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Urban Blue-Green Infrastructure (BGI) Toolkit for Enhanced Resilience Towards Urban Flooding: The Case of Machilipatnam

INTERIM REPORT

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1. Background of the Project

Urban flooding has become an increasingly pressing issue in the face of climate change and rapid urbanization. The intensification of extreme weather events, such as heavy rainfall, coupled with the loss of natural drainage systems due to urban development, has heightened the frequency and severity of floods in cities worldwide. Climate change contributes to rising sea levels, erratic precipitation patterns, and more frequent storms, while urbanization leads to a proliferation of impervious surfaces, such as roads, pavements, and buildings. This reduces the capacity of urban areas to absorb rainfall, resulting in increased surface runoff and overwhelmed drainage systems.

Floods are caused by a combination of natural and anthropogenic factors. Natural triggers include intense rainfall, cyclones, storm surges, and inadequate drainage in floodplains. Anthropogenic activities, such as deforestation, encroachment on natural waterways, and unplanned urban sprawl, further exacerbate flooding risks. The transformation of natural landscapes into urban areas disrupts hydrological cycles, reducing groundwater recharge and increasing the volume and velocity of runoff. Poor maintenance or outdated stormwater infrastructure aggravates these issues, leaving cities vulnerable to waterlogging and inundation during heavy rains (Youssef et al., 2015).

Coastal cities are particularly vulnerable due to their exposure to both inland flooding from rainfall and coastal flooding from storm surges and rising sea levels. The increasing frequency of extreme events poses a significant threat to urban populations, infrastructure, and ecosystems in these regions. Addressing these challenges requires innovative, sustainable solutions that go beyond conventional grey infrastructure like stormwater pipes and concrete channels.

Blue-Green Infrastructure (BGI) is emerging as a nature-based solution that combines natural systems with engineered approaches to manage urban water sustainably. “Blue” elements, including rivers, lakes, wetlands, and water channels, work in tandem with “green” elements like vegetated areas, parks, bioswales, green roofs, and urban forests. Together, these systems mimic natural hydrological processes, improving the city’s ability to absorb, store, and manage water (Brears, 2023). BGI offers multiple advantages in managing urban flooding. It enhances water infiltration into the soil, reduces the volume and velocity of surface runoff, and provides temporary storage for excess water. Unlike traditional grey infrastructure, which is designed for single-purpose flood control, BGI delivers co-benefits. It improves air quality, promotes biodiversity, and mitigates urban heat island effects by introducing greenery and water features into urban landscapes. BGI also creates recreational spaces, contributing to the overall quality of life for urban residents. The role of BGI in mitigating flooding goes beyond stormwater management. By restoring and preserving natural water cycles, it builds resilience against climate change impacts while aligning with sustainable urban development goals. Moreover, it addresses societal challenges, such as reducing disaster risks and supporting the transition to more liveable and adaptive urban environments. BGI represents a shift toward a more holistic approach to urban planning, one that integrates ecological, social, and economic considerations to create resilient cities equipped for the challenges of the future.

The adoption and integration of BGI into urban planning frameworks are essential to combat the increasing threats posed by climate change and urbanization. By leveraging the natural functions of ecosystems, BGI presents an opportunity to create sustainable, multifunctional urban spaces that are not only capable of managing floods but also enhancing urban liveability and environmental health.

A critical aspect of climate change is the increasing frequency and severity of extreme weather events. Climate change is expected to change the frequency and intensity of rainfall, triggering more frequent flooding. Many Indian cities, particularly coastal cities, are already facing frequent flooding causing extensive damage to society and city infrastructure. In addition, urban development increases flood risk in cities due to local changes in hydrological conditions. The increase of impermeable surfaces in cities reduces the infiltration of rainwater and increases surface runoff resulting in urban flooding. Both climate change and urbanization exacerbate the flood risks in many coastal cities and strain existing urban infrastructure systems. In this scenario, the development of nature-based solutions such as BGI is recommended as a solution. BGI can be implemented at regional, neighbourhood and site scales. Due to the variety of BGI components and spatial heterogeneity of cities, regional characteristics influence the development of BGI components for a city and, subsequently, the benefits derived from it. Thus, cities in each region need to develop the layout and design of BGI components that are appropriate to the topography, and climate, particularly precipitation patterns. BGI Toolkits are crucial for cities for equipping local agencies with the resources needed to support the realization of climate resilience through the development of Blue-Green Infrastructure.

Urban Local Bodies (ULBs) in India play a pivotal role in urban development, infrastructure growth, and improving citizens' quality of life. As first responders to flooding impacts, ULBs manage emergency responses and develop resilient infrastructure. The BGI toolkit equips ULBs with strategies for stormwater management and climate resilience, offering insights into global best practices and specific tools for pilot projects at the neighbourhood scale. It serves as a foundation for broader BGI implementation in cities.

Machilipatnam, Andhra Pradesh, is the selected study location. Situated on the southeast coast, this historic port town is highly vulnerable to cyclones, storm surges, and monsoonal flooding due to its low-lying geography. Frequent severe weather events and urbanization exacerbate flood risks, making Machilipatnam a critical case for developing and demonstrating the effectiveness of BGI in mitigating urban flooding and enhancing resilience.

2. Literature Review

The literature review explores various global and Indian case studies that highlight the effective use of Blue-Green Infrastructure (BGI) and nature-based solutions for stormwater management and urban flood resilience. These studies provide valuable insights into planning and implementing BGI strategies tailored to local contexts. The best practices for the Urban Blue-Green Infrastructure (BGI) are discussed further, that include International as well as Indian best practices. The learnings from these case studies are carried forward for the development of a comprehensive BGI toolkit for the study area, Machilipatnam, focusing on enhancing resilience and mitigating urban flooding.

2.1. International Best Practices

2.1.1. New York City (NYC)'s Cloudburst Resilience Planning by Ramboll

The study by (Ramboll, 2023) emphasizes several key aspects for effective Blue-Green Infrastructure (BGI) implementation. Ramboll applied a four-step approach to cloudburst resilience planning at NYC, as shown in Figure 1, as an iterative process. It strongly advocates for multi-functionality, suggesting that BGI solutions should be designed to provide various co-benefits beyond flood resilience, such as improved air quality, recreation spaces, and ecological benefits. Economic justification is also crucial, highlighting the importance of a robust business case for BGI and the use of Benefit-Cost Analysis (BCA) to assess economic feasibility, considering both costs and co-benefits. Furthermore, the report stresses climate change considerations, explicitly incorporating future climate change scenarios into its analysis, indicating that BGI design must account for long-term resilience. Integrated planning

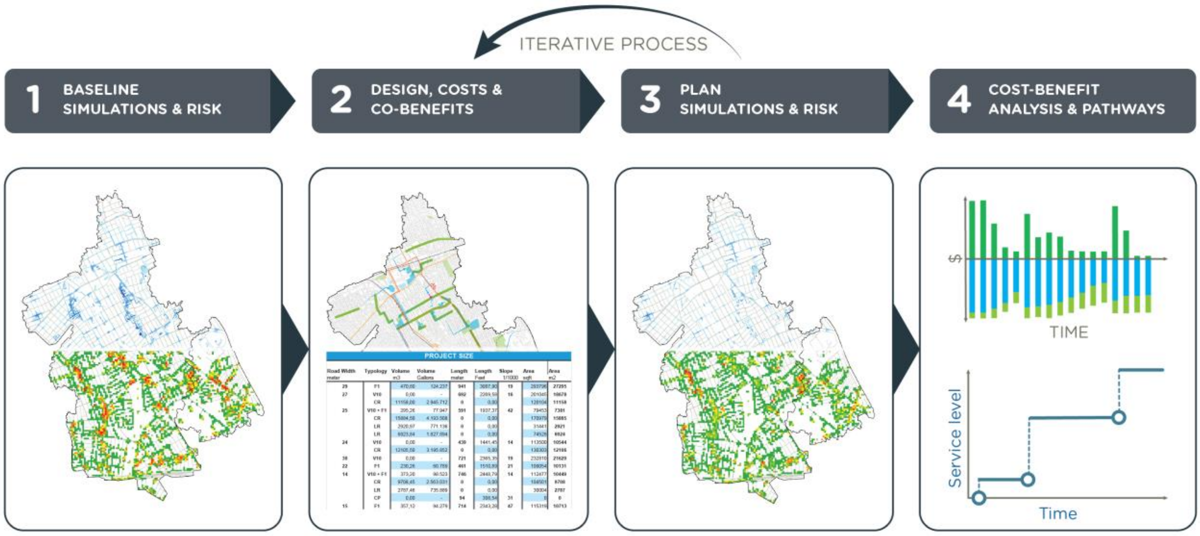

Figure 1: Ramboll's 4-step approach to cloudburst resilience planning at NYC (Source: Ramboll, 2017)

is essential for effective BGI implementation, requiring consideration of the connections between BGI and other urban systems to promote a holistic approach. Community co-benefits are vital for social acceptance and long-term success, emphasizing that BGI should provide co-benefits that improve the everyday lives of communities, with strategies to identify and maximize relevant co-benefits. While the New York study focuses on city-wide implementation, the toolkit should also consider the scalability of successful BGI interventions within Machilipatnam. Finally, the report relies on data and modelling to assess flood risk and BGI effectiveness, indicating the importance of data collection and analysis for informed decision-making (Ramboll, 2017) (Ramboll, 2023).

2.1.2. Copenhagen’s Cloudburst Management Plan

Copenhagen's Cloudburst Management Plan by Ramboll, initiated in 2012 following the destructive 2011 floods and backed by a substantial budget, employs a dual strategy to optimize urban flood protection. This plan combines nature-based solutions with engineered infrastructure, implementing surface-level blue-green solutions like "cloudburst boulevards" and retention basins in areas with space, while utilizing underground drainage tunnels and pipes in denser downtown areas. This comprehensive approach involved coordinating across municipalities and engaging citizens in property-level rainproofing. Refer **Error! Reference source not found.** for seeing how Ramboll have done a detailed site analysis and utilised various thematic layers for BGI Plan preparation at Copenhagen.

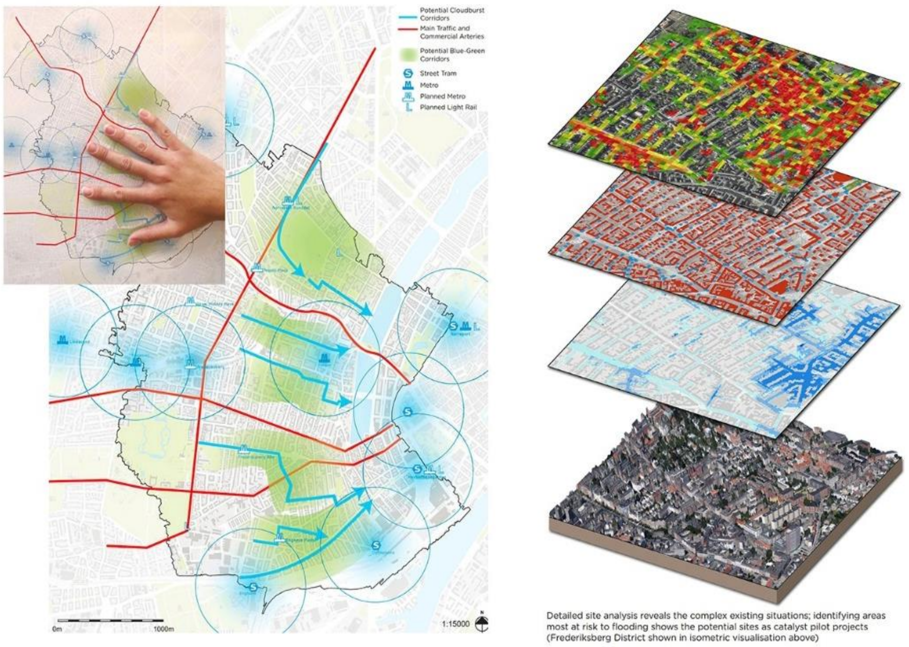

Figure 2: Detailed Site Analysis and Layers used for BGI at Copenhagen (Source: Ramboll, 2012)

Copenhagen's strategy demonstrates the effectiveness of integrated grey-green infrastructure, justified by a clear cost-benefit rationale that weighed the investment against potential damages. The plan established a new safety standard by prioritizing green retention for its added amenities and climate benefits but also incorporating underground pipes where necessary. For cities like Machilipatnam, Copenhagen's example underscores the importance of proactive, long-term master planning for flood resilience, combining BGI as a first line of defence with engineered solutions in critical areas, and employing a cost-benefit approach to secure resilience funding.

2.1.3. Singapore - ABC Waters programme

Figure 4: Overview of SIT Campus Heart (Source: PUB Singapore, 2024)

Singapore's "Active, Beautiful, Clean Waters" (ABC) Programme, launched in 2006 by Singapore's PUB (National Water Agency), is a nationwide initiative to transform utilitarian drains into naturalized waterways. It integrates stormwater management with urban design by daylighting and greening canals, creating lakes, wetlands, and riverside parks in housing estates and new developments. The program is guided by comprehensive ABC Waters Design Guidelines (PUB Singapore, 2024), which provide best practices for on-site detention, bio-treatment (raingardens, bioswales), and waterfront landscaping. Dozens of projects, from the iconic Bishan-Ang Mo Kio Park River restoration to

Figure 3: Comparison of Hydrological functions under the Traditional and ABC Waters Management Strategy (Source: PUB Singapore, 2024)

neighbourhood canal upgrades like Punggol Waterway and SIT Campus at Punggol North (Refer Figure 4), demonstrate how concrete channels were redesigned into meandering streams with recreational trails and rich vegetation. Singapore also introduced an ABC certification scheme to encourage developers to include BGI features in private projects.
Singapore's case exemplifies a holistic water-centric development approach, treating water as an environmental asset rather than just a hazard. By mainstreaming BGI citywide, Singapore improved flood control while enhancing water quality, biodiversity, and urban liveability. The ABC approach, endorsed at the highest level, institutionalized sustainable stormwater practices in planning and construction. Key outcomes include the attenuation of runoff peaks through distributed measures, the rejuvenation of urban landscapes, and greater public appreciation of waterways. Singapore exemplifies how clear design guidelines and policy support can scale up BGI, making the city more climate-resilient and aesthetically attractive. (Refer Figure 3)

Machilipatnam can learn from Singapore that functional infrastructure can double as a public amenity. Applying ABC principles, such as rain gardens, vegetated detention ponds, and tree-lined bioswale corridors, can transform Machilipatnam's flood control measures into opportunities for beautification and recreation. The Singapore experience also highlights the need for supportive policies; Machilipatnam's planners could develop local BGI design standards or incentives to ensure new developments include permeable surfaces and drainage-friendly landscaping. Moreover, a long-term vision to become a "sponge city" or "garden city" can rally public and political support. In essence, Singapore provides a proof-of-concept that investing in nature-based stormwater systems yields dividends in resilience and quality of life, offering a compelling blueprint for Machilipatnam's climate-adaptive growth.

2.2. Indian Best Practices

2.2.1. Ahmedabad - BGI network in urban areas - Geospatial approach

As given in the research paper by (Kaur & Gupta, 2022), a city-scale study in Ahmedabad utilized a geospatial approach, employing GIS and remote sensing, to design an integrated blue-green network for stormwater management. This data-driven analysis identified existing parks, gardens, and lakes as natural nodes for water storage and linked them via optimal corridors, following natural drainage paths. Multi-criteria suitability analysis and least-cost path modelling were applied to map where new green corridors would most effectively convey runoff, creating a BGI network plan that complements the city's conventional drainage system.

This approach revealed the high potential for BGI in Ahmedabad, demonstrating how connecting fragmented green/blue spaces can reduce waterlogging and enhance groundwater recharge, even in heavily urbanized areas. The study's methodology, leveraging open-source datasets and GIS, offers a pragmatic and replicable tool for cities, including Machilipatnam, to cost-effectively identify strategic BGI interventions. By adopting similar GIS mapping to link natural drainage lines with green corridors, Machilipatnam can improve storm runoff capture and bolster groundwater resources, providing a template for evidence-based BGI planning.

2.2.2. South Buckingham Canal in Chennai by Sponge Collaborative

The Sponge Collaborative or Team Sponge's work titled "The Sponge Handbook: Using the Landscape Approach to transform the South Buckingham Canal Area" was facilitated by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and the Urban Design Collective as part of the 'Cities Fit for Climate Change' global project (Biswas et al., 2019).

Chennai initiated the "Eyes on the Canal" project in 2019, an open design competition aimed at reimagining a 3.5 km stretch of the historic Buckingham Canal as resilient BGI. Supported by GIZ's Cities Fit for Climate Change project, this initiative sought innovative ideas to restore canal-side open spaces, increase permeability, and reconnect the canal with surrounding communities (Refer Figure 5). Local NGOs facilitated community participation through activities like neighbourhood workshops and "river walks," working alongside city officials to ensure that designs reflected public needs and local knowledge.

