRZ) framework already governing the eastern wards, so that the proposed wetland restoration zones reinforce rather than duplicate existing CRZ-IB and CRZ-III protections.
- A formal no-objection linkage between the UFC and the KMC building permission department, requiring UFC sign-off for any new construction proposed within Zone A.

This sequence follows the logic that a spatial proposal only becomes enforceable once it is embedded in the statutory planning instrument that actually governs land development decisions.

9.6.3 Phased Implementation Roadmap

Implementation is sequenced across three horizons, prioritising interventions in the four Critical wards (9, 10, 14, and 20) identified in Table 9.7, before extending to the three Medium-priority wards (11, 12, and 49) and the remainder of the city.

Table 9.10: Phased implementation roadmap *Source: Compiled by Author*

Phase	**Timeframe**	**Key Actions**	**Linked Proposal Component**
Phase 1 Stabilise	Years 0–2	Notify Zone A/B/C in Master Plan; constitute UFC and Ward Committees; clear canal encroachments in Wards 9, 10, 14, 20; install pump stations at lowest-lying High-risk points	Policy zoning; drainage improvement (pump stations)
Phase 2 Build	Years 2–5	Construct priority stormwater drains and widen canals within 800 m of existing channels; begin retention pond	Drainage improvement (canal widening,

		land identification and acquisition; commence wetland restoration pilots along eastern shoreline	new drains); blue-green infrastructure
Phase 3 Consolidate	Years 5–10+	Complete retention pond network and mangrove/wetland buffer restoration; extend Zone B conditions city-wide; institutionalise 5-year GIS-based reassessment cycle	Blue-green infrastructure; policy zoning (city-wide roll-out); monitoring

This phasing reflects two principles evident in the underlying risk assessment: first, that regulatory and low-cost institutional measures (zoning notification, committee formation) can be actioned almost immediately and should precede capital-intensive works; and second, that engineered drainage works, which address the most acute drainage deficiency gaps (Section 9.3.4), are prioritised ahead of nature-based restoration, which requires longer lead times for land identification, ecological establishment, and community consensus.

9.6.4 Financing Mechanisms

Table 3.6 identifies the absence of clear, budget-appropriate financing models as a recurring gap in flood resilience research and practice in India. The framework proposes a blended financing approach rather than reliance on a single source:

- Convergence with existing national urban missions (such as AMRUT) for drainage and stormwater components, since these already fund municipal water and sanitation infrastructure.
- Access to the State Disaster Mitigation Fund and District Disaster Management Authority allocations for pump stations and canal desilting, consistent with the mitigation-linked mandates already listed against DMD and SDMA in Table 3.5.
- Multilateral and bilateral climate finance (for example, development-bank lines of credit historically used for urban flood and drainage works in Indian coastal cities) for larger retention pond and wetland restoration components.

- Municipal own-revenue and public–private partnership models for maintenance of blue-green assets, particularly where retention ponds or restored wetlands can be co-located with public open space or eco-tourism uses that generate local revenue.
- A ring-fenced municipal flood resilience maintenance line, since Table 3.6 specifically notes that research rarely tracks the ongoing maintenance costs of green infrastructure, and that hidden maintenance costs are a common cause of project failure.

9.6.5 Participatory and Community Engagement Mechanism

Section 3.4 of this thesis establishes that participatory, bottom-up processes increase the legitimacy, cost-effectiveness, and contextual fit of flood resilience measures. The implementation framework operationalises this principle specifically for Kakinada as follows:

- Ward Flood Resilience Committees in Wards 9, 10, 14, and 20 conduct participatory mapping exercises to validate the GIS-derived risk and vulnerability findings (Sections 9.3.2–9.3.3) against lived experience before construction begins.
- A standing grievance redress channel, housed within the UFC, through which residents in high-priority wards can flag drainage blockages, encroachments, or construction delays.
- Targeted awareness and preparedness training in Wards 10, 11, 12, and 49, which combine high population density with elevated social vulnerability (Section 9.3.3), so that structural works are complemented by community-level preparedness.
- Deliberate inclusion of informal settlements and economically weaker residents in planning consultations, in direct response to the climate gentrification risk noted in Section 3.4.2, so that flood-prone land is not simply vacated by those able to relocate while poorer residents remain exposed.

9.6.6 Monitoring, Evaluation, and Feedback

Table 3.6 highlights the absence of standardised, long-term monitoring as a critical research and practice gap. The framework closes this loop by treating the GIS-based methodology developed in Sections 9.3.1–9.3.4 not as a one-time assessment but as a repeatable monitoring instrument:

- A 5-year reassessment cycle, re-running the flood risk and composite vulnerability classification (Tables 9.4 and 9.5) using updated elevation, land use, and rainfall data, to check whether High-risk area coverage is declining.
- Annual physical progress indicators for each phase of Table 9.10 (length of canal widened, number of pump stations commissioned, hectares of wetland restored), reported by the UFC to the SDMA.
- Outcome indicators tracked at ward level for the four Critical wards, including flood extent during monsoon events, drainage response time, and displacement incidence, to test whether the priority-ward targeting in Table 9.7 is translating into measurable risk reduction.
- A public-facing dashboard maintained by the UFC, consistent with the transparency and awareness-generation responsibilities already assigned to municipal and state authorities in Table 3.5.

