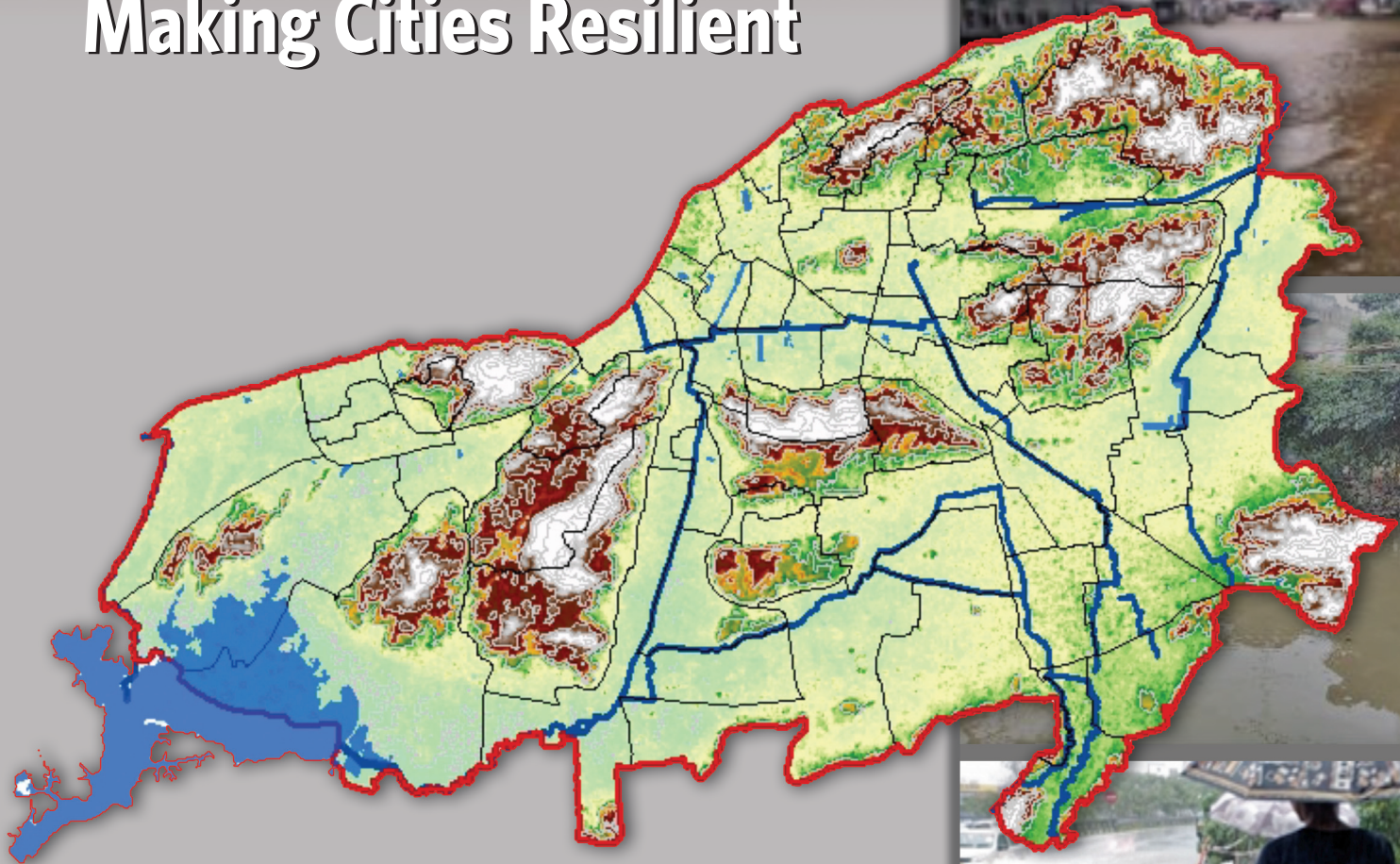




Resilient India - Disaster free India



# Development of Flood Risk Assessment Framework and a Roadmap for Making Cities Resilient



**Guwahati**





# Development of Flood Risk Assessment Framework and a Roadmap for Making Cities Resilient

Guwahati

**National Institute of Disaster Management**

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## Development of Flood Risk Assessment Framework and a Roadmap for Making Cities Resilient: Guwahati

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## FOREWORD

Urban flooding has become one of the most pressing challenges confronting India's rapidly growing cities. With changing climate patterns intensifying extreme weather events and unplanned urbanization straining existing infrastructure, flood risks have escalated dramatically—impacting millions of lives, livelihoods and critical urban systems. In this context, the need for robust, science-based flood risk assessment and resilient urban planning has never been more urgent.

National Institute of Disaster Management (NIDM) is committed to strengthening the country's disaster preparedness and resilience through research, capacity building, and strategic partnerships. This study on Flood Risk Assessment and Roadmap for Making Cities Resilient: A Case Study of Guwahati, undertaken in collaboration with the Resilience Innovation Knowledge Academy (RIKA), Walter P Moore and IIT, Guwahati, represents a significant milestone in advancing India's urban flood resilience agenda.

The study has been carried out as part of the NIDM-GIZ grant agreement on "Enabling Cities on Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) for Sustainable Urban Development in India", a sub-project under the Sustainable Urban Development - Smart Cities II (SUDSC-II) programme. This initiative is jointly implemented by GIZ and Ministry of Housing and Urban Affairs (MoHUA), Government of India on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ).

**आपदा प्रबंधन महाविचार: पूरा भारत भागीदार**





Guwahati, like many Indian cities, faces complex flood challenges driven by rapid urban growth, climate variability and infrastructural constraints. This comprehensive study not only assesses these risks in detail but also provides a practical, actionable roadmap tailored to local conditions, policy gaps and capacity needs. It underscores the importance of integrating data-driven approaches with established national guidelines such as those issued by NDMA and global frameworks like the Sendai Framework for Disaster Risk Reduction.

I am confident that the findings and recommendations presented in this study will serve as a valuable resource for policymakers, urban planners, disaster managers and all stakeholders involved in building resilient cities. I hope that this work will inspire continued collaboration and commitment toward safeguarding India's urban future from the escalating risks of floods and other disasters.

I congratulate the entire team for their dedication and insightful contributions and encourage all cities to adopt and adapt these learnings from this study to strengthen their flood resilience and disaster preparedness efforts.



(Madhup Vyas)



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(Dr. Garima Aggarwal)



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# Abbreviations

|       |                                             |
|-------|---------------------------------------------|
| ASDMA | Assam State Disaster Management Authority   |
| BIS   | Bureau of Indian Standards                  |
| BL    | Base Line                                   |
| CBOs  | Community Based Organisations               |
| CCA   | Climate Change Adaptation                   |
| CSR   | Corporate Social Responsibility             |
| DDMA  | District Disaster Management Authority      |
| DDMP  | District Disaster Management Plan           |
| DA    | Drainage Area                               |
| DM    | Disaster Management                         |
| DRM   | Disaster Risk Management                    |
| DRR   | Disaster Risk Reduction                     |
| DSS   | Decision Support System                     |
| EIA   | Environmental Impact Assessment             |
| FGD   | Focus Group Discussions                     |
| HRVA  | Hazard Risk and Vulnerability Assessment    |
| KII   | Key Informant Interview                     |
| GoA   | Government of Assam                         |
| GIS   | Geographic Information System               |
| GMC   | Guwahati Municipal Corporation              |
| GMDA  | Guwahati Metropolitan Development Authority |
| GPS   | Global Positioning System                   |
| HFL   | High Flood Level                            |
| ICT   | Information and Communication Technology    |



|       |                                              |
|-------|----------------------------------------------|
| IDF   | Intensity-Duration-Frequency                 |
| IoT   | Internet of Things                           |
| IMD   | India Meteorological Department              |
| LIDAR | Light Detection and Ranging                  |
| MAH   | Major Accident Hazard                        |
| MIS   | Management Information System                |
| MLD   | Million Liters Per Day                       |
| NDMA  | National Disaster Management Authority       |
| NDMP  | National Disaster Management Plan            |
| NbS   | Nature-based Solution                        |
| NGO   | Non-governmental Organisation                |
| PPP   | Public-Private Partnerships                  |
| UAV   | Unmanned Aerial Vehicle                      |
| SDMP  | State Disaster Management Plan               |
| SDGs  | Sustainable Development Goals                |
| SDMP  | State Disaster Management Plan               |
| SFDRR | Sendai Framework for Disaster Risk Reduction |
| SHGs  | Self-Help Groups                             |
| SIA   | Social Impact Assessment                     |
| SNDP  | Strategic Nala Development Programme         |
| TPD   | Tonnes Per Day                               |
| WSEL  | Water Surface Elevation Level                |







## Executive Summary

Flooding has emerged as a critical challenge in India, affecting over 40 million hectares of flood-prone regions across states and union territories, with significant economic impacts. Rapid urbanization and climate change have exacerbated flood risk by intensifying precipitation, altering soil and vegetation conditions and impacting drainage capacities. Recent extreme events, such as the 2023 Delhi floods and the 2022 Bengaluru Flood, illustrate how rapid urban expansion, inadequate planning and human intervention have weakened urban resilience. In response, the National Disaster Management Authority (NDMA) established guidelines for a more proactive approach to urban flooding management, focusing on disaster preparedness, resilience-building, and policy alignment with frameworks such as the Sendai Framework for Disaster Risk Reduction (SFDRR).

This study, commissioned by the National Institute of Disaster Management (NIDM) and implemented by the Resilience Innovation Knowledge Academy (RIKA) in collaboration with Walter P Moore and IIT Guwahati, aimed to develop a Flood Risk Assessment Framework and a Roadmap for resilient city planning. It is a stepping stone to bolster the flood resilience of urban centres in India through activities ranging from the development of a flood risk assessment framework, undertaking detailed consultations and surveys to identify capacity gaps, development of responsibility matrices, capacity building exercises and identifying suitable recommendations for future development. The study assessed the unique urban flood challenges, existing capacity, and opportunities for mitigation and adaptation, addressing policy gaps, climate vulnerabilities and infrastructure deficiencies. This is significant as Guwahati has been experiencing multiple incidents of urban flooding over the years with recent urban floods having affected several critical infrastructures as of the end of September 2024. Through consultations and sample surveys it was observed that, though different in size and urban development stages, many cities face similar flood risks due to inadequate drainage infrastructure, urban encroachment, and outdated planning mechanisms. Lack of robust city-specific disaster management frameworks further exacerbates the threat to infrastructure, livelihoods, and public health. In light of projected climate change impacts, the cities require a strong framework that integrates modern data-driven methodologies for comprehensive flood risk mitigation.

The methodology designed for this flood risk assessment project emphasized an inclusive approach integrating hydrological and hydraulic modelling with stakeholder insights. Primary and secondary data were sourced from multiple channels, including historical rainfall records, topographic data, and past flood incidents. A Systematic Literature Review (SLR) provided a foundation of knowledge on urban flood patterns, climate impacts, and risk management strategies specific to the Indian context. Stakeholder engagement and local consultation meetings were held with Municipal Officials, Development Authorities, Disaster Management Authorities, Community Leaders and vulnerable population representatives. In Guwahati, consultations highlighted needs in frequently inundated areas (like Gandhibasti, Lachit Nagar, Rukminigaon), offering insights into household vulnerabilities and existing coping mechanisms. Gender and Social Inclusion (GESI) integration for



inclusion of the vulnerable demographic groups (e.g., women, elderly, disabled) were identified and their unique needs were incorporated into the data collection, and planning process, ensuring that flood mitigation efforts are equitable and comprehensive.

Using HEC-RAS 1D modelling, the study analysed water surface elevations, depth, and extent of inundation for different storm return periods (10-years, 25-years and 100-years) and climate change scenarios. This provided an understanding of future flood risks through assessments under projected climate change scenarios. Soil hydrological groups (e.g., HSG-C/D with high runoff unless drained) were assessed, offering insight into water retention capacity and drainage functionality. Specific drainage channels (nallahs) in Guwahati were evaluated to identify flood hotspots and obstructions from encroachments or silt build-up. Intensity-Duration-Frequency (IDF) curves were analysed to project rainfall impacts over different return periods. The study assessed how future rainfall patterns could worsen urban flood risks in light of climate change, especially in high-density residential areas with limited natural drainage.

Stakeholder capacities and gaps were assessed by Key Informant Interviews (KIIs) with government officials and the community to assess local capacities for flood management and response. The study highlighted that the municipal body has identified staff for response and relief but there is potential for improvement on aspects of waste management mechanisms; training of staff in disaster risk management, nature-based solutions, maintenance of drainage systems; awareness campaigns with vulnerable communities; mobilizing volunteer networks, and participation from NGOs and SHGs. Social vulnerability mapping gathered data on household preparedness, access to information, and communication channels. It was identified that community members in wards with inadequate social infrastructure, funding and support systems felt more unsafe.

Findings from Guwahati reveal the specific gaps in flood risk mitigation. Guwahati has a drainage infrastructure largely dated and undersized for the expanding population, which fails to accommodate heavy rainfall and results in waterlogging, especially in low-lying areas like Sarumotoria. High levels of siltation in major drains restrict water flow, worsening flood risks. Unique challenges pertain to the proximity of drainage channels to oil pipelines like in the Saukuchi area where de-siltation activities cannot be effectively performed. Flood return period analysis using hydraulic modelling for different flood return periods (10-years, 25-years and 100-years) reveals that certain landmarks, such as Japorigog Durga Temple, SEAUJ Residency and L.P. School are affected under extreme climate change scenarios. Many open channels, particularly in densely populated areas, generate foul odours and contribute to disease spread. Seasonal desilting is inadequate due to heavy silt accumulation and poor maintenance schedules. Currently, Guwahati relies on 18 Automated Weather Stations (AWS) for flood alerts, which is below the recommended coverage for the city's size. This limits the city's capacity to provide timely, localized warnings. The community interactions indicated insufficient solid waste management systems, with low waste segregation levels at only 40%. It contributes to blockages in drainage channels thus intensifying flooding risks. As only 22% of households have access to a sewerage network thus increasing the risk of contamination and diseases. The absence of wastewater treatment facilities further degrades water quality in flood-prone areas. The lack of ward-specific disaster management plans leaves government and community infrastructure vulnerable during floods. Community interviews suggested that more than 60 percent of respondents did not



receive any guidance on urban flooding from the government. Collaborative efforts by CBOs and NGOs for flood-related awareness are minimal. No regular safety audits are conducted for essential buildings, such as hospitals and schools, compromising resilience.

The city faces increased water surface extents for the 100-years return period storm events and under climate change conditions. This trend suggests that current stormwater infrastructure and drainage systems need to be strengthened to handle future climate impacts. A recurring theme is the limited participation of NGOs, SHGs, and volunteer networks in flood response and management. Limited waste management and lack of comprehensive sewerage systems contribute to heightened public health risks. Additionally, community awareness campaigns are rare, especially on topics like waste segregation and sanitation, which are critical to reducing flood risks. Based on the findings, there is a need for critical interventions in the flood resilience planning of the urban system of Guwahati. This can be achieved by formulating phase-wise key recommendations laid down. The following give a brief summary of the general and city-specific recommendations for short (0-2 years), medium (2-5 years) and long (5-10 years) terms.

### Short-term Recommendations

- Conduct a safety audit of all identified critical infrastructures especially schools and hospitals in Division 4 and 5.
- Regularization in waste collection and change in behavioural practices related to waste management in Division 1, 2 and 4.
- Upgrade and maintain drainage networks with regular desilting schedules, silt traps and periodic hydraulic assessments.
- Plan to implement public wastewater collection and safe disposal systems to ensure the safety of natural water bodies.
- Identify solutions for rainwater harvesting like rain gardens and floating wetlands in urban green spaces to enhance stormwater absorption.
- Enhance awareness of the community members particularly those using community facilities such as schools and hospitals.

### Medium-term Recommendations

- Provision of a new stormwater drainage network with consideration to key parameters of precipitation intensity, catchment delineation, percolation characteristics, surface runoff, elevation etc. at areas like Sarumotoria, Saikia road wireless.
- Decentralized compost plants near market areas, like Paltan Bazar, Uzan Bazar, etc. with the responsibility to women's Self-help Groups for operations.
- Introduction of alternative livelihood activities such as engaging women in DM, waste management workforce with support from NGOs.

- Promote the use of emerging technologies for high-resolution data for planning and integrating spatial and economic strategy.
- Secure dedicated budgets for flood preparedness activities and promote public-private partnerships to manage risk.

### Long-term Recommendations

- GIS mapping of all stormwater and sewerage networks being laid, including information on topographical features, gradient information, proximity to water supply network, number of crossings with railway tracks and National Highways.
- Formalize multi-stakeholder committee including District Administration, Forestry Department, and urban local body to strategize solutions on blue-green features, particularly in high-risk areas and curb illegal encroachment of eco-sensitive zones like near water bodies and hill areas.
- Revise urban planning codes to include climate-sensitive measures and restrict encroachment near flood-prone zones.
- Implement low-cost, decentralized wastewater treatment systems to protect local water bodies from contamination.

The future of disaster resilience in Guwahati hinges on a coordinated, multi-stakeholder approach that incorporates community awareness, infrastructure improvement, and robust policy frameworks. Policy makers and decision-makers could consider the phase-wise recommendations for improving the overall resilience of the cities. Implementing the recommended actions within the designated timelines will enhance urban resilience to future climate impacts, support sustainable growth, and protect critical infrastructure. This could be achieved by prioritizing and focusing on low-performing parameters through targeted action plans. Besides, the good aspects could be further strengthened and to showcase good practices. Further, comprehensive flood mitigation master plans could also be formulated in this regard for each of the cities. Municipal authorities are encouraged to initiate these changes in collaboration with state agencies, NGOs, and local communities, leveraging the outlined responsibility matrix to ensure accountability and sustained action.



**Prof. (Dr.) Amir Ali Khan**  
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# 1 Introduction

## 1.1 Background

India is geographically located in a high disaster-prone region and has been under the continuous impact of natural hazards, which include floods, cyclones, landslides, earthquakes, heatwaves and tsunamis. In India, out of 28 states and 8 union territories, around 27 are disaster-prone and more than 40 million hectares (mha) out of 329 mha of India is flood-prone (NDMA, 2019). A total of 5,161 urban local bodies are prone to urban flooding. (NDMA, 2023). Recent years have seen severe cyclonic activity in the Arabian Sea and Bay of Bengal due to global warming leading to concentrated heavy rainfall leading to urban floods. Some of the most devastating floods like in Mumbai (2005), Chennai (2015) and Srinagar (2014) were caused by periods of intense rainfall. Additionally, human intervention in the environment creates a greater chance of urban floods. Rapid development and change in land use directly influence the vegetation cover and slow down water flow, reduce water-retention capacity, etc leading to increased chances of urban flooding. Urban flood increases the flood peaks from 1.8 to 8 times and flood volumes by up to 6 times. Every year an estimated damage to houses and public utilities of Rs. 1805 crores is caused due to floods only (NDMA, 2019). Despite urban flooding being a problem for decades, there has been insufficient attention paid to planning specific initiatives to address it. The Mumbai floods of 2005 paved the way for specific actions and guidance for urban flooding in India. Because of the extent of the disruption caused by these urban floods, the authorities realized that many factors contribute to urban flooding, necessitating the development of effective response plans.

National Disaster Management Authority (NDMA) developed the National Guidelines for the Management of Urban Flooding in order to enhance national efforts to manage urban flood disasters and fortify the goal of adopting a more proactive, mitigation-focused approach to pre-disaster preparedness.

Intergovernmental Panel on Climate Change (IPCC) Report suggests an increase in the number of extreme disaster events in India. Now not only there are more disasters occurring, but they are also getting more complex and multifaceted. Some of the recent urban flooding incidents were in Hyderabad in 2020 and 2021, Delhi in July 2023, Bengaluru and Ahmedabad in 2022 and Chennai in November 2021 (Singh, 2022). Hyderabad faced over 33 life losses in the 2020 floods (Somasekhar, 2020), Bengaluru experienced a stoppage of water supply in many parts during the 2022 floods as pumping stations were completely submerged and in Delhi over 25,000 people had to be relocated during July 2023 floods (Sphere India, 2023). These events have caused irreparable damage to life, property, livelihoods, and infrastructure. Such flooding events can be linked to the rapid growth in urbanization, anthropogenic impacts on the environment like construction on the beds of rivulets, rivers, and lakes, encroachment on natural drainage etc. For instance, the built-up cover has increased by 41% in 0-20 km of the city center in Hyderabad and by over 65% in 0-20 km of the city centre in Bengaluru between a span of only 15 years between 2000 to 2015 (WRI, 2020). This has led to a major challenge of decreased water-retention capacity thus exacerbating the risks of flooding.

Rapid population expansion has intensified the demands on infrastructure services in Indian cities, of which many are already operating beyond their capacity. In Tier II cities like Guwahati and Pune increased imperviousness, siltation, and surface runoff attribute to urban flooding incidents (Sarmah, 2018; Kumar, 2021). Imperviousness is increased by features such as paved spaces like large parking lots, roads, and underpasses that lead to frequent and severe waterlogging. Guwahati has lost almost 60% of its water spread due to urbanization up until 2020 (DTE, 2020). Instances of overwhelmed drainage systems, uncontrolled dumping of solid waste, and increased wastewater discharged into existing stormwater drains/rivers can lead to disruption of the flow of waste water and reduced carrying capacity. Such incidents have occurred in the past leading to flooding and epidemics during the monsoon in cities like Guwahati, Siliguri (Sarmah, 2018).

The projected impact of climate change like altered frequencies and severity of hydro-meteorological hazards such as floods are giving rise to complex and cascading urban risks in the cities. It is aggravated by the pressure of urbanization on cities. Under such complex risk scenarios, fragile urban systems often break in, triggering cascading impacts on other inter-connected urban systems and services. The increasing incidence of climate change-induced events has compounded urban challenges, manifesting in recurrent flooding and exacerbated urban heat island effects. Thus, there is a need for an evidence-based framework that undertakes a holistic and multi-dimensional systems approach to understand and manage evolving flood risks being faced by Indian cities. There is also significant potential in a comprehensive assessment of urban flood risks due to limited consideration of critical aspects such as operational concepts, structural

evolution of urban flood resilience, and benefits of nature-based solutions (NbS) like green infrastructure design in past assessments (Prashar et. al., 2023).

The Sustainable Urban Development Smart Cities II (SUDSC-II) project jointly implemented by GIZ on behalf of the German Federal Ministry of Economic Cooperation and Development (BMZ) and Ministry of Housing and Urban Affairs (MoHUA). The project aims to develop climate-induced disaster-resilient sustainable habitats. It supports MoHUA and partner cities in resilient, sustainable approaches and solutions for urban development including infrastructure that considers disaster risk management (DRM) and the leave-no-one behind principle. Through the sub-project 'Enabling cities on Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) for Sustainable Urban Development in India' under SUDSC-II) National Institute of Disaster Management (NIDM) has assigned the task of conducting a study on 'Development of Flood Risk Assessment Framework and a Roadmap for Making Cities Resilient' to the consortium of Resilience Innovation Knowledge Academy (RIKA) India Pvt. Ltd., Walter P. Moore (WPM) and Indian Institute of Technology Guwahati (IIT-G). This project was undertaken in two cities: Guwahati and Manikonda.

In collaboration with the municipal offices at Guwahati, the current study engaged departments set up to maintain various services in these cities, like urban local bodies, town planning, and allied departments to understand their capacities for management of flood risks. After analysis of existing datasets and reports on urban flooding, planning, and rainfall patterns flood risk at ward and zonal levels within the city was assessed. Multiple rounds of stakeholder consultations at the city and the NIDM office,



in Delhi were conducted. It was identified that, historically, flood disaster management strategies were mostly focused on riverine floods, but during the course, it was recognized that the causes and tactics to deal with urban flooding are different across zones of the city. It was observed that the overall resilience of the community has weakened as a result of the effects of migration, economic inequality, population expansion, and environmental deterioration. It suggested that the only appropriate course of action to mitigate and manage the potential effects of disaster and climate change is through the integration of disaster risk reduction and climate change adaptation into development initiatives. This has to be done in all varied sectors and in all development projects and programmes across these crucial sectors. This study was developed based on the existing challenges and capacities to provide a set of actionable recommendations for Guwahati.

## 1.2 Objectives

With the overall aim of enhancing the capacities and building the resilience of urban centres against climate and disaster risks, particularly those of floods, the following are the key objectives of the current assignment:

- 1 Developing a flood risk assessment framework for Indian cities
- 2 Developing a roadmap for building the resilience, particularly to urban floods

## 1.3 Scope and Limitations

The current study aims to achieve the broad outcome of enhancing the resilience of cities against urban flood risks. In this regard, the project team was required to develop a flood risk assessment framework, a roadmap for building

resilience, particularly to urban floods, a training module on the risk assessment towards flood mitigation and imparting training(s) for the relevant stakeholders from the identified cities/states. The scope of work under the assignment includes:

- 1 Background study & study area profiling - Review of literature, policy documents, relevant stakeholders, existing datasets, tools development (literature informed)
- 2 Flood risk assessment in study area - Underlying causes, hydraulic and hydrologic analysis, ground truthing, conditions of vulnerability of population & assets in hotspots, experience & capacity of local governance, existing initiatives, potential solutions
- 3 Roadmap setting & capacity building - Evidence-based Flood Risk Assessment (FRA) framework, recommendations on risk management, a roadmap for resilience building, training/capacity building sessions on developed resources

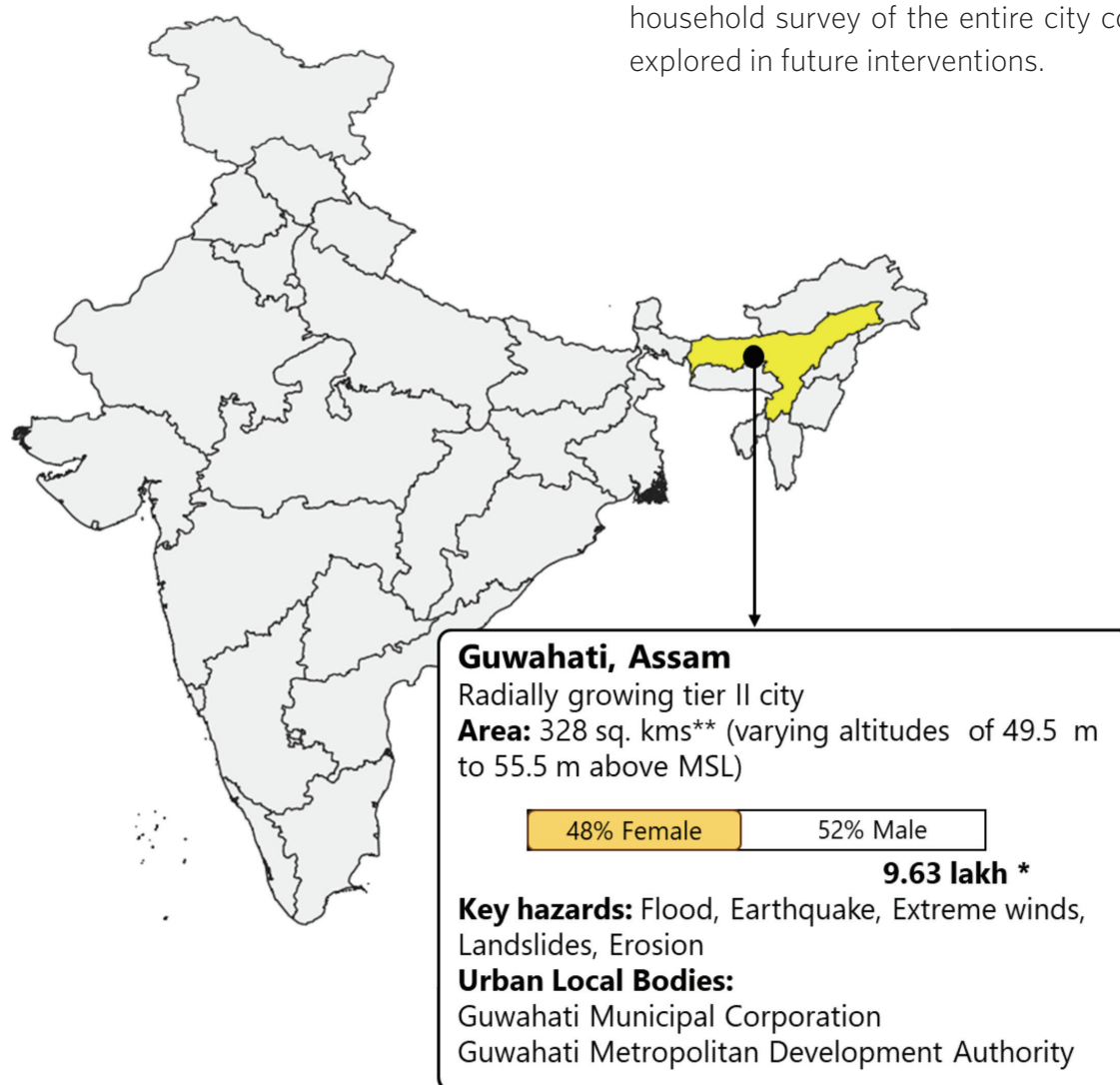
The study has a specific focus on floods, particularly urban floods in the study areas of Guwahati. Guwahati city is a prominent economic centre in northeastern India having a riverine port with hills surrounding it which has faced recurrent flooding and waterlogging throughout the rainy season. The city lies in Assam state where 34% of the land area is affected by floods on a decadal basis (Sphere India, 2022). Details of the study areas are shared in Figure 1. This study will help to promote and localize some of the priorities for action laid down under the Sendai Framework for Disaster Risk Reduction (SFDRR).

The study is fast-paced and short-term study which included the collection of specific primary and secondary information and datasets. Some



significant limitations and measures undertaken for them were:

- Lack of unavailability of recent datasets with the urban local bodies. Some data from secondary sources were used to fill data gaps. Consultant reports and academic papers were reviewed for the latest information.
- Few datasets could not be used due to resolution and accuracy challenges. E.g. coarse resolution soil data, inadequate information on invert levels, outfall locations etc. The best available datasets were used in these cases.
- Procedural delays due to elections & floods (occupied authorities) were faced in Guwahati. Alternatively, multiple visits were made to identify specific information through focus group discussions and household surveys.
- The reluctance of authorities and the community to share information. Data gaps were filled from information available in secondary sources like published reports, plans etc.
- Due to the short duration of study, the most suitable 1D modelling was used to obtain results. A detailed topographical survey, higher resolution HEC-RAS modelling and household survey of the entire city could be explored in future interventions.



\* Census 2011 data \*\*Area as per Draft Master Plan 2045

Figure 1. Study Area

## 2 Literature Review

Once a rare event, urban flooding is now a serious problem that occurs frequently in India's largest cities. Climate change intensifies urban flooding episodes, causing unexpected and severe impacts. The IPCC report AR6 highlights the negative effects of human-caused climate change on the Indian subcontinent, such as increased dry spells, more extreme rainfall, and a surge in heatwaves and cyclonic events. Given that disasters have increased fivefold over the previous fifty years, the World Meteorological Organisation (WMO) and the United Nations Office for Disaster Risk Reduction (UNDRR) emphasize that climate change increases the likelihood of catastrophes and diminishes community resilience. This indicates that without effective disaster management strategies, urban systems can fail or come to a standstill.

Events in Guwahati (2022), Hyderabad (2020), Patna (2019) and Kochi (2018) have brought attention to the urgent need for all-encompassing plans that combine better flood risk reduction with specific consideration to the condition of drainage networks and solid waste management. Floods in Chennai (2015), Kashmir (2014), Surat (2006) and Mumbai (2005) show how persistent this issue is. Cities with an increasing urban population like Chennai, Guwahati and Hyderabad face challenges where their aging sewage system, designed for a much smaller population, struggles to cope with the city's current demands. Storm intensity and urban waste accumulation in these cities have increased, necessitating an integrated strategy for disaster management, ecological preservation, and urban design. Taking into account this problem of flood risk, the Indian government has started several important projects to reduce urban flooding. National Disaster Management

Authority (NDMA) formulated the National Guidelines on 'Management of Urban Flooding' in 2010 in response to the growing risk of urban floods. These guidelines provide a list of preparatory and mitigation measures meant to increase urban areas' measures against floods. These guidelines also highlight the necessity of integrated approaches to urban management. The government for the Urban Flood Risk Management Programme (UFRMP) has allocated approximately Rs. 2500 crore, targeting seven major cities—Mumbai, Chennai, Kolkata, Hyderabad, Ahmedabad, Bengaluru and Pune focused on sectors of urban infrastructure, improving drainage systems that are frequently clogged by waste, and implementing advanced early warning systems.

The following sections detail the existing conditions, opportunities to strengthen interventions, good practices, and various aspects necessary for the flood risk assessments for urban areas.

### 2.1 Status of Drainage System in India

Currently, stormwater drainage in India is considered lower in priority than drinking water and sanitation. However, to protect metropolitan areas from urban flooding in a phased fashion, compatible with the availability of resources, storm water drainage systems need to be designed and built in an organized manner, considering many aspects of design, operation and maintenance, and economics. Some of the prominent factors responsible for the drainage conditions in India are:

- Cities' natural drainage systems are in peril, leading to increasing flooding due

to inadequate storm water drainage infrastructure. The flooding situation has worsened due to the non-availability of properly engineered stormwater drainage infrastructures (CPHEEO 2019). The problems are compounded by encroachment and rampant dumping of garbage and solid waste into drains on the one hand, and a lack of preventive maintenance on the other.

- Underground drainage facilities in core areas of megacities are often century-old brick masonry pipes. The present storm water collection network in these cities is primarily intended to function as a combined system for sewage and storm water runoff. Augmentation and restoration, including the separation of storm water from sewage in such facilities, present the highest level of obstacles for municipal engineers and financial resources.
- According to the Report on Indian Urban Infrastructure and Services published by the former Ministry of Urban Development (MoUD) in March 2011, the storm water drainage network covers only about 20% of the road network and catchments. This is insufficient to address storm water disposal in today's cities.
- The Manual on Storm Water Drainage System by CPHEEO suggests that urban flooding issues are exacerbated due to the widespread dumping of garbage and solid waste in the drains. Illegal disposal of construction and demolition waste along with poor maintenance of existing drainage systems often obstructs the storm water runoff causing localized flooding.