This competition demonstrated that engaging communities and experts can yield innovative solutions and enhance public awareness of BGI. The winning proposals, aligned with the

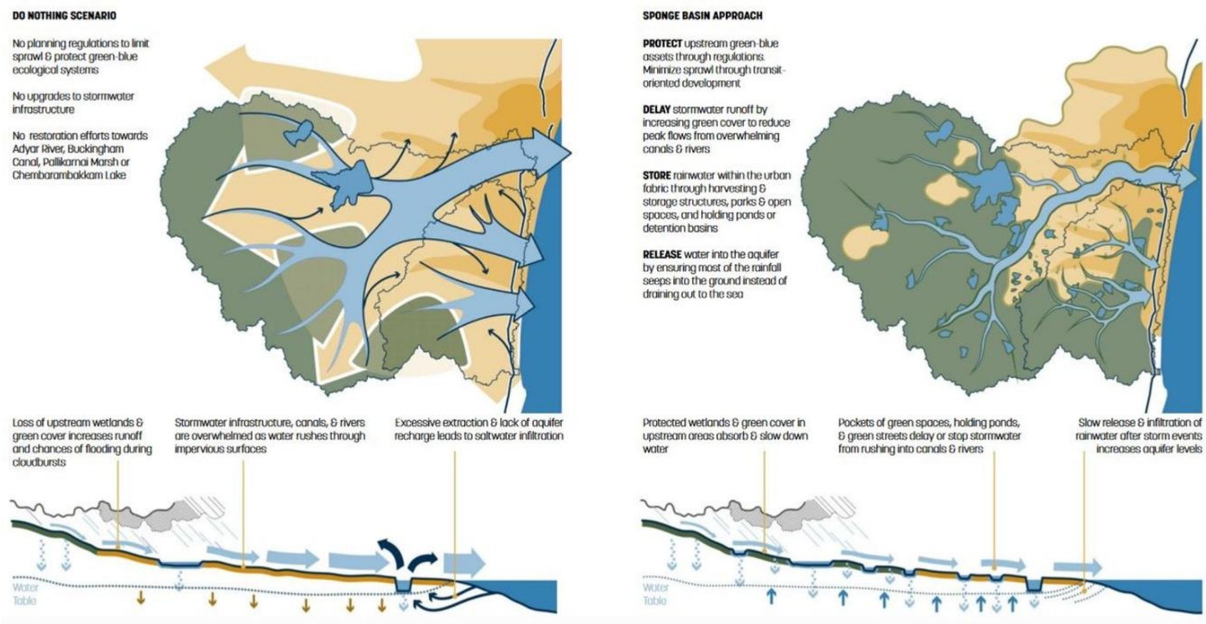

Figure 5:Comparison of Sponge Basin Approach and Do-Nothing Scenario at Chennai (Source: Biswas et al., 2019)

Resilient Chennai strategy, integrated social, ecological, and economic resilience into urban design, preparing the city for future floods. This participatory planning approach has spurred broader action, with city agencies undertaking the restoration of 210 other water bodies and wetlands and improving cross-department coordination for flood resilience. Chennai's efforts highlight the value of local engagement in a coastal city's flood strategy, showing cities like Machilipatnam the impact of involving citizens and stakeholders in co-designing BGI solutions to enhance flood mitigation and build public "ownership" of BGI as a climate adaptation asset.

2.2.3. Kochi Mullassery Canal

As given in the research paper by (Sánchez & Govindarajulu, 2023), Kochi's experience highlights the transformative power of citizen participation in urban planning, demonstrating how bottom-up initiatives can directly influence official land-use policy. The Mullassery Canal "urban lab" empowered residents to actively shape redevelopment efforts, fostering a renewed sense of community stewardship over waterways. This collaborative approach not only produced plans for canal clearance and the addition of recreational spaces but also strengthened social resilience, with "water" emerging as a unifying civic vision for Kochi's neighbourhoods. The restoration of the Mullassery Canal, alongside wetland conservation, is expected to mitigate future urban floods, enhance ecosystem services like groundwater recharge, and create new recreational amenities.

This case emphasizes the importance of combining scientific input with community wisdom for locally tailored solutions. Kochi's model, which includes protecting wetlands and cleaning canals, can guide cities like Machilipatnam in restoring their own water bodies and green spaces as a flood defence network. It validates the "sponge city" approach within an Indian context, where citizen engagement and inter-agency collaboration lead to practical outcomes. For Machilipatnam, adopting a participatory framework similar to 'EnteKochi' could ensure that BGI interventions are culturally accepted, maintained, and contribute to long-term climate adaptability (Sánchez & Govindarajulu, 2023).

2.3. Key Comparative Insights of International and Indian Best Practices

The above case studies, though diverse in context, collectively highlight that blue-green infrastructure is a cornerstone of climate-adaptive urban planning, especially for flood-prone coastal cities. All six examples demonstrate how integrating natural water management into the city fabric can reduce flood risks and provide co-benefits like improved groundwater recharge, urban cooling, biodiversity habitat, and quality public spaces.

Notably, the Indian cases (Chennai, Kochi, Ahmedabad) show that even in fast-growing cities with limited prior BGI integration, targeted interventions from community-driven canal clean-ups to GIS-based network planning can kick-start a resilience transition. Meanwhile, the international cases (Copenhagen, Singapore, New York) illustrate the value of formal frameworks and long-term investments, whether it's a city-wide cloudburst masterplan, nationwide design guidelines, or a robust cost-benefit analysis, a strategic approach ensures that BGI is systematically embedded in urban development.

A key insight across the board is the importance of community and multi-stakeholder involvement. In Chennai and Kochi, residents became co-creators of resilience their participation not only generated contextually appropriate solutions but also fostered local stewardship of BGI assets (Sánchez & Govindarajulu, 2023). This bottom-up energy complements the top-down support seen in Singapore (where government vision and policy enabled widespread implementation) and New York (where authorities are actively seeking community buy-in for neighbourhood cloudburst projects). For Machilipatnam, this suggests that effective BGI planning should blend grassroots engagement with institutional commitment. Engaging citizens (like Chennai's "Eyes on the Canal" or Kochi's "EnteKochi" did) can ensure solutions are well-used and maintained, while strong leadership and clear guidelines (akin to Singapore's ABC model or Copenhagen's prioritized roadmap) can provide the necessary resources and regulatory backing (Sánchez & Govindarajulu, 2023).

Table 1: Literature study Inferences of International and Indian Best Practices (Source: Author, 2025)

Case Study Area & Project details	Implement-ation Year	Key Inferences
New York – Cloudburst Resilience Planning (Ramboll, 2017) (Ramboll, 2023)	2025	• Evidence-based planning ensures targeted interventions. • Community engagement in maintenance of BGI enhances project success.
Copenhagen – Cloud Burst Management Plan (Ramboll, 2012)	2012	• Advanced modelling improves flood preparedness. • Strong policy backing ensures systematic implementation.
Singapore – ABC Waters programme - Projects (PUB Singapore, 2024)	2012	• Policy-driven BGI ensures large-scale impact. • Long-term investment is crucial. *(Referring to ABC projects at Kallang River-Bishan Ang Mo Kio Park project and at Sungei Pandan, Sungei Ulu Pandan and Geylang River completed in 2012)*
Ahmedabad – (Kaur & Gupta, 2022)		• Public-private partnerships can support BGI. • Multi-functional design ensures long-term viability.
Chennai South Buckingham Canal – (Biswas et al., 2019)	2023	• Grassroots engagement enhances BGI sustainability. • Integrating traditional water wisdom can complement modern infrastructure. • Hydrology in urban planning is crucial, and upstream wetlands must be protected • Adopt Sponge principles early on.
Kochi Mullassery Canal – (Sánchez & Govindarajulu, 2023)		• Active citizen participation can drive long-term success. • GIS-based planning helps prioritize interventions.

Another comparative takeaway is how multi-functional design and co-benefits drive success. All cases moved beyond seeing flood infrastructure in purely technical terms. Singapore's parks and waterways, Copenhagen's landscaped retention streets, and New York's green schoolyards all serve everyday functions even when it's not raining – be it recreation, aesthetics, or environmental education. This multi-functionality not only maximizes the value of investments but also builds public support: people are more likely to champion and preserve infrastructure that they can enjoy daily. Machilipatnam should therefore prioritize BGI interventions that address flooding and enhance the urban experience.

Finally, these case studies stress the need for a forward-looking, adaptive strategy. Climate projections indicate more extreme rainfall for cities worldwide, and the responses from Copenhagen to New York reflect a shift towards anticipatory planning. Machilipatnam, as a coastal city with monsoonal extremes, can significantly benefit from a similar proactive stance. Developing an “Urban BGI Toolkit” with lessons from these cases means incorporating: a visionary plan (like Copenhagen’s and Singapore’s) that sets targets for flood safety and green coverage; a robust analytical foundation (like Ahmedabad’s and NYC’s use of data and modelling) to identify the best interventions; and a phased implementation roadmap (addressing critical flood zones first, as all cities did post-disaster).

In sum, the comparative insight for Machilipatnam is clear, by learning from both local Indian initiatives and global best practices, the study area can craft a comprehensive BGI-based resilience strategy that is practical, inclusive, and tuned to both present needs and future climate challenges. This synergy of community empowerment, scientific planning, and policy support will be key to turning Machilipatnam into a safer and more sustainable coastal city.

3. Study Area and Problem Description

The section describes the study area Machilipatnam, Andhra Pradesh, briefly as a coastal city facing increasing vulnerability to frequent flooding and cyclones. Understanding the specific challenges posed by various hazards in Machilipatnam is crucial for the development of an effective Blue-Green Infrastructure Toolkit.

3.1.Regional Context

The study area, Machilipatnam is located in Krishna District of Andhra Pradesh (AP) state, India (Refer Figure 6). It is in the close vicinity of the Andhra Pradesh Capital Region, 60 km away from Vijayawada towards coast. Geographical coordinates of Machilipatnam are 16° 11' 22.28" E and 81° 8' 15.48"N (MUDA, 2023) (Krishna District Website, 2025).

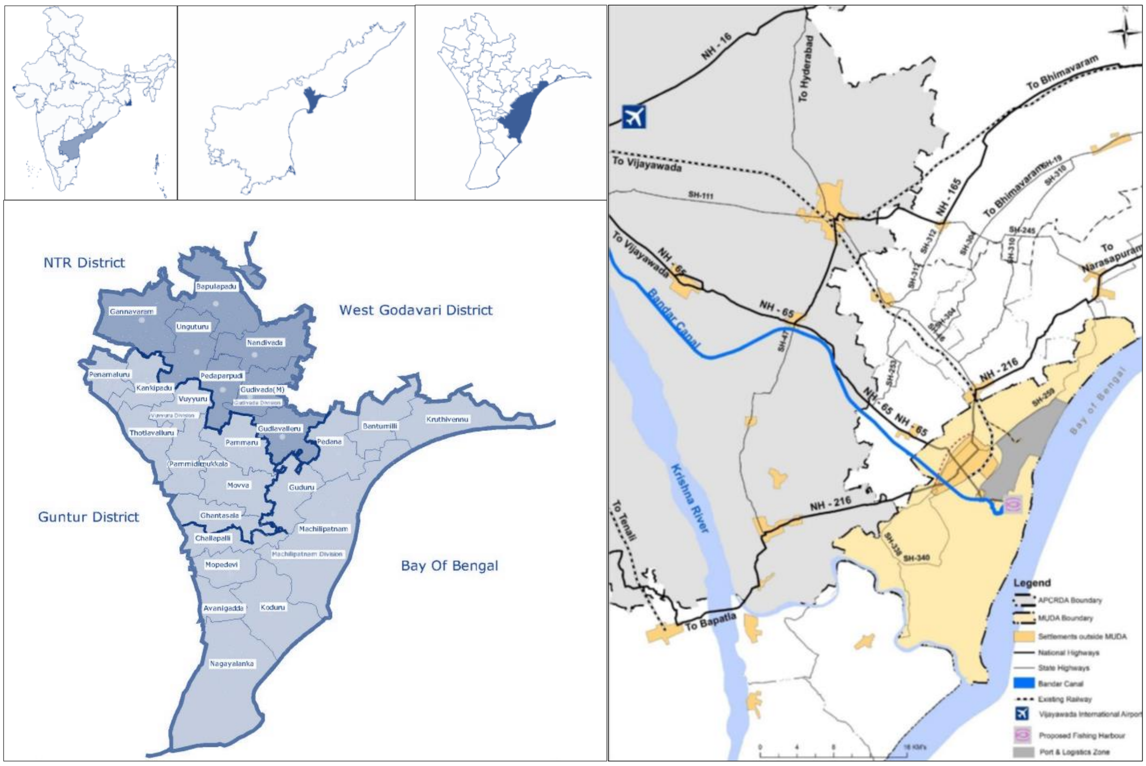

Figure 6: Regional Context of study area – Machilipatnam (Source: Krishna District Website, 2025; MUDA, 2023)

3.2.Problem Description in the Study area

Andhra Pradesh, situated along India’s south-eastern coastline, is highly susceptible to the impacts of both frequent flooding and severe cyclonic events. The state's geography, characterized by a long coastline and the presence of major river deltas, makes several of its districts and Mandals particularly vulnerable to these natural hazards. As evidenced in the provided maps illustrating Mandal-level flood and cyclone proneness across Andhra Pradesh, a significant portion of the coastal belt experiences recurrent inundation due to heavy rainfall, storm surges associated with cyclones, and the overflowing of rivers. These events often lead to widespread damage to infrastructure, agricultural lands, and residential areas, significantly impacting the livelihoods and well-being of the local population.

From the Mandal level study conducted by Andhra Pradesh State Disaster Management Authority (APSDMA) for entire AP state, it can be observed that the study area Machilipatnam is prone to Flooding, Storm Surge, Cyclones and Heatwaves, based on the data published on website, in 2024. Refer Figure 7, Figure 10, Figure 9 and Figure 8 for observing affected locations, including Machilipatnam Mandal.

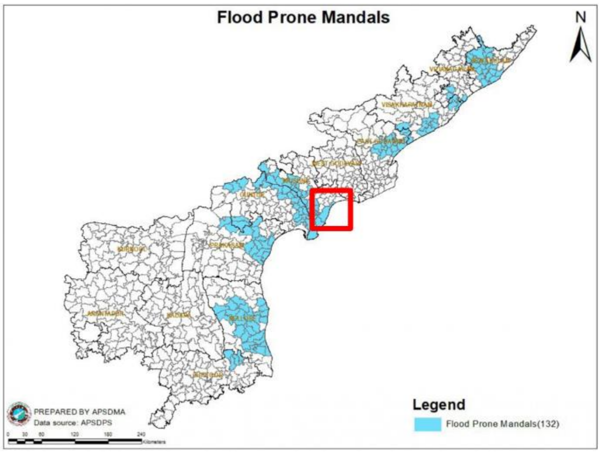

Figure 8: Flood Prone Mandals of AP where Machilipatnam is highlighted (Source: APSDMA, 2024)

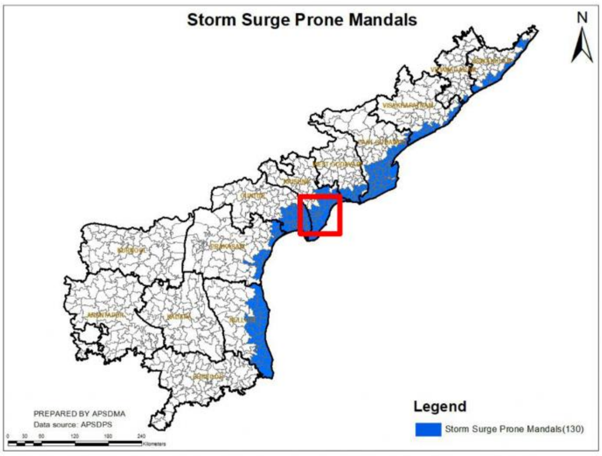

Figure 7: Strom Surge Prone Mandals of AP where Machilipatnam is highlighted (Source: APSDMA, 2024)

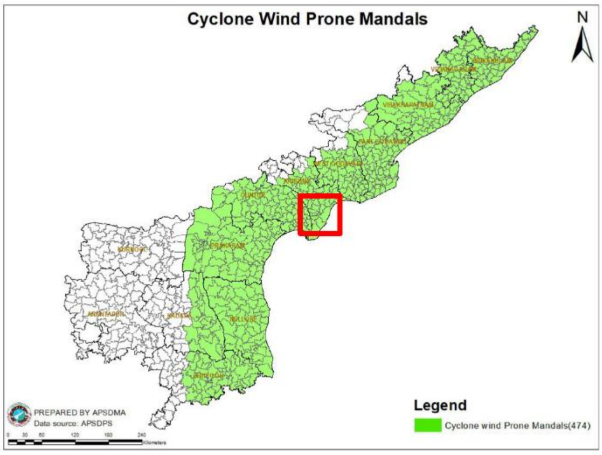

Figure 9: Cyclone Prone Mandals of AP where Machilipatnam is highlighted (Source: APSDMA, 2024)

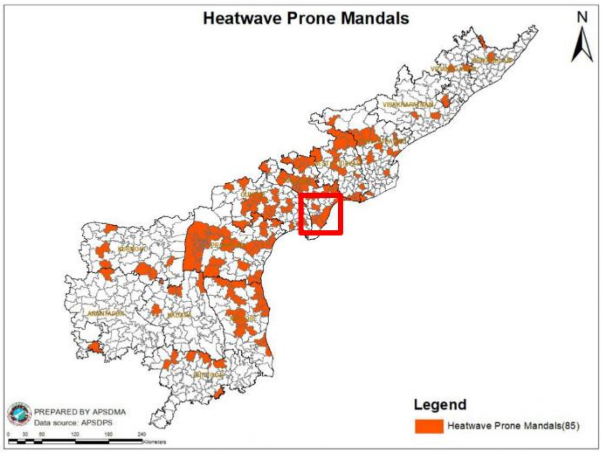

Figure 10: Heatwave Prone Mandals of AP where Machilipatnam is highlighted (Source: APSDMA, 2024)

Within this context of heightened vulnerability in Andhra Pradesh, the study focuses on Machilipatnam, a historic port city located on the state's southeast coast (16.17°N 81.13°E). Machilipatnam, also known as Masulipatnam or Bandar (Port in Persian), is the administrative center of the Krishna district in Andhra Pradesh. The city has ancient origins, with evidence suggesting it was a major trading hub even before the arrival of European powers. The British East India Company established a trading post here in the 17th century, further boosting its commercial importance. Machilipatnam is the 16th largest urban centre with municipal corporation status in Andhra Pradesh among 110 urban local bodies. Plan Area is spread over