9.6.7 Summary Implementation Matrix

Table 9.11 consolidates the framework by linking each proposal component from Section 9.3.5 to its responsible institution, financing route, and implementation phase, providing a single ground-implementation reference for Kakinada.

Table 9.11: Summary implementation matrix *Source: Compiled by Author*

Proposal Component	**Responsible Institution**	**Financing Route**	**Phase**
Zone A / B / C notification (Table 9.6)	UFC + KMC Town Planning Dept.	Municipal / State budget (regulatory, low-cost)	Phase 1
Canal encroachment clearance	KMC + Irrigation Dept.	Municipal budget / SDMF	Phase 1

Pump station installation	Irrigation Dept. / KMC Engineering	SDMF / DDMA allocation	Phase 1
New stormwater drains & canal widening	KMC Engineering Dept.	AMRUT / urban infrastructure mission	Phase 2
Retention pond development	KMC + Water & Sanitation Dept.	Climate finance / PPP	Phase 2–3
Wetland / mangrove restoration	Forest & Environment Dept. + UFC	Climate finance / CSR	Phase 2–3
Ward-level monitoring & M&E dashboard	UFC (nodal)	Municipal own-revenue	Ongoing, all phases

9.6.8 Anticipated Barriers and Mitigation

Drawing on the implementation gaps catalogued in Table 3.6, three barriers are most likely to constrain execution in Kakinada, along with the corresponding mitigation built into this framework:

- Inter-departmental coordination failure - mitigated by housing all proposal components under the single-nodal Urban Flooding Cell rather than distributing them across departments with no shared accountability.
- Land acquisition delays for retention ponds and wetland restoration - mitigated by sequencing these components into Phases 2–3, allowing time for identification and negotiation, while Phase 1 focuses on interventions within existing public rights-of-way (drains, canals, pump stations).
- Weak long-term maintenance financing for blue-green infrastructure - mitigated by the ring-fenced municipal maintenance line proposed in Section 9.6.4 and by co-locating assets with revenue-generating public uses where feasible.

Taken together, this implementation framework converts the analytical and spatial proposal developed in Sections 9.1–9.5 into a sequenced, institutionally owned, and financially grounded pathway for action, while remaining adaptable.

10. CONCLUSION

This study highlights the growing vulnerability of Indian coastal cities to flooding as a result of climate change, sea-level rise, extreme rainfall events, and rapid urbanization. Through a comprehensive review of literature, policy frameworks, case studies, and GIS-based spatial analysis of Kakinada, the research identified key physical, environmental, and socio-economic factors contributing to flood risk and vulnerability. The findings demonstrate that effective flood resilience cannot be achieved through standalone measures but requires an integrated approach combining nature-based solutions, technological interventions, grey infrastructure, and participatory governance. The proposed framework provides a practical and adaptable planning tool for reducing flood risks, enhancing adaptive capacity, and supporting sustainable urban development. While developed for Kakinada, the framework can be applied and refined for other coastal cities facing similar challenges. As climate-related hazards continue to intensify, adopting integrated and proactive resilience strategies will be essential for safeguarding communities, infrastructure, and ecosystems while ensuring long-term urban sustainability.

REFERENCES

Ali, S., & George, A. (2022). *Social Inclusivity : A Case Study on Community Resilience on Kerala Flood- Social Inclusivity : A Case Study on Community Resilience on Kerala Flood-2018* (Issue February). Springer Singapore. https://doi.org/10.1007/978-981-15-9585-1

Aloscious, A. A., Artuso, M., & Torabi Moghadam, S. (2025). Nature-Based Solutions for Flood Mitigation: The Case Study of Kochi. *Sustainability (Switzerland)*, *17*(5). https://doi.org/10.3390/su17051983

Ambily, P., Chithra, N. R., Firoz C, M., & Viswanath, S. (2024). Ecological Flood Resilience Index (EFRI) to Assess the Urban Pluvial Flood Resilience of Blue-Green infrastructure: A case from a southwestern coastal city of India. *International Journal of Disaster Risk Reduction*, *113*(January), 104867. https://doi.org/10.1016/j.ijdrr.2024.104867

Anand, R., Saw, V. K., Scholar, M. S., & Scholar, P. D. (n.d.). *Rapid Industrial Development and Changing Weather Patterns Impacting Lives in Relation to Uttarakhand and Mumbai / Chennai Floods*. *15*(1), 1–12.