## 2.2 Techno-Legal Instruments

After the Disaster Management Act of India was passed in 2005, the Disaster Risk Management process underwent a substantial evolution. The prime authority for disaster management in India is the National Disaster Management Authority (NDMA), which is led by the Prime Minister. The Disaster Management Act of 2005 governs the institutional framework used by authorities at the state and district levels for disaster management. The National Disaster Management Plan and the National Policy on Disaster Management, 2009 offer the government agencies at all levels a structure and guidance. The Disaster Management Act, 2005 was also imposed during the COVID-19 response as it envisaged the role of all ministries and agencies in the measures to be taken for the response to the emergency situation.

The Disaster Management Act, 2005 provides the legal and institutional framework for “the effective management of disasters and for matters connected therewith or incidental thereto”. It provides for the establishment of National Disaster Management Authority (NDMA), State Disaster Management Authority (SDMA) and District Disaster Management Authorities (DDMA) at the National, State and District levels with financial and administrative powers. The act also provides guidelines for the creation of the National Disaster Response Fund, and National Mitigation Fund, the establishment of funds by State Government and the allocation of funds by Ministries and Departments for Emergency Procurement. The act also provides for the establishment of the National Disaster Response Force (NDRF). Some of the other plans and policies that directly or indirectly influence flood risks are reviewed in Table 1 below:

**Table 1: Review Existing Policies and Guidelines**

| Document Reviewed                         | Key Features                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Opportunities to Strengthen Flood Hazard                                                                                                                                                                                                                                                                                                      |
|-------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| National Disaster Management Policy, 2009 | <ul style="list-style-type: none"> <li>▪ Expanding the scope of disaster management activities to build a resilient and safe India.</li> <li>▪ Covering institutional, legal and financial arrangements related to all stages of DM.</li> <li>▪ Development of techno-legal regulations for safe building, municipal practices and compliance.</li> <li>▪ Multi-hazard strategy, in consideration of cooperation, partnership and technological interventions.</li> <li>▪ Addresses the concerns of all sections of society through community-based disaster management.</li> <li>▪ Focus on last-mile integration of the policy, plans and execution.</li> <li>▪ Cooperation with national, regional and international agencies.</li> <li>▪ Capacity building and training for personnel in DM.</li> <li>▪ Promotes multi-sectoral synergy.</li> </ul> | <ul style="list-style-type: none"> <li>▪ Various flood risk typologies especially urban flood management need to be highlighted.</li> <li>▪ Promotion of data collection, analysis and dissemination systems to support evidence-based decision-making.</li> <li>▪ A component of cascading risks is absent.</li> </ul>                       |
| National Environment Policy, 2006         | <ul style="list-style-type: none"> <li>▪ Regulatory reforms for effective environmental management.</li> <li>▪ A streamlined process for environmental and forest clearances.</li> <li>▪ Development of environmental standards based on scientific research.</li> <li>▪ Promotion of clean technologies and innovation for sustainable development.</li> <li>▪ Emphasis on environmental awareness, education and information dissemination.</li> <li>▪ Encouragement of partnerships and stakeholder involvement in environmental conservation.</li> </ul>                                                                                                                                                                                                                                                                                            | <ul style="list-style-type: none"> <li>▪ Institutionalize watershed management plans.</li> <li>▪ Integrating disaster risk assessment and mapping.</li> <li>▪ Promoting sustainable land use planning and zoning regulations.</li> <li>▪ Implementing awareness and promotion of nature-based solutions and watershed development.</li> </ul> |

| Document Reviewed                            | Key Features                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Opportunities to Strengthen Flood Hazard                                                                                                                                                                                                                                                                                                                                                                     |
|----------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| National Disaster Management Plan, 2019      | <ul style="list-style-type: none"> <li>▪ Framework and direction for all government agencies to mainstream responsibilities and intervention strategies with consideration to all phases of the DM cycle.</li> <li>▪ Founded on the DM Act and NPDM 2009 and integrates mandates from SFDRR, SDG and Paris Agreement.</li> </ul>                                                                                                                                                                                     | <ul style="list-style-type: none"> <li>▪ Timeframe for periodic O&amp;M of drainage systems.</li> <li>▪ Solid-waste containment, prevention of release and management guidance.</li> <li>▪ Interconnection of drainage network.</li> <li>▪ Mechanisms to limit extreme expansion of human footprint in cities.</li> <li>▪ Clear delineation of responsibilities of state and parastatal agencies.</li> </ul> |
| National Action Plan on Climate Change, 2008 | <ul style="list-style-type: none"> <li>▪ Integrates a vision for green and ecologically sustainable development into all facets of national development, including urban areas, agriculture, industr, and ecological systems.</li> </ul>                                                                                                                                                                                                                                                                             | <ul style="list-style-type: none"> <li>▪ The mission on sustainable water is adaptive and lacks quantified targets.</li> <li>▪ Limited convergence of Mission on sustainable habitats with existing AMRUT due to multi-departmental and sectoral approaches, respectively.</li> </ul>                                                                                                                        |
| National Urban Policy Framework, 2018        | <ul style="list-style-type: none"> <li>▪ Takes a comprehensive and consistent approach with two axes of philosophical perceptions and</li> <li>▪ Functional aspects of urban space and management.</li> <li>▪ The component of environmental sustainability highlights the need for planners to adapt to the local environmental landscape while protecting natural drainage and contours.</li> <li>▪ Highlights the need for risk financing mechanisms at all levels with a focus on local institutions.</li> </ul> | <ul style="list-style-type: none"> <li>▪ Mechanisms for consideration of environmental impact assessment in urban planning.</li> <li>▪ Potential for integration of watershed management and consideration.</li> <li>▪ Emphasis on nature-based solutions in addressing urban flood.</li> </ul>                                                                                                              |

| Document Reviewed                                      | Key Features                                                                                                                                                                                                                                                                                                                                                                                                                                   | Opportunities to Strengthen Flood Hazard                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|--------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| State Disaster Management Plan – Assam, 2022           | <ul style="list-style-type: none"> <li>Includes strategies that direct the management of disaster risk and the mitigation of multi-hazard risk in development processes at all levels and in all areas of the Assam government.</li> <li>In accordance with the DRR Roadmap that ASDMA authorized, it aims to strengthen DRR in Assam and its integration into programmes.</li> <li>Includes projections of climatic variabilities.</li> </ul> | <ul style="list-style-type: none"> <li>Lack of segregated data on damage and loss caused by various types of flooding.</li> <li>Potential to enhance mechanism to collect locational data on urban flooding using crowd-sourced platforms.</li> <li>Mechanism to include disaster risk reduction in schemes for social justice.</li> <li>Specific directions to address cascading and compounded risks.</li> <li>Timeline on maintenance of critical infrastructure, storm water drainage, dams and embankments, could be included.</li> </ul> |
| District Disaster Management Plan – Kamrup Metro, 2024 | <ul style="list-style-type: none"> <li>Coordinated, and comprehensive approach to disaster management.</li> <li>Achieving mitigation, preparedness, response and recovery are all guided by the DDMP.</li> <li>Delineates roles and responsibilities of various line departments.</li> <li>Includes seasonal mitigation measures related to urban floods.</li> </ul>                                                                           | <ul style="list-style-type: none"> <li>Consideration of disability is limited to response whereas inclusion should be prominent in all stages of DRR.</li> <li>Mitigation measures to prevent the release of pollutants from industries into water bodies.</li> </ul>                                                                                                                                                                                                                                                                          |
| City Disaster Management Plan – Guwahati, 2022         | <ul style="list-style-type: none"> <li>The City Disaster Management Plan aims to share the top methods used by different disaster management organisations.</li> <li>Identifies emergency support functions by different agencies in the city.</li> </ul>                                                                                                                                                                                      | <ul style="list-style-type: none"> <li>Mechanism to regularly monitor structural condition of critical infrastructure in flood-prone areas.</li> <li>Alternate facility identification for critical infrastructures.</li> <li>Distribution of roles and responsibilities for mitigation activities not defined.</li> <li>Scope for integrating gender-sensitive planning and capacity building for DRM.</li> </ul>                                                                                                                             |



| Document Reviewed              | Key Features                                                                                                                                                                                                                                                                                    | Opportunities to Strengthen Flood Hazard                                                                                                                                                                                                                                                                                                               |
|--------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Guwahati Development Plan 2025 | <ul style="list-style-type: none"> <li>Plan to deal with rapid urbanization, new emerging socio-economic issues and related urban issues in the Guwahati city.</li> <li>Highlights the projected development areas and permissible limits with consideration to eco-sensitive zones.</li> </ul> | <ul style="list-style-type: none"> <li>Prioritize limiting constructions such as townships, and bungalows in eco-sensitive zones.</li> <li>Risk-sensitive approach to land use planning which restricts development in flood-prone zones.</li> <li>Improvement of carrying capacity of drains within city limits and new development areas.</li> </ul> |

Source: Developed from Disaster Management Plans at country, state, district, city levels and other relevant policy documents

## 2.3 Good Practices

To achieve sustainable urban development, action-oriented planning with a strong mobilization strategy, capacity building, and monitoring mechanisms are essential to provide a safe and secure habitat. Integration of the practice of risk management within the governance, planning, and operations of local authorities like municipal bodies and allied departments can effectively accomplish urban disaster risk reduction. The local-level disaster risk reduction activities such as risk-sensitive land use plans are important for strengthening disaster risk governance at the micro level. Certain exemplary practices that have been followed around the world are discussed in the following paragraphs. The characteristics or practices observed in the case can form the base criteria for delivering suitable strategies for risk and resource management, and future land use planning and can serve as a basis for development goals to be implemented by the municipal body of Guwahati to ensure resilience. The practices discussed are not necessarily

global best practices but best-suited practices in relatable conditions or can guide in building the roadmap for making cities more resilient.

### Multi-layer Approach and NbS in The Netherlands

More than half of the Netherlands is below sea level, prompting the country to seek creative water management techniques while shifting focus to mitigating flooding as part of sustainable urban design. Protective dikes along the coastline and rivers are examples of proactive and preventive steps taken by the country to combat the ongoing threat of flooding. The Flood Protection Act, now called the Water Act since 2009, establishes flood protection standards and has introduced a 6-year assessment of the flood defenses. The country takes a multi-layer approach as shown in Figure 2 where prevention, protection, and planning are integral parts. It functions on prevention from granting building permits in its high flood-prone areas, planning on what to do when flooding occurs, and spatial

planning measures like compartmentalization to address nature conservation, recreation and infrastructure. E.g. implementation has been done on the island of Dordrecht, known as “Self-reliant Island of Dordrecht”.

Delta Program of Netherlands is an approach to flood risk management, with a system of dams barriers, dikes, and other protective measures. The program focuses on integrated water management strategies, such as sustainable drainage systems, water storage facilities, and water reuse activities. This leads to better water resource management, less water shortages, and greater resistance to climate change impacts. It also encourages Nature-based solutions and ecosystem restoration activities, such as wetland rehabilitation, river restoration, and habitat conservation e.g. ‘Wide green dike’ as a nature-based solution against flooding. ‘Wide green dike’ is a historical design that uses solely natural materials, such as clay covered in grass, and has a gently sloping seaward face blending into the adjacent salt marsh. This has been significant in bringing together experts on water management, civil society, and authorities from all levels of government. The program targets to identify barriers and drivers in implementing NbS to flooding so that regions with similar geography can replicate it.



*Figure 2. Multi-layer Approach of Netherlands on Safety, Prevention, Sustainable Spatial Planning and Disaster Management*

*Source: Beleidsnota Waterveiligheid 2009-2015*

### **Institutional Mechanisms and Flood Early Warning Technology in Japan**

Japan underwent rapid development economically and militarily during the late 19<sup>th</sup> and early 20<sup>th</sup> century where the municipal body now plays a central role in disaster management. According to the Disaster Countermeasure Basic Act, the municipal body is responsible for establishing a local disaster management plan, emergency operations such as warning systems, issuing evacuation recommendations and orders, and relief activities. The approach

to risk assessment chosen is based on risk type and local characteristics, while also taking into account different stakeholders' requirements. Another aspect considered important is the capacity building of the city's residents. The Life Safety Learning Center is developed by the Tokyo Fire Department at different locations in the city of Tokyo to provide an experiential facility to share disaster preparedness knowledge. The center has earthquake simulations, drills for typhoons, and flood information sharing with evacuation knowledge.



### Low-cost Automated Flood Early Warning System (FEWS)

Dependence on manual systems for last-mile dissemination of early warning has led to delays in response to flooding incidents in Japan. Most FEWS, especially for small rivers, are manual which makes risk identification difficult, particularly in remote areas. Low-cost, on-site FEWS systems have been earlier installed by Yamagata Prefecture by the Ministry of Water Resources, Japan. These use carbon and magnesium inside a water battery which when dipped in water undergo a chemical reaction magnesium oxidizes and releases electrons and carbon facilitates reduction leading to the flow of electrons that generates electric current which triggers off signals. It is an automated, and low-cost on-site solution that uses flood water to generate electricity which further powers emergency evacuation light signals and alarms. It is useful, particularly in areas where a systematic early warning system is missing. When connected to an electric source and the internet, the advanced version can relay the generated signals through an IT network for wider transmission or can be integrated with other dissemination channels. This system has been tested at a pond at Keio University, Japan with different variations. A modified version of a similar water battery-powered Flood Early Warning Dissemination System (FEWDS) is being installed and tested in Uttarakhand by the RKA team.

The Act on Sediment Disaster Countermeasures 2001 provides the base for the development of land use zoning in the area. The non-structural measures like identification of hazardous areas and provision of information for decision-making are based on this act. The act highlights the designation of warning and special warning areas for sediment-related disasters, which are prime for land use zoning. This highlights the need for risk-sensitive planning for land use.

The zonation is done by “red” and “yellow” for special warning areas as shown in Figure 3. Red zone residents are at severe risk to their lives and health whereas yellow are at moderate. The act also aims to enable residents to share information for their decision-making. The City Planning Act mentions a criterion of delineation of the urbanization promotion area and the urbanization control area based on vulnerability to floods, tsunamis, and storm surges.

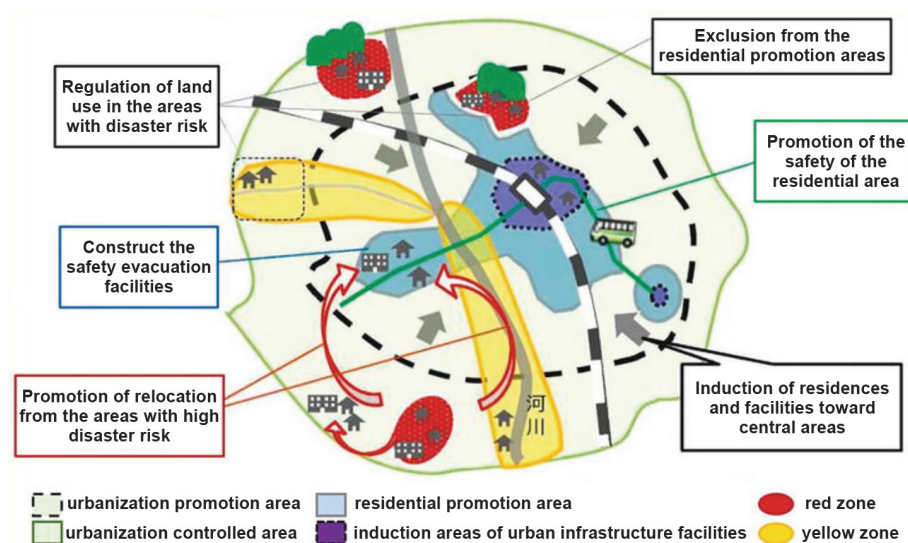


Figure 3. Countermeasures for Disaster Mitigation Risk-sensitive Planning

Source: Karashima, K. & Ohgai, A., 2022

Local disaster management plans are formed by the local Disaster Management Council which has a representation of local government and line departments. The national government provides essential help to local governments while the city government facilitates consensus among stakeholders through the Disaster Management Council. Wherever practicable, solutions include multi-functional systems that offer benefits beyond flood risk management. It is also vital to create and implement clear governance systems. At the center of each NbS project, is the community that plays a vital role (Sharma, S. and Ayuba, D., 2024; International Bank for Reconstruction and Development, 2022).

Some initiatives across the globe were reviewed from the perspective of NbS in flood mitigation as summarized in Figure 4. Japan displays technologically advanced systems for disaster

risk reduction and thus is an important center for technical knowledge sharing with the world. Nature-based solutions such as the sites East Kolkata Wetlands, and integrated storm water drain in Chennai have varied costs associated based on scale. These solutions are comparatively efficient and cheaper than data-driven early warning system establishment or formation of underground storage of stormwater. The reviewed practices indicate that developing resilient infrastructure, such as flood barriers and green spaces is beneficial for mitigating flood risk. Restoring wetlands and floodplains can reduce the impact of floods while promoting biodiversity. Reliable early warning systems enhance preparedness and response to flood events, saving lives and reducing damage. In addition, building capacities of local communities in flood risk management ensures better understanding, compliance and resilience.

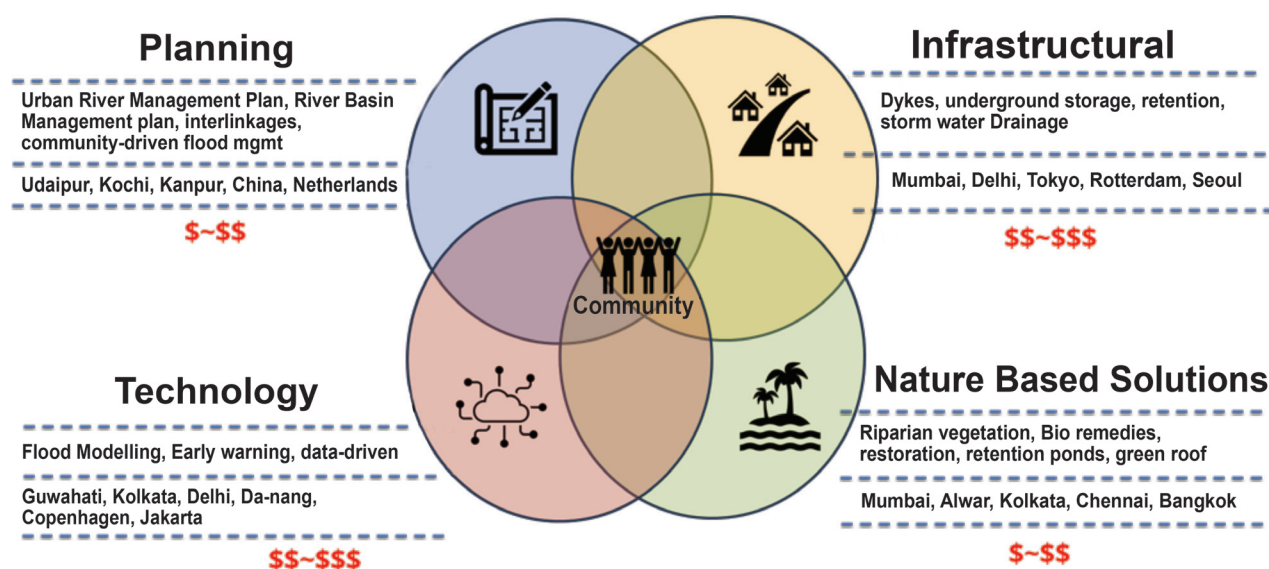


Figure 4. Other Examples of Initiatives to Improve Flood Resilience

Source: Authors' compilation

## 2.4 Components of Flood Risk Assessment

Many plans, policies, research articles, scientific papers, and journals were reviewed in a systemic manner using keyword searches indicating prominent aspects of the flood risk assessment. The process of risk assessment majorly uses the frequency of events, exposure, and vulnerability. It can look into hazard intensity, which is the spatial distribution of the measurable negative consequences of a particular hazardous phenomenon. It was observed that for assessing different hazards and their domino effects the systematic hazard interaction and their classification have been used in previous studies (Liu, et. al., 2015; Marzocchi, et. al., 2009). From the perspective of **hazard assessment**, utilizing satellite imagery, meteorological data, and geographical data has been made easier and more effective by the application of GIS techniques. Studies in the past have given consideration for cascading risks with spatial and temporal aspects being used to analyse information (L.F. Guimarães et.al. 2021, Li. J. et. al. 2023). In addition, water depth and return period are the most commonly used components to assess flood hazards (Rangari et. al. 2021). Thus, based on the literature, hazard intensity and frequency along with the systemic hazard interactions have been incorporated into the flood risk assessment framework as shared in the following section.

For the **exposure assessment**, aspects such as the percentage of impermeable ground (%), built-up area, road density (paved roads), number of protected buildings, critical infrastructure, and groundwater level have been considered by studies related to flood risk assessment (Kumar et.al. 2021, Garrote et al. 2020, Chang H, et al. 2021, Kramer et al. 2016). Although the effects of physical structure on people during disasters have been investigated, further research is necessary to fully understand the impact of

social, economic, and environmental issues. The degree of risk induced through floods depends on various social, physical, institutional, natural, and economic factors that vary from one area to another (in this study, ward and division). Hence, the degree of risk induced varies for each area.

Füssel, 2010 states two approaches for calculating vulnerability to flood risk: theory-based and data-based approaches (Füssel, 2010). Data-based approaches are extremely specific to situations and have constraints on data availability. Reclassification, indexing, modelling, and multi-criteria approach are some of the commonly used techniques for risk assessment (Pathak et. al. 2020, Sarmah et. al. 2020, Ahmed et. al. 2024, Sundaram et. al. 2021). This study thus uses a theory-based approach by assigning weights to selected indicators. Although there might be uncertainties, the weighing of variables has proved effective in studies (Lein, 2010). Expert knowledge and system characteristics play an important role in the approach of using vulnerability indicators and have been found to be more effective than computer modelling and other methods (Nasiri, et al., 2016). The approach for vulnerability assessment for Guwahati uses weights to estimate the vulnerability for all the floods and other hazards.

**Physical** considerations directly affect the structures in the event of natural hazards and further define their vulnerability. The physical components in the vulnerability assessment study generally include the type of buildings, kind of roof, wall and floor. In addition, covers the physical characteristics of roadways, building styles, vital infrastructure (such as water and electricity supplies) and medical facilities (such as fire departments and ambulances) (Winrock International India, n.d.). The damage to physical

structures like buildings, roads, bridges, and public utilities can be caused by lateral pressure or velocity forces, erosion of foundations gradual weakening due to waterlogging, and other effects (World Bank, 2016). Construction type is an important function while determining the dead weight. Brick houses, wooden houses, and masonry flood retaining walls can cause differential levels of damage and hence variation in weight is given accordingly. The factors encompassed in this study consider the elements that are either directly or indirectly connected to the location and kind of the built environment. These are referred to as physical factors.

The degree of growth in terms of human development metrics and the general well-being of people, communities, and society is correlated with **social** factors. It covers things like common areas, literacy rates, and collective organisational methods and traditional values. Access to money and fundamental socioeconomic infrastructure are examples of **economic** considerations. The study employed many indicators under the heading of economic aspects, such as the source of income, annual income, access to insurance schemes, financial institution accessibility, and industry areas.

Studies have established the exposure and vulnerability aspects are equally important while approaching the vulnerability concept (Bohle, 2001). According to United Nations, flood risk vulnerability is scored from 0 to 1 i.e., no damage to full damage (United Nations, 1982). Managing flood with the goal of the safety and well-being of the public and minimizing loss is one of the main responsibilities of city authorities in flood prone areas. Studies consider different sides of flood risk assessment and have also included the aspect of sensitivity of population using indicators like population density, gender and age (Murillo-Garcia, et al., 2015). The type of

building that could be damaged is another major criterion to assess the vulnerability (World Bank, 2016).

Through the literature review following were the key components identified for consideration in order to design the flood risk assessment framework as shown in Section 3.

- Flooding variables considered: water depth, return period.
- Exposed elements: Humans, Buildings, Animals.
- Cascading hazard: Spatial and temporal aspect.
- Physical dimension: Percentage of impermeable ground (%), Built-up area, Road density (Paved roads), Number of protected buildings, Critical infrastructure, Groundwater level.
- Social dimension: Population density, hospitals, number of registered volunteers.
- Economic and political dimension: GDP, subsidy after disaster.
- Natural dimension: Green infrastructure.
- Assessment: Reclassification, indexing, modelling.

## 2.5 Framework for Flood Risk Assessment

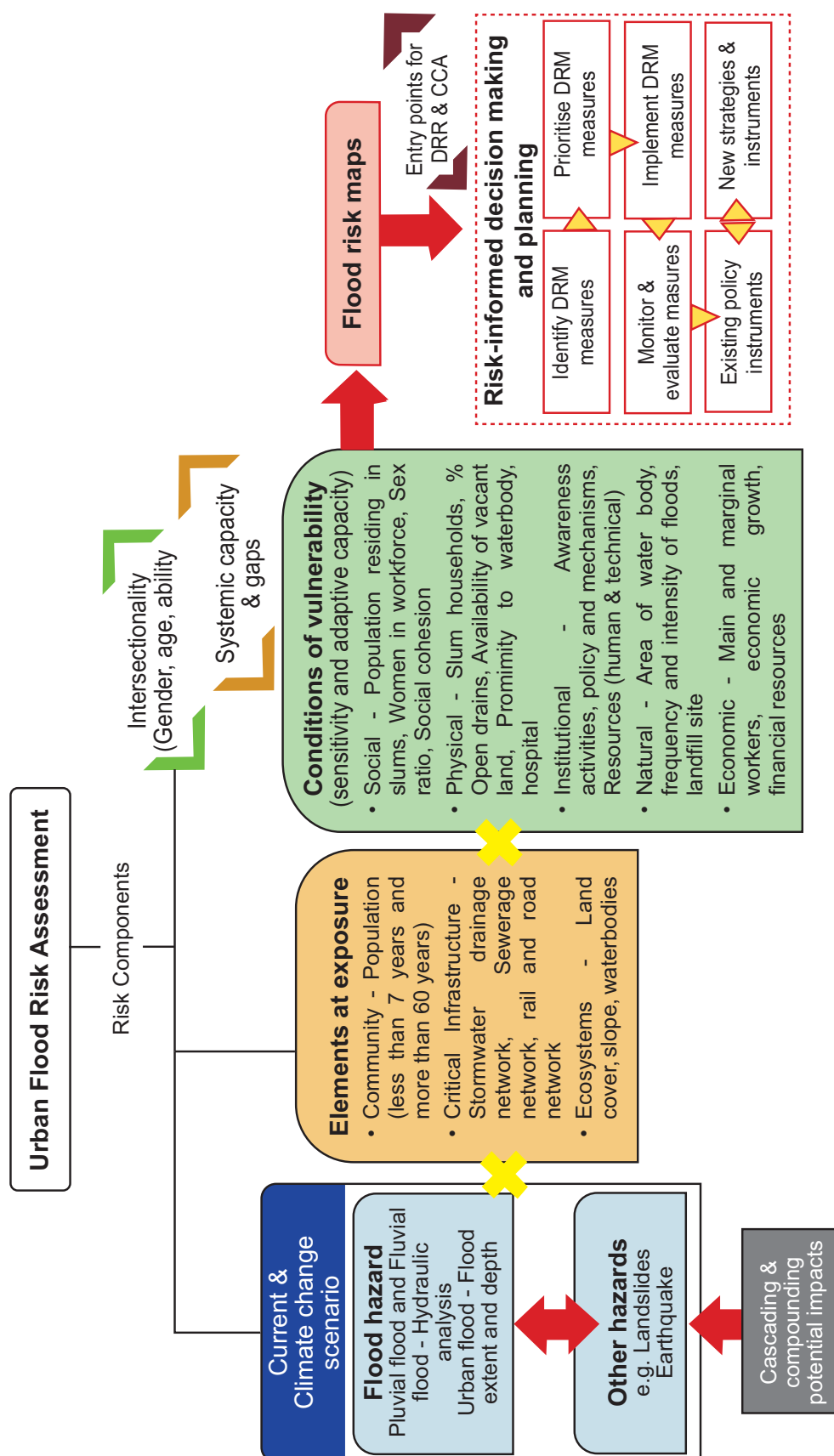


Figure 5. Conceptual Framework for Flood Risk Assessment



### 3 Approach and Methodology

Disaster risk is context-specific (UNDRR, 2019). While it can be driven by local, national, regional, or global factors, disaster risk demonstrates varied local and specific characteristics that are shaped by local patterns and interplay of exposure, vulnerability, adaptive capacities, and resilience. The non-linear changes in the intensity and frequency pattern of the natural and biological hazards make the risk more dynamic over time and scale. Such changes can be better gauged and perceived at a local level wherein the local government, local communities and other key stakeholders like Community-Based Organisations (CBOs), Non-Governmental Organisations (NGOs), private sector, etc. are actively engaged and have an instrumental role in the disaster risk reduction (DRR) and disaster risk management (DRM) processes. In line with the paradigm shift brought forth by the Sendai Framework, the focus of the plans should be on disaster risk management rather than only disaster management.

Climate change is expected to adversely impact the progress and processes targeted at strengthening resilience and adaptation. Key aspects to be considered for addressing climate-induced disaster risks and resilience in cities are: (a) Increasing focus on working at the local level — a shift from central government to local government and community level (b) Increasing focus on multi-disciplinary, multi-stakeholder approach (c) Evolution from theory to practice i.e., from technology to implementation. The pressures of urbanization, along with the expected impact of climate change, which is very likely to affect the frequency and intensity of hydrometeorological hazards such as floods, are creating complex and cascading

urban risks in cities. In such complicated risk circumstances, fragile urban systems frequently break in, resulting in cascading effects on other interconnected urban systems and services.

The Sendai Framework for Disaster Risk Reduction (SFDRR) 2015-30 echoes the need for the same, supported by strengthening the existing mechanisms for disaster risk governance at all levels while being mindful of new and emerging risks. In this regard, the role of local government and community is immense not only as first responders but also as well aware, risk-informed and resilient stakeholders for disaster risk management. One of the guiding principles of the SFDRR lays great emphasis on “empowering local authorities and local communities to reduce disaster risk, including through resources, incentives and decision-making responsibilities, as appropriate”. At the national level, the paramount importance of engaging with and enhancing the capacities of local government and local communities is also resonated by the Prime Minister’s 10 Point Agenda on Disaster Risk Reduction. It calls for building on local capacities and initiatives for enhancing disaster risk reduction (DRR). It further underscores that such efforts not only lead to risk reduction but also create opportunities for local development and sustainable livelihoods along with duly imbibing the traditional good practices and indigenous knowledge.

### 3.1 Overall Approach

The approach for this assignment as shown in Figure 6 is guided by the Global Risk Assessment Framework (GRAF) (UNDRR, 2019) and Words into Action Guidelines on National Risk Assessment and Local DRR and Resilience Strategies, in which risk assessment is central to ensuring risk-informed, disaster-resilient and sustainable planning and processes at a city level; thereby furthering the efforts of local administration and other stakeholders towards the four Priorities for Action (PFA) laid down under the SFDRR, namely, understanding disaster risk, strengthening disaster risk governance, investing in DRR for resilience building and enhancing disaster preparedness for better response and ensuring “building back

better” through post-disaster response and recovery.

The aspect of “whole-of-government” approach as emphasized by the 2021 United Nations Climate Change Conference (COP26) to act on risks and opportunities from climate change has been considered. The technical approach of local DRR and resilience lays down that the local government should be playing a leading role in developing and implementing the local DRR and resilience strategies with an active engagement of the local community while other stakeholders like government at a higher level, private sector, and academia should be playing a supporting role.

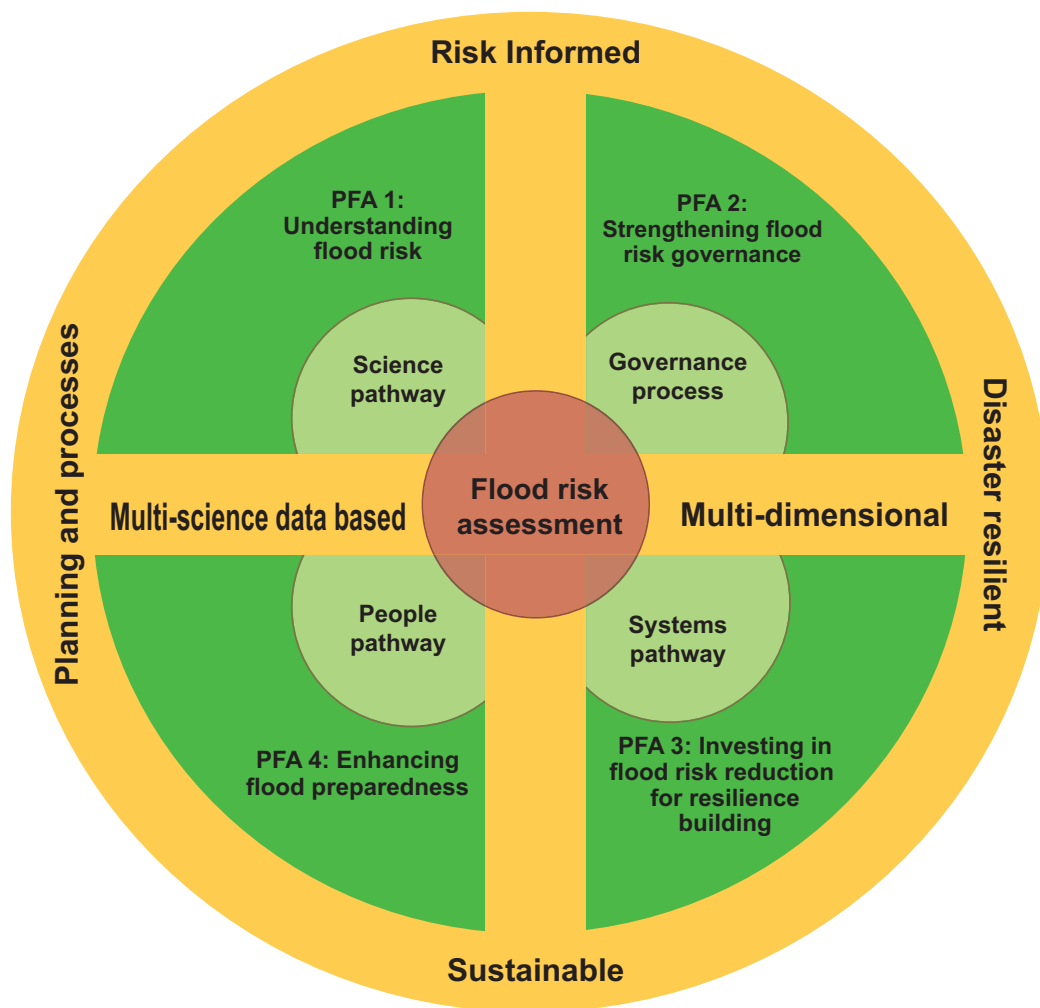


Figure 6. Approach for the Project



In addition, according to the National Disaster Management Plan 2019, specific aspects need for early warnings, mapping vulnerable and at-risk populations, developing a stakeholder engagement strategy and efficient interagency and stakeholder cooperation have been highlighted. It calls for the preparation of an accountability matrix and outlining methods for monitoring, assessing, and revising plans (NDMA, 2019). These have been crucial in helping state and district administrations in India to control urban floods. Contextualising these guidelines locally is crucial, to guarantee their efficient maintenance and building of resilience. A few cities—like Chennai’s Chennai Climate Action Plan (CCAP) and Mumbai’s Mumbai Climate Action Plan, March 2022—have included urban flood management in their climate action plans. There is a scope to establish a formalised governance structures and plans for managing urban flooding.