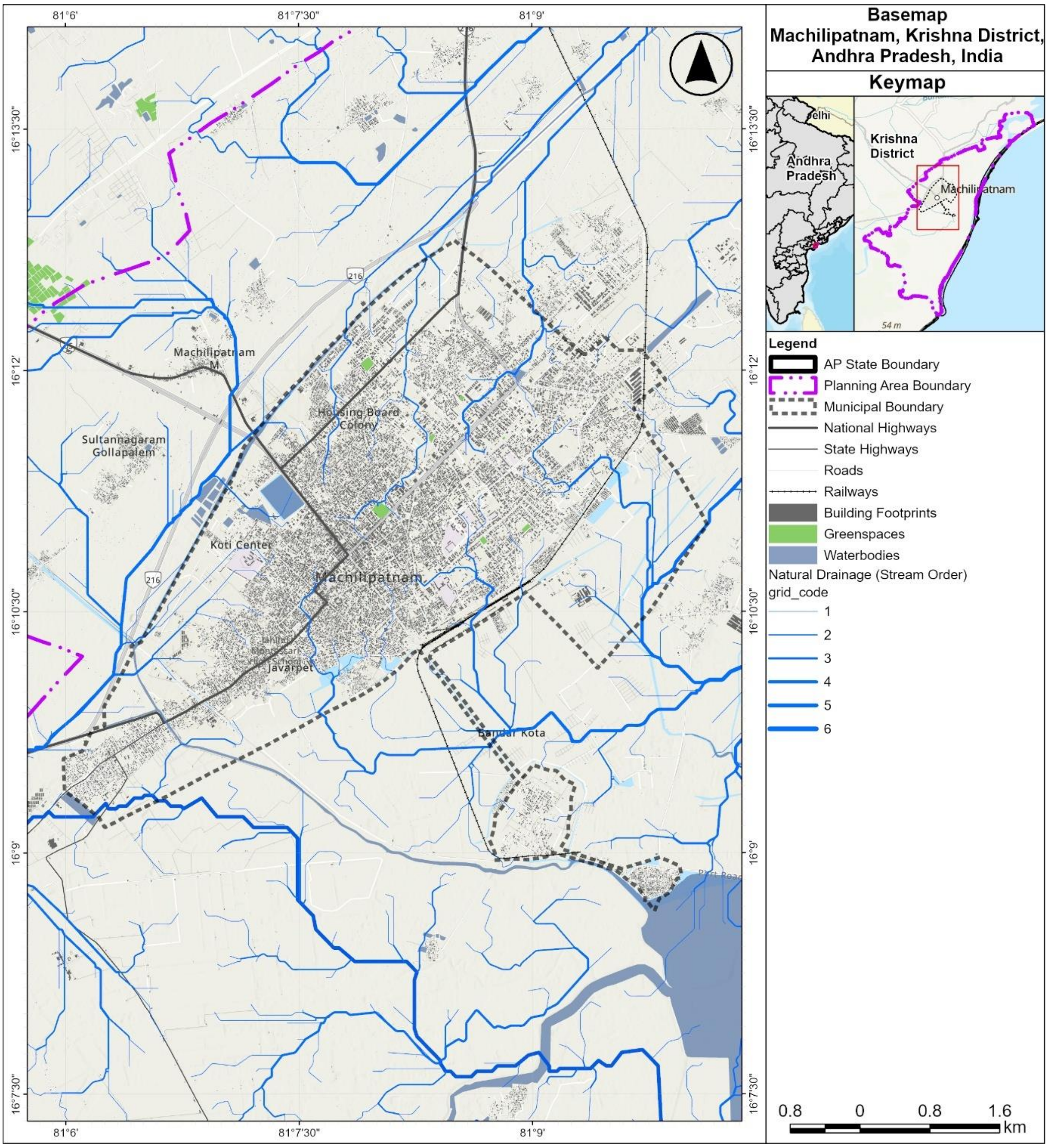

Figure 11: Basemap - Municipal extent, showing Settlements, Road Networks, Natural Drainage, Open spaces and Waterbodies (Source: Author, 2025)

~402 sq.km. comprising of areas under Machilipatnam Municipal Corporation (~24 sq.km.) and 29 villages (~378 sq.km.) thus comprises of Urban (71%) and Rural (29%) Population (MUDA, 2023). The base map of Machilipatnam Municipal Corporation (Municipal extent) is shown in Figure 11.

Machilipatnam faces a dual threat from both coastal flooding, often exacerbated by storm surges during cyclonic events originating in the Bay of Bengal, and inland flooding due to heavy monsoon rainfall. The city's low-lying topography further compounds its susceptibility to inundation, making it particularly vulnerable during severe weather episodes. Consequently, Machilipatnam has been identified as a critical location for developing and implementing nature-based solutions like Blue-Green Infrastructure to enhance its resilience against these recurring and intensifying flood risks.

Machilipatnam by virtue of its geographical location along the Eastern Coastal stretch of India, is the most vulnerable. According to the Hazard Assessment prepared by the Machilipatnam Municipal Corporation (supported by APSDMA and UNDP), cyclones, heat waves and floods are the natural hazards identified in Machilipatnam based on one-to-one consultation (refer Figure 12). Further, Cyclones and Heat waves have high chance of occurrence followed by Flood (moderate chance of occurrence) and Drought as per the Risk mapping carried out for Machilipatnam Mandal (MUDA, 2023).

Revenue Mandal	Cyclone	Flood	Drought	Heat wave
Vijaywada (Urban)	M	H	L	H
Machilipatnam	H	M	L	H

Risk Mapping	High Chance of Occurance	Moderate Chance of Occurrence	Low Chance of Occurrence

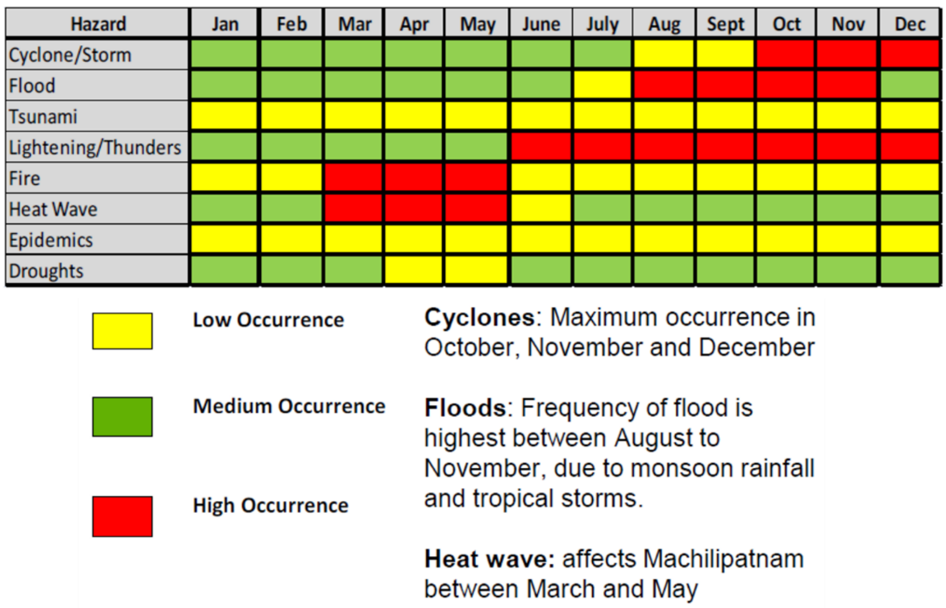

Figure 12: Risk Mapping for Machilipatnam Mandal (Source: MUDA, 2023)

4. Objectives & Detailed Methodology

4.1. Aim and Objectives

This project aims to develop a Blue-Green Infrastructure Toolkit for Machilipatnam located on the east coast of Andhra Pradesh with the following objectives:

1. To analyse the existing stormwater infrastructure network and capacity of the city based on the regional natural drainage pattern and linkages
2. To analyse the existing condition's response to various future extreme events and identify the issues
3. To develop Conceptual Blue-Green Infrastructure Plans (BGIP) for the city
4. To evaluate the performance of proposed BGI in flood mitigation in various future scenarios
5. To develop detailed design elements BGI, such as bioswale, detention and retention areas in public spaces, for a selected neighbourhood

4.2. Methodology

This research aims to develop a Blue-Green Infrastructure Toolkit for a sub-city (a sub-watershed within a city) located on the east coast of southern India. The methodology for developing the Blue-Green Infrastructure (BGI) Toolkit for Machilipatnam, Andhra Pradesh, will commence with the creation of a comprehensive Compendium of BGI Tools. The proposed process and methods, detailed in the form of stages or phases, are shown in the Figure 13. The first phase will involve a thorough exploration of existing knowledge regarding BGI, encompassing an overview of various BGI approaches and their specific components, a detailed analysis of the multifaceted benefits that BGI can offer to urban environments, and a

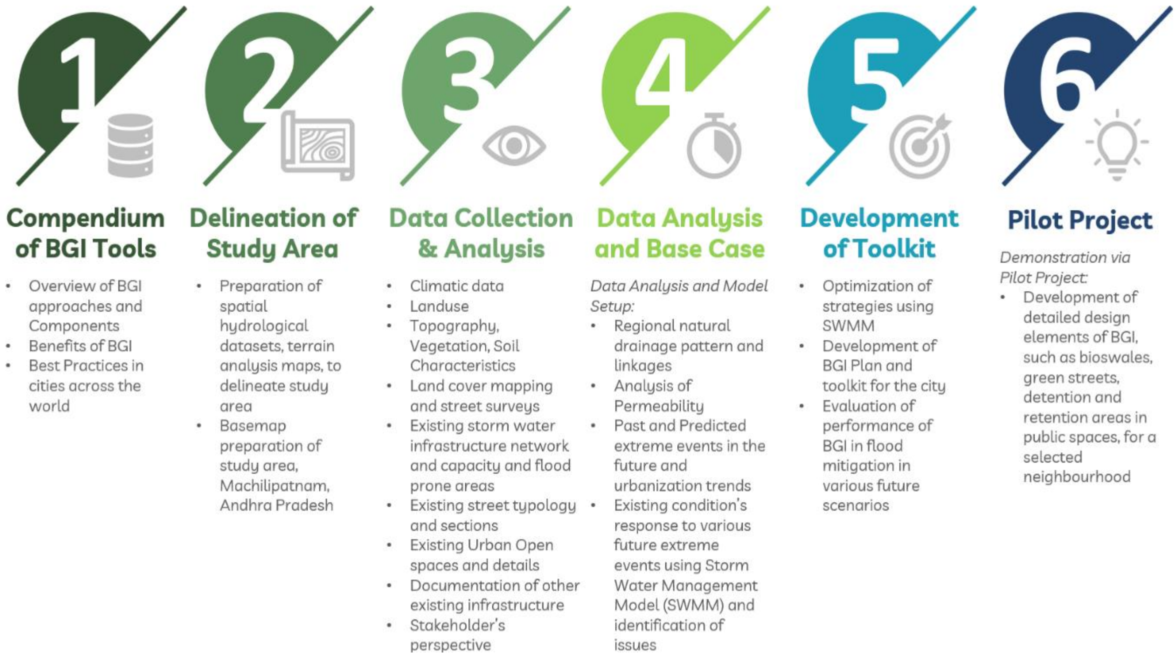

Figure 13: Stages of the Project (Source: Author, 2025)

review of best practices and successful BGI implementations in cities across the globe facing similar challenges. Following this, in second phase, foundational understanding, the project will proceed to Study Area Delineation, where the specific geographical boundaries of the study within Machilipatnam will be clearly defined, likely focusing on a sub-city or a particularly flood-vulnerable sub-watershed. The subsequent third phase, will involve intensive Data Collection and Preliminary Analysis. This will entail gathering a wide array of data crucial for understanding the study area's characteristics, including climatic data such as rainfall patterns and extreme weather events, historical, present, and future land use information, and the collection of stakeholder perspectives through surveys and consultations. Furthermore, this phase will involve the acquisition and processing of crucial spatial data layers for integration into a Geographic Information System (GIS). These thematic layers (refer to Figure 14) will form the foundation for subsequent analysis and will include a soil type map, a slope map derived from topographic data, a layer delineating pervious and impervious surfaces obtained from land cover mapping, a layer indicating road proximity, and a drainage density map. It is anticipated that further research may identify additional relevant thematic layers that will be incorporated into this dataset. Upon the completion of data collection, the project will move into Data Analysis and Base Case development, the fourth phase. This phase will involve a

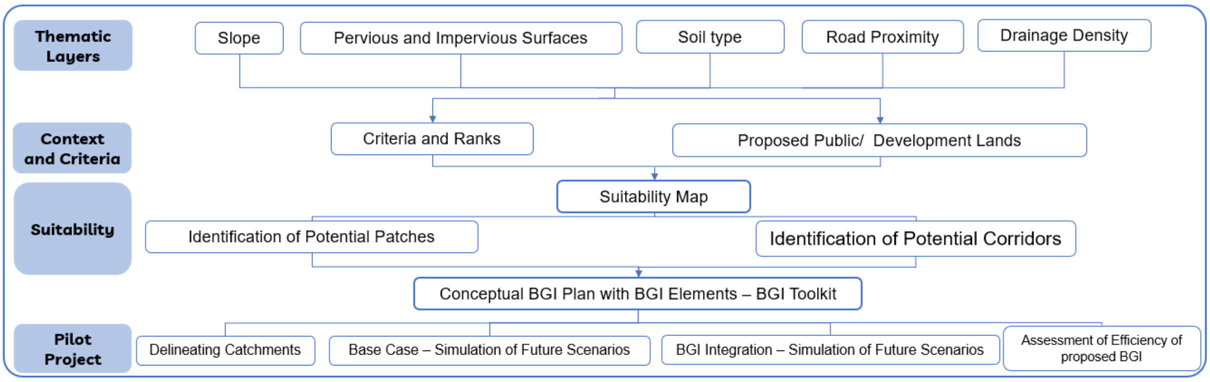

Figure 14: Detailed Methodology from Stages 4 to 6 (Source: Author, 2025)

detailed analysis of the collected data, including the integration and analysis of the aforementioned GIS layers. These layers will be crucial for understanding the spatial distribution of factors influencing BGI suitability. For instance, the soil type map will inform infiltration potential, the slope map will guide the placement of certain BGI elements, the pervious and impervious surfaces layer will highlight areas contributing to runoff, road proximity will indicate potential locations for green streets, and drainage density will reveal areas with existing drainage networks. This phase will also involve setting up and calibrating the Storm Water Management Model (SWMM).

Key activities will include analysing the regional natural drainage patterns and linkages, conducting a thorough analysis of permeability across the study area, examining past and predicted future extreme weather events and urbanization trends, and using the SWMM model to simulate the existing condition's response to various future extreme events to identify critical issues and vulnerabilities. The fifth phase will be the Development of the Toolkit. This will involve utilizing the analysed GIS layers in an overlay analysis to identify suitable sites for various BGI interventions, optimizing the identified BGI strategies using the SWMM model to maximize their effectiveness, developing a comprehensive BGI Plan and the associated toolkit document tailored for Machilipatnam, and rigorously evaluating the performance of the proposed BGI interventions in mitigating flood risks under various future scenarios. The final phase of the methodology will be the Pilot Project. This will involve a practical demonstration of the BGI plan through the development of detailed design elements for specific BGI components, such as bioswales, green streets, and detention and retention areas in public spaces, within a selected neighbourhood of Machilipatnam. This pilot project will serve as a real-world test and showcase of the BGI toolkit's applicability and effectiveness.

4.3.Deliverables

The BGI toolkit will serve as a comprehensive document that provides an overview of Blue-Green Infrastructure (BGI) approaches and components, showcasing best practices from across the globe. It will include conceptual Blue-Green Infrastructure Plans (BGIP) tailored to the selected sub-city, outlining methodologies and BGI components such as retention areas, green streets, conveyance streets, and bioswales. Furthermore, the toolkit will demonstrate the application of BGIP through a pilot project, featuring detailed design and implementation strategies for BGI components at the neighbourhood scale, enabling local agencies to enhance urban resilience against flooding.

5. Description of Data Used (or to be used)

A critical component of the study is the utilization of appropriate and reliable data. This section provides a comprehensive description of the data used, including its sources, based on its relevance to the study area analyses. Understanding the nature of this data is essential for interpreting the subsequent results and conclusions. In the context of Machilipatnam, the following data were collected for carrying out the analysis and developing BGI. The data collected from various organizations listed in Table 3, are given below:

- Existing Land Use including following
    - Road network - Road typology/ hierarchy
    - Parks, Open spaces
    - Water bodies – Rivers, ponds, streams/canals, sea, etc.
    - Land ownership map (available government lands)
    - Eco-sensitive zones (wetlands)
- Physical Infrastructure- Exiting and Proposed
    - Drainage Network (Stormwater & Sewage) infrastructure - drainage lines, Sewage Treatment Plants, etc.
    - Street Utilities - Electricity supply and telecommunication infrastructure, etc.
    - Water Supply and Management - Water Supply lines, Over-Head Tanks, etc.
- Soil Type and Permeability maps
- Ground water level and quality
- Proposed infrastructure development plans and projected data for the physical infrastructure proposals

The integration of parks, open spaces, and water bodies in urban areas forms the foundation of BGI. Furthermore, the integration of permeable surfaces, such as permeable pavements or rain gardens, in urban drainage systems is a crucial component of BGI. Data about existing drainage infrastructure, along with soil type, informs the design of these systems. Understanding the topography of Machilipatnam is essential for planning the placement of blue-green elements, such as retention ponds, as topographic maps can identify low-lying areas that are more likely to be flood-prone, offering opportunities to create retention basins to absorb excess water during heavy rain events.

In addition to data on existing conditions, the proposed infrastructure development plan and draft master plan were collected to assess current deficiencies in infrastructure, anticipate future challenges that the city may face and forecast multiple potential future scenarios. Considering the various possible future scenarios while developing BGI plans ensures that BGI can adapt to changing conditions and remain resilient in the face of unforeseen challenges. Few of the key data collected on Machilipatnam are presented in this section, divided into 4 sub-sections, namely, Regional level (Watershed/ State/ District level), Mandal level - Machilipatnam Mandal extent, Municipal level - Machilipatnam Municipal extent and Zonal level - within Machilipatnam Municipal extent.