Aziz, F., Wang, X., Mahmood, M. Q., Awais, M., & Trenouth, B. (2024). Coastal urban flood risk management: Challenges and opportunities − A systematic review. *Journal of Hydrology*, *645*(PB), 132271. https://doi.org/10.1016/j.jhydrol.2024.132271

Carvalho, P., & Spataru, C. (2023). Gaps in the governance of floods, droughts, and heatwaves in the United Kingdom. *Frontiers in Earth Science*, *11*(May), 1–15. https://doi.org/10.3389/feart.2023.1124166

ChennailFlood_NIDM2021.pdf. (n.d.).

Daro Justine, Y. E., & Seenath, A. (2025). Vegetative nature-based solutions for coastal flood risk management: Benefits, challenges, and uncertainties. *Ocean and Coastal*

Management, *261*(August 2024), 107520. https://doi.org/10.1016/j.ocecoaman.2024.107520

Disaster, N., & Authority, M. (n.d.). *No Title*.

Du, S., Scussolini, P., Ward, P. J., Zhang, M., Wen, J., Wang, L., Koks, E., Diaz-Loaiza, A., Gao, J., Ke, Q., & Aerts, J. C. J. H. (2020). Hard or soft flood adaptation? Advantages of a hybrid strategy for Shanghai. *Global Environmental Change*, *61*(December 2019), 102037. https://doi.org/10.1016/j.gloenvcha.2020.102037

Jodhani, K. H., Patel, D., Madhavan, N., Gupta, N., & Kumar, S. (2024). Results in Engineering Unravelling flood risk in the Rel River watershed , Gujarat using coupled earth observations , multi criteria decision making and Google Earth Engine. *Results in Engineering*, *24*(August), 102836. https://doi.org/10.1016/j.rineng.2024.102836

Krishnan, P., Ananthan, P. S., Purvaja, R., Joyson Joe Jeevamani, J., Amali Infantina, J., Srinivasa Rao, C., Anand, A., Mahendra, R. S., Sekar, I., Kareemulla, K., Biswas, A., Kalpana Sastry, R., & Ramesh, R. (2019). Framework for mapping the drivers of coastal vulnerability and spatial decision making for climate-change adaptation: A case study from Maharashtra, India. *Ambio*, *48*(2), 192–212. https://doi.org/10.1007/s13280-018-1061-8

Memorandum, A. (2018). *Kerala Floods – 2018*. *August*.

Monckeberg, E., & Gómez, S. (2025). Exploring the potential of coastal cities to address climate change towards an inclusive, equitable and politically engaged orientation. *Anthropocene Coasts*, *8*(1). https://doi.org/10.1007/s44218-025-00099-5

Ndille, R., & Belle, J. A. (2014). Managing the Limbe Floods: Considerations for Disaster Risk Reduction in Cameroon. *International Journal of Disaster Risk Science*, *5*(2), 147–156. https://doi.org/10.1007/s13753-014-0019-0

Parkash, S., Kaur, H., & Bindal, M. K. (2022). *Floods Challenges and its Management*

Case Study of Gujarat Floods - 2017 (Issue March).

Pramod, G., & Chadchan, J. (2023). Urban coastal resilience - An assessment. *AIP Conference Proceedings*, *2763*(1). https://doi.org/10.1063/5.0158720

Prashar, N., Lakra, H. S., Shaw, R., & Kaur, H. (2023). Urban Flood Resilience: A comprehensive review of assessment methods, tools, and techniques to manage disaster. *Progress in Disaster Science*, *20*(September), 100299. https://doi.org/10.1016/j.pdisas.2023.100299

Ren, S., Ghaffar, B., Mubbin, M., Haseeb, M., Tahir, Z., Hassan, S. S., Kucher, D. E., Kucher, O. D., & Abdullah-Al-Wadud, M. (2025). Multisensor Remote Sensing and AI-Driven Analysis for Coastal and Urban Resilience Classification. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *18*, 9166–9180. https://doi.org/10.1109/JSTARS.2025.3554793

Seenirajan, M., Natarajan, M., Thangaraj, R., & Bagyaraj, M. (2017). *Study and Analysis of Chennai Flood 2015 Using GIS and Multicriteria Technique*. 126–140. https://doi.org/10.4236/jgis.2017.92009

Singh, A., Sreeparvathy, V., Debdut, S., Pregnolato, M., & Wright, N. (2025). Journal of Hydrology : Regional Studies A critical review of flood risk assessment in Kerala Post-2018 : Methodological approaches , gaps , and future directions. *Journal of Hydrology: Regional Studies*, *58*, 102262. https://doi.org/10.1016/j.ejrh.2025.102262