**Approach:** Under this approach, flood risk assessment is central to ensuring risk-informed, disaster-resilient and sustainable planning and processes at a city level; thereby furthering the efforts of local administration and other stakeholders towards the four Priorities for Action (PFA) laid down under the SFDRR. Under this, the flood risk assessment will be guided by multi-hazard (all types of prominent hazards in an urban context), multi-component (beyond hazard- understanding conditions of exposure, vulnerability & capacity and underlying complex interactions) and multi-dimensional (lenses of social, economic, physical, structural and ecological considerations for understanding vulnerability & capacities) approaches. Figure 6 highlights the key elements of GRAF including causal pathways people, science and systems and governance.

**Science Pathway/Component:** Understanding the existing status of and gaps within the prevalent flood risk assessment methodologies. It enabled the project team to design a robust flood risk assessment framework that addresses the identified gaps and is informed by field-based evidence and existing and emerging tools and technologies. It uses the lens of coverage, interoperability, standards, availability and accessibility for doing so. It also considers the science behind the hazards and conditions of exposure using principles of multiple disciplines such as hydrology, geoinformatics, climate science, etc.

**Systems Pathway/Component:** Fostering systems thinking in the design and implementation of the flood risk assessment by focusing on the interconnections, inter-dependencies and correlations across and in between different urban systems including the urban ecosystems. It leads to gauging inter-dependencies across & within varied components of urban systems e.g. critical infrastructures.

**People Pathway/Component:** Comprehending contexts and needs of at-risk populations; differential vulnerabilities (all-of-society & intersectionality approach) are underpinned in the design and implementation of the flood risk assessment framework and resilience building roadmap. It helps understand and map the differential conditions of exposure and vulnerabilities experienced by different sections of populations residing in varied pockets of the city.

**Governance Component:** Understanding gaps/ enablers in existing institutional frameworks and instruments; maps, tools, plans and guidelines, challenges & opportunities faced by urban local bodies, and other government stakeholders in using them (All-of-government approach). It helps the project team to have a

representative understanding of the needs and usage for different end-users including the city administrators and other key stakeholders. It further led the team to map the ongoing initiatives and efforts in this regard which resulted in laying down well informed and duly streamlined city-specific resilience-building roadmap and training module.

Overall, an effective risk assessment and resilience-building strategy should envisage working towards the management of disaster risks rather than just the management of disasters. It should be laid with a long-term perspective and considerations for existing & emerging and complex risks and not just for the ad-hoc management of a single disaster event. Further, with sustainable development as one of its key guiding principles, the local DRR and resilience strategy should strive to integrate and make DRR inherent to development planning.

The study reflects the four dimensions of risk—

hazard, exposure, vulnerability, and capacity through a comprehensive review of literature, both national and global, along with other scientific literature. The hazard considerations in this study includes possibility of a physical event, trend, or physical impact that could result in death, serious injury, or other health effects, as well as destruction or loss of property, infrastructure, livelihood, ecosystems, and environmental resources. It refers to physical events or impacts related to climate change. Exposure refers to the existence of individuals, livelihood, species or ecosystems, infrastructure, environmental services, functions and resources, as well as economic, social, or cultural assets, in locations and circumstances where they may suffer negative effects. Vulnerability is the tendency or inclination to experience negative consequences. A multitude of ideas and components are included in the same, such as sensitivity or susceptibility to injury and the inability to cope.

### 3.2 Gender Equality and Social Inclusion (GESI) Integration

The concept of gender sensitivity has been developed as a way to reduce barriers to personal and economic development created by societal constructs. Incidents like the Indian Ocean Tsunami of 2004 impacted women severely with 70 percent of fatalities being women in Banda Aceh, and 91 percent of fatalities after Cyclone Gorky in Bangladesh in 1991 were women (Carlsson, R., Helene, M., Trohanis, Z. E., 2012). These highlighted how disasters impact gender groups differently. The need and importance of including gender in DRR and understanding vulnerabilities of gender groups and the ways important to bring gender equality in DRR.

The existing socio-cultural norms related to gender influence the decision-making capacity and access to resources. Such inequalities are structurally embedded into societies. As a

result, women bear the brunt of a disaster in a much-aggravated way than men. One example is when the disaster-induced loss of livelihood acts as a catalyst to increase domestic violence (Daalen et. al. 2022).

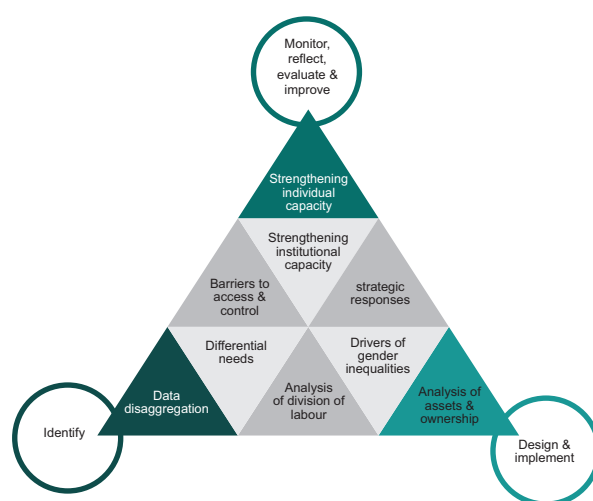


Figure 7. GESI Integration in Risk Planning

Source: Adapted from CRIDF, 2019 & ADB, 2022

As represented in Figure 7, GESI integration has to be considered at all stages of disaster risk planning from identification to design and implementation and monitoring and evaluation.

In this regard, for the present study the following considerations were made:

- Identification of vulnerable gender groups and their differential needs. Data disaggregation is important to analyse the condition in detail. The approach targeted to understand cross-cutting issues (class, caste, religion, age, ability, literacy, employment, etc.) and intersectionalities prevalent.
- Considerations pertained to identifying specific vulnerabilities or reasons that magnify the vulnerabilities, specifically information on the literacy of women, the employment status of women, and their representation

and engagement in flood management and decision-making. E.g. the data collection tool gathers information on literacy levels that vary between women, young adults, and elderly women and can be representative of their access to information.

- The information was captured through stakeholder consultations where women-stakeholder participation provided in-depth information on barriers to access.
- In the study gender representation, aspects of strengths and weaknesses along with vulnerabilities are analysed based on data collected from women for household information and awareness.

Table 2 highlights the GESI-specific considerations used in this project to ensure inclusivity in the study. Details of the same are present in data collection tools as Annexure 1.

**Table 2. The GESI Checklist Used in this Study**

| Type                         | Considerations in Primary Data Collection                                                                                                                   |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| GESI Specific Indicators     | The extent of engagement of women networks, SHGs in flood risk management, training, etc.                                                                   |
|                              | % of women in the workforce                                                                                                                                 |
|                              | Availability of funds for women and women-led businesses affected by flood                                                                                  |
|                              | Separate capacities of officials of different genders                                                                                                       |
| Participation and reflection | Engaging different stakeholders in meaningful ways (ensuring listening to what they have to say) — Female government employees, community members included. |
|                              | Disaggregation of groups for data collection                                                                                                                |
|                              | Transparent and responsible data collection                                                                                                                 |
|                              | Opportunity to report and reflect upon their engagement in the intervention                                                                                 |

### 3.3 Methodology

Urban flooding is a common occurrence in major cities with high economic activity, such as Bengaluru, Chennai, Mumbai and Gurugram. A comparatively higher number of people have been exposed to the risks and vulnerabilities associated with natural hazards, global warming, and climate change-related phenomena like heat waves, droughts, and flash floods as a result of urbanisation. These risks and vulnerabilities are made worse by underdeveloped infrastructure, a shortage of affordable housing, and the rise in informal settlements, which are frequently found in dangerous or low-lying areas (MoHUA 2020).

Cities are the primary locations for the usage of resources and the largest producers of waste. The solid waste profile of urban regions includes garbage from homes, waste from building and demolition projects, e-waste, and other sources, all of which are predicted to worsen and expand in the upcoming decades due to rapid urbanisation (MoHUA, 2020). There are open landfills dispersed around the cities as a result of the low capability for collecting solid waste. Building resilience in cities requires a far-sighted vision and rigorous policy frameworks. To mainstream urban resilience and risk reduction strategies, long-term planning procedures must incorporate both existing and emerging climate hazards.

In this regard, the methodology for the assignment is **evidence-led conceptualisation** as illustrated in Figure 8. These include the key steps of systematic literature review, conceptualisation, and field testing of the flood risk assessment framework. Through this, the evidence-led conceptualisation of the envisaged flood risk assessment framework has been undertaken along with proposing a resilience-building roadmap and evidence-based recommendations for mitigation, preparedness, and NbS. The methodology also highlights the steps for flood risk assessment using both primary and secondary datasets along with multiple stakeholder consultations. GIS tools were used to form a composite overlay of pieces of information: hazards, exposure and vulnerabilities, highlighting the high-risk areas in the city. A thorough roadmap with a focus on aspects of localization, integration with development planning, monitoring and regulatory mechanisms, multi — and cross-sectoral engagements, risk communications, local actions, etc., as a part of the study, ascertain steps to build a resilient city. The final findings and capacity building of the government stakeholders were also integral to the successful completion of the study.

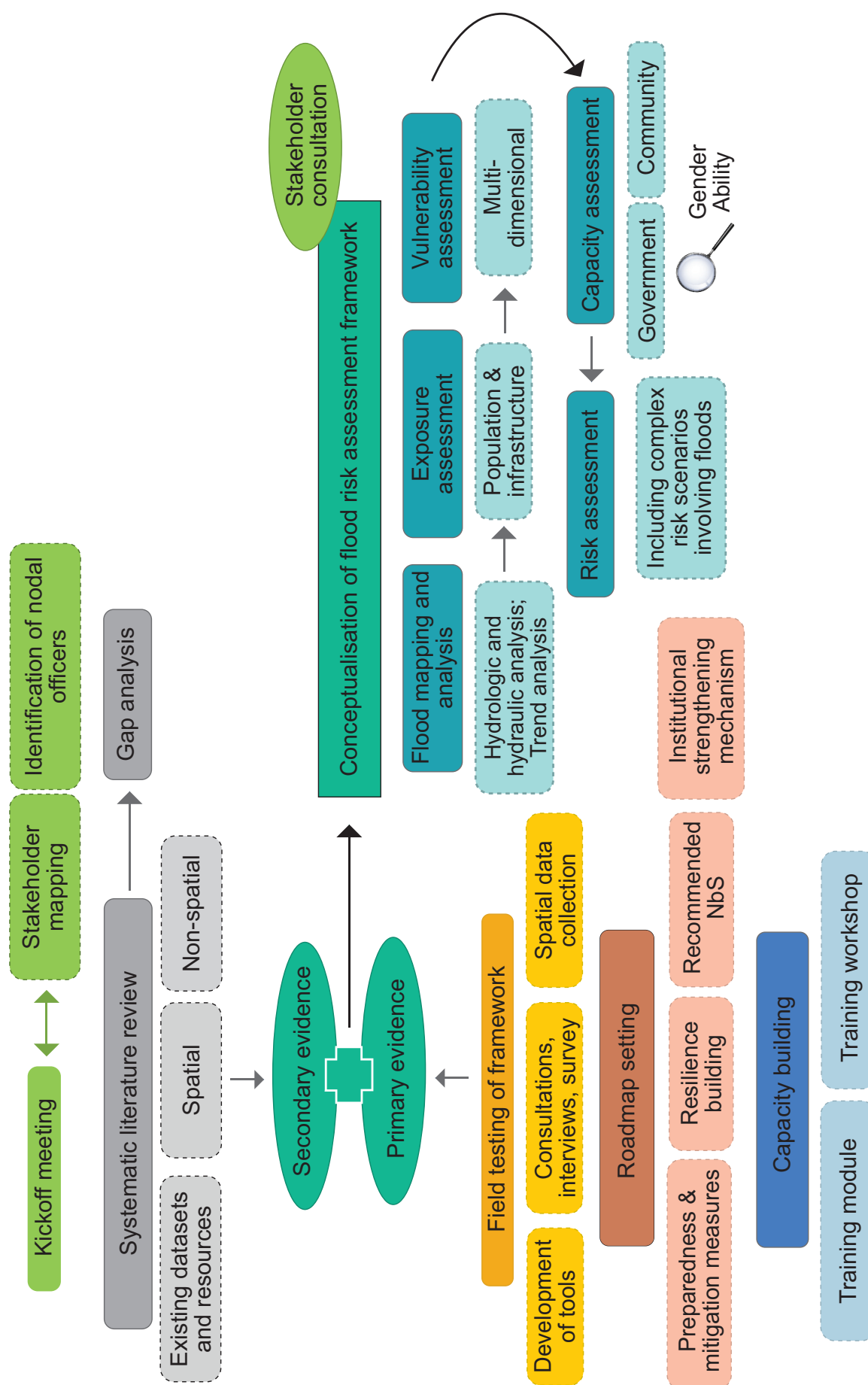


Figure 8. Detailed Methodology for Evidence-based Conceptualisation of Risk Assessment

Source: Authors' compilation

### 3.3.1 Systematic Literature Review

After the Disaster Management Act of India was passed in 2005, the disaster risk management process underwent a substantial evolution. The prime authority for disaster management in India is the National Disaster Management Authority (NDMA), which is led by the Prime Minister. The Disaster Management Act, 2005 and amendment 2025 governs the institutional framework used by authorities at the state and district levels for disaster management. The National Disaster Management Plan and the National Policy on Disaster Management, 2009 offer the government agencies at all levels a structure and guidance. The existing plans and policies at all levels have some opportunities for improvement which were studied in detail through a SWOT analysis process.

Existing frameworks and tools for flood risk assessment and flood resilience assessment were reviewed in detail to identify and map the key dimensions and indicators. This included an in-depth study of existing guidelines, frameworks, plans, and reports of similar assessments being done by other cities through

a study of web portals of relevant government bodies and departments along with relevant academic papers on the topic through keyword searches on reputed academic search engines as shown in Figure 9.

For the study following plans and policies were reviewed in detail:

- National Disaster Management Policy, 2009
- National Disaster Management Plan, 2019
- National Environment Policy, 2006
- National Action Plan on Climate Change, 2008
- National Urban Policy Framework, 2018
- State Disaster Management Plan – Assam, 2023
- District Disaster Management Plan – Kamrup Metro, 2024
- City Disaster Management Plan – Guwahati, 2023
- Guwahati Master Plan 2025
- Guwahati Draft Master Plan 2045

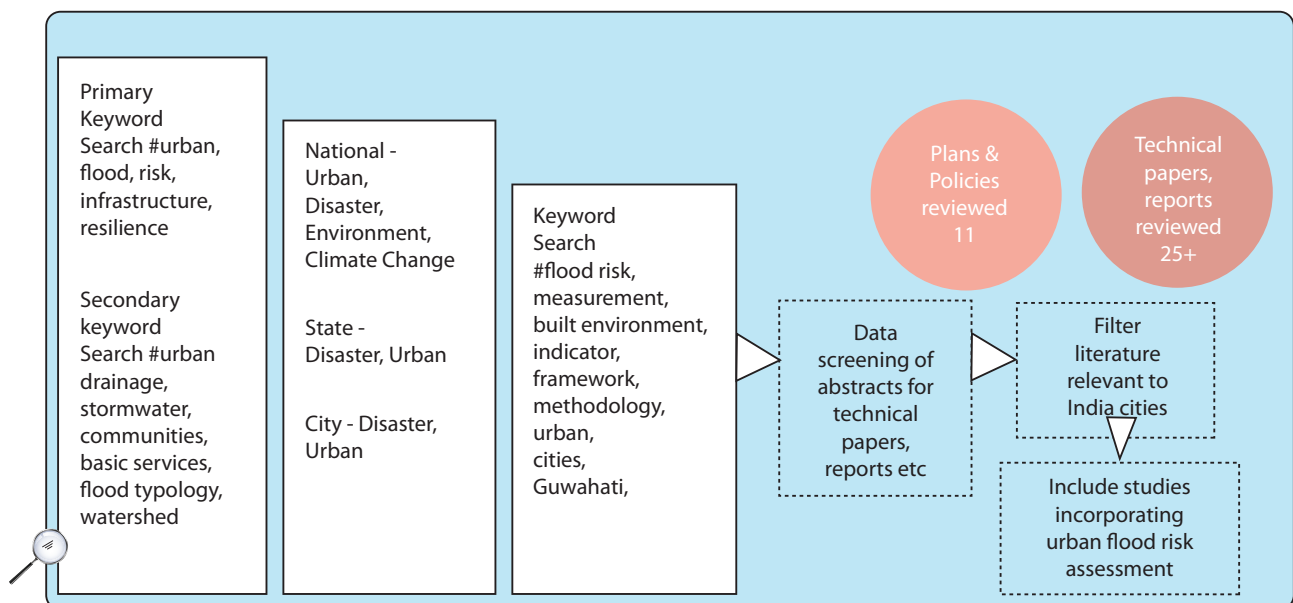


Figure 9. Literature Review Process

A renewed sense of urgency and necessity for strengthening disaster risk governance and enhancing resilience through well-integrated and risk-informed policies, plans, programmes, and budgets at all levels of governance was infused among the member nations by the Sendai Framework for Disaster Risk Reduction (2015–2030) (SFDRR). In order to achieve the goals directed by the SFDRR, the DRM systems must specify the goals and particular objectives for lowering disaster risks along with relevant activities. To mainstream their implementation, policies must be linked to strategies for sustainable development and climate change

adaptation as shared in the opportunities to strengthen flood considerations discussed in Chapter 2. The principle of increasing disaster resilience through targets for vulnerability reduction and capacity building is also embodied in the Sustainable Development Goals (SDGs). By strengthening the institutions and weakening the factors of risk like poverty, gender discrimination, food insecurity and social disparity, the SDGs can promote resilience. Early warning, risk mitigation, and management of hazards are indirectly prioritised through SDG 1, 11, 13, which is especially relevant given the flooding scenarios in Guwahati.

### 3.3.2 Framework: Flood Hazard & Exposure Analysis

Flood hazard and exposure analysis is a crucial process for assessing and managing flood risks to communities and infrastructure. It involves the potential for flooding in a specific area by considering factors such as historical flood data, topography, rainfall patterns, and river basin characteristics as shown in Figures 10 and 11 below. The methodology and the technical aspect are based on the Storm Water Drainage Systems Manual, Volume 1 by the Central Public Health and Environment Engineering Organization (CPHEEO). Figure 10 involves steps of data collection involving collecting Digital Elevation Models (DEMs) and rainfall records spanning 30 years (1994–2023) for the analysis and Intensity-Duration-Frequency (IDF) curves generation using the Gumbel distribution method. The hydrological analysis includes drainage area delineation

and the time of concentration calculation. It also involves peak flow calculations using the Rational method for different return period rainfall events and the climate change scenario. A climate change scenario analysis considers examining 10 years of rainfall data (2014–2023) to construct corresponding IDF curves, with a specific focus on a 100-year return period. Hydraulic analysis includes the 1D steady state analysis, as it simplifies the modeling of flow in open channels, making it computationally efficient and easier to implement, to assess the flood risk to Guwahati. Additionally, it also involves assessing the vulnerability of buildings, transportation networks, utilities, and people to flood impacts. This analysis helps in understanding the potential consequences of flooding on both human and material resources.



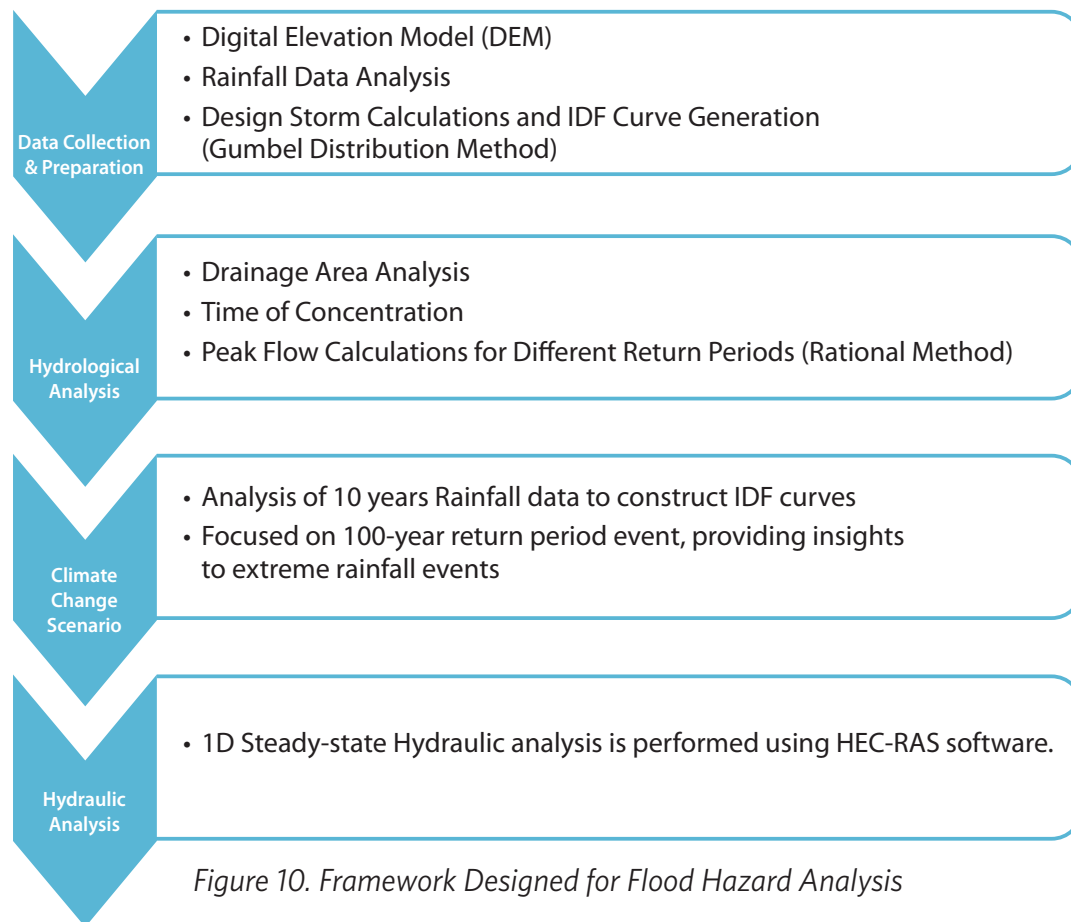


Figure 10. Framework Designed for Flood Hazard Analysis

The process of flood hazard and exposure analysis is detailed below:

- **DEM (Topography/Terrain):** Data is obtained from ISRO's Bhuvan website, and used for catchment delineation in ArcGIS software.
- **Rainfall Analysis:** According to Central Public Health and Environment Engineering Organisation (CPHEEO) guidelines, the Gumbel distribution method was utilized to transform the highest 24-hour rainfall recorded over the past 30 years.
- **Intensity-Duration-Frequency (IDF) Curves,** thereby determining rainfall intensities for specific durations based on desired return frequencies.
- **Hydrologic Analysis:** modelling involves rainfall-runoff modelling. The process determines the volume of water from a given storm event that will transform into runoff on the landscape.
- **Catchment Delineation:** is the process of identifying and mapping the geographical boundaries of an area that contributes water flow to a particular point of a river.
- **The Longest Flow Path** signifies the route from a headwater, typically the ridge line of the drainage area, to the outlet, which is longer than all other flow paths in length within the drainage area and is used in the calculation of  $T_c$ .
- **Time of Concentration ( $T_c$ ):** An important component of peak flow calculations. It is required to obtain the corresponding rainfall intensity from IDF curves. The time of peak runoff is dependent on the time of concentration (Annexure 2).
- **Peak Flow** is the main output of the hydrologic analysis. It is defined as the maximum flow

of the entire catchment, contributing to its outlet. This will occur when the given intensity of rainfall begins instantaneously and continues until the time of concentration. (**Rational method** is used in the Calculations:  $Q=CIA$ ) (Annexure 2).

- Climate Change Scenario:** Assessment follows the Storm Water Drainage Systems Manual, Volume 1 by CPHEEO. The method used to assess changing trends in rainfall intensity involves analyzing 10 years of rainfall data (2014-2023) and constructing the corresponding IDF (Intensity-Duration-Frequency) curve. The analysis will focus on a 100-years return period.

- Hydraulic Analysis:** is used to determine the flood risk to the project site by understanding the water surface elevation, depth, and extent of the inundation. Peak flows are used as input. 1D-steady hydraulic analysis is performed using HEC-RAS version 6.4.1. Multiple cross-sections are analysed to assess flood risk. Steady flow conditions are described using **energy and Manning's equations**. The results include **water surface elevations and extent of inundation** for different return period events. (Detailed calculations are shared in Annexure 2).

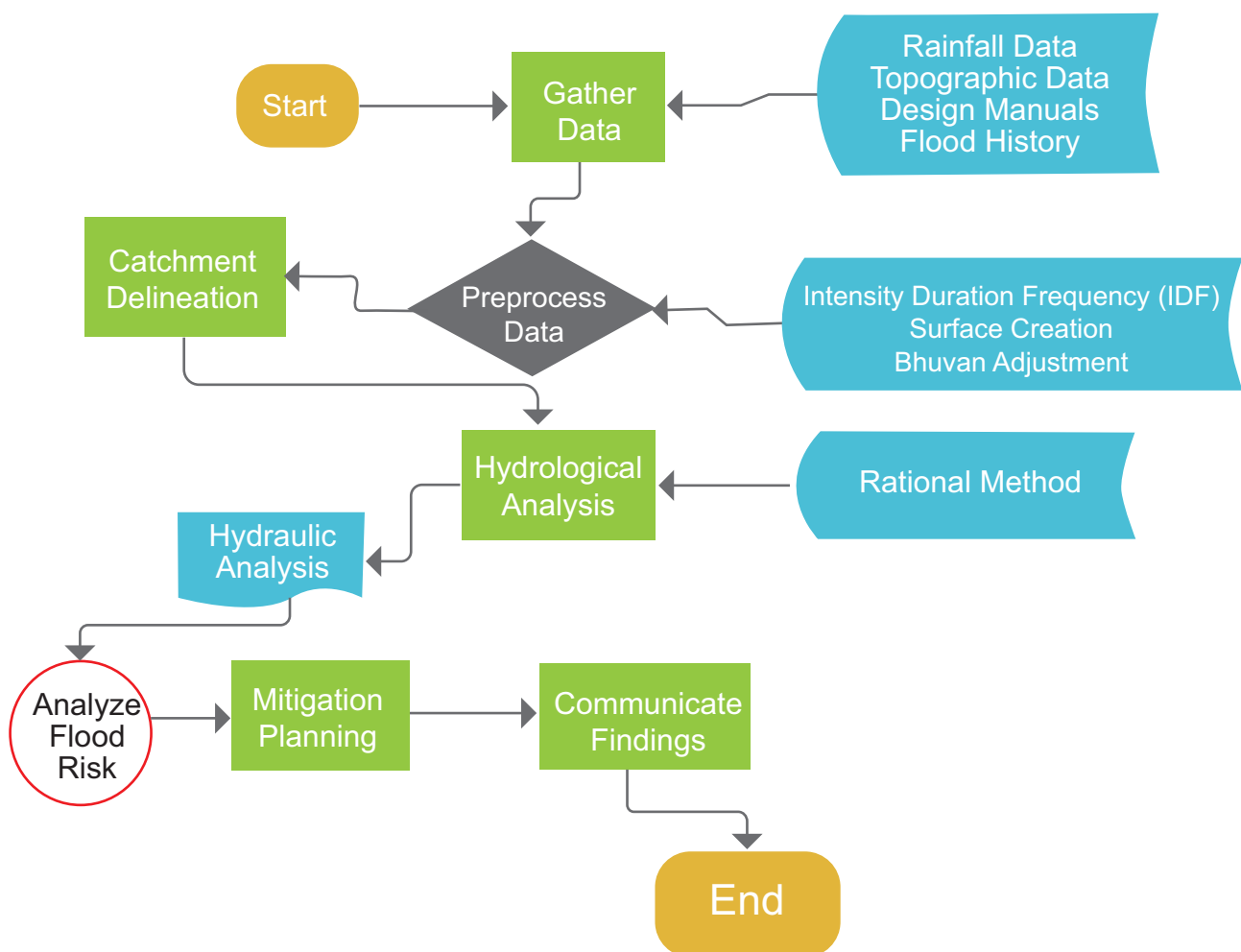


Figure 11. Framework Designed for Flood Hazard and Exposure Analysis

### 3.3.3 Framework: Flood Vulnerability & Capacity Analysis

The flood vulnerability and capacities are evaluated using the SPINE framework as shown in Figure 12 which uses specific considerations:

- **Social Inclusion:** Acknowledge that some residents in a city have received preferential treatment than others due to various underlying factors. Therefore, the risk assessment should take into account the needs and experiences of individuals from all socioeconomic backgrounds, as well as those who are diverse in terms of gender, age, colour, religion, and ethnicity.
- **Physical Infrastructure Safety:** Disaster impacts are aggravated when infrastructures are weak or poorly maintained. This can lead to compounding effects and multiplied damages.
- **Institutionally Responsive:** Ensure that policies and services are designed, planned and managed based on the needs of residents and address local and emerging hazards.
- **Natural Integrity:** The resources (natural) are judiciously used. Encroachments can lead to flooding incidents, not maintaining building bye-laws can lead to further waterlogging, hamper drainage flows, etc.
- **Economically Viable:** Identify monetary conditions at the household-level and the availability of funds and budget at the institutional level to identify and implement measures to fix issues.

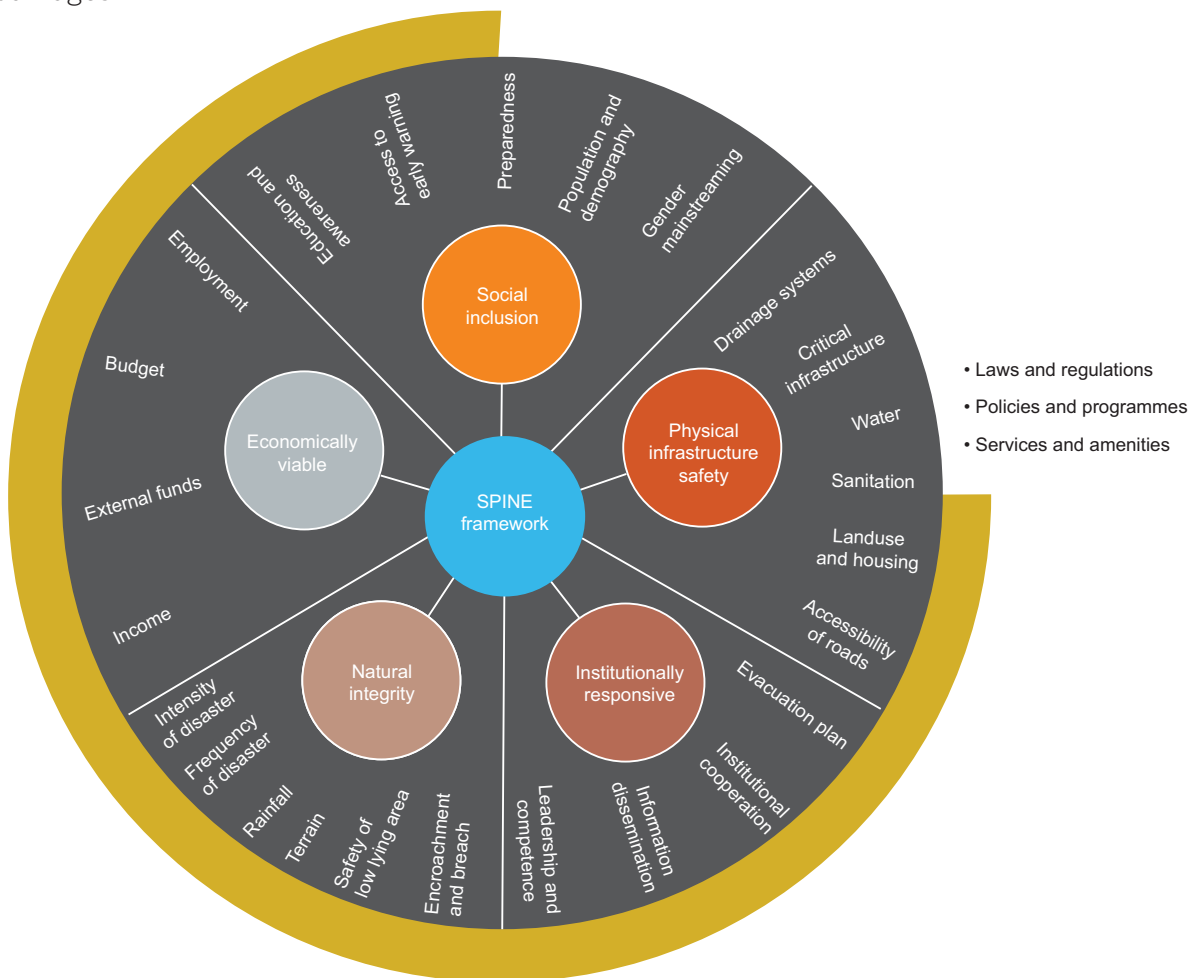


Figure 12. Framework Designed for Vulnerability and Capacity Analysis

The identified dimensions and parameters were used to design the data collection tools as shared in the next subsection. Some challenges evident throughout the city were reflected in the information shared. Ratings on stakeholder inputs allowed us to identify highly vulnerable areas. All the parameters were normalised by bringing them to a common scale. For this, the min-max normalisation was used to make them unit-free. The normalisation is based on the functional relationship of the parameters with risk such that the value assigned is 1 where the condition is poor or vulnerability is high and 5 where the condition is good and vulnerability is low as shown in Figure 13. The list indicates the 5 dimensions and parameters under each dimension along with the number of indicators marked in brackets against each parameter.