5.1.At Regional level (Watershed/ State/ District level)

1. Ground Water level data

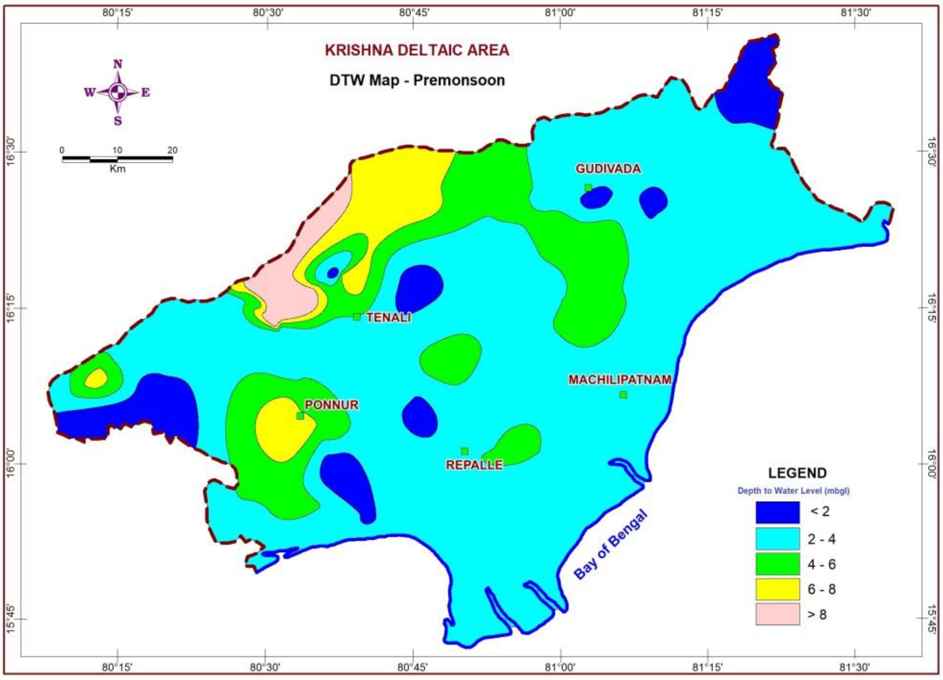

Figure 15: Depth to Water Level - Pre-Monsoon (2019) (Source: CGWB & Krishna, 2021)

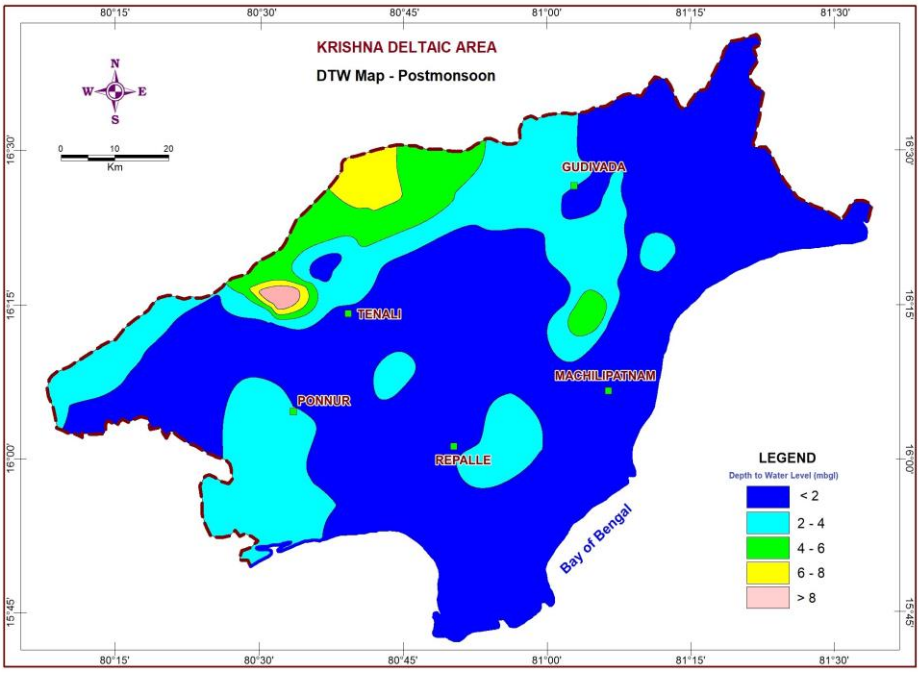

Figure 16: Depth to Water Level - Post-Monsoon (2019) (Source: CGWB & Krishna, 2021)

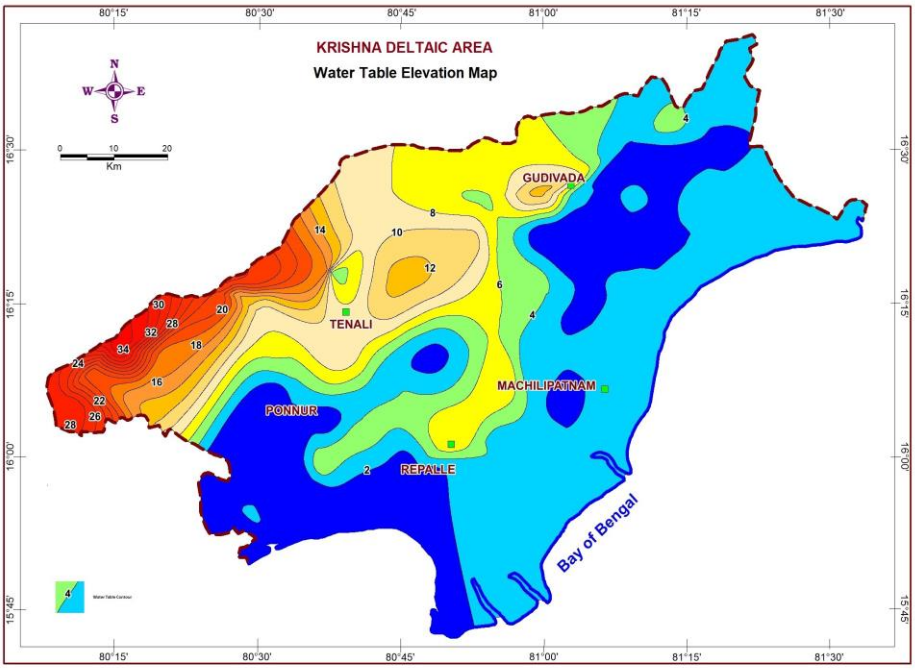

Figure 17: Water Table Elevation data (Source: CGWB & Krishna, 2021)

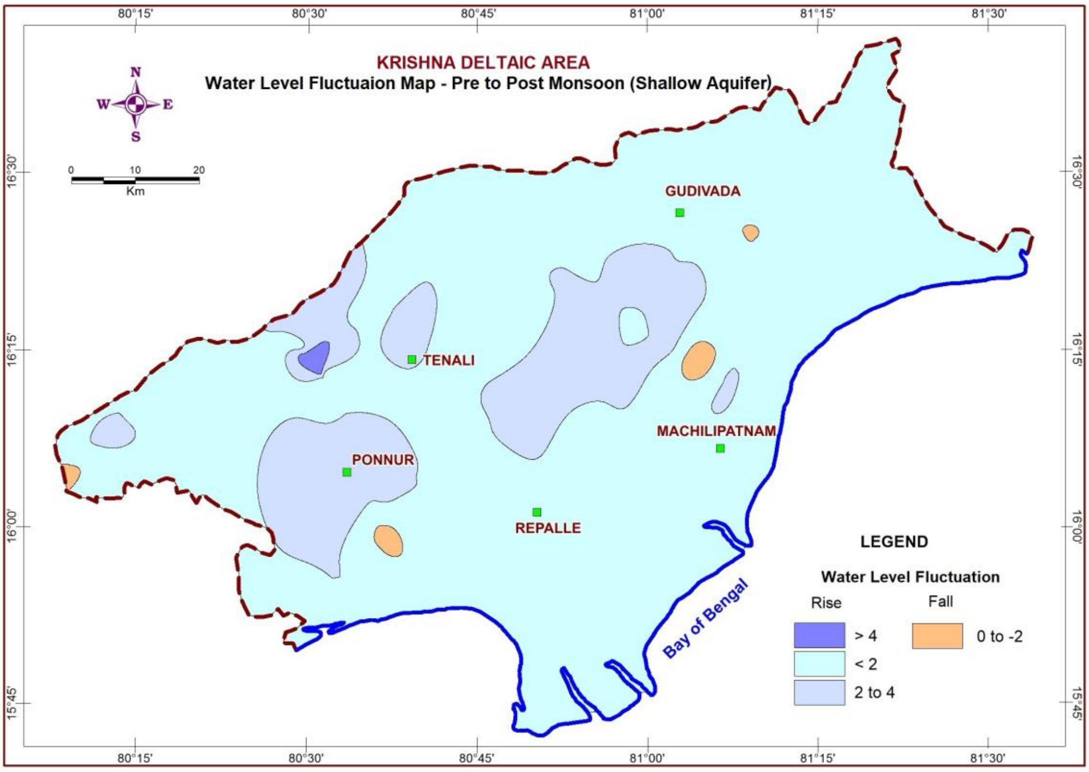

Figure 18: Shallow Aquifer - Water Level Fluctuation (Pre to Post monsoon, 2019) (Source: CGWB & Krishna, 2021)

2. Soil type

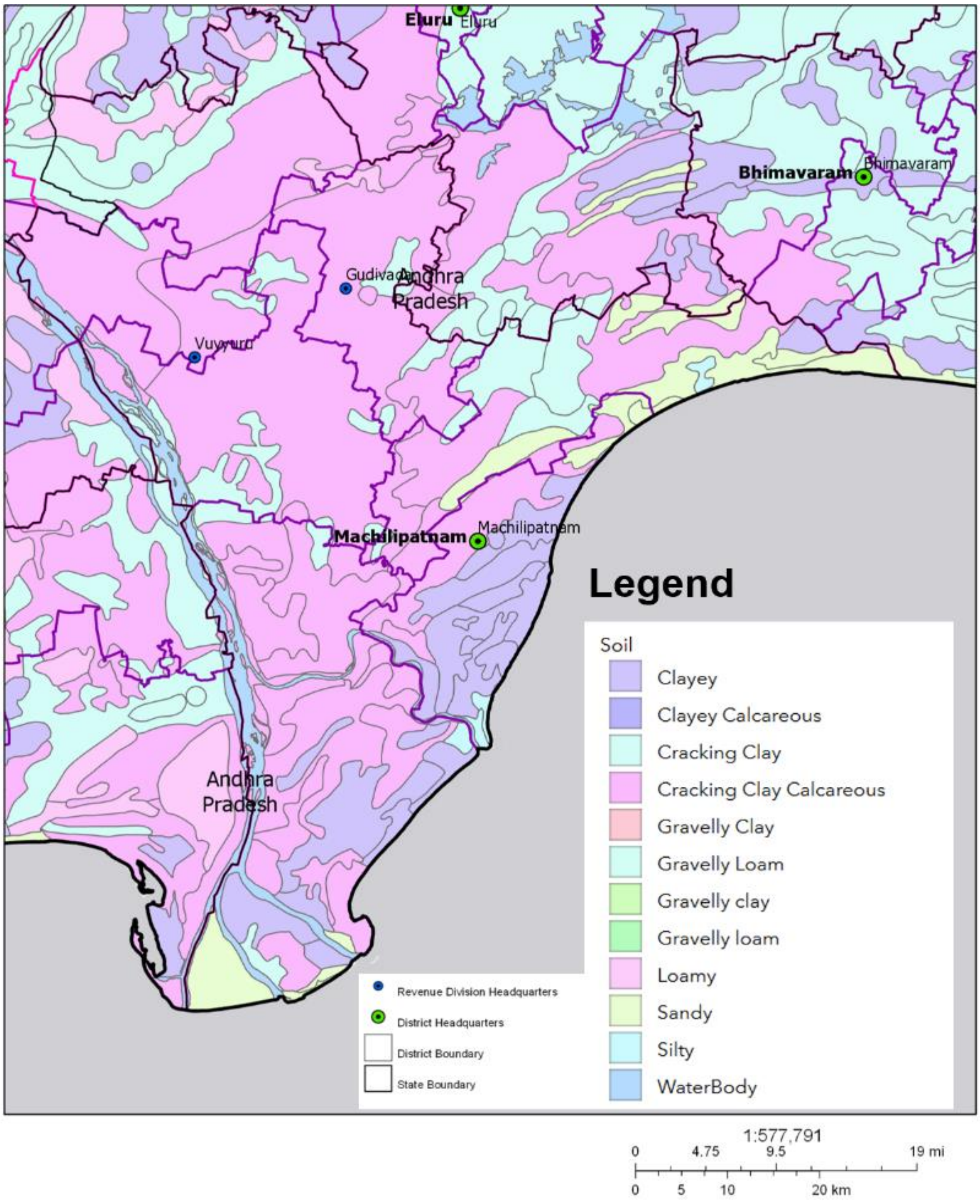

Figure 19: Soil Type data - Machilipatnam (regional context) (Source: APSAC Web GIS portal, 2025)

5.2. At Mandal level – Machilipatnam Mandal extent

1. Natural resources (Waterbodies, Stream Networks, Watersheds)

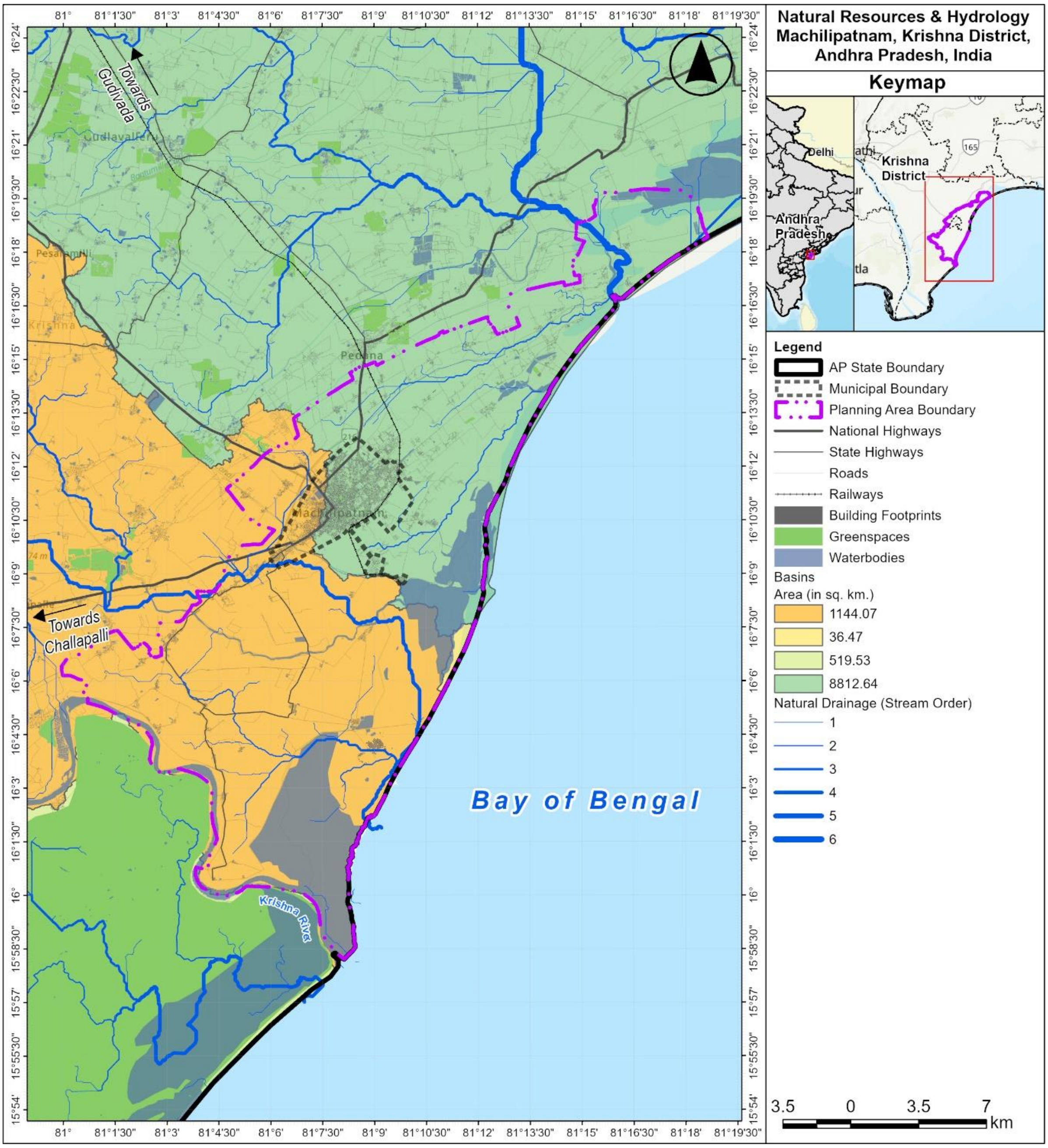

Figure 20: Natural resources and Hydrology – Mandal Extent (Waterbodies, Stream Networks, Watersheds) (Source: Author, 2025)

2. Soil Type

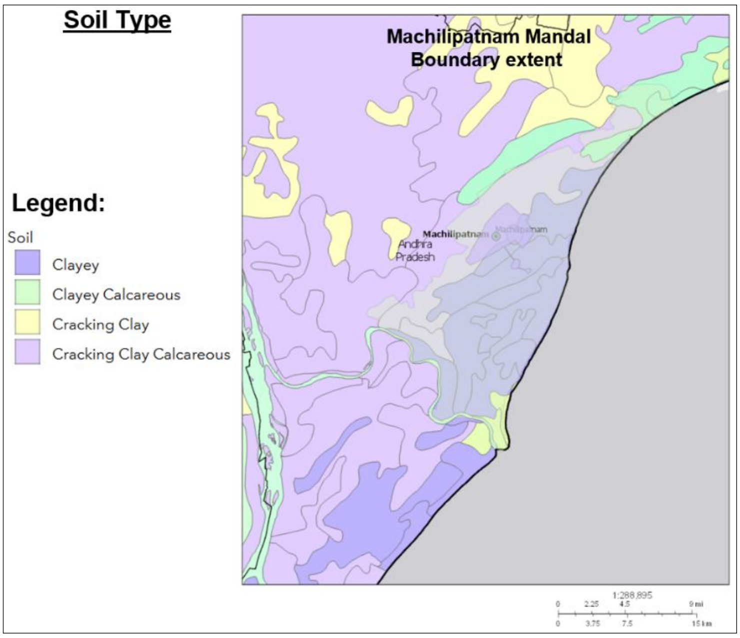

Figure 21: Soil type Machilipatnam Mandal extent (Source: APSAC Web GIS portal, 2025)