Valente, S., & Pinho, P. (2025). Adaptive Planning Approaches for Coastal Climate Adaptation: Process and Key-elements. *Environmental Management*, *75*(4), 1013–1038. https://doi.org/10.1007/s00267-025-02117-1

Xu, X., O'Sullivan, J. J., Abolfathi, S., Keenahan, J., Pearson, J. M., & Salauddin, M. (2025). Advances in understanding the challenges and opportunities of hybrid sea defence approaches for coastal resilience. *Environmental Challenges*, *19*(August 2024), 101130. https://doi.org/10.1016/j.envc.2025.101130

National Disaster Management Authority. (2024). Floods. https://ndma.gov.in/Natural-Hazards/Floods

Times of India. (2019, September 25). Sea levels rising faster, Indian cities at high flood risk: IPCC. https://timesofindia.indiatimes.com/ind

Centre for Science, Technology and Policy. (2024). Sea level rise scenarios and inundation maps for selected Indian coastal cities. https://cstep.in/drupal/sites/default/files/2024-07/Sea%20level%20rise%20scenarios%20and%20inundation%20maps%20for%20selected%20Indian%20coastal%20cities.pdf

Press Information Bureau. (2024, July 30). Sea-level rise and coastal city vulnerabilities. https://www.pib.gov.in/PressReleseDetailm.aspx?PRID=2150834

Annexure: ArcGIS Pro Geoprocessing Steps and Tool Settings

This annexure documents the ArcGIS Pro tools, parameters, and Raster Calculator formulas used to produce each spatial output referenced in Chapter 9 — Conceptual and Methodological Framework. The annexure is organised by stage and corresponds to the figure numbers used in the main text. All rasters are in UTM Zone 44N (EPSG:32644) at 30 metre resolution, clipped to the 50-ward Kakinada municipal boundary.

A1 — Stage One: Existing Conditions (Figure 9.1)

The LULC map was sourced directly from the Kakinada Master Plan shapefile. No geoprocessing derivation was required. The file was loaded into ArcGIS Pro and symbolised using Unique Values on the land use zone field. CRZ zones (IA, IB, II, III, IVB) were symbolised separately using the colour scheme from the Master Plan legend. Ward boundaries were overlaid as a white outline for spatial reference.

A2 — Stage Two: Flood Risk Assessment

A2.1 — Figure 9.2(i): Digital Elevation Model (dem_ward_clipped.tif)

Step	ArcGIS Pro Tool	Parameters
1	Data Management > Projections > Project Raster	Input: srtm_clip.tif | Output CRS: WGS 1984 UTM Zone 44N (EPSG:32644) | Resampling: Bilinear | Output: dem_utm.tif
2	Data Management > Raster > Clip Raster	Input: dem_utm.tif | Clip Feature: ward_boundaries.gpkg | Use Input Features for Clipping Geometry: Yes | NoData: -9999 | Output: dem_ward_clipped.tif
3	Symbology	Stretch | Colour scheme: Terrain or Elevation #1 | Set layer transparency to 40% for use as base layer

A2.2 — Figure 9.2(ii): Slope Map (slope.tif)

Step	ArcGIS Pro Tool	Parameters
1	Spatial Analyst > Surface > Slope	Input: dem_ward_clipped.tif | Output Measurement: DEGREE | Z Factor: 1 | Output: slope.tif
2	Symbology	Stretch | Colour scheme: Yellow to Red | Min label: 0 deg (Flat) | Max label: 15.4 deg (Steep)

A2.3 — Figure 9.2(iii): Flow Accumulation Map (flow_accumulation.tif)

Step	ArcGIS Pro Tool	Parameters
1	Spatial Analyst > Hydrology > Fill	Input: dem_ward_clipped.tif | Output: dem_filled.tif | Removes spurious depressions that interrupt flow calculation
2	Spatial Analyst > Hydrology > Flow Direction	Input: dem_filled.tif | Flow Direction Type: D8 | Output: flow_direction.tif
3	Spatial Analyst > Hydrology > Flow Accumulation	Input: flow_direction.tif | Data Type: Float | Output: flow_accumulation.tif
4	Spatial Analyst > Reclass > Reclassify	Input: flow_accumulation.tif | Reclassification Method: Natural Breaks | Number of Classes: 5 | Labels: Very Low / Low / Moderate / High / Very High
5	Symbology	Classify (5 classes) | Colour scheme: White to Dark Blue | Very Low = White | Very High = Dark Navy Blue

A2.4 — Figure 9.3: Flood Risk Assessment Map (flood_risk_ward.tif)

Step 1 — Prepare Euclidean Distance rasters from proximity features:

Distance Raster	Input Feature Layer	Max Distance
dist_coast.tif	Coastline layer (from OSM)	2,000 metres
dist_canal.tif	Waterways layer — canals and drains (from OSM)	300 metres