The process involved the selection of indicators based on a detailed relevant literature review, and stakeholder consultation, followed by data collection at ward and division levels. However, due to the unavailability of certain datasets, some indicators had to be excluded from the computation for each city. These absent datasets are attributed to various reasons like limited monitoring setup and insufficient data collection processes with urban local bodies. The list of complete indicators, including those excluded, is part of the data collection tools provided in Annexure 1. The data gaps may impact the replicability of the risk assessment as some indicators with minimal priority for Guwahati may be more relevant for other cities.

| Social                                                                                           | Physical                                                                                                                                                                        | Institutional                                                    | Natural<br>(Environmental)                                 | Economic                                                        |
|--------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|------------------------------------------------------------|-----------------------------------------------------------------|
| Demographic Condition (5)<br>Access to Information (5)<br>Disaster Preparedness and Capacity (5) | Land use and Housing Condition (7)<br>Water and Sanitation Condition (7)<br>Road Condition and Accessibility (5)<br>Critical Infrastructure (7)<br>Drainage System Capacity (5) | Competence in DRM (5)<br>Knowledge Sharing and Collaboration (5) | Disaster Frequency and Intensity (4)<br>Landuse Change (1) | Employment and Income Condition (5)<br>Budgetary Allocation (5) |

Indicator Rating for Qualitative Data

|                     |                |          |                |                     |
|---------------------|----------------|----------|----------------|---------------------|
| Very Poor Condition | Poor Condition | Moderate | Good Condition | Very Good Condition |
| 1                   | 2              | 3        | 4              | 5                   |

Figure 13. Dimensions and Parameters (no. of indicators) Developed for Vulnerability Analysis

The following two considerations are part of the risk assessment framework's vulnerability component:

- Sensitivity is the degree to which climatic fluctuation affects a system in a positive or in a negative way.
- Adaptive capacity, or the capacity of humans, institutions, or systems, to react to climatic or anthropogenic causes and adapt to possible harm, or consequences.

### 3.3.4 Tools of Primary Data Collection

The data collection tools are specific survey formats and guiding questions for the stakeholder and household level interviews are shared in Annexure 1. All questions were asked to the respondents and only the questions which were answered were considered for the evaluation and further reflection. The pool of questions can

be considered as a master document that can be used with variations for different cities and requirements. Table 3 shows the detailed tools used and the level of engagement along with the specific dimension it corresponds to based on the previous subsection.

**Table 3. Tools for Data Collection**

| Tool                            | Purpose                                           | Level of Engagement                                      | Dimensions Used                                                                             |
|---------------------------------|---------------------------------------------------|----------------------------------------------------------|---------------------------------------------------------------------------------------------|
| Questionnaires for Consultation | Vulnerability & Capacity Assessment; Gap Analysis | State and District Officials Division and Ward Officials | Primarily Institutional, Social, Physical, Institutional, Natural (Environmental), Economic |
| Guide for FGDs                  | Vulnerability & Capacity Assessment; Awareness    | Household/Community                                      | Social, Economic, Physical, Natural (Environmental)                                         |
| Guide for Visual Survey         | Vulnerability & Capacity Assessment               | Houses, Drainage Channels & Networks at Hotspots         | Physical, Environmental                                                                     |

The collected data are assessed at the administrative division/zone level for Guwahati as guided by NIDM and other stakeholders in the

Stakeholder Consultation meeting in May, 2024. The primary and secondary data were used for risk calculations as detailed in Annexure 2.

### 3.3.5 Information Validation: Vulnerability & Capacity Analysis

Through consultation with various stakeholders, the project team was able to identify priority areas for flood risk mitigation and adaptation in

the short, medium, and long-term and lay down the actionable items and the resilience-building roadmap for each of the identified priority areas.

At multiple levels, the perception and challenges varied and allowed for a holistic understanding of key pressures. A brief distribution of consultations at urban local bodies is shared in Table 4, further details of which are shared in Annexure 5.

**Table 4. List of Consulted Agencies and Stakeholders**

| Stakeholders Consulted                                                                     | No. of Consultation |
|--------------------------------------------------------------------------------------------|---------------------|
| <b>State Level Agencies</b>                                                                |                     |
| State Disaster Management Authority (SDMA)/State Disaster Response Department              | 1                   |
| Department of Housing & Urban Affairs (DoHUA)/Municipal Administration & Urban Development | 1                   |
| Town and Country Planning — Town Planner, Engineers                                        | 2                   |
| Flood and River Erosion Management Agency of Assam (FREMAA)                                | 1                   |
| <b>District Level Agencies</b>                                                             |                     |
| District Disaster Management Authority/Disaster Management Cell                            | 1                   |
| <b>City Level Agencies</b>                                                                 |                     |
| Urban Local Body — Commissioners, Assistant Commissioners                                  | 6                   |
| Engineering and Works Staff                                                                | 12                  |
| Development Authority - Town Planner & Planning Staff                                      | 2                   |
| <b>Community Level</b>                                                                     |                     |
| Community Members/Households                                                               | 25 HH               |



**Figure 14. Data Collection Activities Conducted at (a) Zonal Municipal Office (b) Community and Households Images: RIKI India**



The method used for the household data collection is shared in Figure 15. It considers the identification of flood hotspots based on stakeholder consultation followed by consideration of Water surface elevation level (WSEL) landmarks calculated by the project team out of which the 5 landmarks with high WSEL were identified and considered for ground data collection. Locations common to

both the list of hotspots and 5 high WSEL were considered along with those specific landmarks that showed up in the WSEL list.

From these, only the residential areas were selected. Further consultation with ULB highlighted the most suitable locations from the list of residential areas to conduct data collection. The data collection was continued till repetitive responses were received.

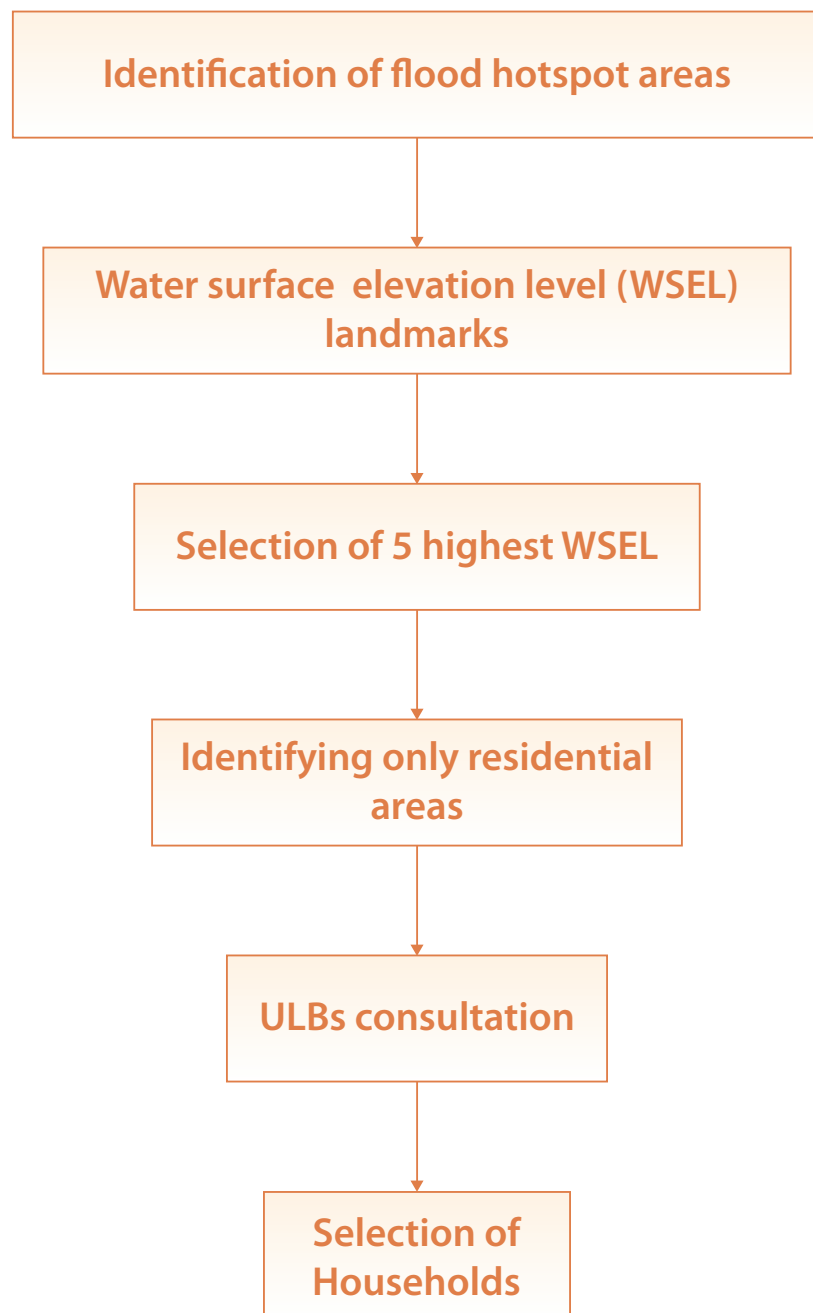


Figure 15. Sampling Process for Household-level Data Collection



### 3.3.6 Data Sources for the Analysis

The data used for the study includes datasets shared by government agencies at Guwahati and available online resources. Table 5 details the data used and their corresponding sources. Other than these data sources reports and past studies were referred which are cited in this report. These were also used for the cross-verification of primary data collected based on the tools shared in Table 4. Based on the data received, the following are the pre-analysis assumptions for the methodology of the study:

- The coordinate system is considered as WGS\_1984\_UTM\_Zone\_46N for Guwahati.
- Bhuvan topographic data is used for the analysis.
- The major structures on the rivers and nallahs are assumed to be already constructed for more than 100-years return period rainfall events. Hence, will not impact the hydraulic analysis of the study. Sufficient information was not available for the smaller structures; hence they are excluded from the analysis.

**Table 5. Sources of Datasets Used for Analysis**

| Categories | Data                                 | Source                                                                                                                       |
|------------|--------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| Social     | Population Density                   | Guwahati Municipal Corporation                                                                                               |
|            | Availability of Health Facilities    | Health Department Data                                                                                                       |
|            | SC/ST Population                     | Guwahati Draft Master Plan 2045                                                                                              |
|            | Extent of Engagement of Women Groups | Guwahati Municipal Corporation                                                                                               |
| Physical   | Ward and City Boundaries             | Guwahati Municipal Corporation                                                                                               |
|            | Land use Land Cover                  | (Bhuvan — Indian Geo-Platform of Indian Space Research Organisation (ISRO))                                                  |
|            | Stormwater Drainage Network          | Guwahati Town and Country Planning Office                                                                                    |
|            | Proximity to Water Bodies            | Project Team Analysis Based on Topographical Maps                                                                            |
|            | Solid Waste Management               | Guwahati Draft Master Plan 2045                                                                                              |
|            | Damage to Infrastructure in the Past | Guwahati Municipal Corporation, Town and Country Planning Office, District Disaster Management Authority Kamrup Metropolitan |
|            | Vacant Land Information              | Guwahati Draft Master Plan 2045                                                                                              |
|            | Change in Built-up Area              | Project Team Analysis Based on the Bhuvan Dataset                                                                            |

| Categories    | Data                                                 | Source                                                                                                                                                                                              |
|---------------|------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Institutional | Presence of AWS, EOC                                 | Guwahati Municipal Corporation                                                                                                                                                                      |
|               | Members of the Emergency Team                        | Guwahati Municipal Corporation                                                                                                                                                                      |
|               | Presence of Evacuation Shelters                      | District Disaster Management Authority, Kamrup Metropolitan                                                                                                                                         |
| Natural       | Rainfall Data                                        | India Metrological Department (IMD) Grid (0.25x0.25o) through MATLAB Code for specific latitude and longitude of the site, India — Water Resource Information System (WRIS)                         |
|               | Topographic Data                                     | Bhuvan Digital Elevation Model (DEM) Data (30 m x 30 m resolution; Cartosat-1 version-3) — (Bhuvan — Indian Geo-Platform of Indian Space Research Organisation (ISRO))<br>Survey Data (from Client) |
|               | Flood History                                        | Specific Site State Water Resources Department Website, NeSDR                                                                                                                                       |
|               | River Discharge Data                                 | India — Water Resource Information System (WRIS), <a href="https://vedas.sac.gov.in/hydro/index.html">https://vedas.sac.gov.in/hydro/index.html</a>                                                 |
|               | Design Manuals                                       | Central Public Health and Environment Engineering Organisation (CPHEEO) Manual, Volume 1 Part A: Engineering Design                                                                                 |
| Economic      | Workforce Engagement (Including Women Participation) | Guwahati Draft Master Plan 2045                                                                                                                                                                     |
|               | Budgetary Allocations                                | Guwahati Municipal Corporation                                                                                                                                                                      |

### 3.3.7 Tools of Data Analysis

In the study, open-source software and tools were used to ensure interoperability and ease of access as shown in Table 6.

**Table 6. Software and Tools for Data Analysis**

| Tool                                                                                    | Purpose                                                                                                                                                                                                                                                                                |
|-----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Google Earth Engine                                                                     | Enables aerial view analysis, location identification, elevation profiling and Street View access.                                                                                                                                                                                     |
| QGIS and ArcGIS                                                                         | Geospatial tools for raster analysis (DEM) and vector creation/modification aid in catchment delineation processes.<br>Analysis of information on hazards, exposure, and vulnerabilities using geoprocessing tools, overlay analysis, etc. for classification and evaluation of risks. |
| US Army Corps-<br>HEC-RAS (Hydrologic Engineering Center — River Analysis System)       | Hydraulic modelling of rivers and channels to simulate water flow and assess flood risk.                                                                                                                                                                                               |
| US Army Corps-<br>HEC-HMS (Hydrologic Engineering Center — Hydrologic Modelling System) | Simulating rainfall-runoff processes and analyzing watershed response to precipitation events.                                                                                                                                                                                         |

## 4 City Profile, Risk Assessment and Roadmap

### 4.1 Introduction

Guwahati is located towards the south-eastern side of Kamrup district on the banks of river Brahmaputra. It is the largest city in Assam, India, and the commercial centre of northeastern India. It is well-connected by road, rail, and air to different parts of the country. It is located

towards the southeastern side of Kamrup district surrounded by Nalbari district in the north, Darrang and Morigaon districts in the east. The city has 60 wards which are delineated into 6 administrative divisions as follows:

- Division 1: Comprising of Wards 1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12, 13, 14, 15
- Division 2: Comprising of Wards 17, 31, 32, 33, 34, 35, 36
- Division 3: Comprising of Wards 37, 38, 39, 40, 50, 52, 53, 54, 55, 56, 57, 58
- Division 4: Comprising of Wards 16, 18, 19, 28, 29, 30
- Division 5: Comprising of Wards 41, 42, 43, 44, 45, 46, 47, 48, 49, 51, 59, 60
- Division 6: Comprising of Wards 10, 20, 21, 22, 23, 24, 25, 26, 27

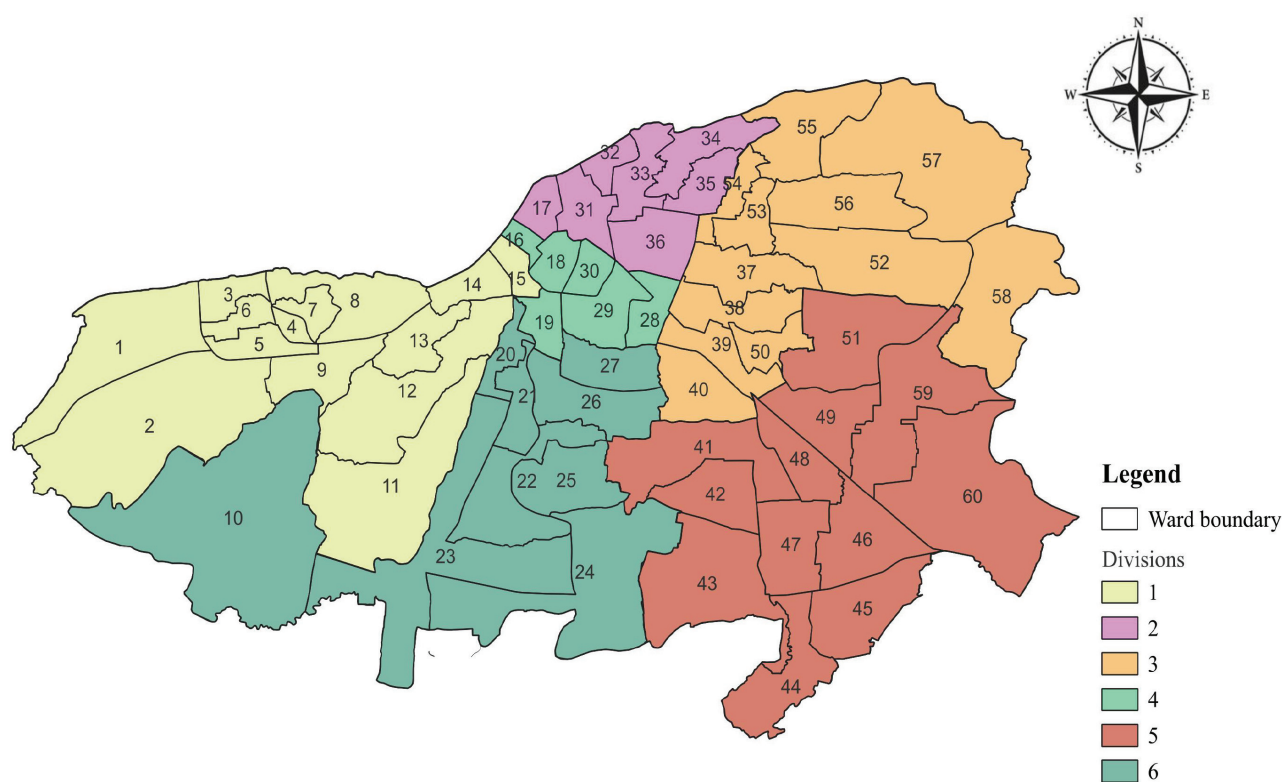


Figure 16. Administrative Divisions of Guwahati

Guwahati city is known for its cultural heritage, such as the Kamakhya Temple, Assam State Museum, Umananda Temple and the

Brahmaputra Riverfront. Figure 17 shows the vicinity of Guwahati City, including the landmark areas and prominent localities. The

city is densely covered by built-up area with over 144.87sq. kms. of area out of the total area of 328 sq. kms. already developed by 2020 with the majority area being used for residential purposes (GMDA, 2024). This is reflected in the land cover map as shown in Figure 18. Some river catchment areas are transformed from a very low-populated region in 1901 to a densely populated region in 2011. The projected population in the master plan area of Guwahati is expected to increase from 11,41,699 in 2011 to 38,63,812 in 2045 (GMDA, 2024). Over the years, this will lead to an increase in housing demand and urban development leading to significant changes in land use and a reduction in open spaces resulting in frequent flooding problems for the city.

Severe flood incidents in 1954, 2012, 2022, and 2024 affected the city. The river Bharlu-Brahmaputra basin flow influences the flood pattern in the city. The city experiences recurrent floods and waterlogging events. For instance, in October 2023, heavy rainfall began on October 3 and lasted till the morning of October 4, inundated prime locations and major roads within Guwahati, including Zoo Road, Rajgarh, Chandmari, Pub Sarania, Bhangagarh, and Satgao. On October 6, Guwahati witnessed flash floods because of the heavy rainfall in a short period (as per consultation with District Disaster Management Authority). According to the Regional Meteorological Centre in Guwahati, the city recorded 167.80 millimeters (mm) of rainfall in those two days. Due to high decadal population growth (17.5% in the GMC area and 149.2% in the GMDA area according to the Draft Master Plan 2045), and fast development, it is challenging to prevent increased flood exposure in Guwahati as spatial demands for development are always high. The Master Plan indicates comparatively higher population density in core city areas which reduces towards less urbanized areas with a total of 217 slum

pockets. Figure 18 shows that majority of area in Guwahati is covered by residential with small component for forest and grasslands. According to the Master Plan 2045, there is an increase proposed in terms of recreational areas open spaces and parks and mixed land use. A significant reduction in protected land in the proposed master plan, with a reduce from 55.83 percent of planning area to only 25.89 percent of planning area. Details of the comparison of existing and proposed land use is shared in Annexure 3.

The city has multiple water bodies like Deepor Beel, Dighali Pukhuri, Silsakoo Beel, Sola Beel (Sarusola and Borsola Beel), and Bondajan Beel. Deepor Beel is a permanent freshwater lake located southwest of the city as shown in Figure 19. It is a Ramsar site and receives no significant inputs other than monsoon runoff from the hills to its south. It serves as the city's natural stormwater reservoir and empties into the Brahmaputra to the north. Earlier, this wetland used to receive water from the Brahmaputra River through a channel called Khanajan when the level of Brahmaputra exceeded the level of the Deepor Beel. After construction of a sluice gate, flow from Brahmaputra to Deepor Beel is generally not allowed. However, the gate is operated to release the water from Deepor Beel to the Brahmaputra in other periods. Considering the change in proposed land use according to Draft Master Plan 2045 it is evident that the multiple water bodies within the city would be at threat due to reduction in the area of protected land. This necessitates interventions that allow for the restoration of water bodies and stringent building laws to prohibit encroachment of drainage channels and forested areas.

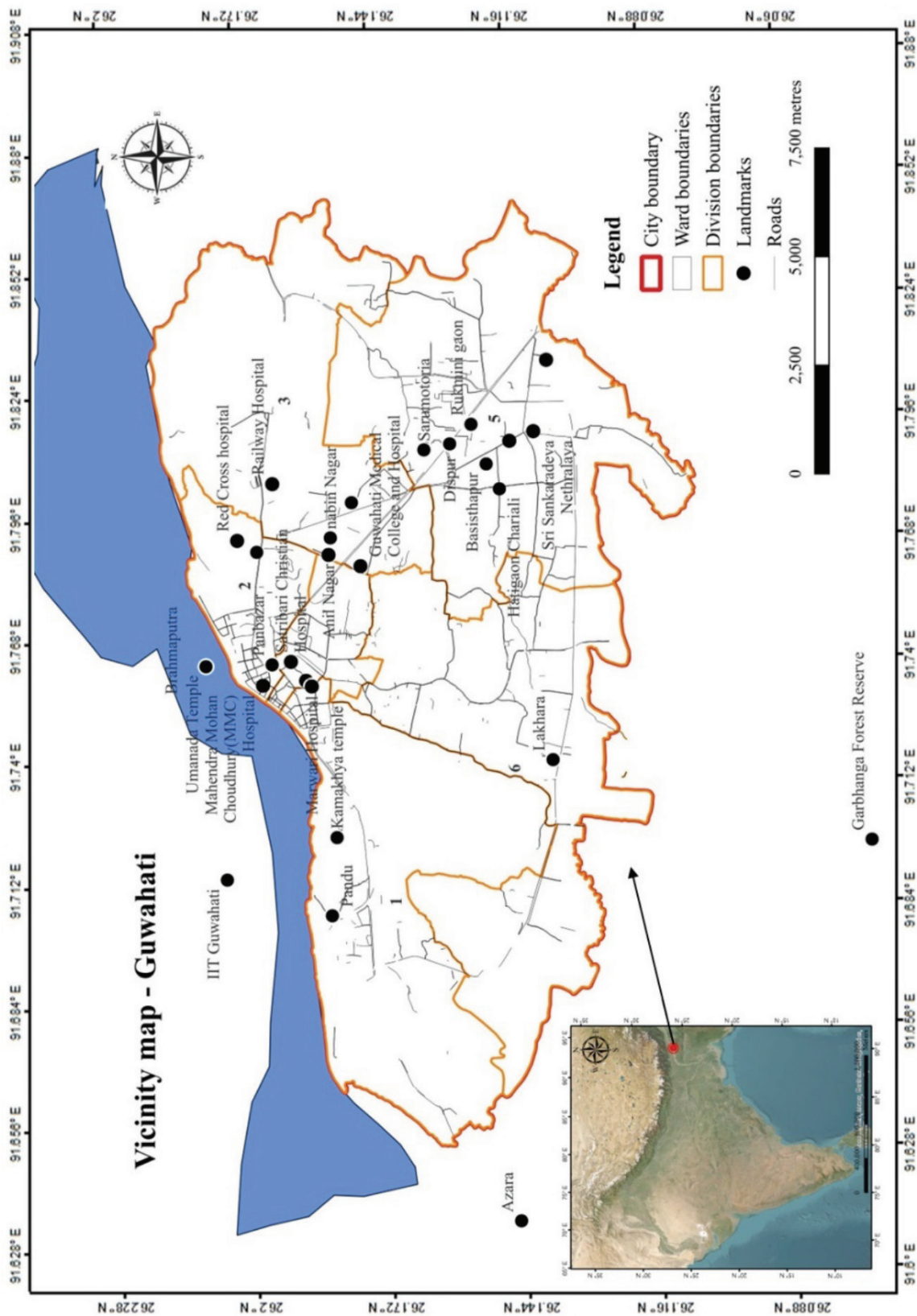


Figure 17. Location and Vicinity Map of Guwahati

Source: Municipal data and satellite imagery



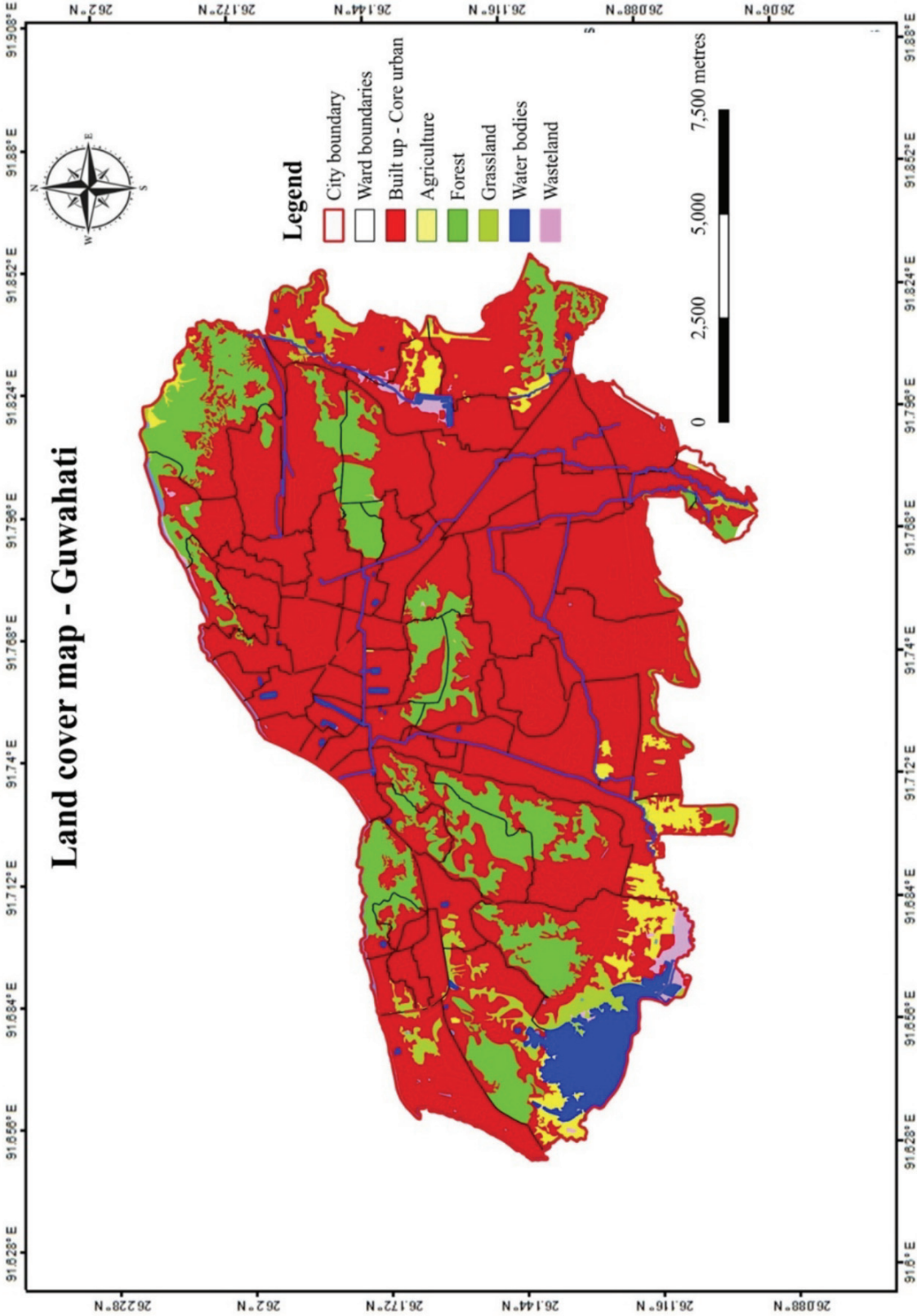


Figure 18. Land Cover Map of Guwahati

Source: Developed from ISRO(SIS DP 2018-23) datasets for this project



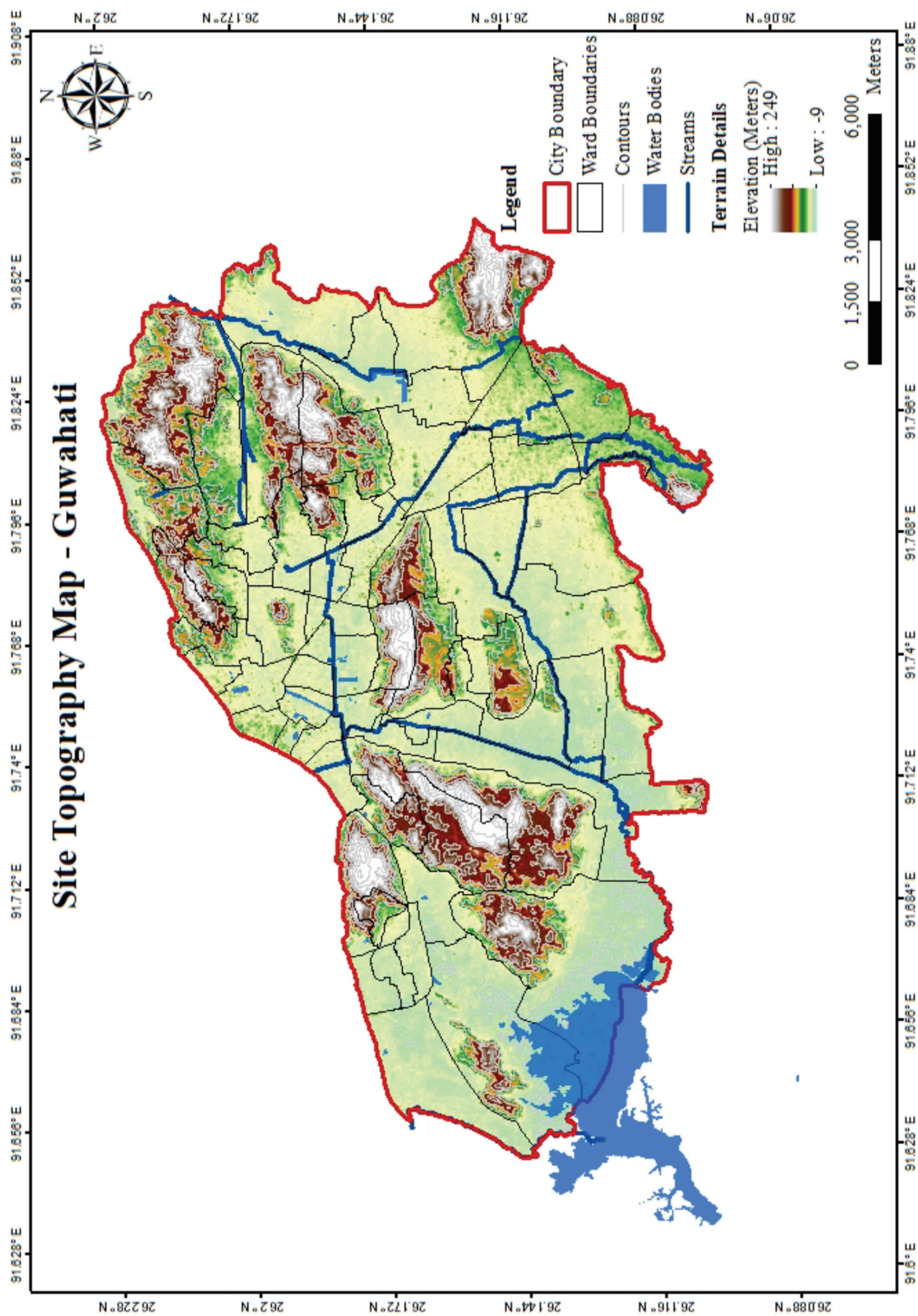


Figure 19. Topographic Details of Guwahati with Prominent Water Bodies

Source: Developed from datasets from Guwahati Municipal Corporation and ISRO

There are multiple streams flowing through the city as shown in Figure 19. Bharalu and Bashistha are two major rivers/streams that flow through Guwahati city. The city's centre is traversed by the Bharalu River, a tributary of the Brahmaputra. River Bharalu is known as Bahini at its upstream and it originates in Meghalaya. The river is known as Bharalu from a location which is near Jonali and discharges into the Brahmaputra River. Another stream connecting Bashistha and Bharalu is called Mora Bharalu and it drains into Deepor Beel by changing its name as Pamohi before meeting Deepor Beel. The Bharalu is the main drainage channel of the Guwahati municipal area. The Amchang Wildlife Sanctuary borders the city to the east and the slopes of the Shillong plateau to the south. The city is dotted by hillocks all around in a plum-in-pudding pattern. The southern and the eastern sides of the city are surrounded by major hills and along the Brahmaputra bank, the northern side of the city, is a series of hills along the periphery except for a portion in the west near Deepor Beel is situated as shown in Figure 19.