3. Groundwater level data - from APWRIMS

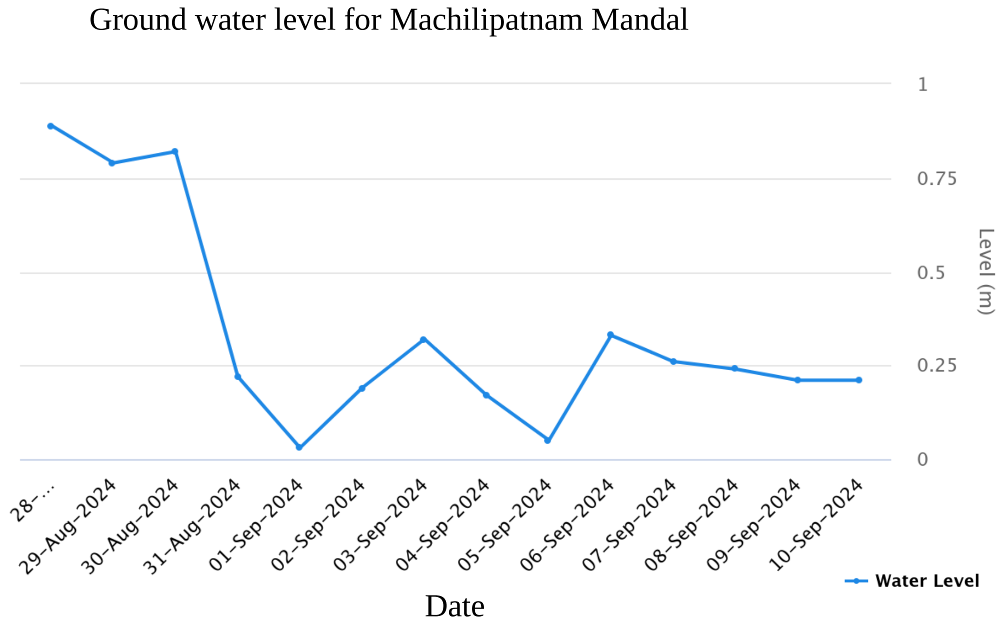

Figure 22: Groundwater level graph for Machilipatnam Mandal (Source: APWRIMS, 2025)

Table 2: Piezometer and Month Wise Ground Water Levels (Meters Below Ground Level) in Feb-2025 (Source: APWRIMS, 2025)

S.No	Piezometer	Feb-24	May-24	Nov-24	Feb-25	Rise (+) / Fall (-) from Current Water Level		
						Feb-24	May-24	Nov-24
1	Machilipatnam(GW)	0.55	0.59	0.22	0.5	0.05	0.09	-0.28
2	Manginapudi-2(GW)	1.56	1.69	0.44	1.3	0.26	0.39	-0.86

4. From Machilipatnam Draft Master Plan 2051 - Machilipatnam Urban Development Authority (MUDA)
    - Existing Land Use (Mandal extent)

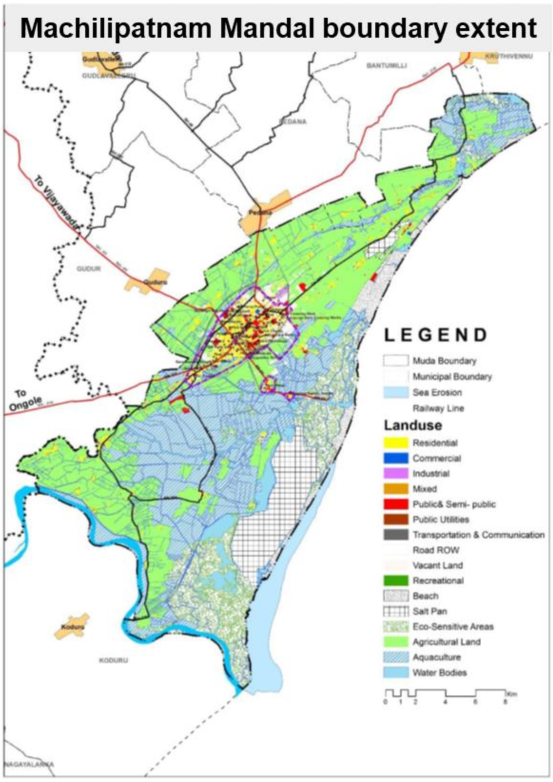

Figure 23: Existing Land Use - Machilipatnam Mandal Extent (Source: MUDA, 2023)

- Existing Land use zone wise (Mandal extent divided to 3 zones in total):

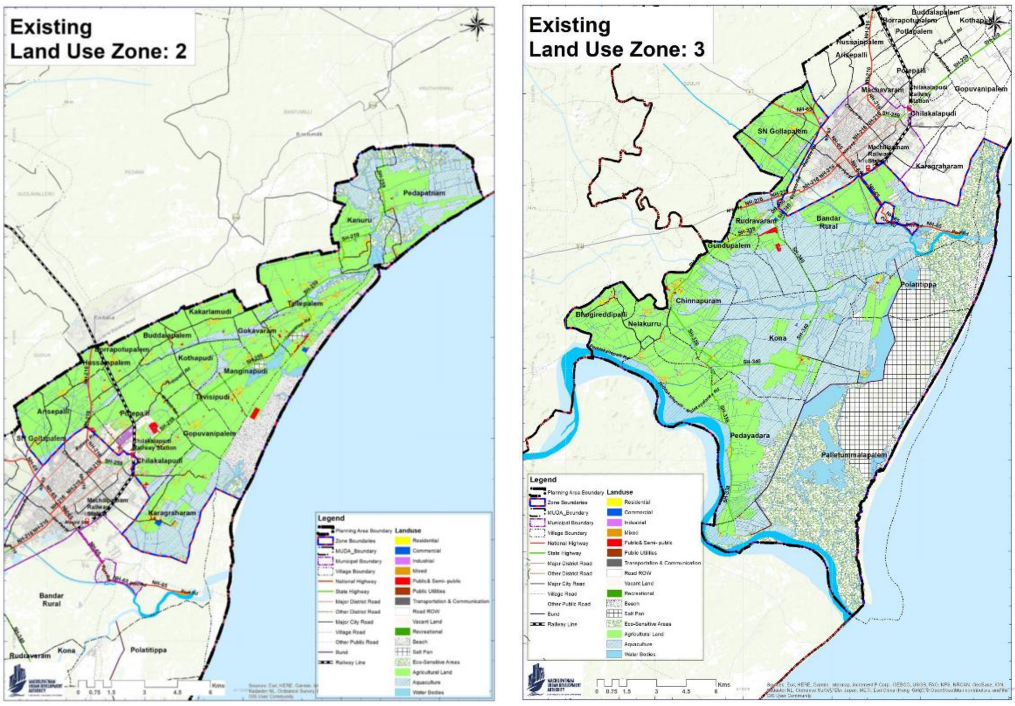

Figure 24: Existing Land Use Zones - Mandal Extent (Source: MUDA, 2023)

5. From Research Paper of Murty et. al. 2023, in collaboration with Andhra Pradesh Space Applications Centre (APSAC)

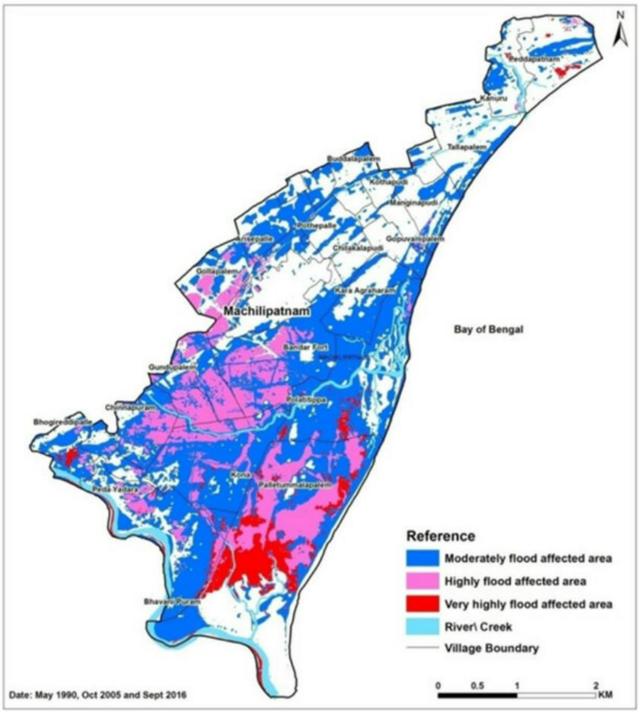

Figure 25: Combined inundation from three flood events (Source: Murty et al., 2023)

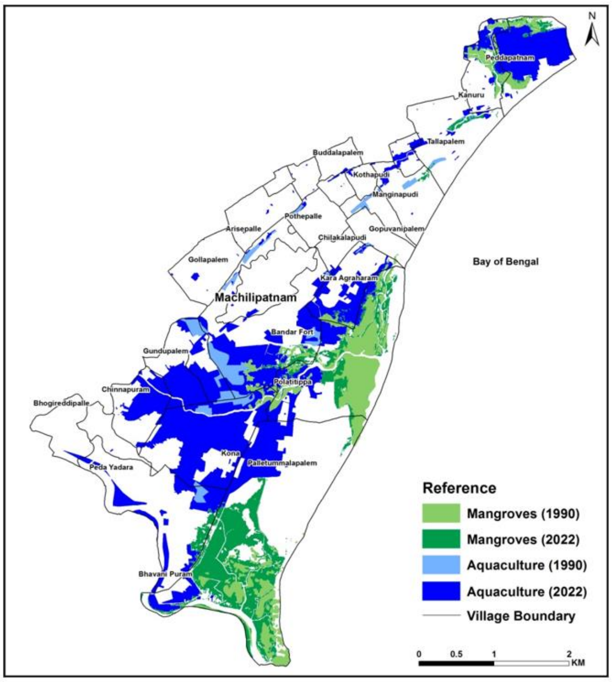

Figure 26: Extents of Mangroves and Aquaculture during 1990 and 2022 (Source: Murty et al., 2023)

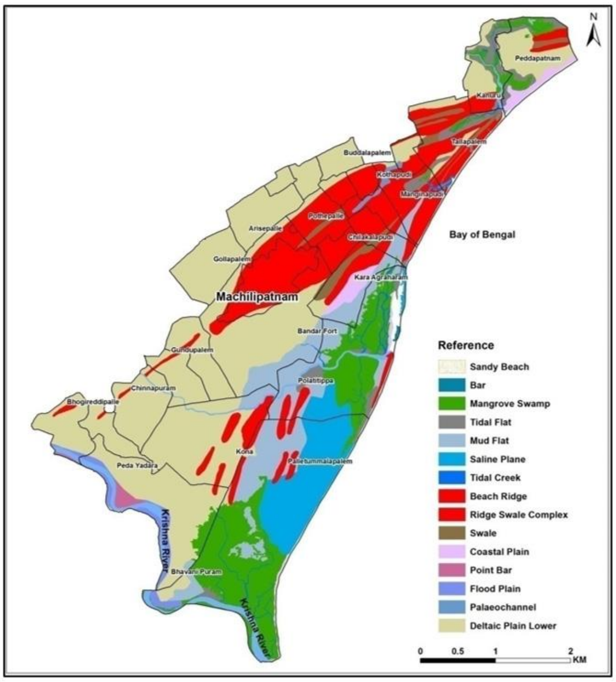

Figure 27: Geomorphology of Machilipatnam Area (Source: Murty et al., 2023)

6. Natural resources (Waterbodies, Stream Networks, Watersheds)

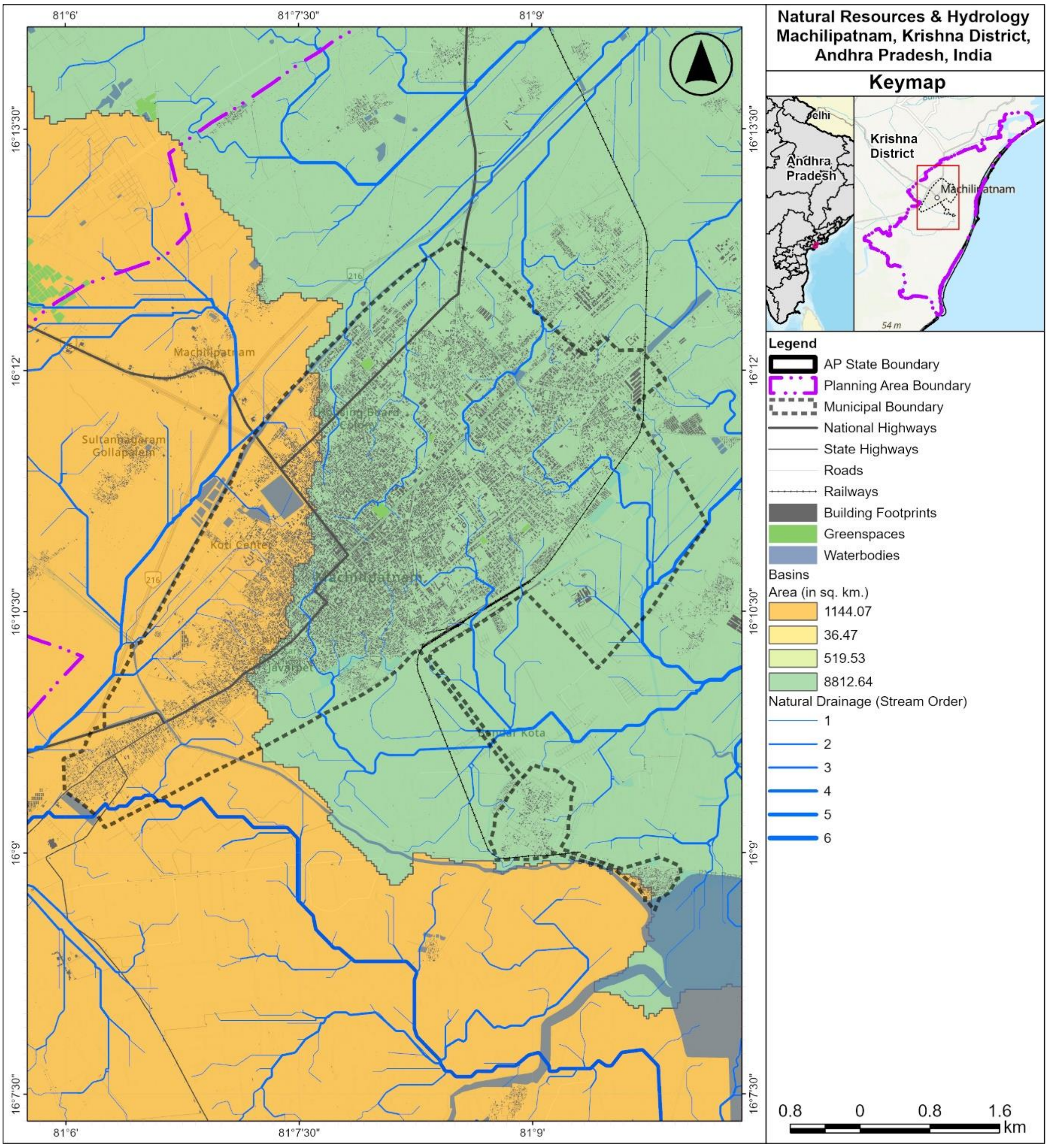

Figure 28: Natural resources and Hydrology – Municipal Extent (Waterbodies, Stream Networks, Watersheds) (Source: Author, 2025)

5.3.At Municipal level - Machilipatnam Municipal extent

- From Machilipatnam Municipal Corporation (Municipal Office):
    - Existing Drains (Map)

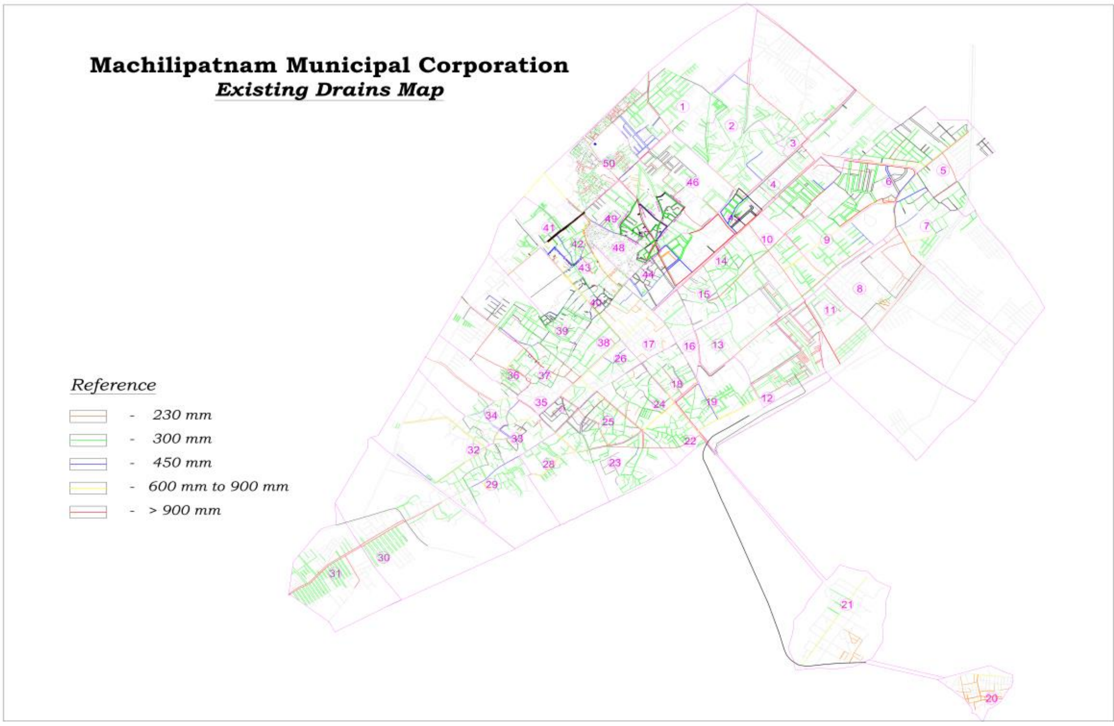

Figure 29: Existing Drains Map (Source: Municipal Corporation, 2025)