Tool used: Spatial Analyst > Distance > Euclidean Distance | Cell size: 30m for both rasters

Step 2 — Raster Calculator formulas to produce normalised 0–1 scores:

Score	Raster Calculator Formula
Elevation Score	*1 - ((dem_ward_clipped.tif - (-6)) / (22 - (-6)))*
Slope Score	*1 - (slope.tif / 15.4)*
Coastal Score	*1 - Con(dist_coast.tif > 2000, 1, dist_coast.tif / 2000)*
Canal Score	*1 - Con(dist_canal.tif > 300, 1, dist_canal.tif / 300)*
Flood Risk Index (Weighted Overlay)	*(0.40 x Elev_Score) + (0.25 x Coast_Score) + (0.20 x Slope_Score) + (0.15 x Canal_Score)*

Step 3 — Classify the Flood Risk Index into 3 categories:

Tool	Parameters
Spatial Analyst > Reclass > Reclassify	Input: Flood Risk Index raster | Method: Natural Breaks (Jenks) | Number of Classes: 3 | New values: 1 = Low Risk, 2 = Medium Risk, 3 = High Risk | Output: flood_risk_ward.tif

Symbology: Unique Values | Value 1 = Yellow #F1C40F (Low Risk) | Value 2 = Orange #E67E22 (Medium Risk) | Value 3 = Dark Red #C0392B (High Risk) | NoData = Transparent

Overlay layers: Add ward_boundaries.gpkg as white outline (no fill, 0.7pt) on top. Add waterways and coastline as blue lines below ward boundary.

A3 — Stage Three: Vulnerability Assessment

A3.1 — Figure 9.4(i): Physical Vulnerability (phys_vuln_final.tif)

Combines building density and drainage stress with equal weights (50% each).

Step	ArcGIS Pro Tool	Parameters
1	Spatial Analyst > Density > Kernel Density	Input: buildings layer (OSM) | Population Field: None | Cell size: 30m | Search radius: 150m | Output: building_density.tif
2	Raster Calculator — Normalise building density	(building_density.tif - Min(building_density.tif)) / (Max(building_density.tif) - Min(building_density.tif)) Output: building_density_norm.tif
3	Raster Calculator — Elevation Score	1 - ((dem_ward_clipped.tif - (-6)) / (22 - (-6))) Output: elev_score.tif
4	Raster Calculator — Slope Score	1 - (slope.tif / 15.4) Output: slope_score.tif
5	Raster Calculator — Drainage Stress	(0.60 x elev_score.tif) + (0.40 x slope_score.tif) Output: drainage_stress.tif
6	Raster Calculator — Physical Vulnerability	(0.50 x building_density_norm.tif) + (0.50 x drainage_stress.tif) Output: phys_vuln_final.tif
7	Symbology	Stretch | Colour scheme: Blue to Red | Min label: Low Physical Vulnerability | Max label: High Physical Vulnerability

A3.2 — Figure 9.4(ii): Social Vulnerability (social_vuln_final.tif)

Combines ward population density (70% weight) and road accessibility (30% weight).

Step	ArcGIS Pro Tool	Parameters
1	Add Field in ward_boundaries attribute table	Field name: pop_density | Expression: [pop] / [area_km2] | Calculates population density (people per km2) per ward
2	Conversion > Feature to Raster	Input: ward_boundaries.gpkg | Field: pop_density | Cell size: 30m | Output: pop_density.tif | Each pixel within a ward receives its ward population density value
3	Raster Calculator — Normalise population density	(pop_density.tif - Min(pop_density.tif)) / (Max(pop_density.tif) - Min(pop_density.tif)) Output: pop_norm.tif
4	Select by Attribute — Extract major roads	Layer: roads | Expression: highway IN (trunk, primary, secondary, tertiary) | Export selected features to: major_roads layer
5	Spatial Analyst > Distance > Euclidean Distance	Input: major_roads | Maximum distance: 2000m | Cell size: 30m | Output: road_distance.tif
6	Raster Calculator — Road Accessibility Score	Con(road_distance.tif > 800, 1, road_distance.tif / 800) Output: road_score.tif | Areas beyond 800m from major road score 1 (most inaccessible)
7	Raster Calculator — Social Vulnerability	(0.70 x pop_norm.tif) + (0.30 x road_score.tif) Output: social_vuln_final.tif
8	Symbology	Stretch | Colour scheme: Purple to Red | Min label: Low Social Vulnerability | Max label: High Social Vulnerability

A3.3 — Figure 9.4(iii): Environmental Vulnerability (env_vuln_final.tif)

Combines wetland loss (40%), canal encroachment (30%), and coastal exposure (30%).