The figure also indicates the significant variation in elevation across Guwahati ranging from 9 to 249 metres above sea level. The riverfront areas are at a lower elevation compared to the areas towards the hills. The city itself is situated at an elevation of approximately 55 meters (180 feet) above sea level. To the south of the city, the terrain rises into the lower reaches of the Khasi and Karbi Anglong hills. The depth of the river Brahmaputra in Guwahati varies from about 10m to 20m. during monsoon, when Brahmaputra and Bharalu remain in spate and overflowed water from the city area cannot move away efficiently which leads to many areas being waterlogged during monsoons.

The city lies in the seismic zone V and was severely impacted by the earthquake event in 1969 and 1897. The region had experienced

earthquakes of 8.7 magnitudes in 1897 and 1950. Tremors from the earthquake in Nepal on 25th April, 2015 were also felt in the city. Guwahati is also prone to disasters like cyclones, and thunderstorms. In the Assam region, at least 45 people died and around 4,000 were injured in the worst cyclonic storm in 2005 (GMDA, 2024).

Another aspect that plagues Guwahati is the fragile ecosystem of the hill belt, which frequently faces landslides, which could potentially signal a disastrous event. The first major landslide of Guwahati city was recorded in Nabagraha area in 1972. The eastern part of the city is frequented by landslide and mudslide incidents during heavy rainfall. There is now concern over the loss of life and property as reported by ASDMA. The collapse of hill slopes, soil erosion brought on by siltation, flash floods, and water logging in low-lying areas all seriously impair the city's sewer and drainage systems. Slope failure is made worse by monsoon-related heavy and persistent rainfall. In past, incidents of landslides have led to casualties and asset losses in areas like Japorigog Hill, Sonaighuli & Jutikuchi Hill series, Nilachal Hill, Fatasil Hill, Jalukbari Hill. Heavy rain on 14 June 2022 caused flooding in urban areas. The heavy rain also triggered a landslide that destroyed homes in the Boragaon area of the city leaving 4 people dead (as per article in Mongabay, 2022). The seasonality matrix of disasters in Figure 20 shows that the city has the probability of being affected by multi-hazards at a time. In addition to these, the city is beset with congested communities, limited vacant space, and narrow streets.

| PROBABILITY PERIOD / SEASONALITY OF DISASTERS |       |     |     |     |     |      |      |     |      |     |     |     |
|-----------------------------------------------|-------|-----|-----|-----|-----|------|------|-----|------|-----|-----|-----|
| Name of Disaster                              | Month |     |     |     |     |      |      |     |      |     |     |     |
|                                               | Jan   | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec |
| Flood                                         |       |     |     |     |     |      |      |     |      |     |     |     |
| Cyclone                                       |       |     |     |     |     |      |      |     |      |     |     |     |
| Fire Accident                                 |       |     |     |     |     |      |      |     |      |     |     |     |
| Earthquake                                    |       |     |     |     |     |      |      |     |      |     |     |     |

Figure 20. Seasonality of Disasters

Source: CDMP, Guwahati

## 4.2 Status of Drainage System

According to the published Flood Atlas of Assam 2016, Guwahati receives heavy rainfall from May to August and an annual average rainfall of 161.19 mm per day. The existing natural drain channels in the city include the Bharalu-Bahini River system, Mora Bharalu River, River Basistha, Lakhimijan Channel, Bondajan Channel, Khanajan River, and Kalmoni River. As a flood mitigation measure the administration has prepared embankments along the key areas in Brahmaputra Valley with 78.14 km lying within the city limits (ASDMA, 2016). The departmental disaster management plan of DoHUA highlights the incorporation of basic flood management guidelines in urban development is underway.

The drainage network in Guwahati is categorised into kaccha, pucca and open and closed drains as shown in Figure 21. Ward no. 2, 9, 22, 23, 43, and 45 are covered majorly by kaccha drains whereas other parts of the city are covered by pucca open drains. Open RCC drains can easily gather solid waste and cause clogging as prominently visible in parts of the city. Some unique challenges in Guwahati: BN Saikia Road Wireless, Saukuchi along the oil pipeline, Bye Lane 9, Pub Sarumatoriya (Div-V) are low laying and no proper gradient of the drain. GMC could not perform desiltation in these areas due to the oil pipelines of ONGC so an alternative kaccha drain along the road was dug.

Table 7. Length of Stormwater Drains in Guwahati

| Particulars            | Drain length |
|------------------------|--------------|
| Total Length of Drains | 1812.00 kms  |
| Closed Pucca Drains    | 12.00 kms    |
| Open Pucca Drains      | 550.00 kms   |
| Kachha Drains          | 1250.00 kms  |

Source: Draft Master Plan 2045 by Guwahati Metropolitan Development Authority

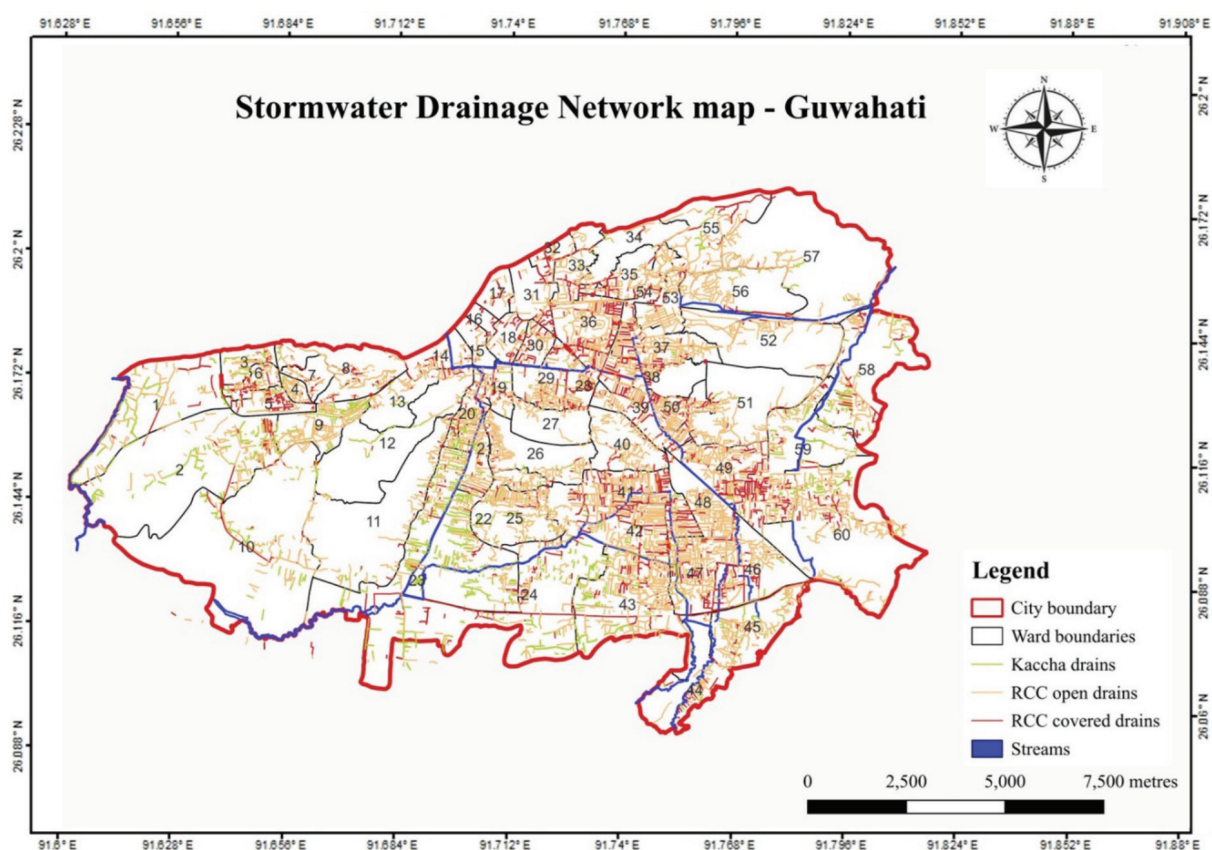
Mission Flood Free Guwahati (2022 onwards) is an ongoing project for mitigating urban flooding issues of Guwahati city. Department of Housing and Urban Affairs along with the District Commissioner Kamrup (M). Specific activities such as de-siltation, pumping station construction, diversion of drains, etc are being undertaken under this project. A total of 292 drains have been taken up for desiltation by GMC (as per municipal data). The municipal

body also engages specific instruments for addressing urban flooding such as dewatering pumps as shown in Table 8. Drains in the city are constructed by different departments and lack of coordination many a time leads to erroneous drainage planning. Heavy sediment yield from the surrounding hills leads to clogging of the drains and this reduces the drainage capacity further to cause waterlogging during high monsoon.

**Table 8. Available Equipment for Addressing Urban Floods in Guwahati**

| 350 LPS Dewatering Pumps at Different Locations of Guwahati |         |
|-------------------------------------------------------------|---------|
| Anil Nagar                                                  | 4 pumps |
| Lachit Nagar                                                | 2 pumps |
| Pandu Port                                                  | 1 pump  |
| Boragaon                                                    | 1 pump  |
| Silsako                                                     | 1 pump  |
| Borsola Beel                                                | 1 pump  |

Source: Compiled from Guwahati Municipal Corporation data



**Figure 21. Drainage Network Categories Guwahati**

Source: Developed from data shared by GMC and GMDA



Except for a small section of the city, there is no constructed stormwater drainage system with high dependence on existing natural drains. The conditions of these channels are not very convincing as they are constantly covered with garbage, waste material and sewage. The city's hill ranges have a significant impact on the drainage. Owing to Guwahati's terrain, a significant amount of the city's wastewater and stormwater travel via several rivulets and canals inside Greater Guwahati to reach the Deepor beel. It eventually empties into the river Brahmaputra via a sluice gate, via the river Khandajan serving as its outflow. There are a few pucca drains in the city centre, along key highways. These do not work properly due to excessive siltation, which has resulted in drain clogs as shown in Figure 22. A total of 641 TPD waste is generated in Guwahati out of which 66 TPD is not collected (as per municipal

data). This waste also affects the water flow by clogging drainage channels.

Drains from residential, commercial, and other locations are discharging wastewater into stormwater drainage channels when it should have theoretically been sent to a sewage system for treatment. In addition, the natural drainage system has been encroached upon as a result of uncontrolled building constructions and dumping practices leading to drains being covered with garbage. The conditions of stormwater drains are poor as they are often covered with garbage, waste material, and sewage at many locations as shown in Figure 22. The Water Resource Department has created a detailed plan for the maintenance and clearance of the channels. These natural waterways become even more crucial because the city lacks a proper drainage system to handle the sewage and wastewater that is produced.

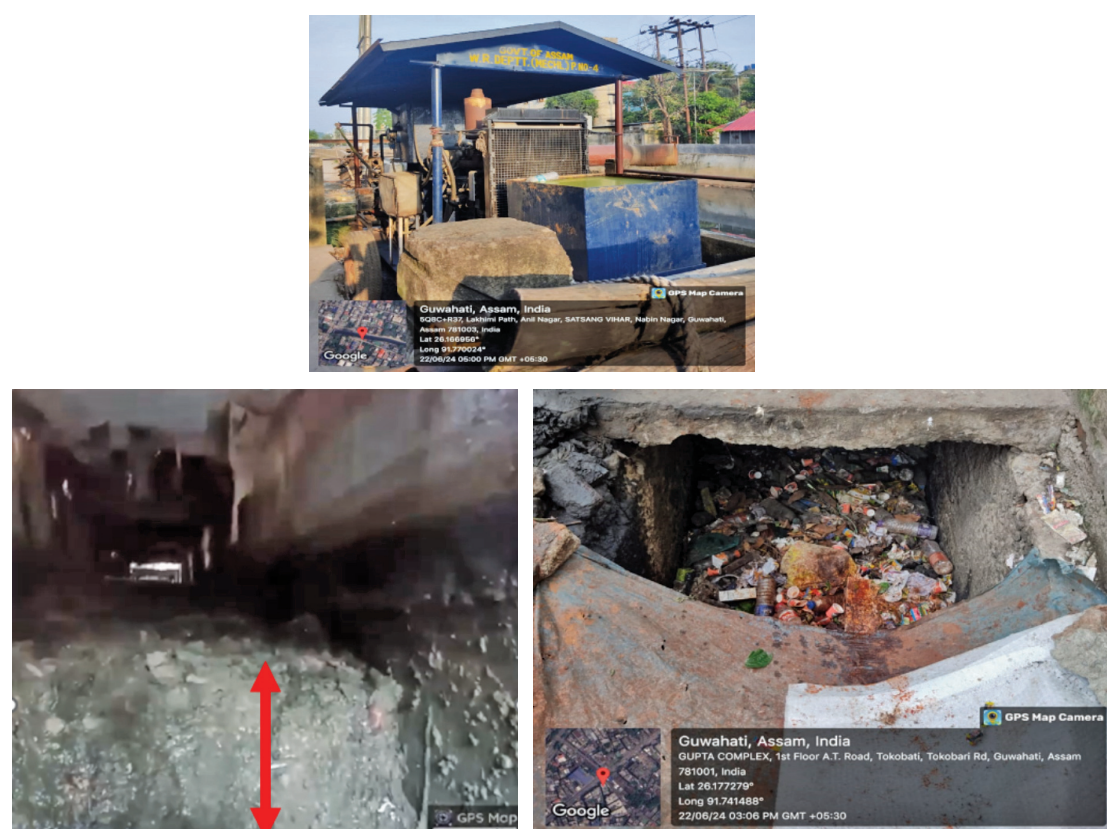


Figure 22. Existing Drainage Network Situation: Dewatering Pump Facility (Top), Silt and Solid Waste Affecting Nallahs at Different Locations (Bottom)

Image Source: RIKA India

Rapid urbanization has led to significant loss of green cover and wetlands, contributing to urban flooding and waterlogging in Guwahati. The eastern part of the city is frequented by landslide and mudslide incidents during heavy rainfall. The clogging of open drains, encroachments like walls, stairs on natural and constructed drains, etc. lead to hindrance in the natural flow of drainage in the city. This has led the municipal corporation to take action of demolishing/partially demolishing a total of 13 bridges over River Bahini. Consultations suggested that extreme rainfall events make existing stormwater networks insufficient for

handling the volume of downpours in addition the loss of vegetation cover in hills has increased the siltation of drains in past years. The key pressures on the stormwater drainage network are mentioned in Figure 23. It is important to note that these are currently the priority considerations for the urban local body however, these pressures might change in the long term due to both internal factors (like the aging of infrastructure, lack of maintenance, reduced carrying capacity, etc.) and external factors (like abruptly changing climatic conditions, political and financial constraints, etc.)

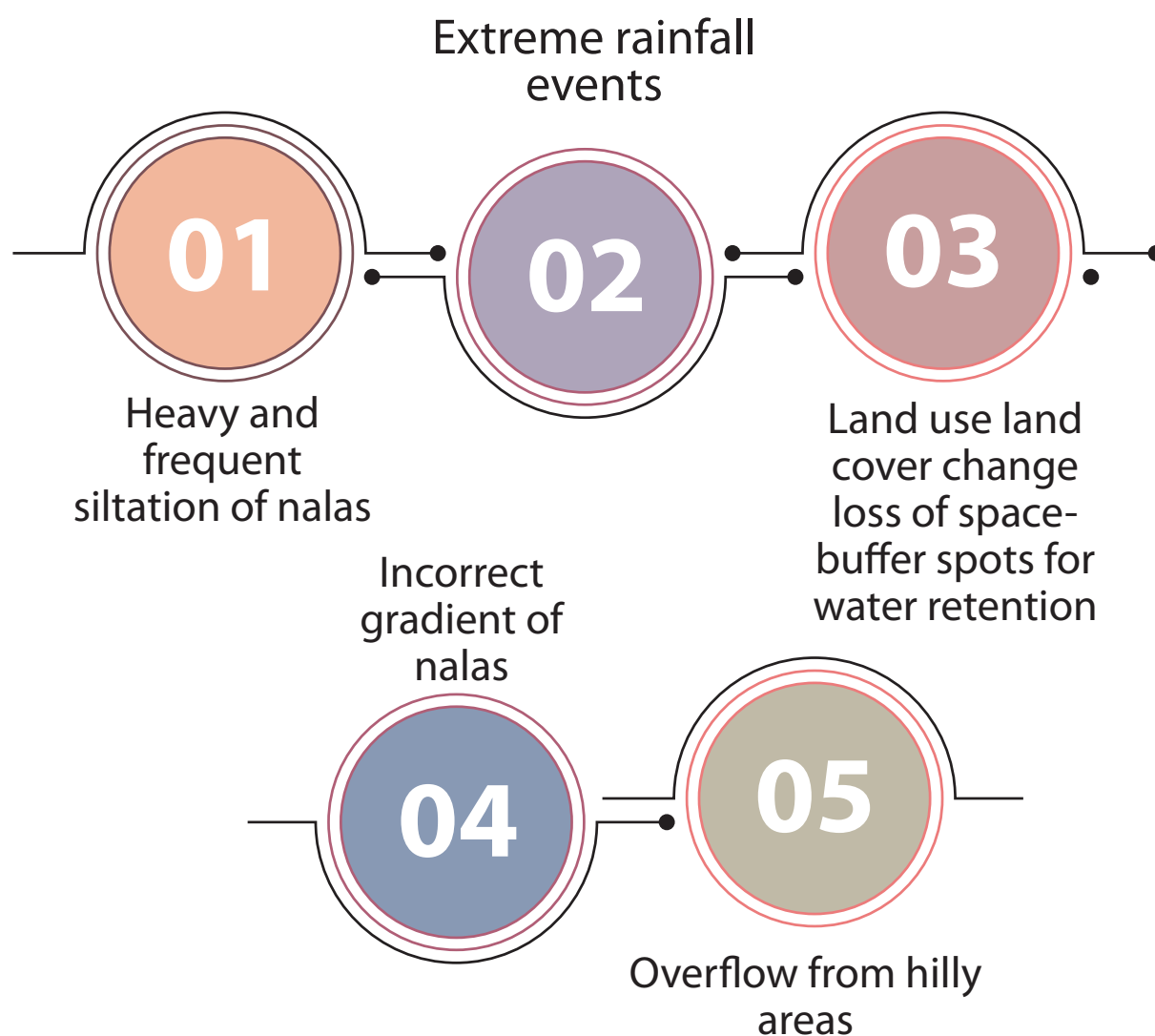


Figure 23. Identified Pressures on Stormwater Networks in Guwahati — Based on Preliminary Consultation

Source: Developed based on preliminary consultation with city officials

## 4.3 Flood Risk Assessment

### 4.3.1 Rainfall Analysis using Intensity-Duration-Frequency Curves

Guwahati receives heavy rainfall during the monsoon season spanning from May to October (ASDMA, 2012). The city's average annual rainfall is 1513.76 mm. The highest recorded rainfall occurred in 1999, reaching an estimated value of around 2000 mm. Average Rainfall (1994-2023): 1513.76 mm while dry year rainfall (green line) of 500 mm occurred in the year 2011. The past few years did not show a significant increase in rainfall over the average rainfall.

The figure below presents a bar chart displaying the annual rainfall data for this period, including

the average annual rainfall and the rainfall during the dry year for Guwahati. The highest recorded rainfall occurred in 1999, reaching an estimated value of around 2097.10 mm, while a dry year (denoted by a green line) of 897.38 mm occurred in the year 2006 as shown in Figure 24. The geophysical location of Guwahati exposes it to excess rainfall in the region making the area more vulnerable to frequent landslides, floods, and other natural hazards. Figure 25 shows the IDF curve for design storm events for 5-, 10-, 25- and 100-year periods.

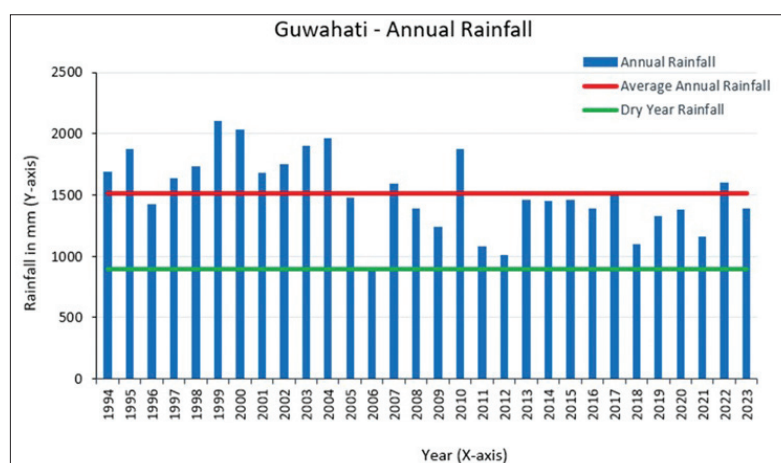


Figure 24. Statistical Representation of Guwahati Rainfall Data

Source: Rainfall data from IMD

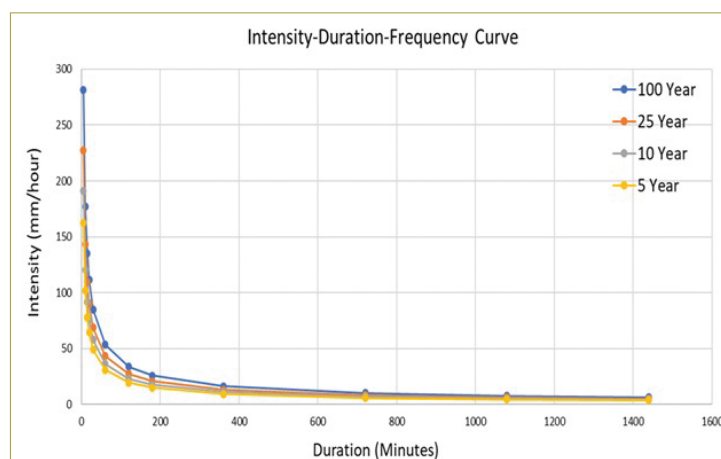


Figure 25. IDF Curve for Design Storm Events of Guwahati

Source: Rainfall data from IMD



### 4.3.2 Climate Change Scenario

In Guwahati, it is expected that more intense rainfall events due to warmer temperatures and altered atmospheric circulation patterns, will lead to increased rainfall intensities for specific durations and return periods. The assessment is conducted following the guidelines outlined in

the CPHEEO manual which involves analysing the past 10 years of rainfall data (2014-2023) and constructing corresponding IDF curves, and will focus on 100-year return period event as shown in Figure 26. The process followed was as described in Subsection 5.3.2.

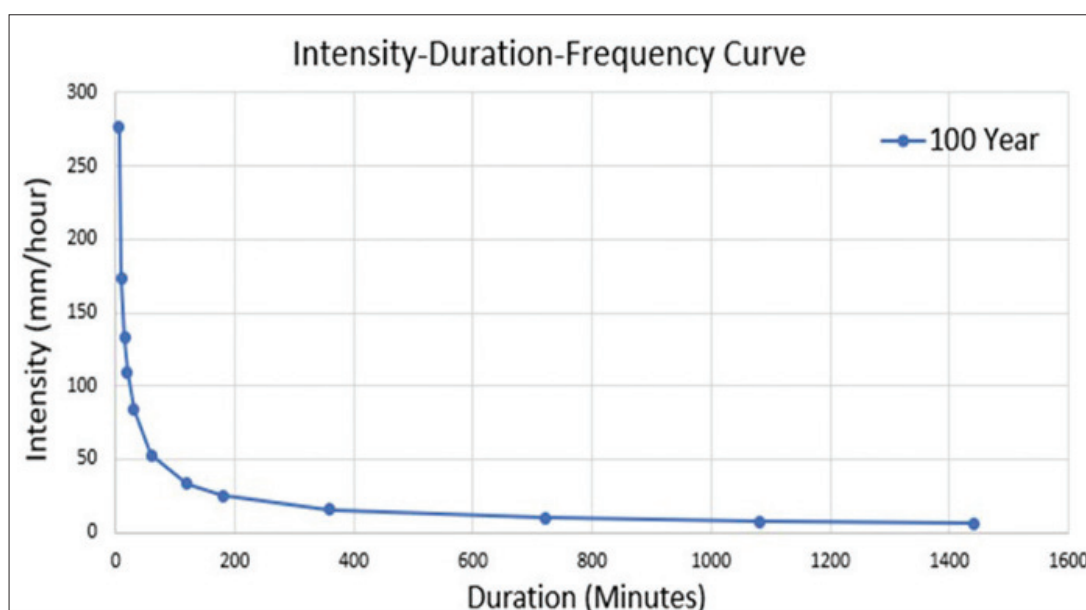


Figure 26. Graphical Representation of the IDF Developed for Climate Change Scenario for 100-year Return Period Event at Guwahati

Source: Rainfall data from IMD

### 4.3.3 Drainage Area (DA) Analysis

The DA Bharalu is estimated to be approximately 110.23 Sq.km (27237.20 ac) as shown in Figure 27. DA Bharalu is majorly a residential area. Morabharalu River also receives diversion flow from the Bharalu River. It flows from northeast to southwest. The DA Morabharalu is estimated to be 15.07 Sq.km (3724.47 ac). DA Morabharalu is a high-density residential area. The flows from the rivers' drainage areas were estimated utilizing the Rational Method as detailed in Annexure 2. Flow path and drainage area analyses supported the conclusion that Bharalu and Morabharalu are the principal rivers impacting the city's drainage and flow accumulation patterns despite parts of Bharalu being diverted to Bashistha River.

For this study, upstream of Bharalu is being considered and many organizations suggest the opening of the sluice gate therefore, the study is trying to understand the worst-case flooding scenario.

Soil type data is analysed using HYSOGs250m data. This dataset represents a globally consistent, gridded dataset of hydrologic soil groups (HSGs) with a geographical resolution of 1/480 decimal degrees, corresponding to a projected resolution of approximately 250 m. HSGs for Bharalu and Morabharalu drainage areas are derived as described in the U.S. Department of Agriculture-Natural Resources

Conservation Service (USDA-NRCS) National Engineering Handbook (USDA, 2009). The DA Bharalu mainly consists of HSG C, which indicates a moderately high runoff potential (typically containing <50% sand and 20- 40% clay). Additionally, some areas within the DA Bharalu are classified as HSG C/D, which signifies a high runoff potential unless drained (typically contains <50% sand and 20-40% clay). The DA Morabharalu consists of soils classified into HSG C, D and C/D categories. The DA Morabharalu is majorly covered by HSG C soils, which have a moderately high runoff potential. HSG D soils present to a lesser extent, have a high runoff potential (typically contains <50% sand and >40% clay).

A flow path delineates the hydrological trajectory of water from one location to another within the drainage area. The longest flow path signifies the route from a headwater, typically the ridge line of the drainage area, to the outlet, which is longer than all other flow paths in length within the drainage area. The DA of the Bharalu is residential area within the city boundary and a hilly area in the south, however Morabharalu DA is completely residential. The Time of concentration for DA Bharalu was 89.07 min (1.48 hr) and for DA Morabharalu was 48.80 min (0.81 hr).

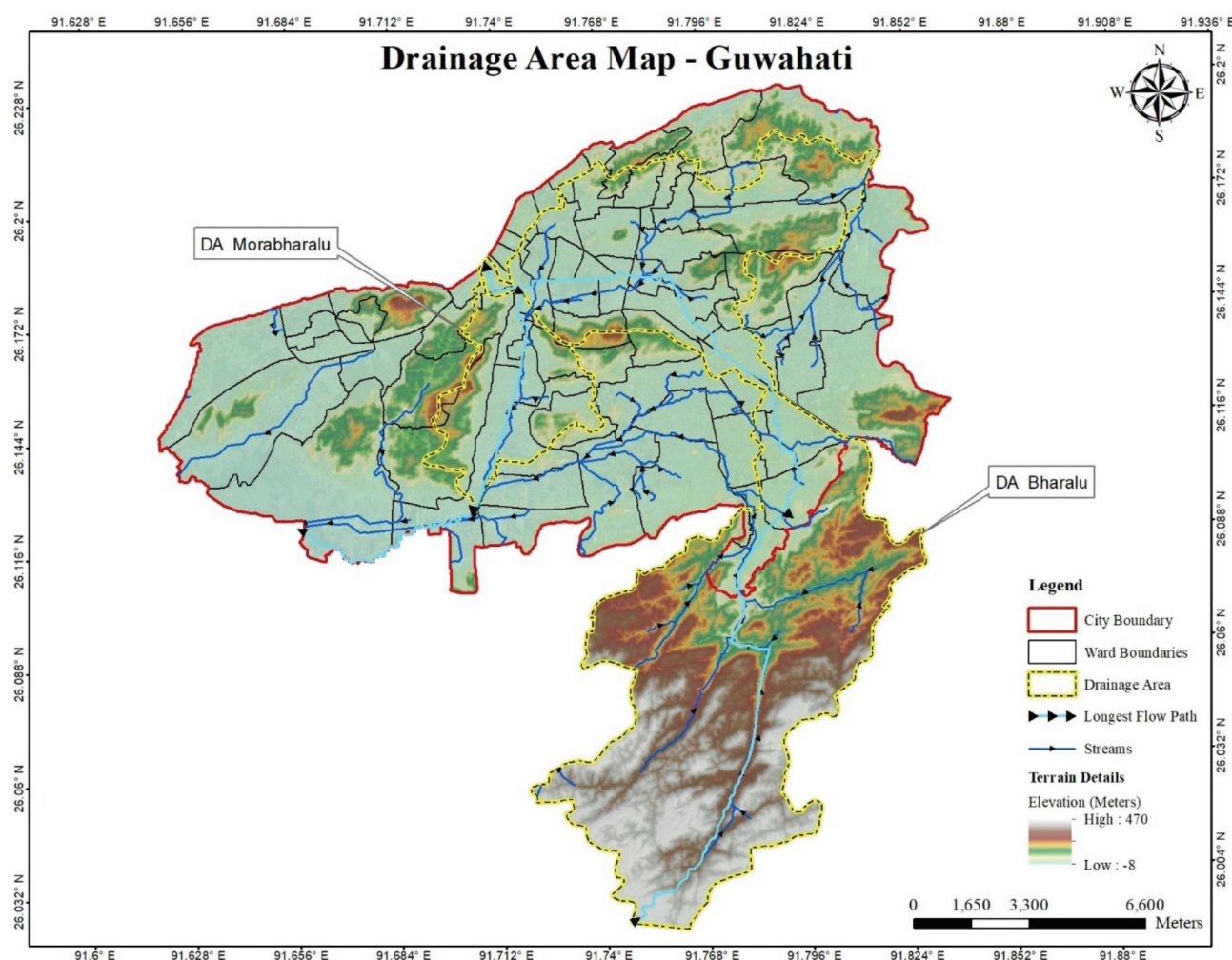


Figure 27. Drainage Area Analysis – Guwahati

Source: Developed from satellite imagery and datasets from IMD, ISRO

### 4.3.4 Peak Flow Analysis

The runoff for the DA Bharalu and DA Morabharalu in Guwahati are used as 0.70 and 0.75 respectively, considering the areas as a high-density residential catchment. On average about a 50% increase in the 100-year rainfall intensity and the peak flows are

estimated to show the climate change scenario. The DA Bharalu indicates a high estimated flow which requires specific consideration from the development and drainage management perspectives. Tables 9 and 10 show the detailed hydrological estimations for various scenarios.

**Table 9. Hydrological Estimations for the Drainage Areas for Different Storm Events for Guwahati**

| Drainage Area  | TC (hrs) | C    | Area (sq. km.) | Intensity (mm/hr) |         |          | Estimated Flow (m3/sec) |         |          |
|----------------|----------|------|----------------|-------------------|---------|----------|-------------------------|---------|----------|
|                |          |      |                | 10-year           | 25-year | 100-year | 10-year                 | 25-year | 100-year |
| DA Bharalu     | 1.48     | 0.70 | 110.23         | 28.43             | 33.74   | 41.59    | 609.28                  | 723.11  | 891.38   |
| DA Morabharalu | 0.81     | 0.75 | 15.07          | 42.23             | 50.12   | 61.78    | 132.61                  | 157.38  | 194.01   |

**Table 10. Hydrological Estimations for the Drainage Areas for Climate Change Scenario for Guwahati**

| Drainage Area  | TC (hrs) | C    | Area (sq.km.) | Intensity (mm/hr) | Estimated Flow (m3/sec) |
|----------------|----------|------|---------------|-------------------|-------------------------|
|                |          |      |               | 100-year          | 100-year                |
| DA Bharalu     | 1.48     | 0.70 | 110.23        | 64.76             | 1387.89                 |
| DA Morabharalu | 0.81     | 0.75 | 15.07         | 92.61             | 290.80                  |

### 4.3.5 One-Dimensional Hydraulic Modelling

Multiple cross-sections are obtained sequentially from left to right, aligning with the direction of flow of the Bharalu and Morabharalu Rivers within Guwahati city, to assess flood risk at the Guwahati. Manning's Roughness Coefficient for the Bharalu River is considered as 0.04 for the channel and 0.08 for both the Left Over Bank (LOB) and Right Over Bank (ROB), according to the CPHEEO manual. For the Morabharalu River, the coefficients considered are 0.04 for the channel and 0.12 for both the LOB and ROB. The hydraulic analysis is used to determine the flood risk to the project site by understanding the water surface elevation, depth, and extent of the inundation. A 1D HEC-RAS model is

developed considering a stretch of nallahs/ rivers covering the extent of the city. Multiple cross-sections are obtained sequentially from left to right, aligning with the direction of flow of the two rivers. For the hydraulic model, the peak flow corresponding to the 10-year, 25-year, and 100-year return period storm event is employed as the upstream boundary condition for the rivers. The downstream boundary condition in the hydraulic model is defined by a known water surface elevation (WSE) of 48.2 meters (m), 48.8 m, and 49.7 m for the 10-year, 25-year, and 100-year return period storm events, respectively<sup>1</sup> aligned with the level of the downstream Brahmaputra River. For the

<sup>1</sup><https://vedas.sac.gov.in/hydro/index.html>

Morabharalu River, the downstream boundary condition in the hydraulic model is defined by a normal depth. Figure 28 visually depicts the extent of the 1D model of the two-stream paths of Bharalu and Morabharalu. The green lines represent the cross-sections.

According to the hydraulic analysis, the WSE for cross-sections is obtained for the 10-year,

25-year, and 100-year events and for climate change scenarios as shown in Figures 29 to 32. Table 11 (a) and Table 11 (b) show the WSE at different cross-sections for the Bharalu River and Morabharalu River, respectively, for 10-year, 25-year, and 100-year events and climate change scenarios with the respective landmarks for each cross-section.