- Existing Water Supply Pipeline (Map)

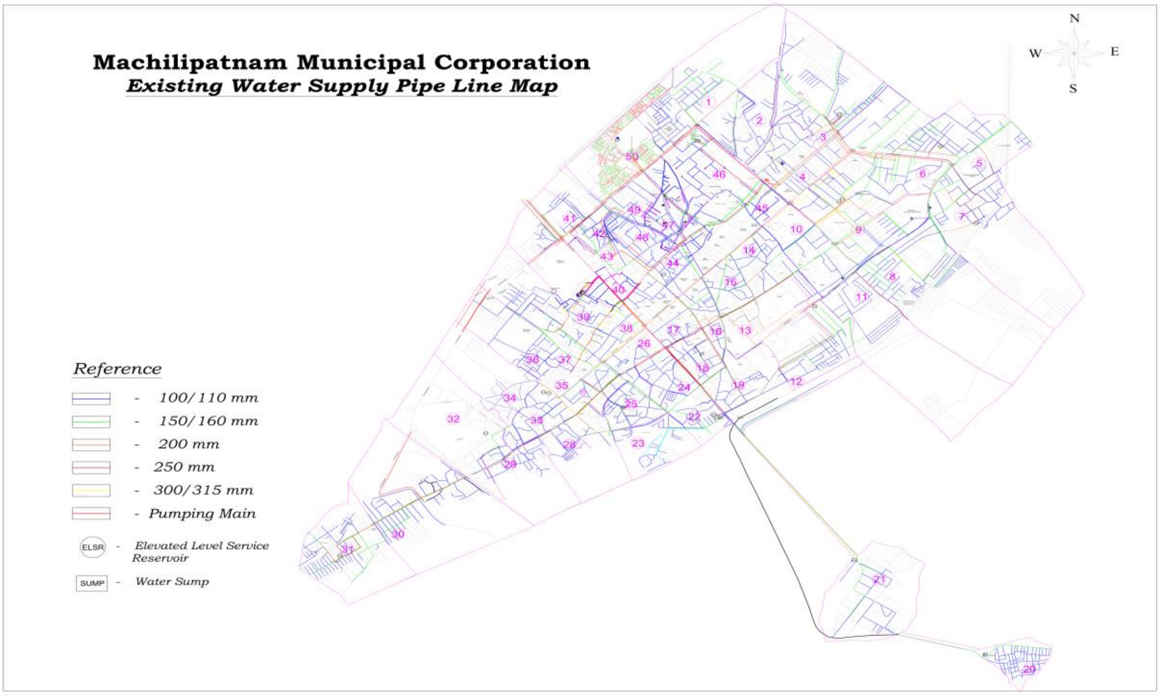

Figure 30: Existing Water Supply Pipeline Map (Source: Municipal Corporation, 2025)

- Bandar Master Plan 2011 - [General Town Planning Scheme] from Machilipatnam Urban Development Authority (MUDA)

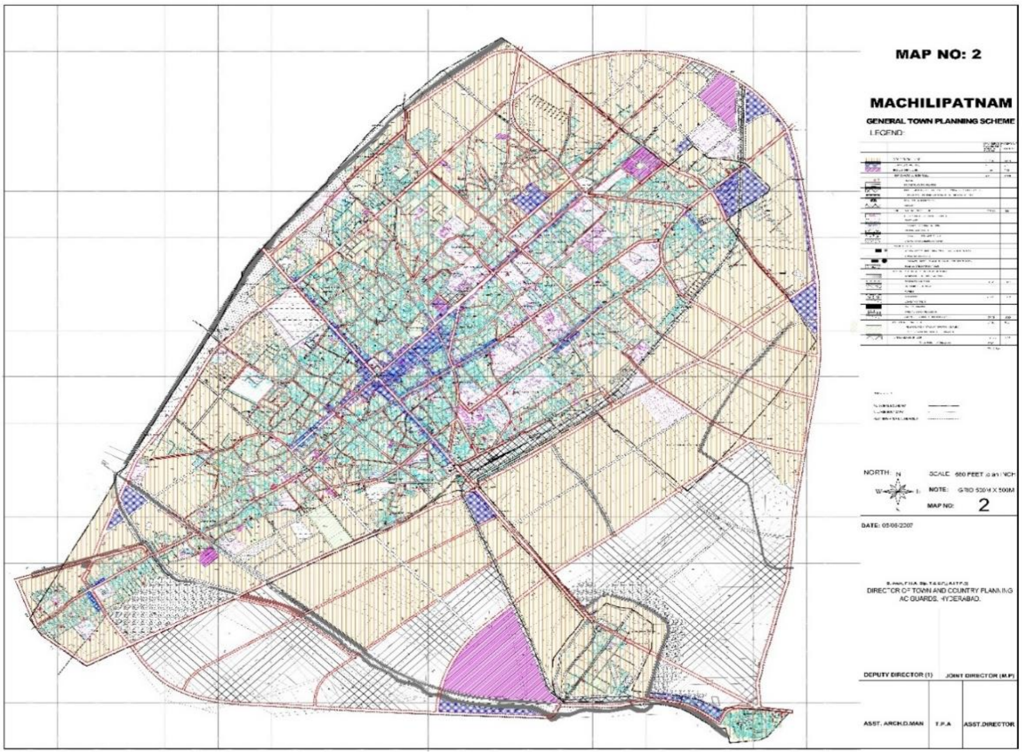

Figure 31: Bandar Masterplan 2011 - General Town planning Scheme (Source: MUDA, 2023)

- Toposheets

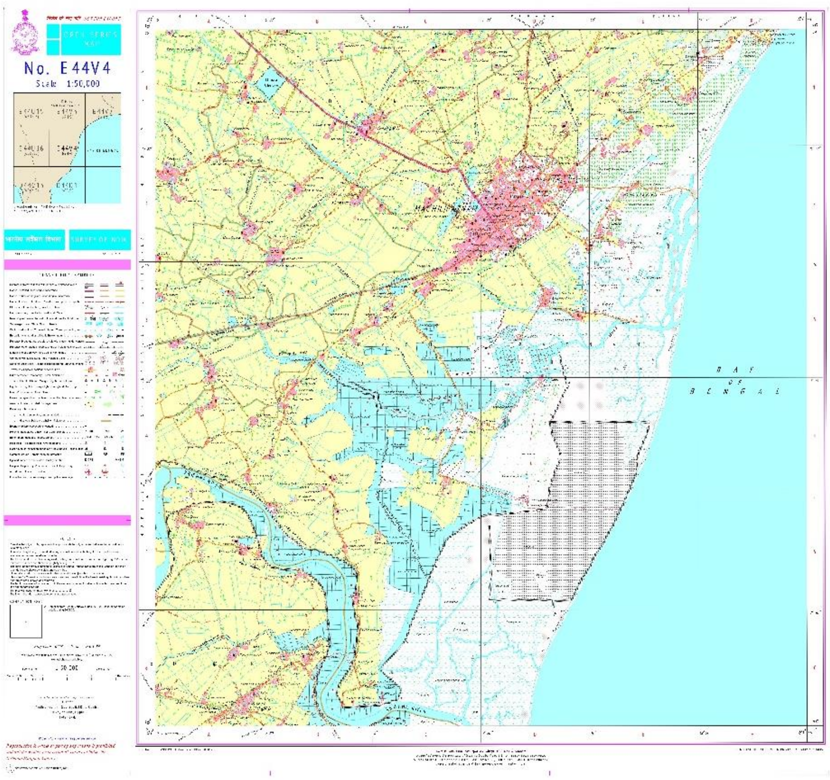

Figure 32: Toposheet (Open Series Map No. E44V4) (Source: Survey of India)

5.4. At Zonal level - within Machilipatnam Municipal extent

- From Zonal Development Plan (ZDP) of Machilipatnam Draft Master Plan 2051 - Machilipatnam Urban Development Authority (MUDA):

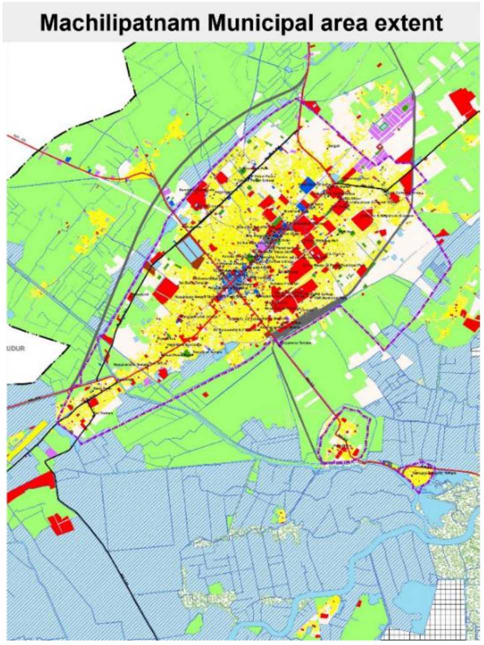

Figure 33: Existing Land Use Map - Municipal Extent (Source: MUDA, 2023)

- Storm Water Drainage Plan Showing the Primary Drains, Secondary Drains & Tertiary Drains in Machilipatnam - for various zones, namely basins 1&2, 3, 4 [Executed, To be executed, Existing drains] (maps)`

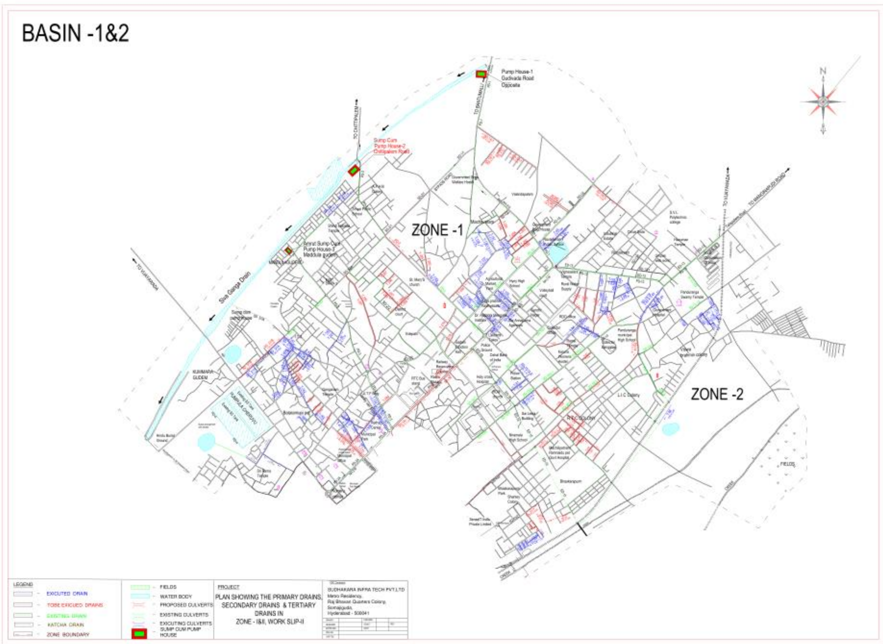

Figure 34: Storm Water Drainage Plan for Basin 1&2 (Source: Municipal Corporation, 2025)

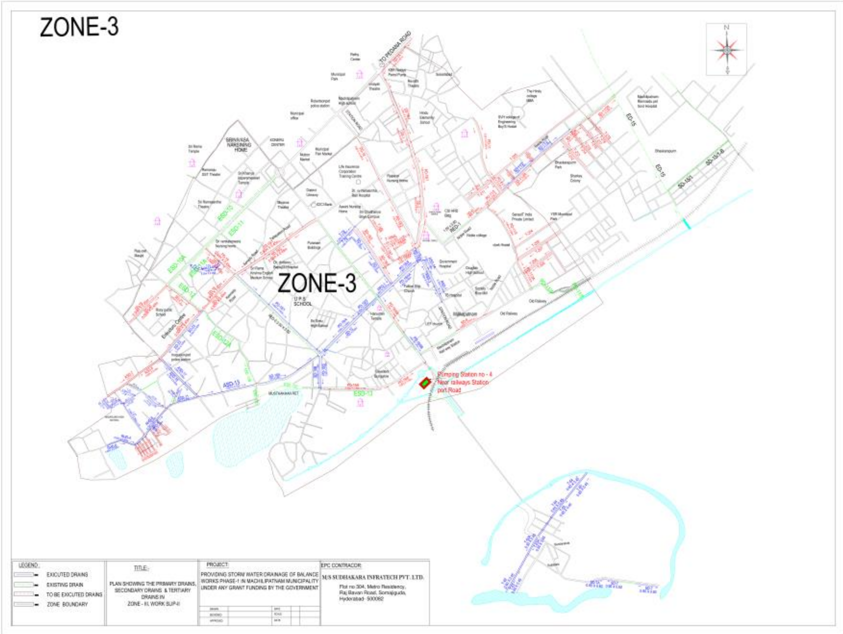

Figure 36: Storm Water Drainage Plan for Basin 3 (Source: Municipal Corporation, 2025)

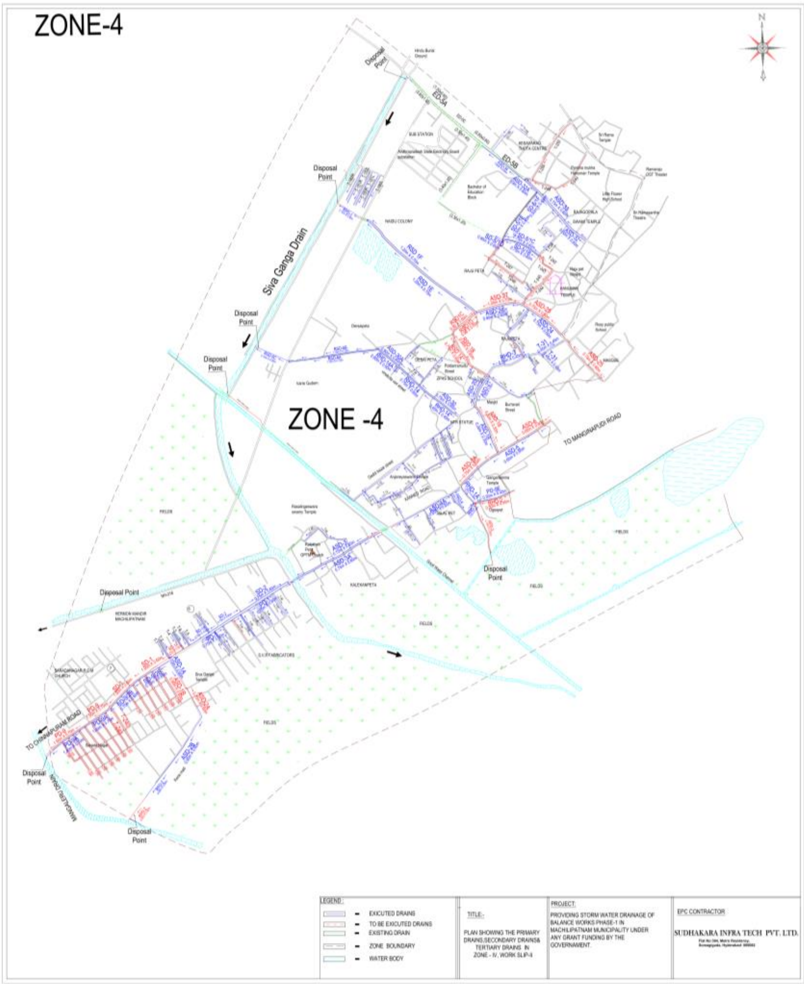

Figure 35: Storm Water Drainage Plan for Basin 4 (Source: Municipal Corporation, 2025)

6. Survey / Field Visit description

The study involved multiple field visits, discussions with key government stakeholders, and correspondence with relevant agencies to obtain data on land use, hydrology, and flood risk management. The field visits were conducted in two phases: Visit 1 (4th March 2025) and Visit 2 (18th March 2025), supplemented by extensive data collection from various state departments.

The field visits were designed to achieve the following objectives, namely, (i) Engagement with Stakeholders - Consultation with government officials and urban planners to understand existing flood management measures, (ii) Data Collection - Acquisition of spatial and hydrological data, including maps, rainfall records, and drainage layouts, (iii) Site Analysis - On-ground assessment of urban flood-prone zones and potential blue-green infrastructure (BGI) interventions, (iv) Validation of Findings - Cross-referencing official records with field observations to ensure accuracy in the study's methodology.

Table 3: List of Officials - Interactions and Collaborations (Source: Author, 2025)

S. No.	Organisation	Name & Designation
1	District Collectorate, Machilipatnam	Shri. D. K. Balaji, I.A.S. (Collector and District Magistrate)
		Smt. Geetanjali Sharma, I.A.S. (Joint Collector and Additional District Magistrate)
2	Machilipatnam Urban Development Authority	Shri. Ravi Shankar, Deputy Collector
		Smt. Shanti Latha, Planning Officer
		Shri. Shiva, Planning Assistant
3	Machilipatnam Municipal Corporation	Shri. Bapi Raju, Commissioner
		Shri. Purushottam, Divisional Engineer
		Shri. Ram Prasad, Divisional Engineer
		Shri. Ayyappa, Town Planning Senior Assistant
4	Indian Meteorological Department, AP	Smt. S. Stella, Scientist - F
5	Andhra Pradesh Space Application Center (APSAC)	Sri Prasada Rao G, Scientist -SF
6	Irrigation Department, AP	Shri. Rajeswara Rao, Assistant Engineer
		Shri. Harish, Assistant Engineer
		Shri. Karim, Assistant Engineer

6.1.Field Visit 1: 4th March 2025

The first field visit focused on the preliminary stakeholder engagement and gathering administrative insights into urban flooding in Machilipatnam. Meetings were held with the following authorities:

- **Machilipatnam Municipal Office**: Discussions with urban planners and engineers provided an overview of drainage infrastructure, existing flood mitigation strategies, and ongoing urban resilience projects.
- **District Collectorate, Machilipatnam:** The session included an analysis of past flood events, policy interventions, and the role of disaster management in urban flood mitigation.