Step	ArcGIS Pro Tool	Parameters
1	Euclidean Distance — from wetlands	Input: wetlands layer (OSM) | Maximum distance: 1500m | Cell size: 30m | Output: dist_wetland.tif
2	Raster Calculator — Wetland Score	Con(dist_wetland.tif > 1500, 1, dist_wetland.tif / 1500) Output: wetland_score.tif
3	Euclidean Distance — from canals	Input: waterways layer (OSM) | Maximum distance: 500m | Cell size: 30m | Output: dist_canal2.tif
4	Raster Calculator — Canal Score	1 - Con(dist_canal2.tif > 500, 1, dist_canal2.tif / 500) Output: canal_score.tif
5	Euclidean Distance — from coastline	Input: coastline layer (OSM) | Maximum distance: 2500m | Cell size: 30m | Output: dist_coast2.tif
6	Raster Calculator — Coastal Score	1 - Con(dist_coast2.tif > 2500, 1, dist_coast2.tif / 2500) Output: coast_score.tif
7	Raster Calculator — Environmental Vulnerability	(0.40 x wetland_score.tif) + (0.30 x canal_score.tif) + (0.30 x coast_score.tif) Output: env_vuln_final.tif
8	Symbology	Stretch | Colour scheme: Green to Red | Min label: Low Environmental Vulnerability | Max label: High Environmental Vulnerability

A3.4 — Figure 9.5: Composite Vulnerability Assessment (composite_vuln_final.tif)

Uses a tercile-based dimension-counting method. Pixels scoring in the highest tercile across all three dimensions are classified as High.

Step	ArcGIS Pro Tool	Parameters
1	Reclassify — Physical dimension	Input: phys_vuln_final.tif | Method: Equal Interval | Classes: 3 | Output values: 0 (low tier), 1 (mid tier), 2 (high tier) | Output: phys_class.tif
2	Reclassify — Social dimension	Input: social_vuln_final.tif | Same settings as Step 1 | Output: social_class.tif
3	Reclassify — Environmental dimension	Input: env_vuln_final.tif | Same settings as Step 1 | Output: env_class.tif
4	Raster Calculator — Count high-tier dimensions	Con(phys_class.tif==2,1,0) + Con(social_class.tif==2,1,0) + Con(env_class.tif==2,1,0) Output: high_count.tif | Value = number of dimensions in which pixel scores high (0, 1, 2, or 3)
5	Reclassify — Composite classification	Input: high_count.tif | 0 to 1 = 1 (Low) | 2 = 2 (Moderate) | 3 = 3 (High) | Output: composite_vuln_final.tif
6	Symbology	Unique Values | Value 1 = Yellow #F1C40F (Low) | Value 2 = Orange #E67E22 (Moderate) | Value 3 = Dark Red #C0392B (High) | NoData = Transparent
7	Overlay layers	Add ward_boundaries.gpkg (white outline) | Add waterways and coastline (blue lines) | Add wetland layer (green outline, no fill)

A4 — Stage Four: Gap Analysis

A4.1 — Figure 9.6(i): Drainage Deficiency (gap_drainage.tif)

Identifies High flood risk pixels with no drain or canal within 400 metres.

Step	ArcGIS Pro Tool	Parameters
1	Euclidean Distance — from waterways	Input: waterways layer (canals and drains from OSM) | Maximum distance: 1000m | Cell size: 30m | Output: dist_drain.tif
2	Raster Calculator — Drainage gap	Con(flood_risk_ward.tif == 3 & dist_drain.tif > 400, 1, 0) Output: gap_drainage.tif | Value 1 = High risk area with no drain within 400m
3	Raster to Polygon (optional)	Input: gap_drainage.tif | Select features where gridcode = 1 only | Produces cleaner polygon display than raster for layout
4	Symbology	Unique Values | Value 0 = No Colour (transparent) | Value 1 = Blue #3498DB | Layer transparency: 30%

A4.2 — Figure 9.6(ii): Retention Areas Needed (gap_retention.tif)

Identifies low-lying areas below 5m elevation with no water body within 300 metres.

Step	ArcGIS Pro Tool	Parameters
1	Euclidean Distance — from water bodies	Input: water_bodies layer (OSM) | Maximum distance: 1000m | Cell size: 30m | Output: dist_water.tif
2	Raster Calculator — Retention gap	Con(dem_ward_clipped.tif < 5 & dist_water.tif > 300, 1, 0) Output: gap_retention.tif | Value 1 = Low-lying area below 5m with no water body within 300m
3	Raster to Polygon (optional)	Input: gap_retention.tif | Select features where gridcode = 1 only

4	Symbology	Unique Values | Value 0 = No Colour (transparent) | Value 1 = Green #2ECC71 | Layer transparency: 30%

A4.3 — Figure 9.6(iii): Weak Ecological Buffer (gap_ecological.tif)

Identifies coastal areas within 1,500m of shoreline with no wetland within 500 metres.