**Table 11. Water Surface Elevations (WSEL) for Different Storm Events and Climate Change Scenarios at Various Cross- Guwahati (a) On the Bharalu River (b) On the Morabharalu River**

(a)

| Cross-Section ID | Landmark                                                                          | WSEL (m)            |       |        |                         |
|------------------|-----------------------------------------------------------------------------------|---------------------|-------|--------|-------------------------|
|                  |                                                                                   | Design Storm Events |       |        | Climate Change Scenario |
|                  |                                                                                   | 10-yr               | 25-yr | 100-yr |                         |
| 1                | Dakhin Ganesh Nagar                                                               | 59.71               | 59.97 | 60.35  | 61.20                   |
| 2                | Bekarapara                                                                        | 51.76               | 51.87 | 51.98  | 52.30                   |
| 3                | Pator Kuchi                                                                       | 50.76               | 50.91 | 51.18  | 51.91                   |
| 4                | NH-27                                                                             | 50.75               | 50.91 | 51.18  | 51.91                   |
| 5                | Bhagaduttapur, Jayanagar Road                                                     | 50.75               | 50.91 | 51.18  | 51.91                   |
| 6                | Rukmini Gaon, Anand Nagar                                                         | 50.75               | 50.91 | 51.18  | 51.91                   |
| 7                | Swaraj Nagar, Dispur                                                              | 50.74               | 50.89 | 51.16  | 51.89                   |
| 8                | Sunderpur Road                                                                    | 50.56               | 50.68 | 50.93  | 51.65                   |
| 9                | Borah Market                                                                      | 48.52               | 49.05 | 49.87  | 50.08                   |
| 10               | Nabin Nagar, Guwahati Medical College and Hospital, R. G. Baruah Road, Geetanagar | 48.43               | 48.98 | 49.82  | 49.97                   |
| 11               | Railway Colony, Bhaskar Nagar, Birubari Jama Masjid, R. G. Baruah Road            | 48.41               | 48.96 | 49.81  | 49.94                   |
| 12               | Ulubari, Apro Colony                                                              | 48.38               | 48.94 | 49.79  | 49.91                   |

|    |                                                               |       |       |       |       |
|----|---------------------------------------------------------------|-------|-------|-------|-------|
| 13 | Chandmari Colony, Iskcon<br>Guwahati                          | 48.36 | 48.92 | 49.78 | 49.88 |
| 14 | Athgaon, Sports Authority of<br>India, Paltan Bazar, GNB Road | 48.30 | 48.88 | 49.75 | 49.81 |
| 15 | Assam state Museum, Gopinath<br>Bordoloi Road                 | 48.20 | 48.80 | 49.70 | 49.70 |

(b)

| Cross-<br>Section<br>ID | Landmark                     | WSEL (m)            |       |        |                               |
|-------------------------|------------------------------|---------------------|-------|--------|-------------------------------|
|                         |                              | Design Storm Events |       |        | Climate<br>Change<br>Scenario |
|                         |                              | 10-yr               | 25-yr | 100-yr |                               |
| 1                       | M B Road                     | 47.41               | 47.59 | 47.82  | 48.24                         |
| 2                       | Cycle factory Masjid         | 47.34               | 47.51 | 47.73  | 48.13                         |
| 3                       | B.R. Road                    | 47.15               | 47.29 | 47.49  | 47.79                         |
| 4                       | ACA Stadium Road             | 44.79               | 44.94 | 45.18  | 45.62                         |
| 5                       | Bhupen Hazarika Path         | 43.40               | 43.55 | 43.74  | 44.16                         |
| 6                       | Jyotikuchi                   | 43.09               | 43.22 | 43.40  | 43.78                         |
| 7                       | Billal Market (Ashraful)     | 42.59               | 42.72 | 42.90  | 43.26                         |
| 8                       | Lachit Garh Path,<br>GARCHUK | 41.85               | 41.97 | 42.16  | 42.48                         |
| 9                       | GMC Road, Boragaon           | 40.81               | 40.95 | 41.08  | 41.40                         |
| 10                      | Swahid Smarak Khetra         | 39.42               | 39.60 | 39.73  | 40.14                         |

The WSEL for different storm events in Figures 29 to 32 shows an increasing trend from the 10-year to the 25-year and then to the 100-year return periods. Under the climate change scenario at 100-year water surface elevation level (WSEL) is higher than the 100-year design storm event, as indicated in Table 15 for different cross-sections. Figures 30 show that, for the 25-year return period, the water surface extends to Shanti Path, Kidzee Ambikagiri Nagar, and Kaushik Villa. These are some of the areas which are not impacted by the 10-year

return period results. For the 100-year return period, the water surface reaches Lachit Nagar Main Road, Govt. Banikant College of Teacher's Education, CPB Road, Rainway Hospital, and Rongpothar Bihutoli, which are not impacted by the 25-year return period. In the climate change scenario, the water surface extends to Japorigog Durga Temple, SEAUJ Residency, Lakhi Market, and L.P. School, areas that are not affected in the 100-year return period.



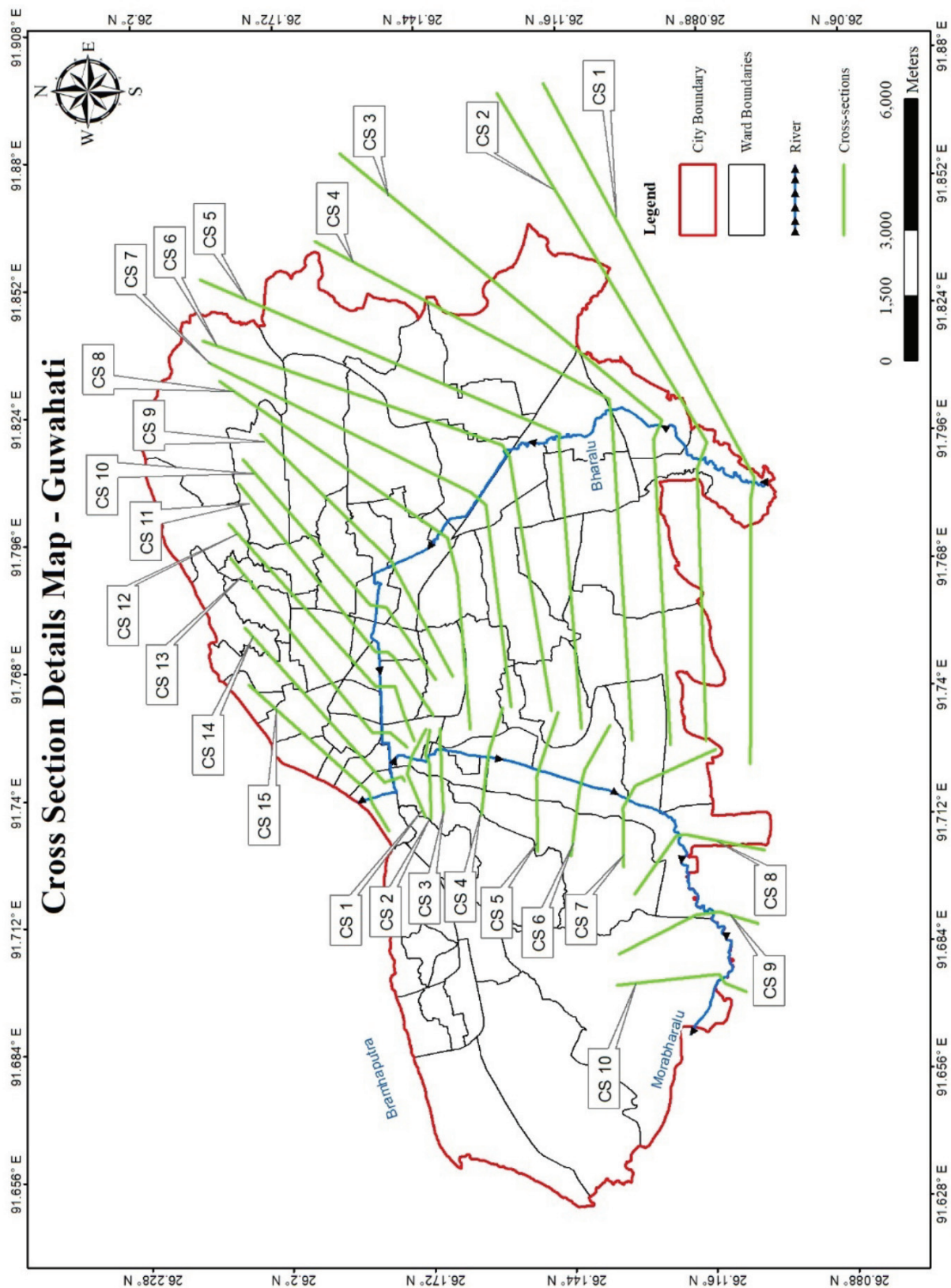


Figure 28. Cross-Section Details of Guwahati



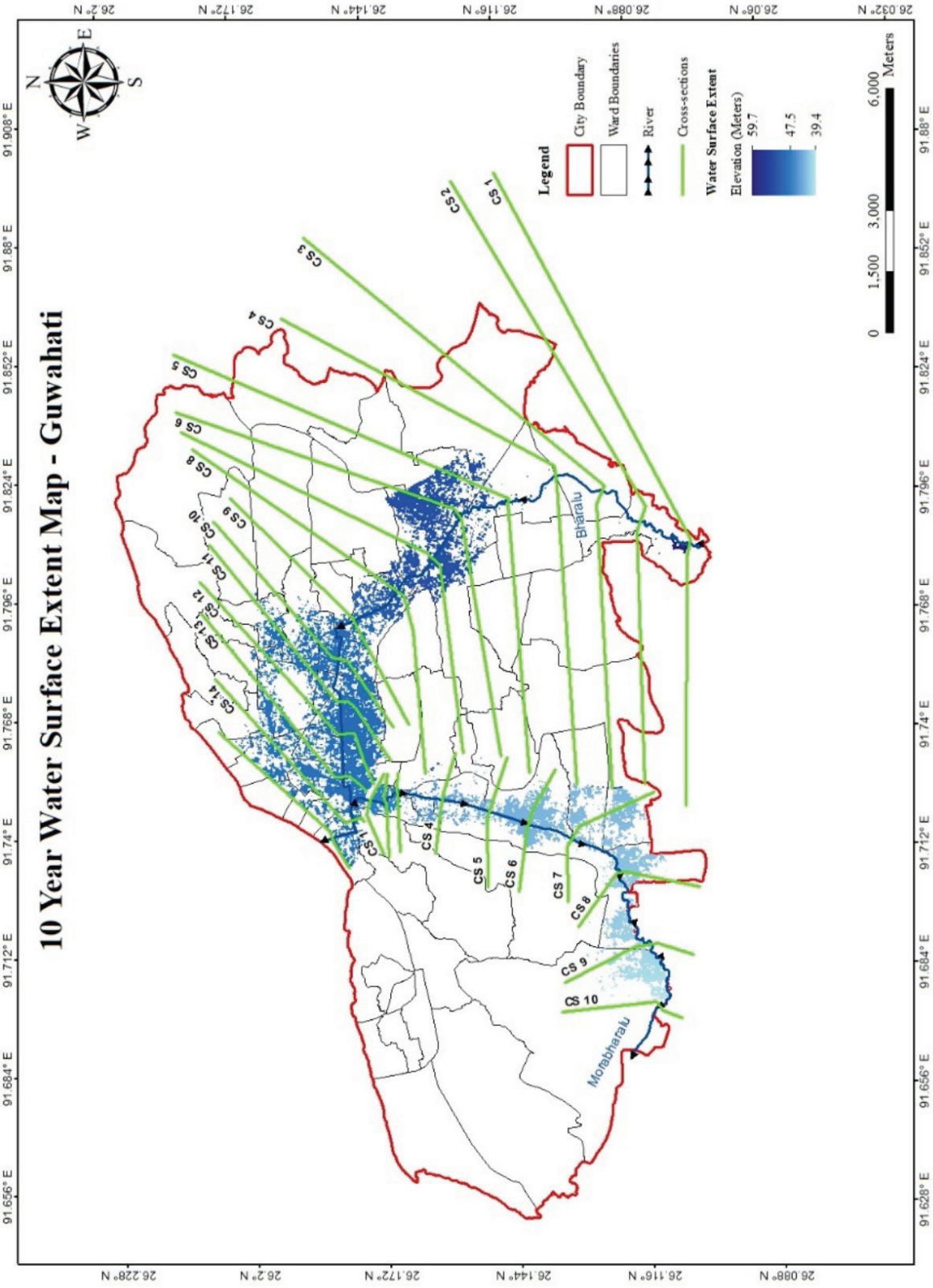


Figure 29. Flood Water Surface Extent at 10-year Return Period – Guwahati  
Source: Developed from IMD, ISRO, municipal office datasets, and field visits

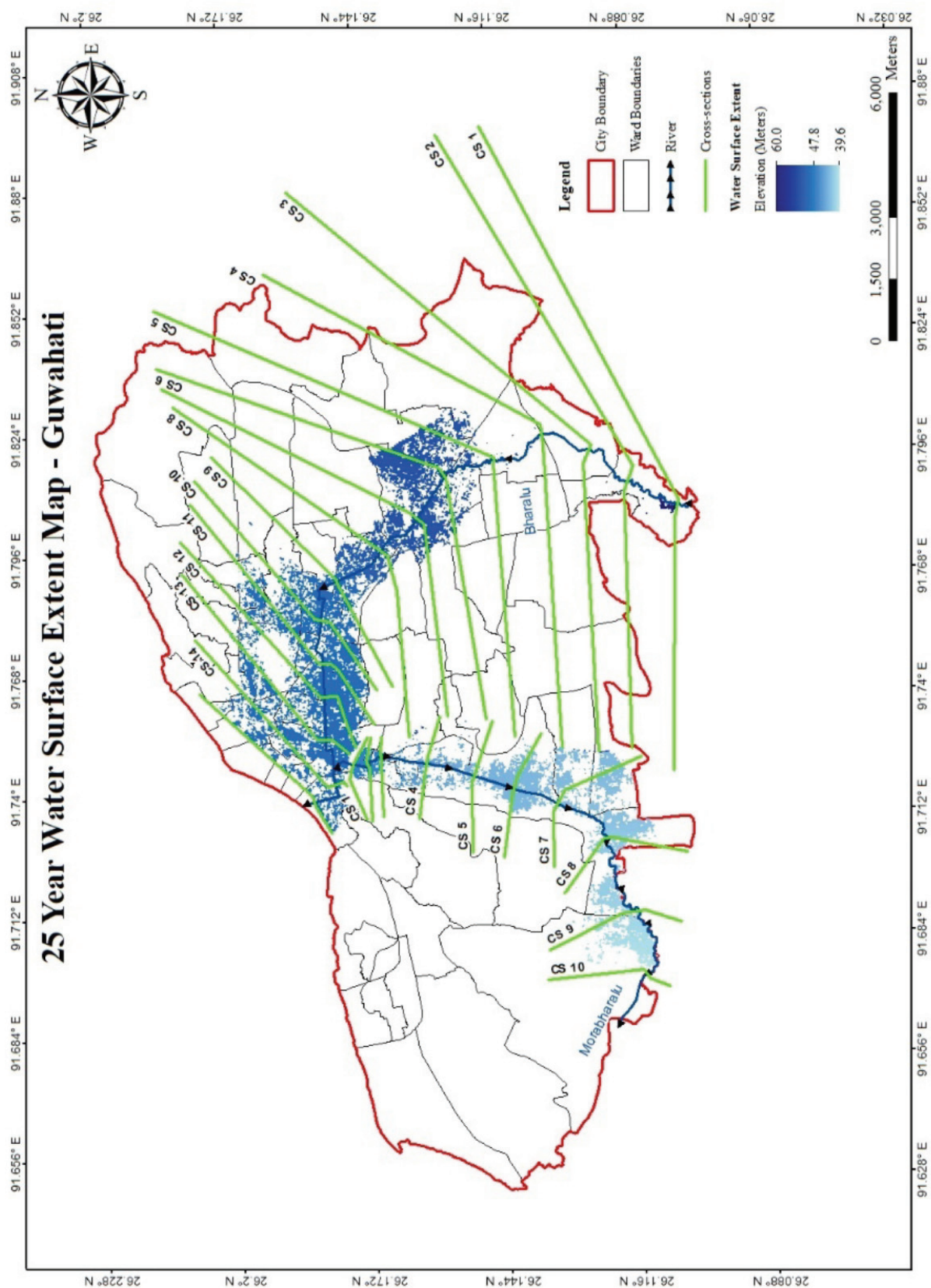


Figure 30. Flood Water Surface Extent at 25-year Return Period – Guwahati

Source: Developed from IMD, ISRO, municipal office datasets, and field visits

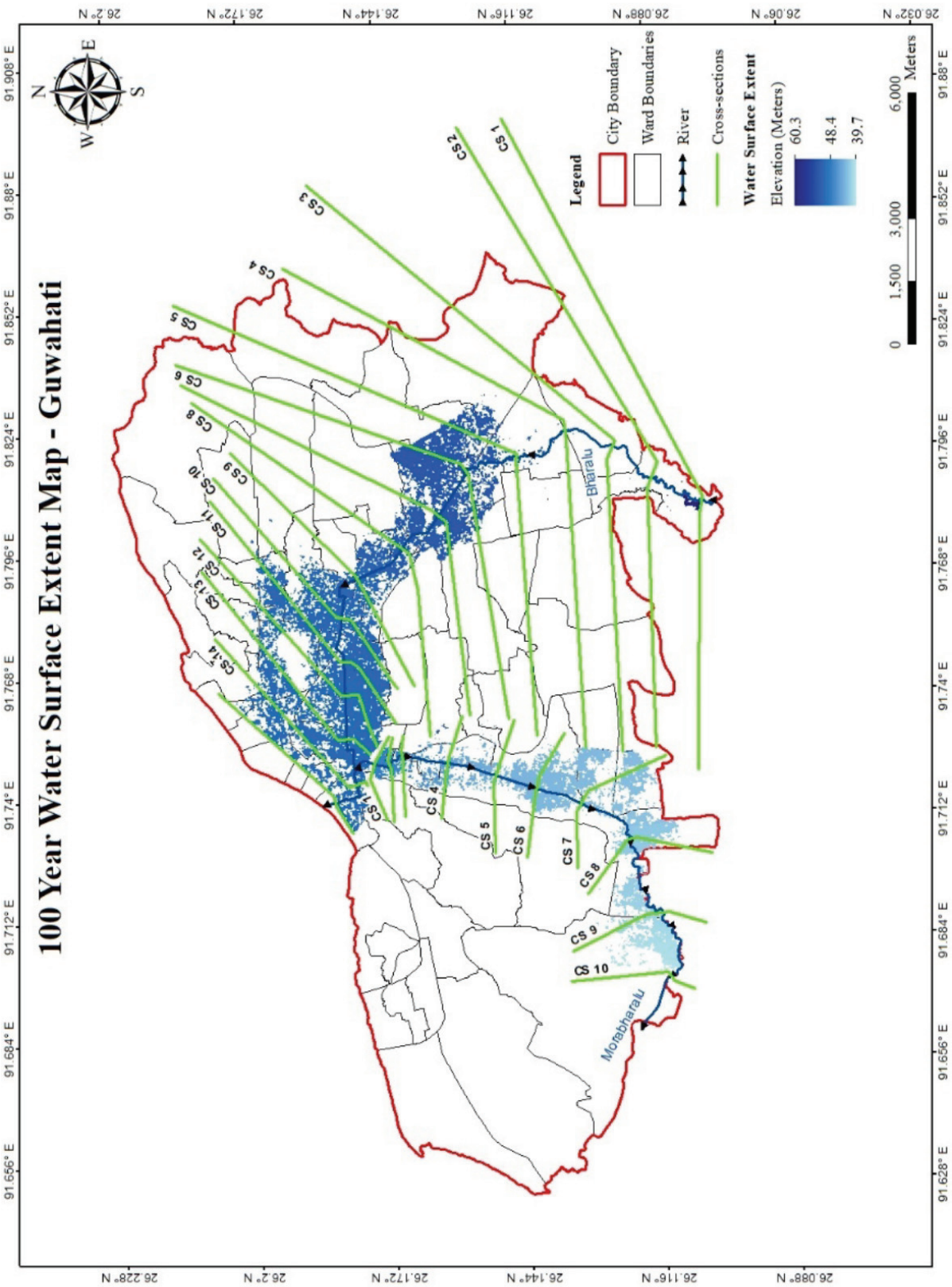


Figure 31. Flood Water Surface Extent at 100-year Return Period – Guwahati

Source: Developed from IMD, ISRO, municipal office datasets, and field visits



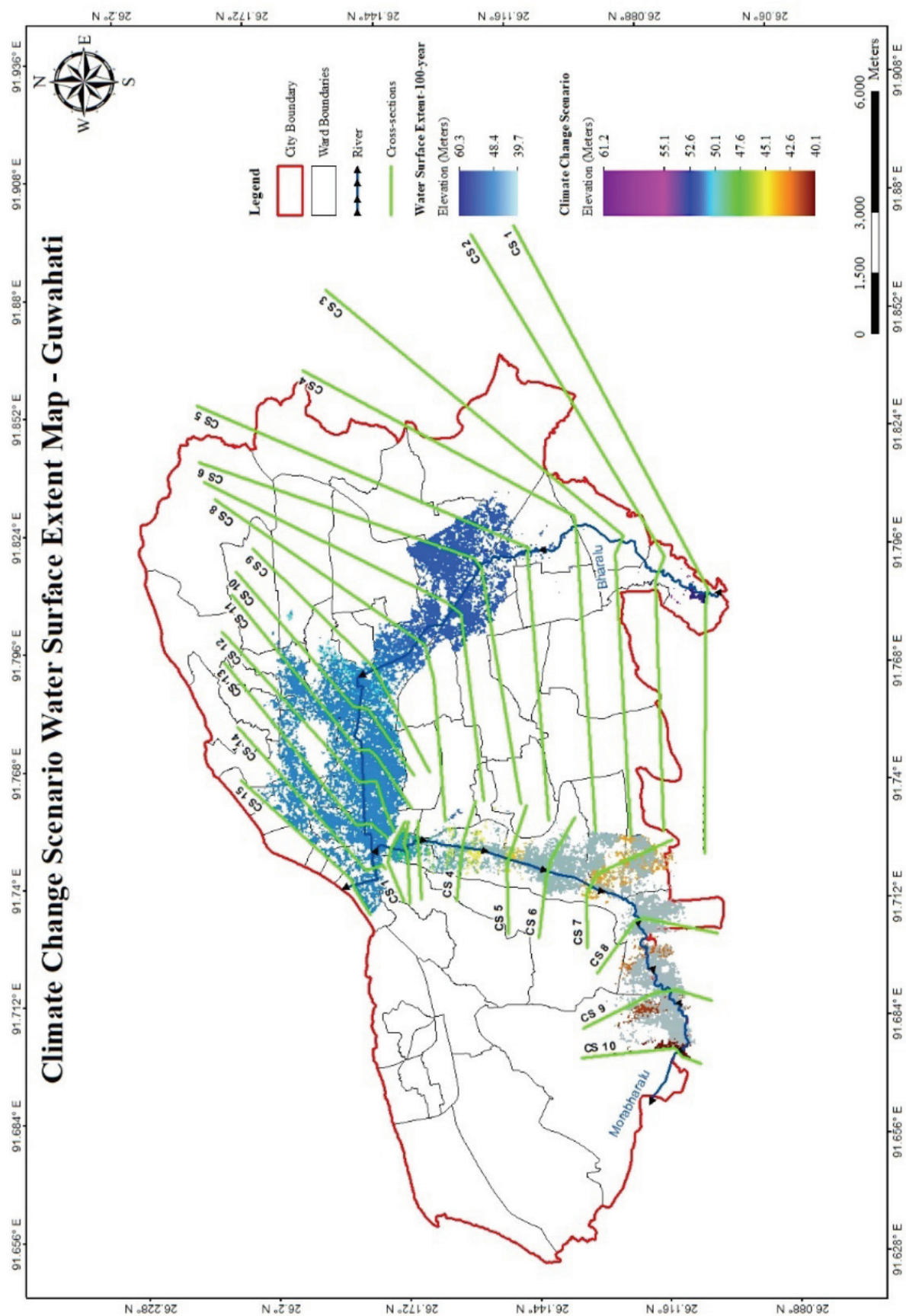


Figure 32. Flood Water Surface Extent at Climate Change Scenario – Guwahati

Source: Developed from IMD, ISRO, municipal office datasets, and field visits

### 4.3.6 Impact of Riverine Flood on Urban Floods

The extent of riverine flooding was determined by collecting High Flood Level (HFL) data from the Brahmaputra River and mapping it with terrain data. On October 15, 1991, the Central Water Commission (CWC) reported a higher HFL of 55.50 m. On July 21, 2004, as per the Assam Water Research and Management Institute Society (AWRMIS)<sup>2</sup>, a High Flood Level (HFL) was 51.46 m. More recently, on June 22, 2024, the HFL was observed to be 48.70 m<sup>3</sup>. Also, the flood extent for Guwahati of Brahmaputra River has been eyeballed from the flood inundation map of June 18, 2022, and the flood inundation maps<sup>4</sup> of August 31, 2023, June 18, 2022, and June 24, 2022. These observed flood level records and flood extents were compared with the Guwahati hydraulic analysis results. The obtained extent indicates that the critical locations mentioned in the previous section in the city are not impacted by Brahmaputra River

flooding (as shown in Figure 33), but due to the Bharalu and Morabharalu rivers in Guwahati. Similar observations are made during the site visit discussions.

However, it is identified that the backflow of the water from the Brahmaputra River into these drainage channels may be responsible for drainage channel overflow incidents. Due to the topography of the city, there is a lack of scope for direct gravity flow of floodwater to the river Brahmaputra. Section 5.2 highlights that urban flooding in Guwahati primarily results from issues such as overflow of stormwater drains, inadequate drain capacity, improper gradient, significant silt accumulation, unregulated garbage disposal, insufficient grit/silt traps, inadequate inlet port sizes, poor maintenance practices, and lack of interconnected drainage systems.

<sup>2</sup>Assam Government: <https://waterresources.assam.gov.in/portlets/flood-information-system>

<sup>3</sup>Vedas Portal: <https://vedas.sac.gov.in/hydro/index.html>

<sup>4</sup>NESDR Portal: <https://www.nesdr.gov.in/map.php>

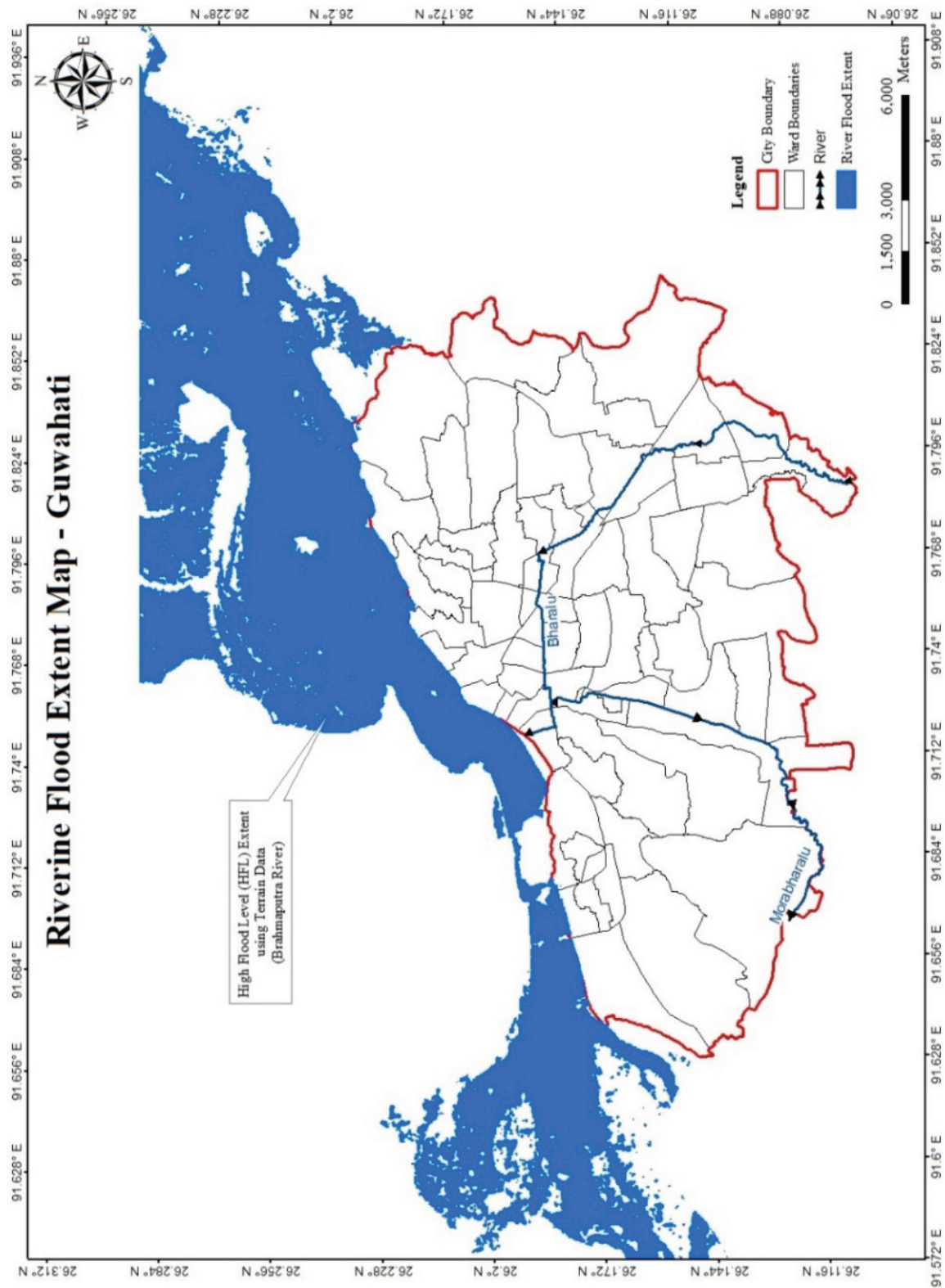


Figure 33. Impact of Brahmaputra River Flooding on Urban Floods

Source: Developed based on data from NESDR, ISRO



### 4.3.7 Flood Hotspots

Wards 1, 11, 14, 15, 16, 17, 20, 21, 24, 25, 26, 27, 40, 41, 42, 43, 44, 49 are chronically inundated in Guwahati. The flood hotspots are frequently affected by flooding incidents which may be caused by one or more factors mentioned in Section 5.2. The pressures are aggravated when two or more factors simultaneously affect a location which is quite often.

Historically, the city had wetlands and diverse species, supported by the nearby Bharalu River. However, the city's burgeoning population and subsequent urbanization led to the encroachment of these wetlands, replaced by large buildings and commercial establishments, resulting in the loss of biodiversity and significant changes to the local ecosystem.

Based on the hydraulic analysis and field visits, it was ascertained that the identified flood hotspots according to analysis align with the ground truth data. As depicted in Figure 34, areas marked in yellow colour points are the critical areas flooded because of the Bharalu and Morabharalu Rivers in Guwahati and areas

marked in cyan colour points are not falling under the flood extents of the rivers, but the waterlogging was observed in these areas.

Thus, the waterlogging in these areas is the reason for urban flooding due to factors such as overflow of stormwater drains, inadequate capacity, improper grading, etc. Some location-specific reasons for flooding are:

- Anil Nagar, Nabin Nagar — geologically the area acts like a basin, thus water accumulation occurs during heavy rain
- Lachit Nagar — Low-lying area, Low capacity of the existing drains
- Rukmini Gaon — The existing drainage systems are often overwhelmed by the volume of water during heavy rains, Back flow from the Bahini River leads to frequent waterlogging and floods.
- The existing drainage system in Chandmari Colony is often clogged due to waste and silt accumulation. The lack of regular maintenance further worsens the situation.