Figure 37: Meeting with Collector at Machilipatnam Collectorate Office (Source: Author, 2025)

- **Machilipatnam Urban Development Authority (MUDA):** Interacted with Deputy Collector, a native of Machilipatnam and got insights on past flooding (flood risk areas) and waterlogging issues of the study area, as well as ground water level details. Interacted with Planning Officer too and collected Map Machilipatnam 2011 Masterplan (previously called as Bandar) – general town planning scheme map.

Key Outcomes:

- Identification of flood-prone zones within Municipal limits (mapping data) as well as Mandal extents (verbal data)
- Compilation of preliminary GIS data for further spatial analysis.

6.2. Field Visit 2: 18th March 2025

The second visit was aimed at validating data from the first visit, expanding the engagement scope, and obtaining additional datasets. Moreover, site visit to important locations of Machilipatnam were aimed along with stakeholder meetings.

- **Site visit (Visual survey):** Refer Figure 38 for major visual surveys conducted on the Field Visit days.

Figure 38: Site Visit - Visual Survey at study area Machilipatnam (Source: Author, 2025)

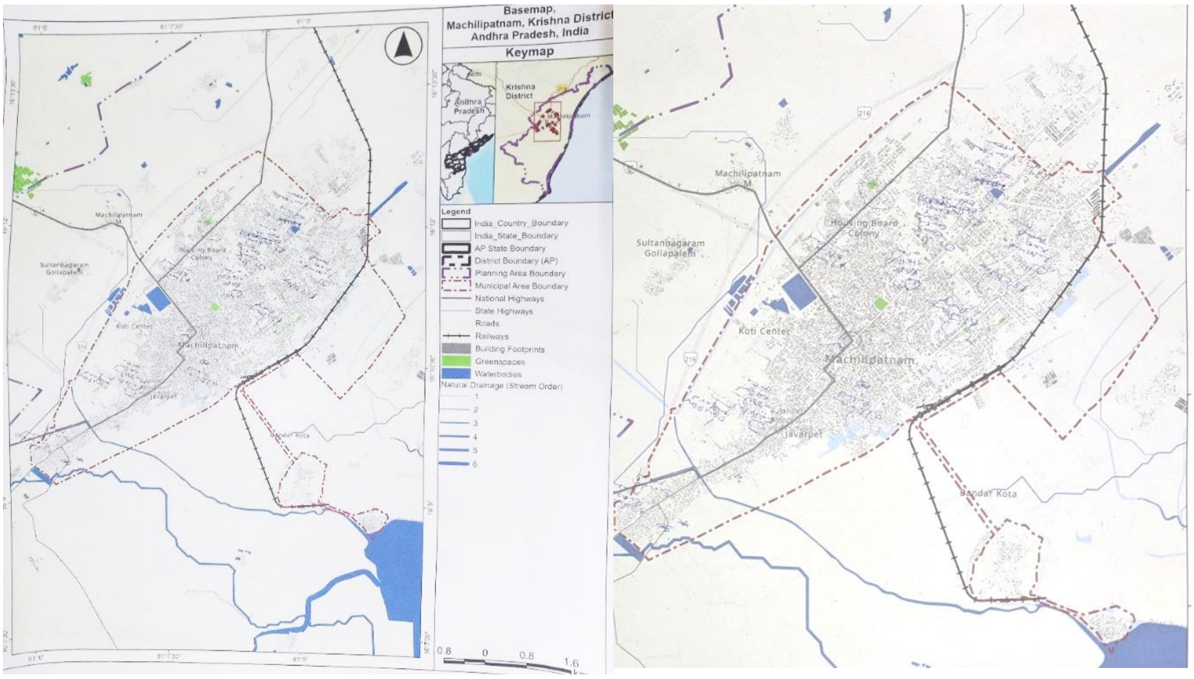

Figure 39: Flooding (Waterlogging) areas marked by Municipal Engineer(Source: Municipal Corporation, 2025)

Key Outcomes:

- Validation of initial GIS datasets with the help of collected maps and documents from Municipal office (majorly)
- Visual survey via Site visits of Cheruvu Lake, Machilipatnam Fishing Harbour, Bandar Port, Siva Ganga Canal, Mangroves (Eco-Sensitive areas), etc. were conducted to analyse the study area Machilipatnam (refer Figure 38)
- Understanding the limitations of existing drainage networks (Municipal office)
- Strengthening institutional coordination for BGI implementation.

7. Preliminary Analysis and Preliminary Findings from Study Area

The study involved a comprehensive data collection and preliminary analysis to understand the existing conditions and vulnerabilities of Machilipatnam. This foundational step is crucial for informing the subsequent development of the Blue-Green Infrastructure Toolkit. Several key datasets were compiled and analysed, providing initial insights into the study area's hydrological characteristics, physical landscape, and urban fabric. The various range of data pertinent to the study area that were collected and prepared included:

Hydrology Mapping and Analysis: These maps provide a fundamental understanding of the natural drainage network within and around Machilipatnam, including the existing drainage patterns, water bodies, and potential flow paths. Preliminary analysis of these maps indicates a network of natural and man-made channels, highlighting the city's interaction with its surrounding water resources.

The study area comes within Krishna River Basin. The Machilipatnam town has been divided into 4 basins and further divided into 4 catchments in basin 1, and 3 catchments in basin 2, based on the detailed study of Topo-contour information and possible outfall locations

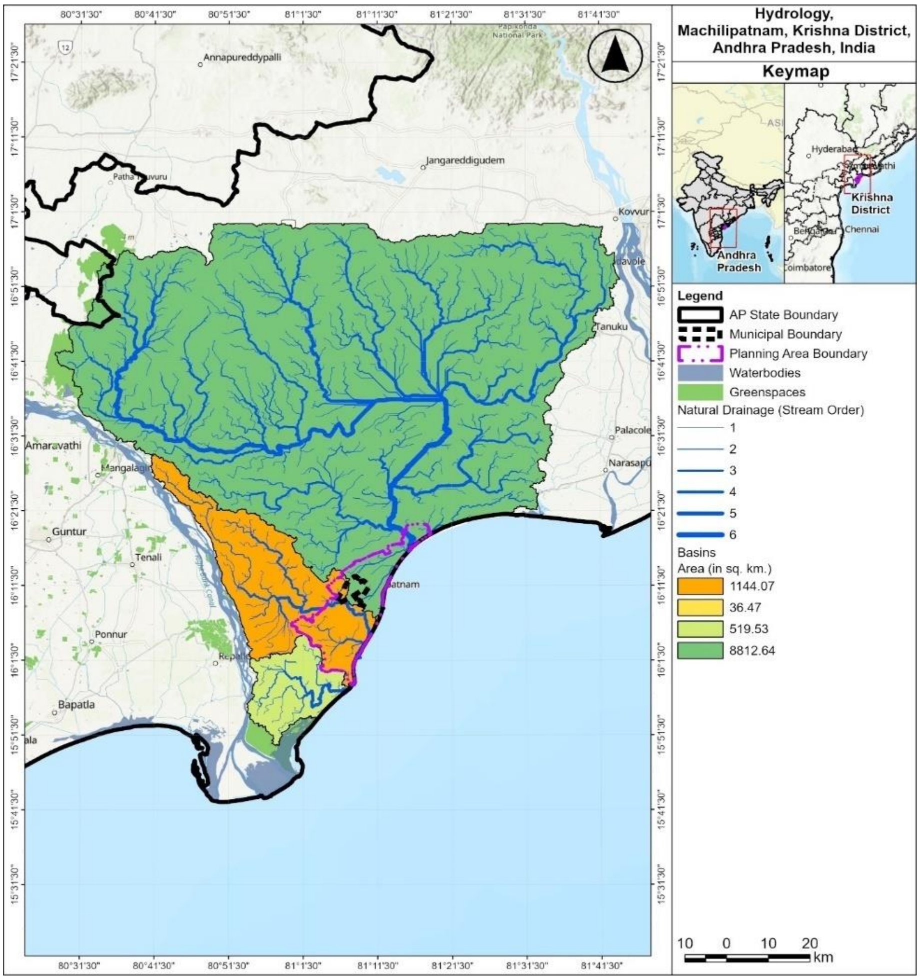

Figure 40: Hydrology Analysis at regional level (Source: Author, 2025)

(MUDA, 2023). As per the hydrology analysis done using Digital Elevation Model dated 10th May 2024, the study area Machilipatnam falls within 4 sub-basins (as shown in Figure 40).

Topography Mapping and Analysis: Topographic data, including contour lines and elevation models, offers insights into the terrain of Machilipatnam. Preliminary analysis of the topography reveals the low-lying nature of the study area (as shown in **Error! Reference source not found.**), particularly its proximity to the coast, which inherently increases its susceptibility to flooding and storm surges.

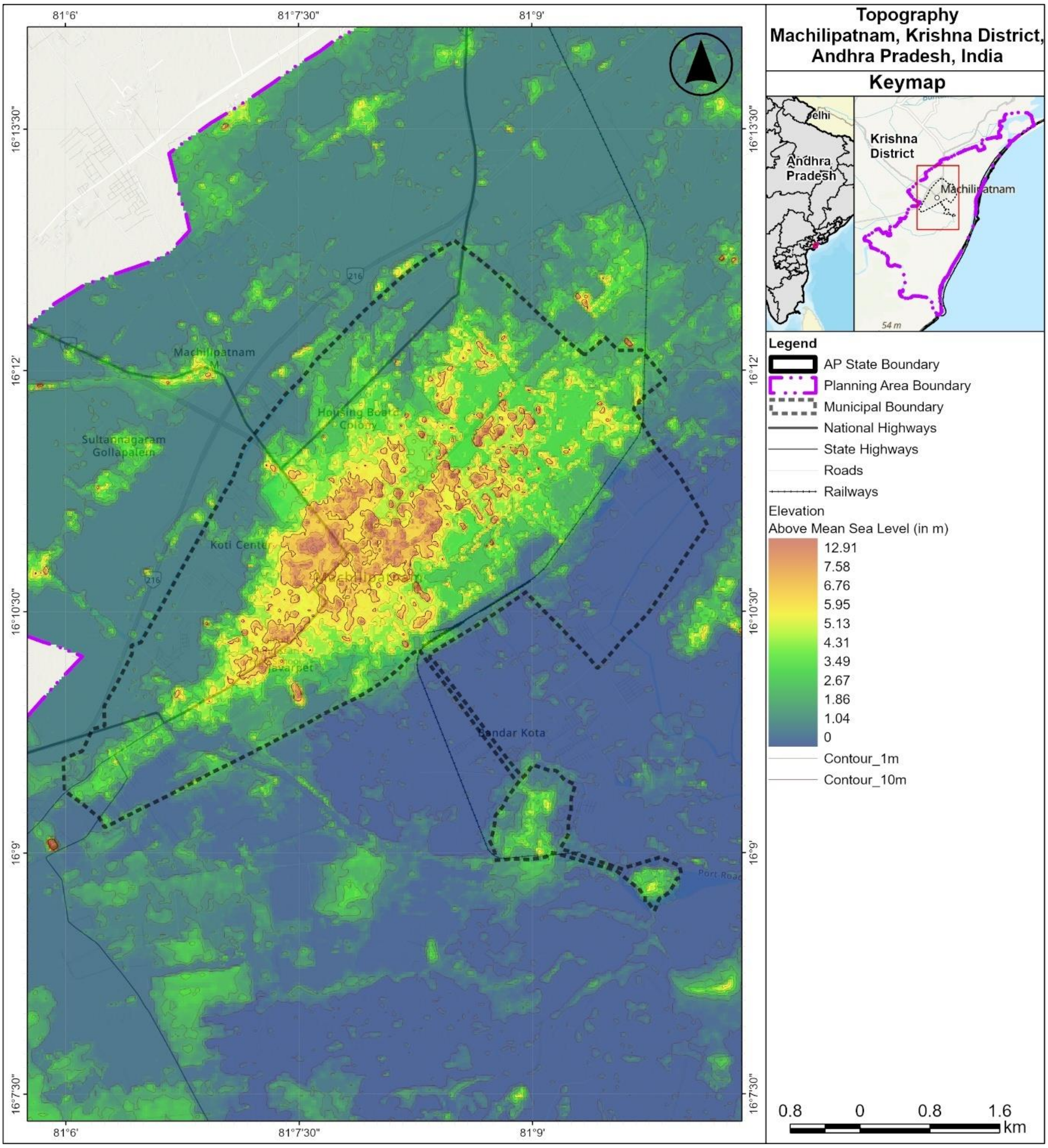

Figure 41: Topography of Machilipatnam Municipal Extent (Source: Author, 2025; DEM from CartoSAT, 10th May 2024, Bhoonidhi NRSC)

Existing Stormwater Infrastructure Network (overlay analysis using data provided by Municipal Office): Information regarding the current stormwater drainage system, including its network layout, capacity, and condition, was gathered to assess its adequacy in managing existing and future runoff volumes. The present status of the existing storm water drainage system is that it covers only about 30% of Machilipatnam Municipal Corporation. Drains in the city serve the dual purpose of carrying storm water in rainy season and wastewater in all seasons. Storm water drainage system for Machilipatnam has gaps (drains interconnection) due to which storm water flow is not reaching to the outfall points resulting in large quantities of storm water overflowing from the gaps of these drains. It is proposed to construct the drains to complete the network of primary and secondary drains to ensure flow of storm water to designated outfall (MUDA, 2023).

Existing Water supply Network (overlay analysis using data provided by Municipal Office): Information regarding the current stormwater drainage system, including its network layout, capacity, and condition, was gathered to assess its adequacy in managing existing and future runoff volumes.

Climatic Data: Historical and current climatic data, including rainfall patterns, temperature variations, and wind speeds, were gathered to understand the meteorological context of the study area and the frequency and intensity of extreme weather events.

Soil Characteristics: Data on the types and distribution of the underlying soil were collected to understand their role in water infiltration and retention. The study area predominantly has clayey and cracking clay calcareous soil type in the study area (refer to Figure 19).

Existing Urban Open Spaces: Information on the location, size, and characteristics of existing urban open spaces was gathered and will be analysed further to assess their potential for enhancement or integration into a BGI network.

Documentation of Other Existing Infrastructure: Data on other relevant infrastructure, such as water supply and sanitation networks, was collected and will be analysed further to ensure the BGI interventions are appropriately integrated.

Inundation (Flooding) Areas Mapping:

Flooding areas have been extracted with the help of Google Earth Engine, where Sentinel 1A data have been utilised to map the same. Two sets of imagery data were used as follows:

1. Before flooding

Date of Imagery: 27th July 2024
Imagery type: Sentinel 1A
Imagery Id:
Copernicus/S1_grd/S1a_iw_grdh_1sdv_20240727t003106_20240727t003131_054939_06b127_57d4
Imagery Courtesy: Sentinel Hub

2. After flooding

Date of Imagery: 1st September 2024
Imagery type: Sentinel 1A
Imagery Id:
Copernicus/S1_grd/S1a_iw_grdh_1sdv_20240901t003107_20240901t003132_055464_06c415_85ab
Imagery Courtesy: Sentinel Hub

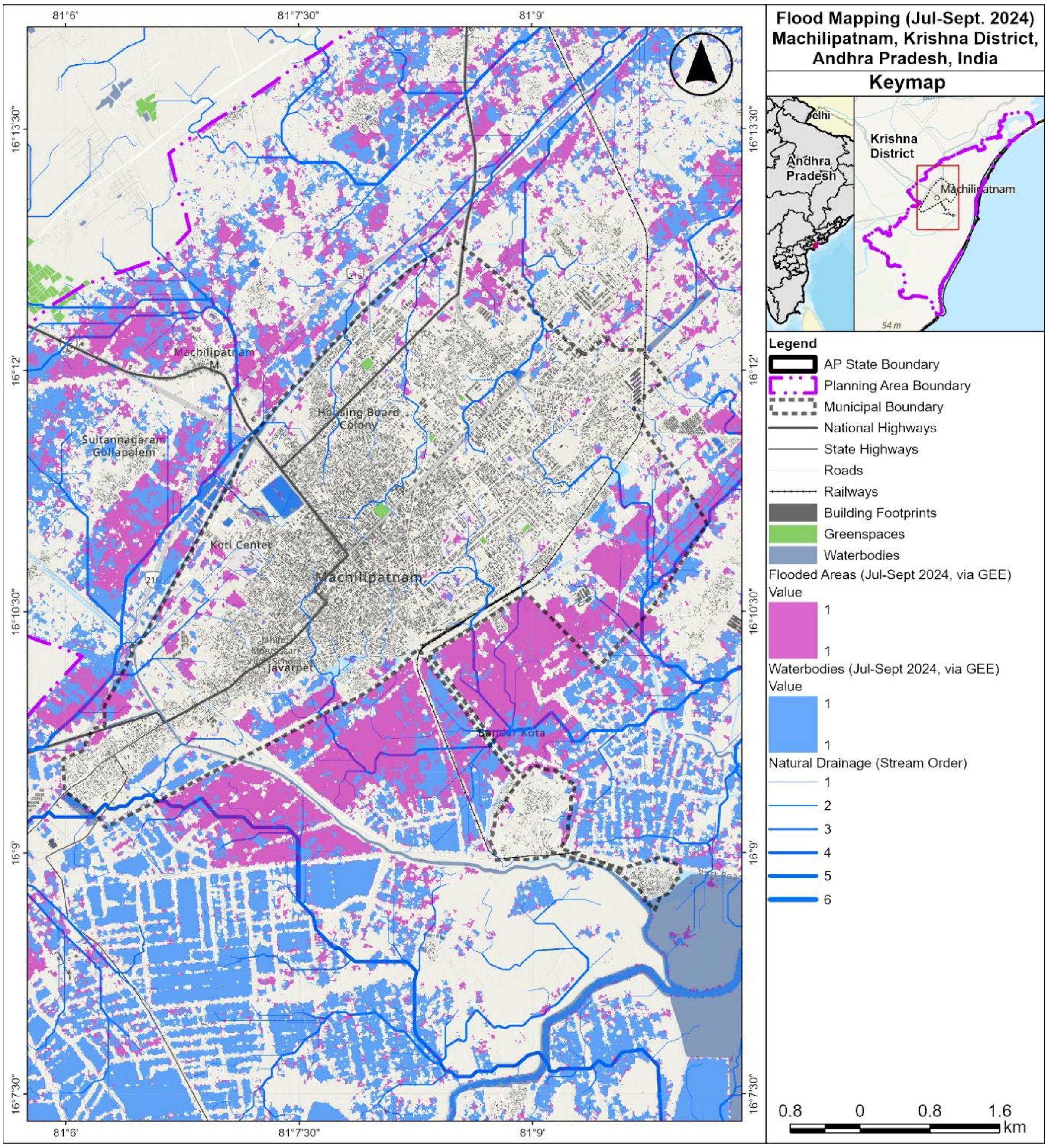

Figure 42: Flood mapping (July-September 2024) – Machilipatnam Extent (Source: Author, 2025)

The flooded Area up to Machilipatnam Mandal extent is about 53.34 sq.km., out of the total geographical area of 407.66 sq.km. Further, existing data and historical records of flood-prone areas within Machilipatnam will be compiled to identify locations with a high risk of inundation.