Step	ArcGIS Pro Tool	Parameters
1	Analysis > Tools > Buffer	Input: coastline layer | Distance: 1500m | Dissolve: All | Output: coastal_zone_1500m polygon
2	Conversion > Feature to Raster	Input: coastal_zone_1500m | Cell size: 30m | Value field: 1 | Output: coastal_zone.tif
3	Euclidean Distance — from wetlands	Input: wetlands layer (OSM) | Maximum distance: 1000m | Cell size: 30m | Output: dist_wetland2.tif
4	Raster Calculator — Ecological gap	Con(coastal_zone.tif == 1 & dist_wetland2.tif > 500, 1, 0) Output: gap_ecological.tif | Value 1 = Coastal area with no wetland within 500m
5	Raster to Polygon (optional)	Input: gap_ecological.tif | Select features where gridcode = 1 only
6	Symbology	Unique Values | Value 0 = No Colour (transparent) | Value 1 = Red #E74C3C | Layer transparency: 30%

A4.4 — Figure 9.7: Composite Gap Analysis Map (MAIN MAP)

Stack all three gap rasters together as transparent layers. Add gap_points.gpkg for representative point symbols.

Layer Order (top to bottom in Contents panel)	Transparency	Notes
ward_boundaries.gpkg	0%	White outline, no fill, 0.7pt — always top layer
gap_points.gpkg — Unique Values on gap_type field	0%	Drainage=Blue circle | Retention=Green square | Ecological=Red triangle | Encroachment=Orange diamond | Size 8pt
gap_ecological.tif	30%	Red #E74C3C
gap_retention.tif	30%	Green #2ECC71
gap_drainage.tif	30%	Blue #3498DB
flood_risk_ward.tif (background context)	30%	Yellow/Orange/Dark Red — shows risk zones underneath gaps
dem_ward_clipped.tif (terrain base)	40%	Terrain colour scheme — bottom layer

A5 — Stage Five: Planning Proposals

A5.1 — Figure 9.8(i): Policy Zones (policy_zones.tif)

Derived directly from flood_risk_ward.tif by re-labelling each risk class as a development control zone.

Step	ArcGIS Pro Tool	Parameters

1	Spatial Analyst > Reclass > Reclassify	Input: flood_risk_ward.tif | Old values: 3 = New value 1 (Zone A), 2 = New value 2 (Zone B), 1 = New value 3 (Zone C) | Output: policy_zones.tif
2	Symbology	Unique Values | Value 1 = Red #C0392B (Zone A — No Development) | Value 2 = Orange #E67E22 (Zone B — Controlled) | Value 3 = Green #2ECC71 (Zone C — Suitable for Growth) | Layer transparency: 30%
3	Raster to Polygon (optional)	Convert to polygon for cleaner boundaries and ward label overlay in layout | Dissolve adjacent same-value polygons

A5.2 — Figure 9.8(ii): Blue-Green Infrastructure Proposals (bgi_proposals.tif)

Two BGI types derived from gap rasters: retention pond sites (Value 1) and wetland restoration zones (Value 2).

Step	ArcGIS Pro Tool	Parameters
1	Raster Calculator — Retention pond sites	Con(gap_retention.tif == 1, 1, 0) Output: retention_sites.tif | Locations from retention gap layer — low-lying areas below 5m with no water body
2	Raster Calculator — Wetland restoration zones	Con(gap_ecological.tif == 1 & dem_ward_clipped.tif < 3, 2, 0) Output: wetland_restore.tif | Ecological gap pixels below 3m elevation — suitable for mangrove re-establishment
3	Raster Calculator — Combine BGI layers	Con(retention_sites.tif == 1, 1, Con(wetland_restore.tif == 2, 2, 0)) Output: bgi_proposals.tif | Where both overlap, retention pond (Value 1) takes priority
4	Symbology	Unique Values | Value 0 = No Colour (transparent) | Value 1 = Dark Green #1A9850 (Retention Pond Sites) | Value 2 = Light Green #91CF60 (Wetland Restoration Zones) | Layer transparency: 20%
5	Add reference layers	Add existing wetlands (green outline, no fill) and water_bodies (blue fill, 40% transparent) to show existing vs proposed features

A5.3 — Figure 9.8(iii): Drainage Improvement Proposals (drainage_proposals.tif)

Two drainage intervention types: new stormwater drains (Value 2) and pump station locations (Value 3). Canal widening was removed from this analysis as the OSM canal dataset was found to be incomplete for Kakinada.