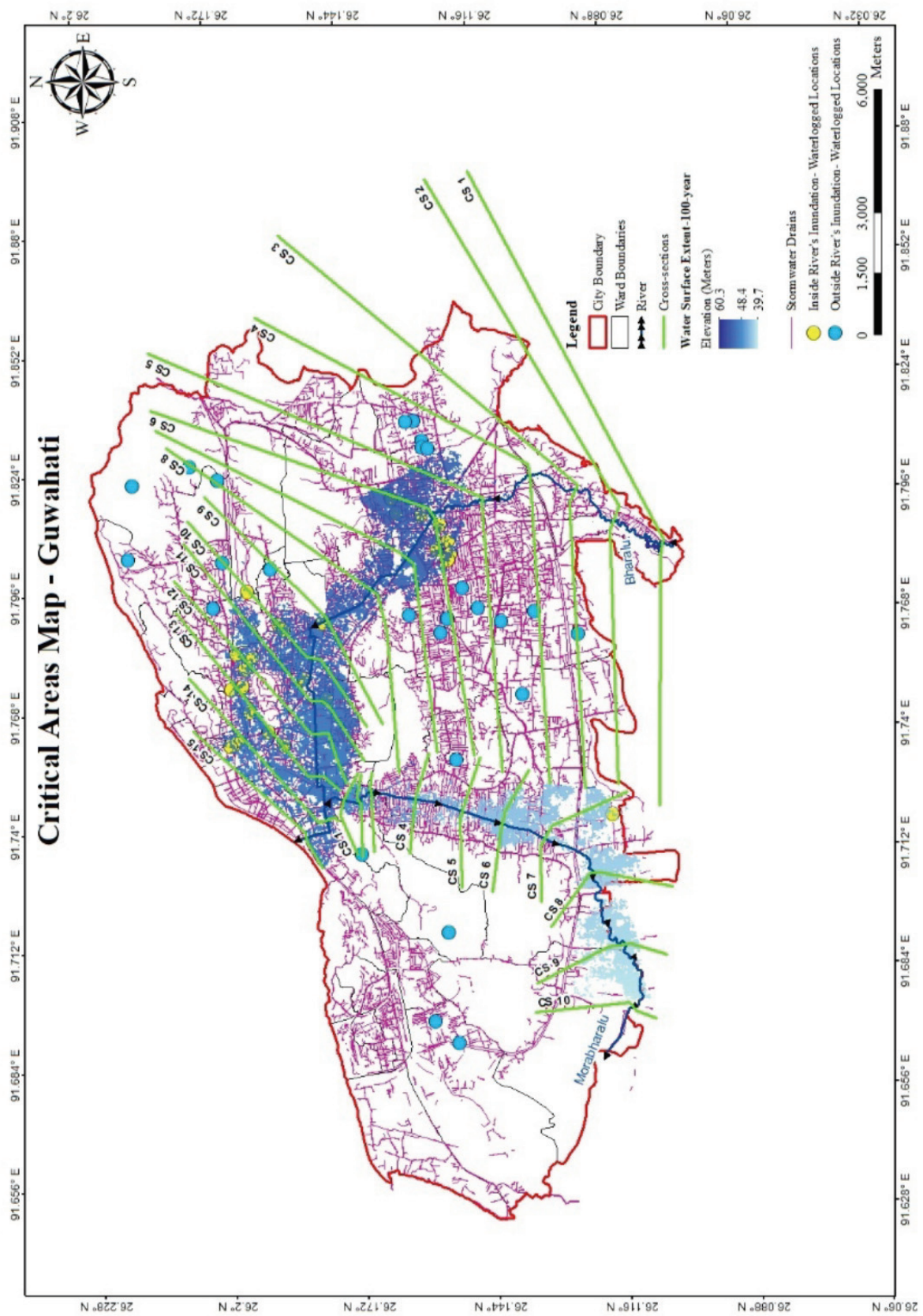


Figure 34. Critical Locations in Guwahati

Source: Developed from field visits, IMD, ISRO datasets

### 4.3.8 Impact on Critical Infrastructure

The critical infrastructures such as some electrical substations, hospitals, and government offices lie in the critically inundated areas making access to these infrastructures difficult during the urban flooding as shown in Figure 35. Flooding issues have affected hospitals, electric substations, bus terminals, and railway stations in the past. In recent past there have been reports of water logging on practically all of the city's periphery roads, leaving people stuck in their cars for hours in the midst of heavy traffic. Due to the flooded roads, reports indicate that people making their way home from work, school children, and even ambulances were trapped until late at night. The arterial roads like Zoo Road, B Baruah Road, GS Road and areas of Nabin Nagar, Anil Nagar, Hatigaon, Ganeshguri are at risk of frequent flooding. Many of the electric substations in the city lie within the critical area of flooding as shown in Figure 35. Electric substations in wards 29, 35, 41 and 53 lie in the critical area of flooding and have the potential threat of short circuits. It was reported that the extreme rainfall events are followed by power cuts in many areas.

From the analysis, almost 70 school buildings lie within the water surface extent of a 10-year flood return period as shown in Figure 35. A significant issue is that some private schools are

operating out of rented space without properly reinforcing the buildings which can be a reason for future threats. With a few exceptions, the majority of the schools that are at risk are newer buildings. A study by ASDMA<sup>5</sup> shows that about 5% of schools are affected by floods and about 10% are vulnerable to slope failure/landslide. The majority of the hospitals in the city are vulnerable as they have plan irregularities which are also amplified by eccentrically arranged cores (as shared by government officials). It was observed from spatial data and the hydrological analysis that some of the government and NGO hospitals like Guwahati Medical College Hospital, Satribari Christian Hospital, Guwahati Lions Eye Hospital, and Railway Hospital could be impacted by situations of flooding in the future. As per the analysis, most of the rail and bus transport networks are at risk of being inundated as shown in Figure 35. Police Headquarters and Dispur Fire Station in Guwahati are located in the critical area of flooding. Many schools in the East, Dispur division are in close proximity to critical flood areas. There is one chemical plant in the city that is at a safe distance from the critical flood area. However, an increase in rainfall and waterlogging situations in the future can lead to accidents in the area.

<sup>5</sup>Status Survey of Hospital & School Buildings In Guwahati City And Retrofitting Solutions: [https://www.asdma.gov.in/project\\_survey.html](https://www.asdma.gov.in/project_survey.html)

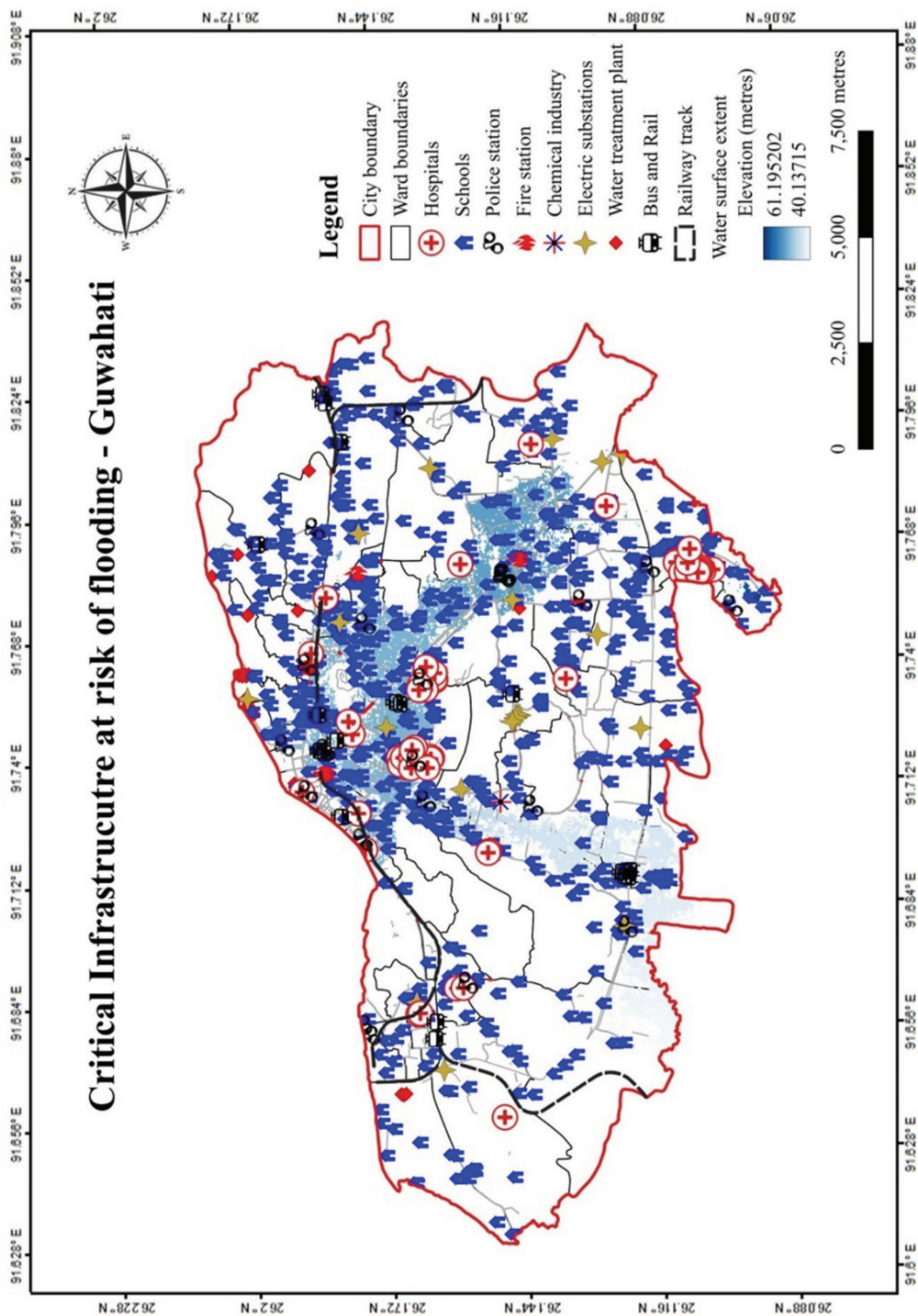


Figure 35. Critical Infrastructure at Risk of Flooding in Guwahati

Source: Developed from Municipal Office, GMDA datasets and field visits



## 4.3.9 Strengths and Weaknesses

### 4.3.9.1 Social

Guwahati has a major population working in the service industry, trade and commerce. The surveyed information suggested that in most of the cases, the residents are aware of the seasons when flooding is anticipated and the duration of inundation as it is a recurrent issue. Even though most of the residents are aware of floods, however, due to lack of community participation they are dependent on the government to take collective mitigation measures. Internet access through social media, FM radio etc, is present yet the effectiveness of the same for communication of emergency information and early warning depends on the usage and understanding of the local community. Ward officials are well aware of their roles during floods, public knowledge about flood threats varies, with some wards showing less awareness.

The literacy rate in Guwahati is 91.47% which is higher than the national average in urban areas with a distribution of male literacy at 94.24% and female literacy at 88.50%. The urban poverty ratio is 9.09 and the unemployment rate is 4.32 with the majority of the employed individuals in salaried positions (Census 2011). Many residents in the city belong to tribes like Boro, Kachari, Karbi, Mising/Miri, Mishimi, Rabha, etc. Mising tribe resides near the Brahmaputra river banks in unique houses built on stilts called *chang ghar* to prevent flood impact. These tribes are very rich in traditional knowledge of agriculture and medicine. Migration for education, employment, and business has driven rapid population growth, placing significant pressure on the city's water supply, infrastructure, and disaster resilience capacity. The division-wise social conditions are highlighted in Table 12.

**Table 12. Population and Demographic Conditions in Guwahati**

| Division | Literacy Rate | Percentage of Slum Population | Percentage Population Below 7 years | Population Density |
|----------|---------------|-------------------------------|-------------------------------------|--------------------|
| 1        | 89.28         | 22.66                         | 9.68                                | 6027.36            |
| 2        | 91.29         | 12.96                         | 9.27                                | 8751.90            |
| 3        | 92.45         | 5.61                          | 9.22                                | 5384.63            |
| 4        | 93.08         | 2.36                          | 9.08                                | 14273.89           |
| 5        | 92.09         | 11.58                         | 9.56                                | 5378.98            |
| 6        | 91.83         | 27.98                         | 9.16                                | 2955.79            |

Source: Draft Master Plan 2045 and consultation

Division 1 has high social vulnerability owing to the low overall literacy rate, large number of people residing in slum areas and higher percentage of population below 7 years as shown in Figure 36. Division 4 despite having high population density is considered less vulnerable due to better awareness among residents, lower percent of residents in slum areas along with access to better early warning and internet facilities than other divisions.

Social cohesion is strong in societies like in AGP Goli (Liladhar Baruah Road) and Sarumotoria Unnyan society in Sarumotoria where there have been strong community participation and, residents have been able to draw attention of government agencies on issues like waterlogging in the area. Owing to this, drains in the areas are regularly maintained and are being constructed anew.

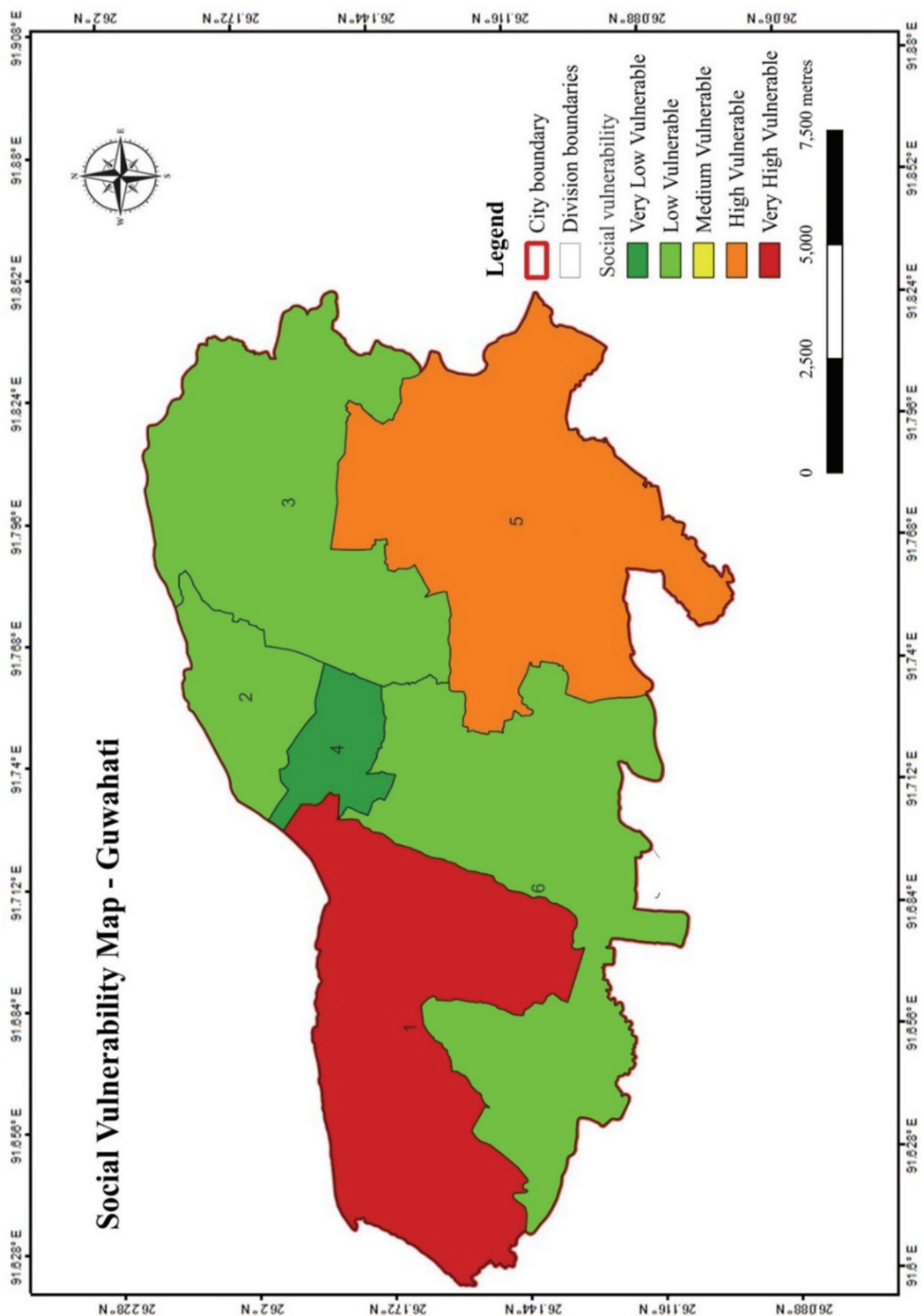


Figure 36. Social Vulnerability Map Guwahati

Source: Developed from field data, secondary reports, Draft Master Plan 2045 and consultation



### 4.3.9.2 Physical

The city has an expanse of unregulated development and violation of building codes. It has led to congestion resulting to compromised “right of way” on roads and along drainage channels. Rampant construction in low-lying areas and flood plains has led to increased flooding in areas such as Uzan bazaar in Division II, AM Road: from GS Road to Namghar Path, Suagpur PB Road in Ward 30, Basishtapur area in Ward 41, Sarumotoria in ward 49 of Division V. According to GMDA data, there are 99 notified slums and 118 non-notified slums in the city. Over 22% of housing and other buildings

in these slums are in dilapidated condition (GMDA, 2024). Built-up in the hilly areas both encroached and permanent have altered the slopes tremendously. These developments have neglected the natural drainage and altered the sensitive local water systems in Guwahati, causing flooding. Table 13 shows the Division-wise break up of slum settlements in Guwahati. On the household level most of the residents who own the houses have raised the floor level, and door sills, filled their compound, and raised their garage several times over the years due to incidences of flooding.

**Table 13. Division-wise Slum Settlements in Guwahati**

| Division | Wards with Slum Settlement          | No. of Households |
|----------|-------------------------------------|-------------------|
| 1        | 3, 4, 5, 6, 7, 8, 9, 11, 12, 13, 14 | 6238              |
| 2        | 17, 34, 36                          | 1195              |
| 3        | 37, 40, 52, 54, 55, 58              | 1536              |
| 4        | 16, 19, 28, 30                      | 215               |
| 5        | 41, 42, 44, 45, 46, 47, 48, 60      | 4125              |
| 6        | 20, 21, 22, 24, 27                  | 2392              |

Source: Authors' compilation from Draft Master Plan 2045 and consultation

In terms of infrastructures and basic services of Guwahati, Census 2011 data suggests these are lower than the national average in terms of percentage of household with access to tap water (from treated source) at 32.64% w.r.t. national average of 84.14% in urban areas across India and only 76.93% of household's wastewater outlet connected to drainage leading to increased chances of contamination and water borne-diseases which are aggravated during flooding. It is observed that the possibility of short-term financial gain from development

has taken precedence over arguments regarding the necessity of “risk-sensitive planning” in the context of flood prevention in the city.

The physical vulnerabilities were calculated with consideration to slum households, residential units within 50 m of waterbody or streams as highlighted in the urban water bodies management guidelines, vacant land that allows for groundwater recharge, frequently waterlogged areas, open drains, and availability of healthcare facilities in each of the divisions.<sup>6</sup> Prioritization to these was made based on

<sup>6</sup>Urban Wetland/Water Bodies Management Guidelines: A Toolkit For Local Stakeholders Volume I (2021) [https://nmcg.nic.in/writereaddata/fileupload/40\\_Urban%20Wetlandwater%20bodiesmanagement%20guidelines.pdf](https://nmcg.nic.in/writereaddata/fileupload/40_Urban%20Wetlandwater%20bodiesmanagement%20guidelines.pdf)

discussion with local division officials. It was identified that proximity to water bodies was considered a significant aspect along with slum households and open drains as these are indicative of poor management of waste and clogging of drains. Additionally, it was suggested that open drain information is important as these can be a source for diseases like malaria, Japanese encephalitis, etc. Figure 37 shows the highly vulnerable areas which are Divisions 5 and 6 which being densely populated have fewer vacant areas and also have more waterlogging points as identified in Section 5.3.7.

At present GMC only supplies to the core city area of Guwahati and the rest is done by deep wells and boring in houses. Because of hard strata below deep borewells are not possible everywhere in the city. According to the Draft Master Plan 2045 of Guwahati, 33% of the water supply demand is fulfilled by surface supply and 67% uses groundwater in the metropolitan area. With the expansion of city roads, many of the water supply network pipes in the core city area have come under roads and footpaths making it inaccessible for maintenance. Some of the supply pipes are passing in close proximity to drains and are at risk of getting contaminated. Open drains are prominent in wards 1, 11, 12, 13 of Division 1, 17, 36 of Division 2, 39, 56, 58 of Division 3, 51 of Division 5, and 10 of Division 6 become foul odor sources and breeding grounds for insects and pests (as reported by division officials and citizen during survey). Reduced capacity of drains due to heavy siltation, damage, and overflow like at Nizarapar Path, Chandmari drains are blocked by silt, overflow of drains at Nabin Nagar, Janapath Rd, Residents colony. In addition, there is an absolute absence of a sewerage system in Guwahati with no wastewater treatment plant resulting in the discharge of untreated wastewater in drains posing a threat of disease spread. The absence

of a sewerage system leads to the release of septic waste in drains without any treatment and contaminates the water bodies and drainage channels. People living in the foothills have raised concerns regarding the cutting of hills for construction and illegal settlements in eco-sensitive zones which leads to massive amounts of soil being washed down by stormwater and clogging the drains leading to overflow and waterlogging.

GMC has given tenders to NGOs for door-to-door waste collection in different wards. It was highlighted by residents that as the NGOs are not charging the residents they have reduced the frequency of collection in these areas even though the GMC has agreed to pay in lieu of the residents based on evidence of waste collected. Only 40% of waste is segregated at source in the whole city. Despite 100% coverage of door-to-door collection being reported by GMC, the household data collection and divisional consultation indicated the average frequency of waste collection in the entire GMC area is around once per 3 days. Areas like Islampur, Punjabi Basti Ward 36, 31 of Division 2 face severe irregularities with waste collection. Dumping of garbage in drains and river channels leads to blockage at the site or downstream in the drainage channel most evident along the Bharalu channel. The drain is blocked by a large amount of garbage and plastic at locations like A.T. Road, near Athgaon, Rukminigaon, and Ulubari. Dumping waste in an open landfill or burning it like in Boragaon dumping site can lead to pollution and increased risk of vulnerability.

Some important industrial sites that lie within the city as enlisted in Table 14 deal with inflammables. The municipal body currently does not have standard operating procedures related to nature-induced technical (NATECH) hazards that may occur and cause severe damage to humans and assets.

**Table 14. Industrial Sites in the City**

| Industrial Site in City                                                          | Type of Industry                                        |
|----------------------------------------------------------------------------------|---------------------------------------------------------|
| Indian Oil Corporation Limited,<br>(Indane Bottling Plant), North Guwahati       | LPG                                                     |
| Indian Oil Corporation Ltd.,<br>(Marketing Division), Guwahati Storage, Noonmati | Motor Spirit (MS) and High-Speed Diesel (HSD), Kerosene |
| Indian Oil Corporation Ltd.,<br>(Aviation Fuel Storage Depot), Guwahati          | Aviation Fuel                                           |
| Indian Oil Corporation Ltd.,<br>(Guwahati Refinery), Noonmati                    | Sulphur Dioxide                                         |
| LPG Plant Sarpara Mirza, Kamrup                                                  | LPG                                                     |
| Indian Oil Corporation Ltd., Tape off Point, Betkuchi,<br>Guwahati               | MS, HSD                                                 |

Source: Disaster Management Plan and Consultation

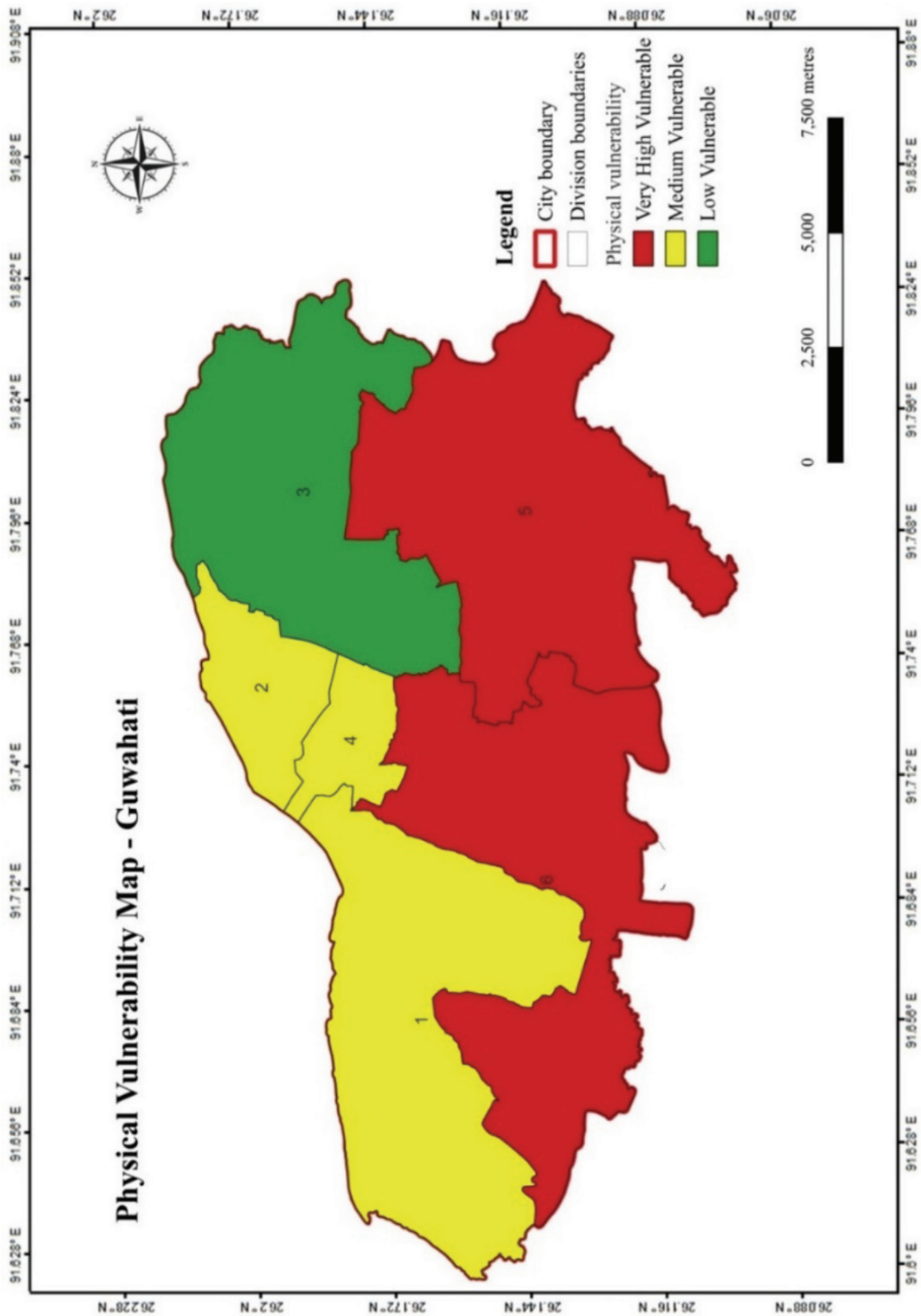


Figure 37. Physical Vulnerability Map Guwahati

Source: Developed from field data, secondary reports, Draft Master Plan 2045 and consultation

### 4.3.9.3 Institutional

Department of Housing and Urban Affairs (DoHUA) along with the District Commissioner Kamrup (M) have initiated the Mission Flood Free, Guwahati in 2022 to mitigate urban flooding issues in Guwahati city. The project has multiple activities being implemented by GMC, PWD, and the Water Resources Department. Specific activities such as de-siltation, pumping station construction, diversion of drains, etc are being undertaken under this project. Discussions with division officials suggested that some significant challenges exist in institutional mechanisms such as lack of dedicated staff in GMC for regular observation and upkeep as flooding is a seasonal issue. They highlighted the lack of accountability in some of the departments that are part of Mission Flood Free Guwahati but are not answerable to the chair of the committee on normal days. Sponge City Master Plan was initiated by GMDA in 2022 with interventions like the rejuvenation of wetlands and the creation of green areas however it has yet to realize full potential in the city.

The departmental disaster management plan of DoHUA highlights the incorporation of basic flood management guidelines in urban development is underway. The divisional offices suggested that there is no formal channel to disseminate information to the public about localised flooding from GMC. As a flood mitigation measure the administration has prepared embankments along the key areas in Brahmaputra Valley with 78.14 km lying within the city limits (ASDMA, 2016). Some interventions like slope stabilization, soil conservation and flood early warning systems have been undertaken by ASDMA along with academic institutions like IIT, Guwahati, TERI, etc. One such intervention is described in the box below. Consultations suggest that DDMA organise awareness programs related to floods but there is no regular schedule leading to reduced effectiveness as repeatability is the key to sensitizing people and increasing their capacity through training.

#### Controlling Urban Flood by Ecological Management Practices<sup>7</sup>

Built-up on hilly areas of the city has led to alteration of the slope in many parts. These changes in land use have neglected the natural drainage and transformed the local water systems in Guwahati, causing flooding and destabilized slopes. Unplanned housing connected to extensive deforestation in Himalayan habitats has exacerbated the issue of flash floods in the downstream region by increasing soil erosion from the hills and its subsequent deposition in the waterways. The movement of more population to the slopes is due to the poor socio-economic condition of the residents in areas such as Baikunthapur Basistha. In addition, because of the unplanned development in the nearby hills, Guwahati is also facing a number of dangers.

One such degraded hilly area is Garbhanga village, which is roughly 0.17 km<sup>2</sup> in size. IIT Guwahati has created a pilot project to use the Ecological Management Practice (EMP) idea, which aims to create a habitat area that is free of hazards, economically viable, and ecologically balanced. The project supported by GMDA, Soil department and ASDMA focussed on the slope restoration through plantation depending on slope angles (e.g. creepers for slope of 50 to 75 degrees, grass for slopes less than 35 degrees and so on), dedicated drainage channels with perforated blocks, step drains, retaining walls and awareness generation among masses. GMDA installed paver blocks and drain with step chutes at the locations identified by IIT Guwahati.

<sup>7</sup>Improving Societal living standard, IIT Guwahati: [https://www.iitg.ac.in/uba/doc/theme/social\\_living.pdf](https://www.iitg.ac.in/uba/doc/theme/social_living.pdf)



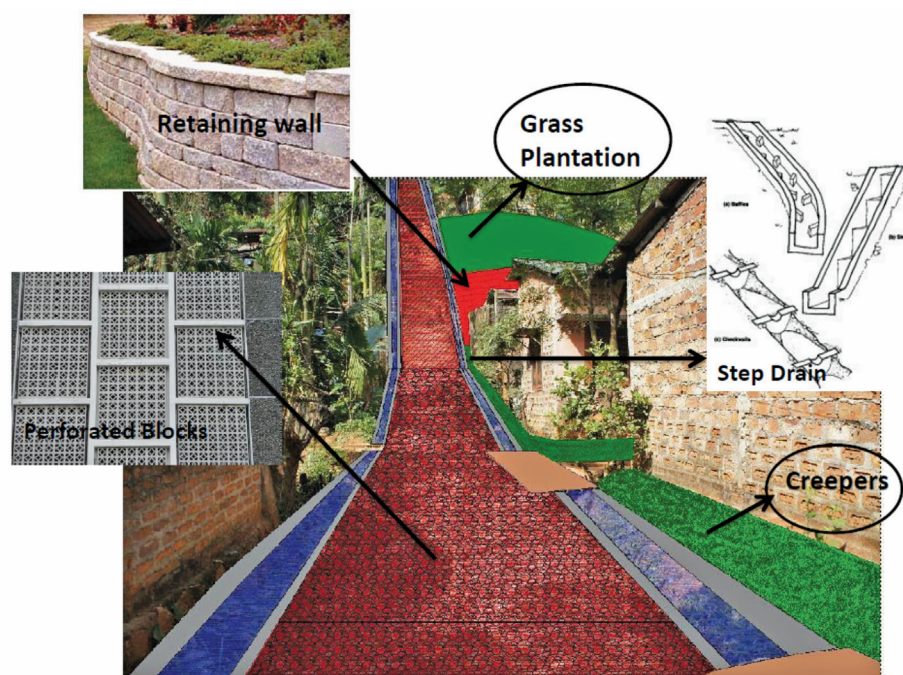


Figure 38. Ecological Management Practices in Guwahati

Source: Civil Engineering Department, IIT Guwahati

Field data suggested most of the waste is collected with about 80% of respondents confirming solid waste was collected by government agencies, 8% by private agencies, 4% said that the waste was collected by community-driven mechanisms and the rest 8% said by others. About 41.7% said that their streets get flooded for 5-8 hrs during heavy rain causing inconvenience to the residents. A higher level of access roads than many residential plots lead to inundation in the houses and by-lanes. This is specifically a challenge for tenants who can't do any structural change to the houses neither they live in nor do they have the funds for the same so they are compelled to relocate. It was observed from community interactions that they are not aware of rehabilitation grants, loans, or schemes provided by the government that can support in rehabilitation, and retrofitting of buildings affected by disasters. Rainwater harvesting is a mandatory provision for buildings over 100 sq. m however community had limited to no knowledge of the condition and functionality of rainwater harvesting in the buildings.<sup>8</sup>

The community interactions suggested that there is a gap in communication with residents on the aspects of flood mitigation, precautions, etc as shown in Figure 39. Only 7 out of 25 respondents said that it should be a priority to mobilize the community through various groups to discuss local issues. Lack of knowledge on waste segregation, and emergency communication are some of the other aspects identified that need strengthening.

Based on the consultations, it is identified that most of the measures taken by GMC and other departments can be categorised as reactive at best except for a few interventions like the construction of drains and large silt chambers at places such as Mother Teresa Road, Bapuji Nagar, and ASEB Nagar Guwahati. The sluice gate and dewatering pumps are not viable solutions for situations when water starts overflowing as has been in the case of Lachit Nagar. These measures are not taken keeping in mind the climate change scenarios and future projected demands.