LULC existing and proposed overlay comparison (using Masterplan Maps) and Pervious and Impervious Surfaces Mapping:

Information on past, present, and projected future land use patterns was compiled to assess the extent of urbanization, the distribution of green spaces, and the prevalence of permeable and impermeable surfaces, using Supervised classification (via Landsat Imagery, from USGS Earth

Explorer, 2025), all of which significantly influence surface runoff and flood risk (Refer Figure 43).

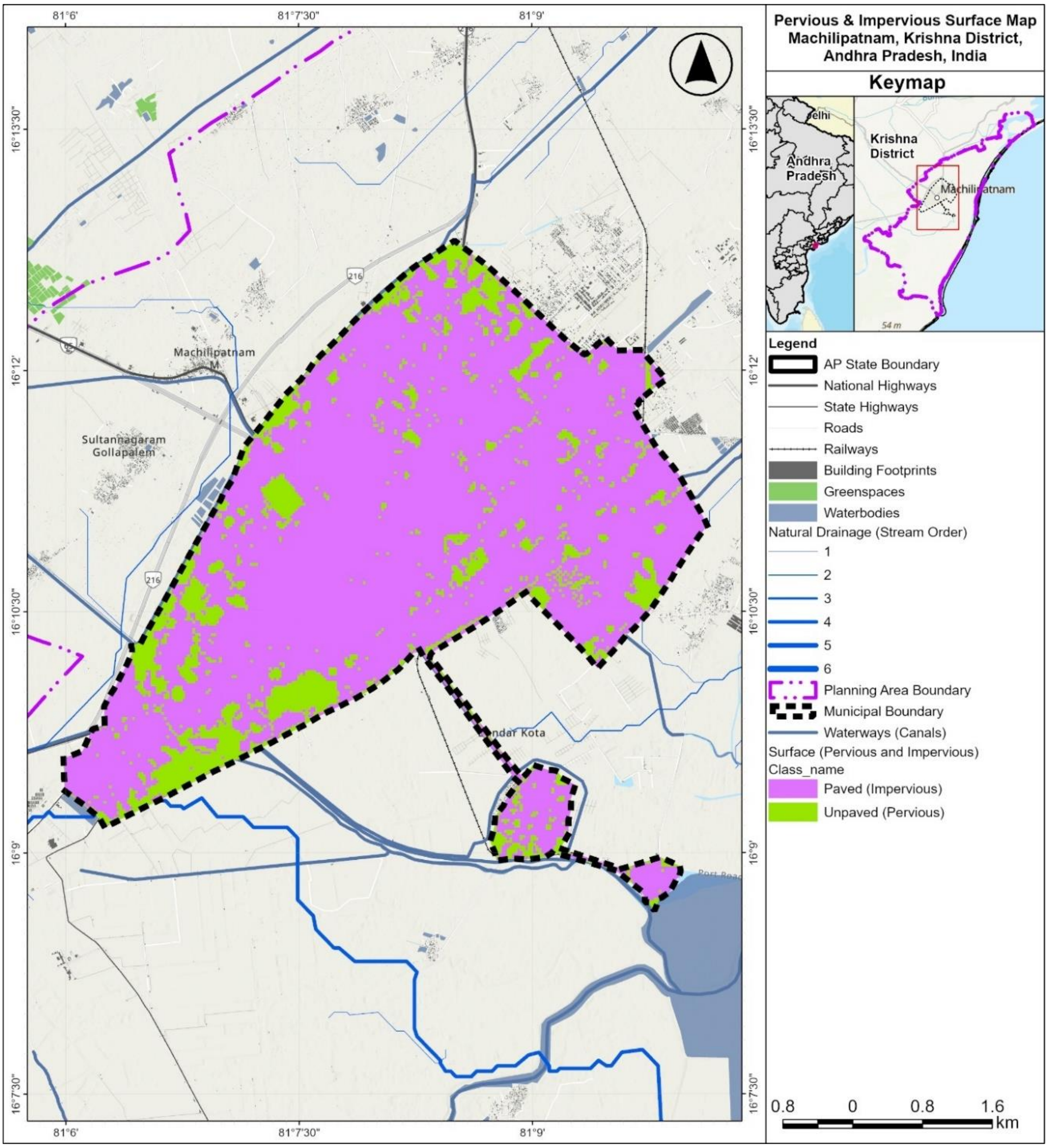

Figure 43: Pervious and Impervious Surfaces Mapping of Machilipatnam Municipal Extent (Source: Author, 2025)

The **preliminary analysis** of the collected data has yielded several key findings (refer Figure 44 for overall analysis map):

- **Low-Lying Topography**: The predominantly low-lying topography of Machilipatnam, particularly towards the coastal areas, makes it inherently vulnerable to both coastal and inland flooding. This is further exacerbated during high tides and storm surges.
- **Existing Drainage Network**: While a stormwater drainage network exists, preliminary assessment suggests potential limitations in its capacity to handle extreme rainfall events, especially considering the increasing urbanization and potential impacts of

climate change. Refer to Figure 45, for seeing the issues of Existing and Proposed Drainage Network at Machilipatnam Municipal extent.

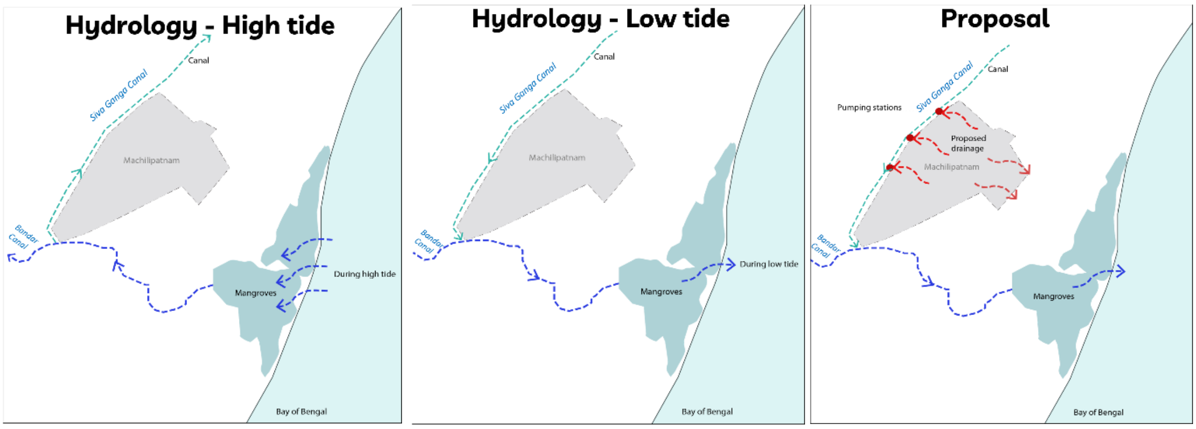

Figure 45: Analysis of Issues of Existing and Proposed Drainage Network (Source: Author, 2025)

- **Increasing Impervious Surfaces:** The ongoing urban development in Machilipatnam has led to an increase in impervious surfaces, reducing natural infiltration and increasing surface runoff, thereby contributing to urban flooding.

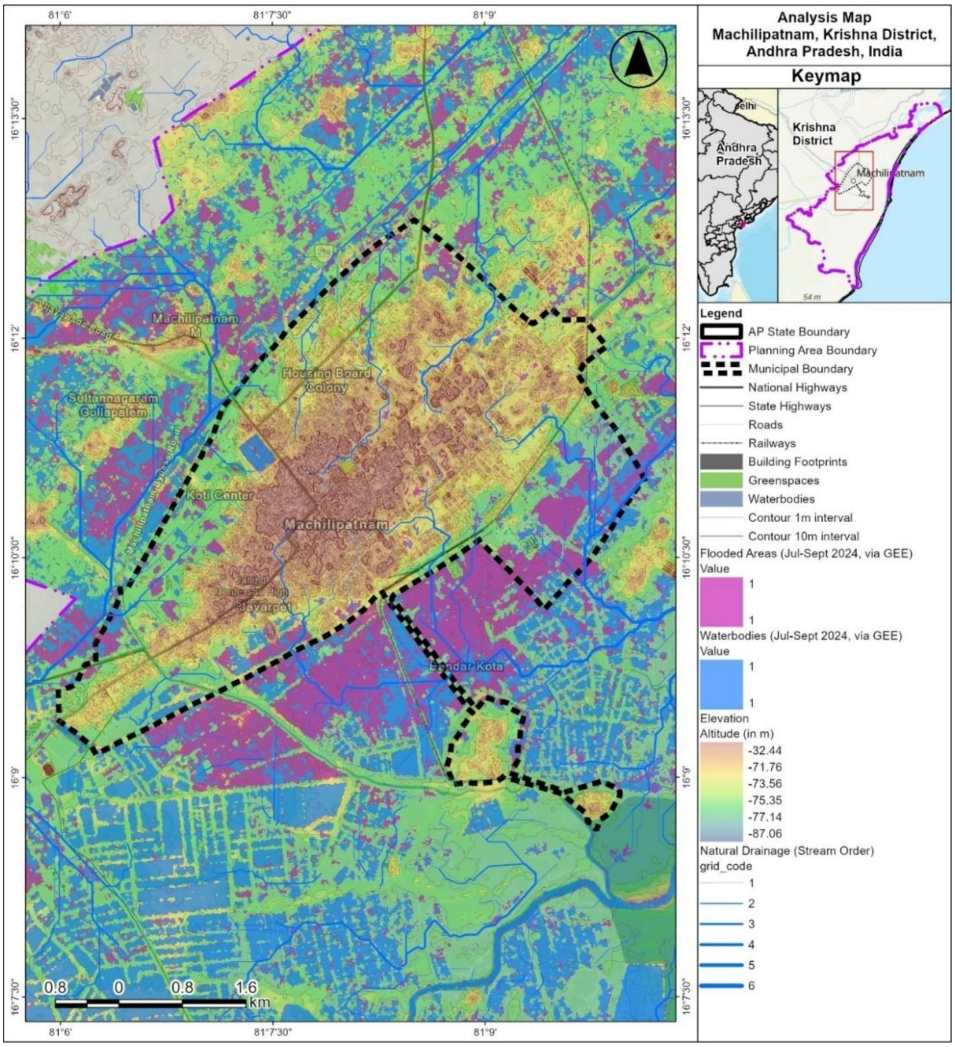

Figure 44: Multi-Analysis Overlay Map - Machilipatnam Municipal extent (Source: Author, 2025)

- **Proximity to Water Bodies:** The study area's proximity to the coast and the presence of various water bodies, while offering potential for BGI implementation, also pose a risk of flooding, particularly during intense rainfall and cyclonic events.
- **Historical Flooding:** Records of past flooding events confirm the study area's vulnerability to inundation, highlighting the need for effective flood management strategies.

These preliminary findings underscore the urgency and relevance of developing a comprehensive BGI Toolkit for Machilipatnam. The subsequent stages of this study will involve a more detailed analysis of this data, including hydrological modelling and the application of the Storm Water Management Model (SWMM), to further understand the dynamics of flooding in the study area and to identify optimal locations and designs for BGI interventions.

8. Way Forward

Moving forward with the development of the Blue-Green Infrastructure (BGI) Toolkit for Machilipatnam, Andhra Pradesh, it is crucial to delve deeper into each stage to fully appreciate the comprehensive approach being undertaken to enhance the city's resilience to flooding. The project, driven by the increasing frequency and severity of extreme weather events exacerbated by climate change and urbanization, aims to provide the Urban Local Body (ULB) of Machilipatnam with a practical and effective toolkit for implementing nature-based solutions.

Further tasks involve establishing clear criteria and assigning appropriate ranks to the thematic layers. These layers, including Slope, Pervious and Impervious Surfaces, Soil type, Road Proximity, and Drainage Density, are fundamental in determining the suitability of different locations within Machilipatnam for various BGI interventions. For instance, the slope of the land will significantly influence the design and placement of retention ponds and bioswales, while the soil type will dictate the infiltration capacity and the types of vegetation that can thrive in green infrastructure. Similarly, the proximity to roads might present opportunities for implementing green streets and permeable pavements, but also pose constraints related to space and existing infrastructure. The criteria for each layer need to be carefully defined, taking into account the specific context of Machilipatnam, the coastal area with a low-lying geography and a history of vulnerability to urban flooding and cyclones. This process will likely involve analysing existing data, conducting site surveys, and potentially engaging with local experts and stakeholders to ensure that the criteria are relevant and accurately reflect the city's unique characteristics. Following the definition of criteria, a robust ranking or weighting system will be developed to reflect the relative importance of each thematic layer in determining overall BGI suitability. For example, in a flood-prone area, drainage density might be assigned a higher weight compared to road proximity.

Once the criteria and ranks are established, the next critical step is to conduct the overlay analysis. This process involves the integration of all the thematic layers based on their defined criteria and weights, typically using Geographic Information System (GIS) software. By overlaying these spatial datasets, areas that meet the specific requirements for different types of BGI can be identified. For instance, areas with gentle slopes, permeable soils, and proximity to existing drainage networks might be highly suitable for retention ponds, while areas with high impervious cover and frequent flooding might be prioritized for permeable pavements and bioswales. The overlay analysis will generate a comprehensive understanding of the spatial distribution of BGI suitability across Machilipatnam. The primary output of the overlay analysis will be a suitability map, which will visually represent the varying degrees of suitability for BGI implementation throughout the city. This map will likely use a color-coded system to indicate areas that are highly suitable, moderately suitable, and less suitable for BGI. The suitability map will serve as a crucial decision-making tool for the subsequent stages of the project, guiding the identification of potential BGI locations.

Based on the insights derived from the suitability map, the next phase involves identifying specific potential patches and corridors for BGI implementation. Patches refer to larger, contiguous areas suitable for interventions like urban forests, parks with retention features, and large-scale permeable open spaces. Corridors, on the other hand, typically refer to linear features such as green streets, bioswales along roadways or waterways, and interconnected networks of green spaces. The strategic identification of these patches and corridors will consider factors such as connectivity, existing land use, proximity to critical infrastructure and flood-prone zones, and the potential for maximizing ecosystem services.

The identified potential locations will then inform the development of a conceptual BGI plan tailored specifically to Machilipatnam. This plan will outline the types and spatial distribution of proposed BGI interventions, taking into account the local context, the specific flood risks identified in the project summary, and the overall goals of enhancing climate resilience and improving water resource management. The conceptual plan will serve as a blueprint for the more detailed design and implementation phases.

For the real-world demonstration of the BGI approach, a critical component is the implementation of a pilot project in a selected neighbourhood of Machilipatnam. It will involve the development of detailed design elements for various BGI components, such as bioswales to manage runoff from streets, green streets with permeable pavements to increase infiltration, and detention/retention areas in public spaces to temporarily store stormwater.

To ensure the effectiveness of the proposed BGI interventions, the project will leverage the Storm Water Management Model (SWMM). This model will be used to simulate the urban hydrological processes within the selected neighbourhood in Machilipatnam and to assess the impact of different BGI strategies on flood mitigation under various future scenarios, including potential increases in rainfall intensity and frequency due to climate change. By optimizing the placement and design of BGI elements based on SWMM simulations, evidence-based recommendations for maximizing the performance of BGI elements in reducing flood risks will be provided. The pilot project will provide valuable insights into the practical challenges and successes of implementing BGI in Machilipatnam, informing the refinement of the toolkit and paving the way for wider adoption across the city.

The culmination of these interconnected steps will be the delivery of a comprehensive Blue-Green Infrastructure (BGI) toolkit for Machilipatnam, Andhra Pradesh. This toolkit will serve as a valuable resource for the Urban Local Body, providing an overview of BGI approaches and components, showcasing best practices from around the world, presenting the conceptual BGI plan and methodology with specific BGI components, and detailing the pilot project demonstrating the application of the plan at the neighbourhood scale. This toolkit will empower the ULB to make informed decisions regarding the implementation of BGI as a sustainable and effective strategy for managing stormwater, enhancing climate resilience, and improving the overall quality of life for the citizens of Machilipatnam. The systematic and data-driven approach outlined in this way forward ensures that the BGI toolkit will be tailored to the specific needs and challenges of Machilipatnam, contributing significantly to its long-term sustainability and resilience in the face of increasing climate risks.

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