Step	ArcGIS Pro Tool	Parameters
1	Raster Calculator — New stormwater drains	Con(gap_drainage.tif == 1, 2, 0) Output: new_drains.tif | All drainage deficiency pixels are proposed for new stormwater drain construction
2	Zonal Statistics as Table	Input zone raster: flood_risk_ward.tif (zone value = 3) | Input value raster: dem_ward_clipped.tif | Statistics: Percentile | Percentile value: 10 | Note the output 10th percentile elevation value
3	Raster Calculator — Pump station locations	Con(flood_risk_ward.tif == 3 & dem_ward_clipped.tif < [10th percentile value from Step 2], 3, 0) Output: pump_stations.tif | Lowest 10% of High-risk zone pixels — gravity drainage insufficient

4	Raster Calculator — Combine drainage proposals	Con(pump_stations.tif == 3, 3, Con(new_drains.tif == 2, 2, 0)) Output: drainage_proposals.tif | Pump stations (Value 3) take priority where they overlap with drain locations
5	Symbology	Unique Values | Value 0 = No Colour (transparent) | Value 2 = Red #E74C3C (New Stormwater Drains) | Value 3 = Purple #8E44AD (Pump Station Locations) | Layer transparency: 20%

A5.4 — Figure 9.9: Integrated Flood Resilience Proposals Map (MAIN MAP)

All three proposal rasters stacked with the DEM terrain as base. Ward boundaries on top for reference.

Layer Order (top to bottom in Contents panel)	Transparency	Notes
ward_boundaries.gpkg	0%	White outline, no fill, 0.7pt — always top layer
waterways layer	0%	Blue lines, 1pt
coastline layer	0%	Blue lines, 2pt
drainage_proposals.tif	20%	Red (New Drains) + Purple (Pump Stations) — top proposal layer
bgi_proposals.tif	20%	Dark Green (Retention) + Light Green (Wetland) — middle layer
policy_zones.tif	45%	Red/Orange/Green zones — base policy layer
dem_ward_clipped.tif	40%	Terrain colour scheme — bottom terrain context layer

A6 — Symbology Reference for All Output Rasters

Complete colour and symbology settings for all GIS output files used in Chapter 9.

File Name	Symbology Type	Values and Colours
dem_ward_clipped.tif	Stretch	Colour: Terrain or Elevation #1 | Transparency: 40% | Use as base layer under all rasters
slope.tif	Stretch	Colour: Yellow to Red | Min (0 deg) = yellow (flat) | Max (15.4 deg) = red (steep)
flow_accumulation.tif	Classify — 5 classes	Colour: White to Dark Blue | Very Low = White | Low = Light Blue | Moderate = Mid Blue | High = Blue | Very High = Dark Navy
flood_risk_ward.tif	Unique Values	1 = Yellow #F1C40F (Low Risk) | 2 = Orange #E67E22 (Medium Risk) | 3 = Dark Red #C0392B (High Risk) | NoData = Transparent
phys_vuln_final.tif	Stretch	Colour: Blue to Red | Min = Low Physical Vulnerability | Max = High Physical Vulnerability

social_vuln_final.tif	Stretch	Colour: Purple to Red | Min = Low Social Vulnerability | Max = High Social Vulnerability
env_vuln_final.tif	Stretch	Colour: Green to Red | Min = Low Environmental Vulnerability | Max = High Environmental Vulnerability
composite_vuln_final.tif	Unique Values	1 = Yellow #F1C40F (Low) | 2 = Orange #E67E22 (Moderate) | 3 = Dark Red #C0392B (High) | NoData = Transparent
gap_drainage.tif	Unique Values	0 = No Colour (transparent) | 1 = Blue #3498DB (Drainage Deficiency) | Layer transparency: 30%
gap_retention.tif	Unique Values	0 = No Colour (transparent) | 1 = Green #2ECC71 (Retention Area Needed) | Layer transparency: 30%
gap_ecological.tif	Unique Values	0 = No Colour (transparent) | 1 = Red #E74C3C (Weak Ecological Buffer) | Layer transparency: 30%
policy_zones.tif	Unique Values	1 = Red #C0392B (Zone A) | 2 = Orange #E67E22 (Zone B) | 3 = Green #2ECC71 (Zone C) | Transparency: 30%
bgi_proposals.tif	Unique Values	0 = No Colour | 1 = Dark Green #1A9850 (Retention Ponds) | 2 = Light Green #91CF60 (Wetland Restoration) | Transparency: 20%
drainage_proposals.tif	Unique Values	0 = No Colour | 2 = Red #E74C3C (New Stormwater Drains) | 3 = Purple #8E44AD (Pump Stations) | Transparency: 20%
ward_boundaries.gpkg	No Fill	White outline, 0.7pt line weight | No fill | Add to every map as top layer
gap_points.gpkg	Unique Values on gap_type field	Drainage Deficiency = Blue circle 8pt | Retention Area = Green square 8pt | Ecological Buffer = Red triangle 8pt | Canal Encroachment = Orange diamond 8pt

End of Annexure