<sup>8</sup>Roof Top Rain Water Harvesting by Ministry of Water Resources: Press Information Bureau dated 12 Dec, 2013 <https://pib.gov.in/newsite/PrintRelease.aspx?relid=101516> Accessed in September 2024

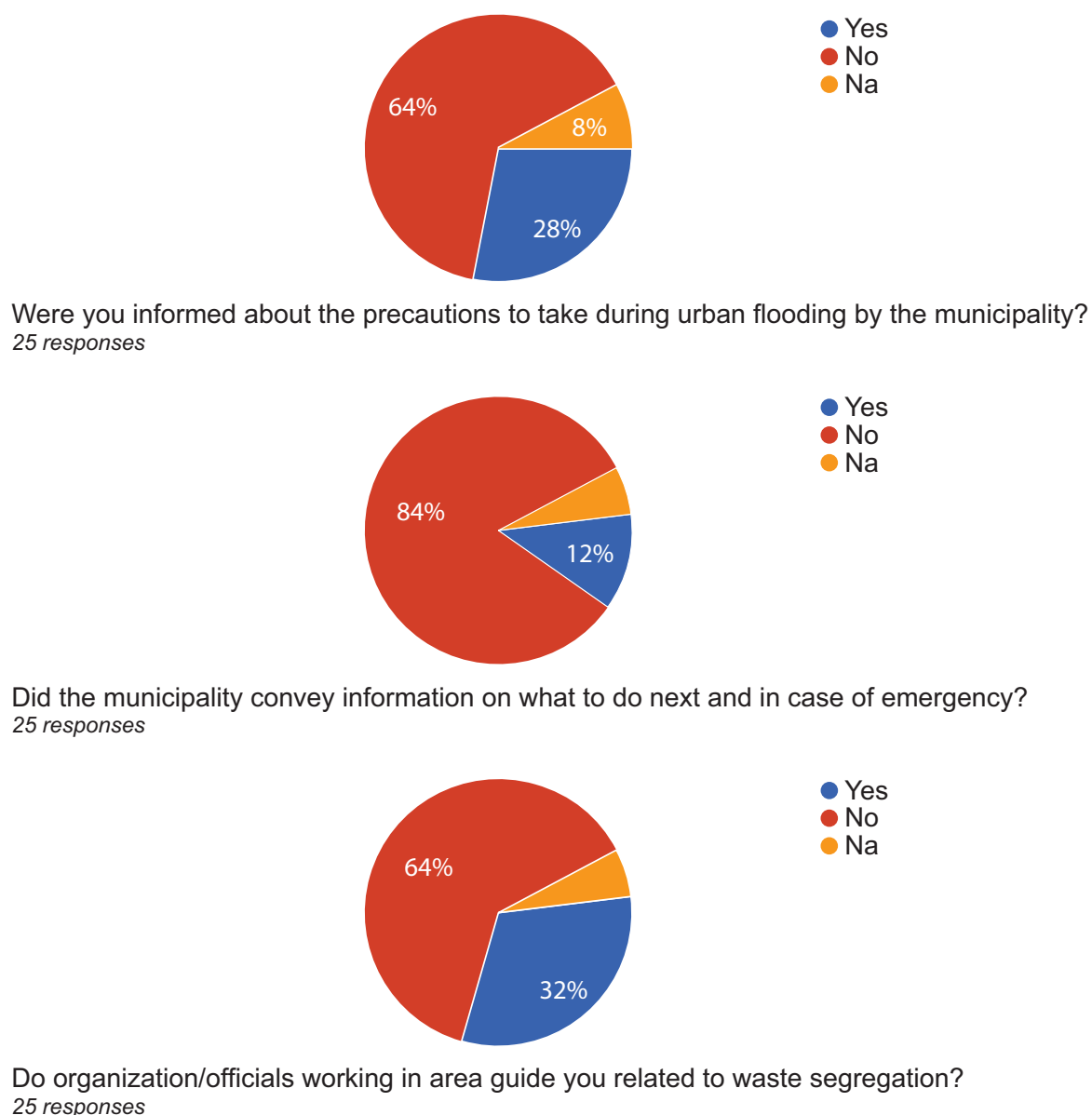


Figure 39. Some Prominent Findings from Household Data Collection

Source: Field data and consultation

#### 4.3.9.4 Natural

Guwahati has a varied landscape with hills, dense forests, and fertile plains. The intensity of urban flood in various parts of the city varies greatly as apart from localised rain and drainage system, water from Meghalaya and runoff from other hilly regions nearby also contribute to increased discharge. There are eight major hill series in Guwahati namely Nabagraha and Sunsali Hill series, Japorigog Hill, Sonaighuli and Jutikuchi Hill series, Narakashur Hill, Nilachal Hill, Fatasil Hill, Jalukbari Hill, Khanapara Hill

and Agyathuri Hills. The slopes of these hills are moderate and the lack of vegetation cover makes them very fragile. Very high discharge of water coming down from the hill overwhelms the drainage capacity in the wards with hillocks and undulating terrain and leads to overflow of water from stormwater drainage. The maximum degree of slope in the above mentioned hills is in the bracket of >30 degrees. Continuous incidents of urban flooding are reported almost every time it rains throughout the rainy season.

The river Morabharalu flows from northeast to southwest. Along with its own drainage area, the Morabharalu River also receives a diversion flow from the Bharalu River. Bahini River starts from the hills in Meghalaya to the South of Guwahati and flows northwards into Guwahati. Most of its catchment lies in the hills of Meghalaya. Many industries, schools, colleges, etc. have been built along the border of Meghalaya which threatens the environment of the city by cutting off hills leading to aggravation

of siltation, and air pollution. These expansions can lead to disasters like landslides and floods. It is identified that encroachment of wetlands that serve as natural reservoirs has reduced the retention capacity of the drainage system causing flood levels to rise in the city. The problem of soil erosion is also significant and is related to several environmental issues such as water logging, siltation and decrease in the groundwater table.

#### 4.3.9.5 Economic

Consultations with the officials of administrative divisions under GMC suggested that there is no external funding or private sector engagement in flood management in the division. It was highlighted that there are no specific subsidies for urban poor or low-income groups during floods. The municipal body does not have the availability of funds for women and women-led businesses affected by floods. In the households surveyed it was identified that 44% were salaried individuals, 24% were self-employed, 20% were students, 8% were receiving pensions and 4% were daily wage earners. 64% were living in their own house, 28% in rented accommodation, 4% with friends or relatives, and the other 4% in other kinds of accommodation. The low distribution of female workers, marginal and main working population indicates that Division

2 has very high vulnerability and Division 4 is medium vulnerable as shown in Figure 40.

The Assam (as per Budget 2024) has allocated funds for capacity building for disaster response related to training programmes on women and child care in emergencies, installation of sanitary vending machines and disposal machines, strengthening of women cadre in search & rescue operations, etc. In general, the majority of the population are salaried individuals followed by a small proportion of self-employed, pensioners, and daily wage earners (NSSO, 2012). Tea, silk, and handloom are the major industries in Guwahati. These industries are highly influenced by changing climatic conditions. Petroleum is another important industry in the Noonmati area of Guwahati.

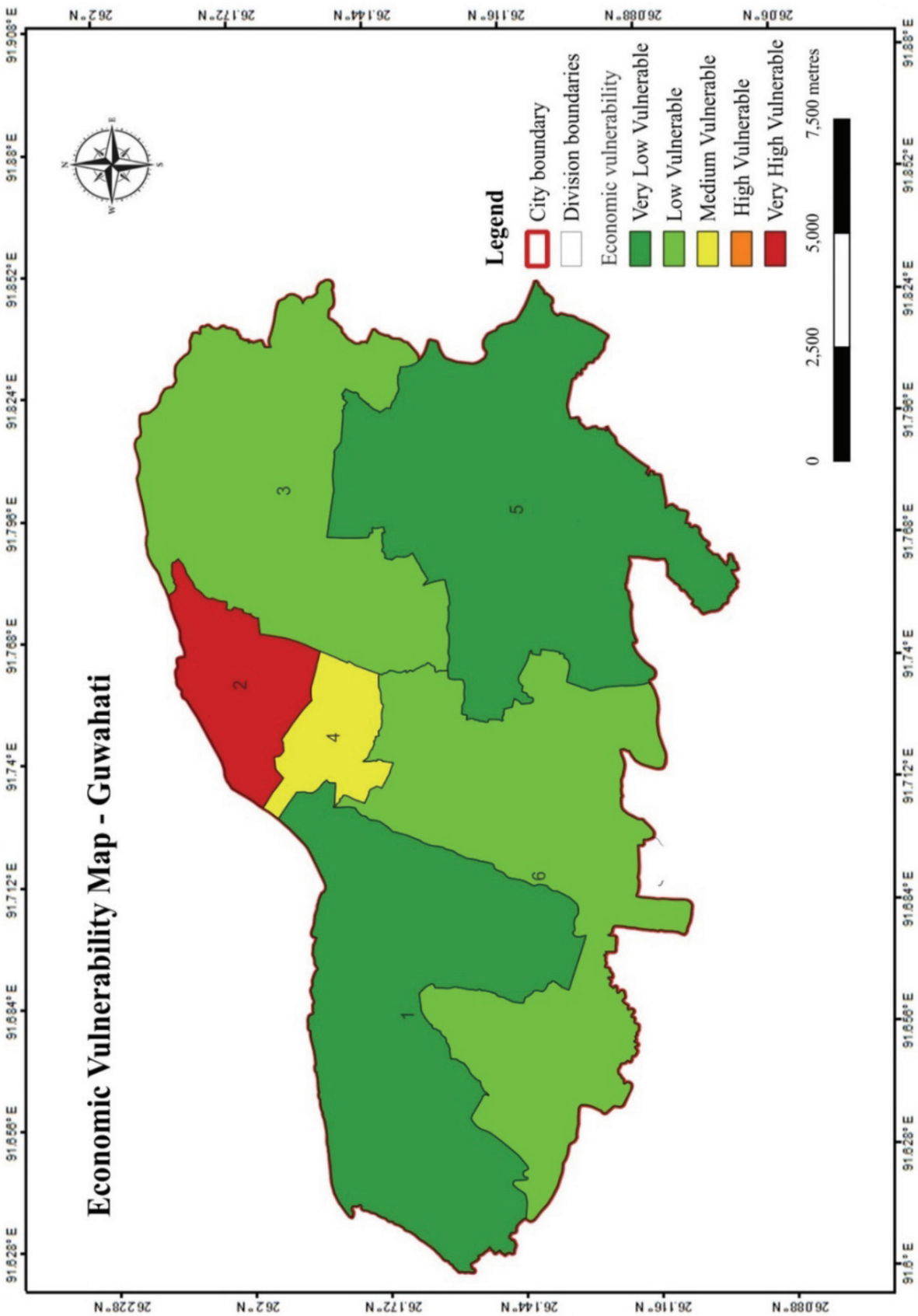


Figure 40. Economic Vulnerabilities in Guwahati

Source: Developed from field data, secondary reports, Draft Master Plan 2045 and consultation

#### 4.3.9.6 Emergent Risks in Guwahati

In Guwahati, due to high-population growth and development, it is challenging to prevent increased flood exposure due to spatial demands for economic development. The urban flood risk index was computed at the administrative division level for Guwahati Municipal Corporation. Based on scores, five categories were created i.e. very high, high, medium, low, and very low risk. Hazard map information includes the hydraulic analysis, flood hotspot, and probable inundation area information. It also considers the residential areas under the water surface elevation extents marked in blue as shown in Figure 41. This was considered in the calculation of vulnerability analysis shared in the previous subsection. Residential units in the vicinity area of Nallahs, are prone to urban flooding incidents and are at threat of being exposed to diseases such as malaria. Areas such as Anil Nagar, Lachit Nagar, and Sarumotoria have a large number of residential units exposed to urban floods and are expected to be impacted by future flooding incidents.

Consultations and ground truthing information suggested a correlation in the critical locations identified from the hydraulic analysis. The hazard and exposure information at the administrative division level under GMC is shown in Figure 42. It incorporates information on key areas that are very highly exposed to urban flooding, high population, slopes of more than 15 degrees, and low coverage of drainage networks. Division 4 is highly exposed due to high population density with the built-up area that affects the natural drainage channels. The detailed observations from the flood hotspots are shared in Annexure 4.

The computations revealed that Division 4, which comprises areas like Lachit Nagar, Panbazar and Anil Nagar was under very high risk, followed

by Division 2 and 6, which fell in the high-risk category with localities like Chandmari colony as shown in Figure 43. The risk is higher around the Bharalu basin in these divisions where most of the drains fall on the upstream side of the river. It is followed by Division 5 which despite having localities that get waterlogged falls in the moderate risk category due to significantly lower population density, higher literacy, coverage of stormwater drainage network and high economic conditions. Followed by Division 1 which is in low-risk and Division 3 in the very low-risk category. These regions are not overtly affected by urban floods and also would not be affected in future scenarios based on hydraulic analysis. The risk profiling presented here will help the Guwahati Municipal Corporation identify the relevant stakeholders and types of interventions needed for managing floods and prioritise the interventions. This would be useful to establish a robust framework for regular monitoring and strategizing development initiatives with consideration of the risks in the area.

**The overall flood risk assessment for Guwahati indicates the following key aspects needing attention from the urban local body and key stakeholders. :**

- Guwahati being an old city has many infrastructures in old and dilapidated conditions such as the drainage system, road network, old government buildings, etc. As many drains in the city have improper or narrow outlets unable to discharge large volumes of stormwater sufficiently the situation would aggravate in situations of climate change.



- Critical infrastructures like schools and hospitals are at risk of being impacted due to flooding incidents in the city. Due to the poor structural strength of many buildings, they are more prone to structural failures during disasters.
- Industrial sites and electric substations within the waterlogged areas can also lead to cascading incidents such as fire at industrial sites, landslides in hilly areas, etc. thus increasing the impact.
- Large amounts of the wastewater of the city are deposited into the wetlands and beels through two major municipal drains and different channels. This leads to severe water pollution, high health risk, and biodiversity impact.
- There has been a significant increase in waste generated in the last 5 years and projected information from GMDA and GMC reports, that timely interventions are needed to curb incidents of clogging of drains due to waste.
- There is a lack of a hilly region drainage network in the city which has resulted in topsoil erosion from hilly parts and led to slope failure. This issue is aggravated by the deforestation and illegal logging practices.
- There are many residential areas that are at risk of inundation. This can expose the residents to an increase in the number of challenges like loss of assets, vector and waterborne diseases, limited access, loss of work, etc.



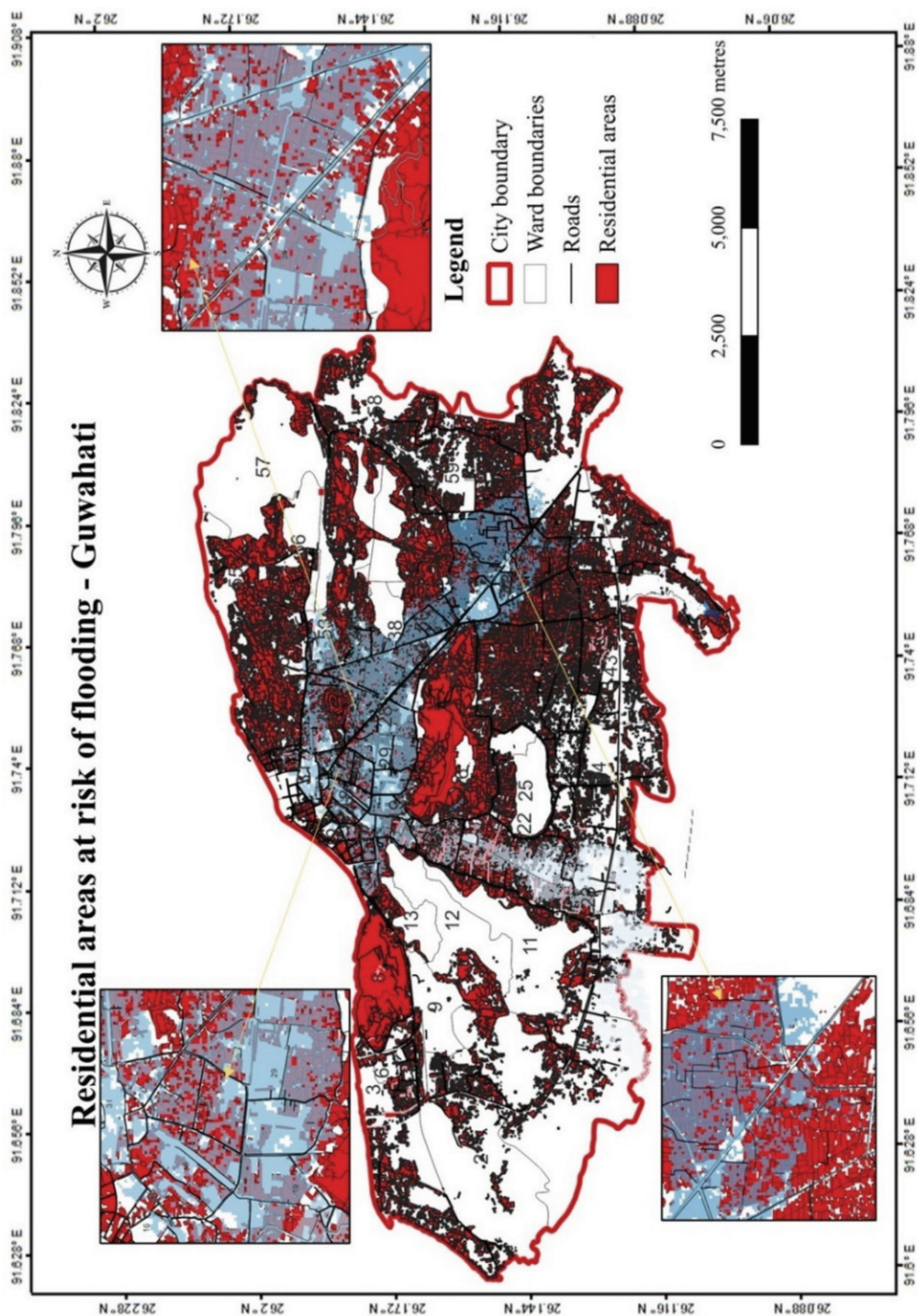


Figure 41. Residential Units Exposed to Flooding in Guwahati

Source: Developed from field data, GMDA dataset and consultation

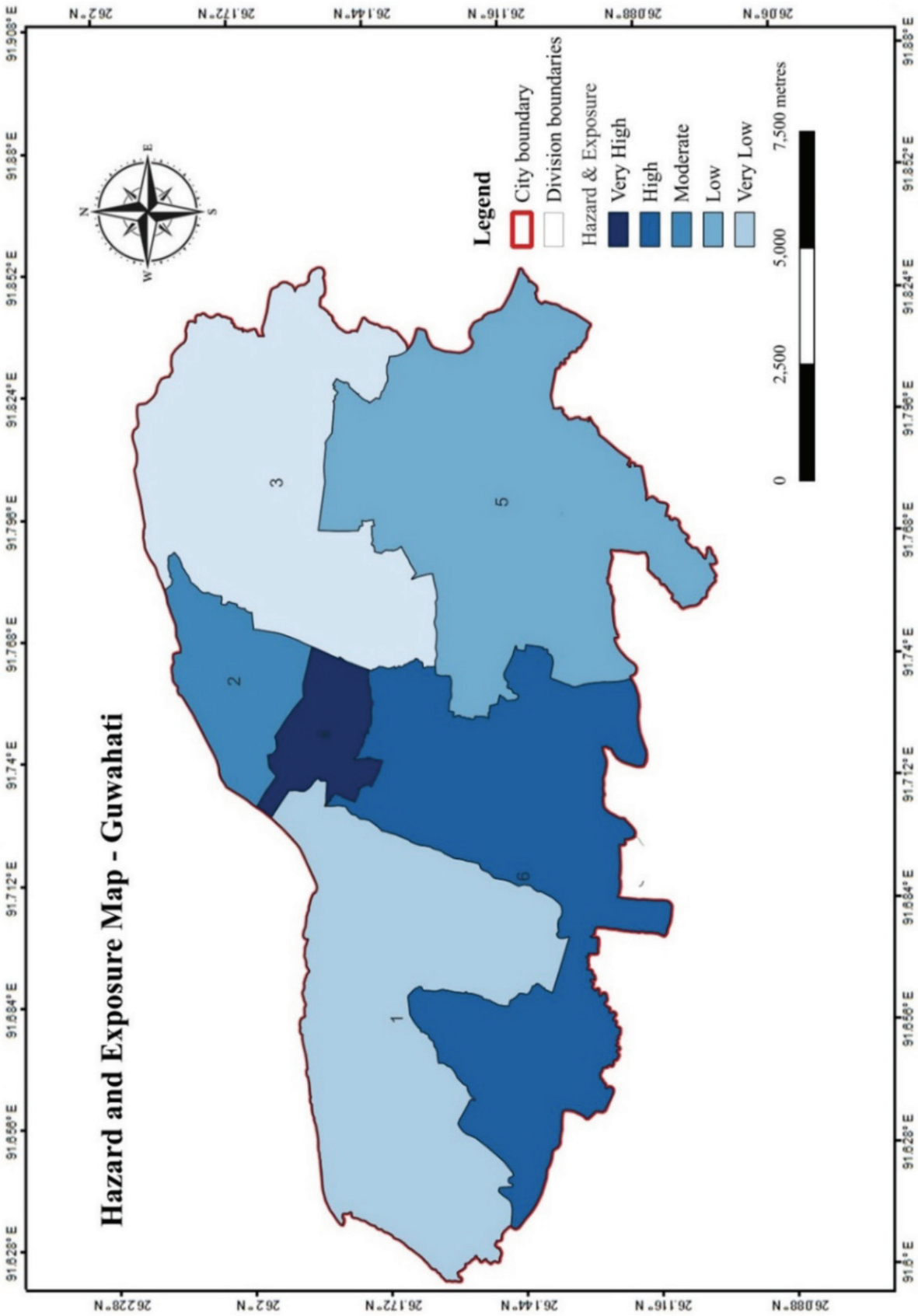


Figure 42. Hazard and Exposure Map of Guwahati  
Source: Developed from Municipal, GMDA datasets, field data and consultation

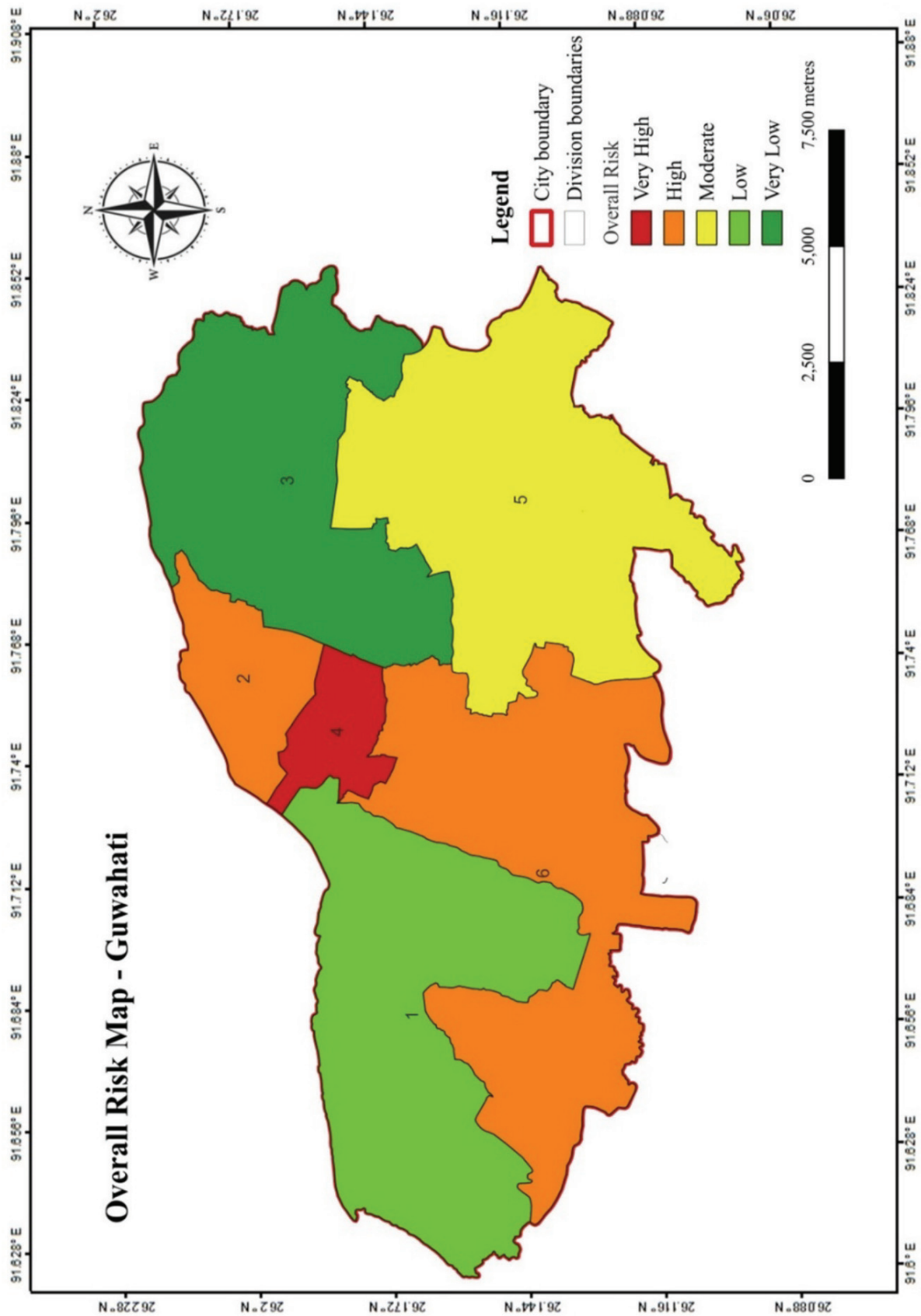


Figure 43. Risk Map of Guwahati

Source: Developed from Municipal, GMDA datasets, field data and consultation



## 4.4 Recommendations and Roadmap for Implementation

The roadmap for implementation of interventions in Guwahati follows the identification of issues or existing conditions as detailed in the previous section, the actions required in the form of recommendations, and potential organizations for action. The recommended actions for Guwahati include both structural and non-structural measures that could be implemented to effectively mitigate and adapt to flood risks. The recommendations are a combination of specific interventions for high-risk localities and city-level interventions. The following section gives detailed recommendations based on the

identified strengths, weaknesses and overall risks in the city. The recommendations were generated for short (0-2 years), medium (2-5 years), and long-term (5-10 years). These timeframes are considered to align with the timeframes of SDGs and the National Disaster Management Plan. As the city has specific challenges with waste management, siltation, sewage network, encroachment, capacity development and periodicity of flood risk reduction following key recommendations would enhance the resilience of the city:

**Table 15. Roadmap with Short, Medium and Long-term Recommendations for Flood Risk Management in Guwahati**

| Components                                                                   | Existing Conditions                                                                                                                                             | Recommendations                                                                                                                                                                                                                                                                  | Potential Organisation for Action                                                                                                                                                                             |
|------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Short-term Recommendations (0-2 years)</b>                                |                                                                                                                                                                 |                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                               |
| Early Warning                                                                | There is a high-risk status of specific wards and frequent urban flooding. There were 4 AWS and 18 new AWS stations were set up by GMDA in and around Guwahati. | There should be prioritization of installing AWS in high-risk divisions. As per the World Meteorological Organisation (WMO) norms, there should be at least one AWS for 10–20 sq km (IMD n.d). So, Guwahati should have 25 or more AWS considering the expanse of the city area. | Guwahati Municipal Corporation, District Disaster Management Authority, Kamrup (M)                                                                                                                            |
| Disaster Management Planning for Govt. Buildings and Critical Infrastructure | <ul style="list-style-type: none"> <li>Currently, safety audits for government infrastructure in high-risk areas are not conducted regularly.</li> </ul>        | <ul style="list-style-type: none"> <li>Issue departmental orders to conduct safety audits of all government offices, hospitals, and other infrastructures. This can be funded through the Resilience Budget for the implementation of the Assam DRR Roadmap 2030.</li> </ul>     | Guwahati Municipal Corporation (including Ward and Zone offices), Guwahati Metropolitan Development Authority, District Disaster Management Authority, Kamrup (M), Fire Department, all concerned departments |

| Components             | Existing Conditions                                                                                                                                                                                                                                                                          | Recommendations                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Potential Organisation for Action             |
|------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|
|                        | <ul style="list-style-type: none"> <li>Updated DM plans are not available for all departments.</li> <li>No proper ward/division-level disaster management committees are present</li> <li>Many critical infrastructures like more than 70 schools are at risk of being inundated.</li> </ul> | <ul style="list-style-type: none"> <li>Conduct a safety audit of all identified critical infrastructures especially schools and hospitals in Division 4 and 5.</li> <li>Ensure retrofitting and repairing activities are undertaken promptly and no new buildings are constructed in flood-prone areas in any wards.</li> <li>Constitution of Ward/Divisional Disaster Management Committees including women and follow up on critical infrastructure conditions through rapid visual screening.</li> <li>Develop Departmental Disaster Management Plans, SOPs and division-level DM plans.</li> <li>Ensure the availability of alternate and secure power supply sources of critical infrastructure.</li> <li>Ensure all government and private hospitals in Division 4 have an updated Disaster Management Plan.</li> </ul> |                                               |
| Solid Waste Management | <ul style="list-style-type: none"> <li>Low level of waste segregation at only 40% of total waste generated.</li> <li>GMC has outsourced waste collection to NGOs but robust monitoring mechanism is needed.</li> <li>The collection of waste from community bins is irregular.</li> </ul>    | <ul style="list-style-type: none"> <li>Identify volunteers and self-help groups, train them and assign door-to-door waste collection/awareness generation responsibility in pilot wards of Division 3 and 4.</li> <li>Regularization in waste collection and change in behavioural practices related to waste management in Division 1, 2, 4.</li> <li>Launch a door-to-door campaign to spread awareness about source segregation, health risks, etc. This step is very important as it establishes a continuing contact with the participants providing feedback and building a bond between the government and the beneficiaries.</li> </ul>                                                                                                                                                                               | Public Health and Sanitation department, NGOs |

| Components              | Existing Conditions                                                                                                                                                                                                                                                                                                                                                                  | Recommendations                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Potential Organisation for Action                                                                                                                                      |
|-------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                         |                                                                                                                                                                                                                                                                                                                                                                                      | <ul style="list-style-type: none"> <li>Provision for placing covered community waste bins at proper distances for people to deposit domestic waste.</li> <li>Ensure detailed supervision of the collection network to cover all community bin locations.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                        |
| Wastewater Management   | <ul style="list-style-type: none"> <li>Only 22% of households (all in the railway colony, IOC colony) have piped sewer but a proper sewage network is not present throughout the city.</li> <li>Contamination of water body due to sewer. BOD value has failed to meet the standard criteria at Deepor Beel.</li> <li>No sewage treatment plants are present in Guwahati.</li> </ul> | <ul style="list-style-type: none"> <li>Conduct regular checks in different zones to ensure households in the city have a septic tank installed are being managed and are fully functioning.</li> <li>Prepare a plan to implement proper public wastewater collection and safe disposal systems to ensure the safety of natural water bodies under the Atal Mission for Rejuvenation and Urban Transformation (AMRUT)</li> <li>Examine probable flashpoints where sewage, flood water, and treated water can get mixed, especially in areas like Rukmingaon.</li> <li>Explore methods to remodel the existing water supply in consultation with experts to prevent contamination.</li> <li>Generate awareness and regularise drives for weed cleaning and engage local communities in bioremediation measures. Further NbS options shared in Subsection 9.3 can be explored.</li> </ul> | Municipal Corporation – Engineering, Water Supply, Public Health and Sanitation Department                                                                             |
| Urban Planning Measures | <ul style="list-style-type: none"> <li>Severe issues of encroachment at Silsako Beel, Bondajan wetland violating building byelaws.</li> </ul>                                                                                                                                                                                                                                        | <ul style="list-style-type: none"> <li>Identification of suitable sites and preparation for expanding basic services for the rehabilitation of the displaced population to avoid encroachment in areas like Silsako Beel and Bondajan channel in the future.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Guwahati Municipal Corporation, Guwahati Metropolitan Development Authority, Forest Department, Culture Department, NESAC, Science and Technology Department, Academia |



| Components                                       | Existing Conditions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Recommendations                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Potential Organisation for Action                                                                   |
|--------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|
|                                                  | <ul style="list-style-type: none"> <li>GMC and GMDA undertake drives to remove encroachments on footpaths, hills, and illegal bridges on drains and near water bodies.</li> <li>However, rehabilitated populations do not have adequate services like in Fatasil, Morasoli and Amingaon.</li> <li>Over 8000 houses are estimated to be in dilapidated condition (GMDA, 2024)</li> <li>Unplanned developmental activities around heritage sites are serious threats</li> <li>Field evidence suggests a lack of efficient enforcement of building codes</li> </ul> | <ul style="list-style-type: none"> <li>Incorporate measures to check the depletion of wetlands like identification and development of areas to form a nature reserve.</li> <li>Incorporate the planning around heritage sites especially preparing a master plan for the heritage sites in Guwahati. Such important sites require separate spaces and measures to protect their surroundings.</li> <li>Introduce LIDAR/UAV technology-based monitoring of conditions of dilapidated buildings.</li> <li>Enforcement of National Building Code/Indian Standard Code of Practice (BIS) and Assam Notified Urban Areas (Other than Guwahati) Building Rules, 2014</li> </ul> |                                                                                                     |
| Operation and Maintenance of Stormwater Drainage | <ul style="list-style-type: none"> <li>Drains are being cleaned and desilted seasonally and at least twice which is not enough due to high siltation in many pockets.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                 | <ul style="list-style-type: none"> <li>A detailed schedule to ensure periodicity of cleaning drains based on the local conditions is required.</li> <li>Engage the urban poor in maintenance and repair works through missions like the National Urban Livelihood Mission in Division 2 which has a high economic vulnerability.</li> </ul>                                                                                                                                                                                                                                                                                                                               | Guwahati Municipal Corporation – Engineering, Public Health and Sanitation, Public Works Department |

| Components                | Existing Conditions                                                                                                                                                                                                                                                                                                 | Recommendations                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Potential Organisation for Action                |
|---------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------|
|                           | <ul style="list-style-type: none"> <li>▪ Clogging of drains due to waste and blockages caused by culverts requires attention.</li> <li>▪ Some flood hotspots have damaged drainage networks which need regular monitoring.</li> <li>▪ During and post-monsoon cleaning is irregular and done as required</li> </ul> | <ul style="list-style-type: none"> <li>▪ Identification and listing of clogged drains, and blockages on drains resulting in urban floods.</li> <li>▪ Install silt traps at locations where heavy siltation is happening to prevent it from overwhelming the drains.</li> <li>▪ Prompt disposal of waste from major drainage channels and improving water quality by bioremediation.</li> <li>▪ Develop and implement an online reporting system (MIS) for documenting damage and loss of the drainage network.</li> <li>▪ Regular aerosol spraying and channelization of stagnant water bodies in the city to prevent malaria spread.</li> <li>▪ Sensitizing and engaging the community for detection of Anopheles breeding places and their elimination.</li> <li>▪ Follow the CPHEEO (Manual on Storm Water Drainage Systems 2019b) in cleaning shallow surface drains.</li> <li>▪ Deepening of the natural water reservoir and drainage channels.</li> </ul> |                                                  |
| Volunteer Group Formation | To ensure mainstreaming participation of volunteer groups, women SHGs in the overall flood management could be done.                                                                                                                                                                                                | <ul style="list-style-type: none"> <li>▪ GMC can encourage residents to constitute and be a part of volunteer groups on floods. The inclusion of women, ex-servicemen, and retired police could be beneficial.</li> <li>▪ Mobilize SHGs, accredited social health activists (ASHA), and auxiliary nurse midwives (ANMs) and resident welfare associations (RWAs) to head the flood risk awareness and monitoring in localities as they hold influence over residents and can support grassroots-level outreach.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                      | Public Health Department, Community Groups, NGOs |

| Components                                | Existing Conditions                                                                                                         | Recommendations                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Potential Organisation for Action                                                                                                                |
|-------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| Regular Mock Drills and Capacity Building | Frequency varies across different wards with some respondents mentioning no mock drills were ever conducted in their areas. | <ul style="list-style-type: none"> <li>Periodic training in high and very high-risk zones should be prioritized</li> <li>Initiate school disaster management plan preparation and awareness programme engaging teachers and students.</li> <li>Adopt gender-sensitive and equitable approaches in capacity development through SHG groups covering all aspects of DRM using funds allocated as per the annual Gender Budget</li> <li>Emergency mock drills involving ULB staff, community-based organisations and volunteer groups should be conducted.</li> <li>Conduct training of the officials on flood risk assessment, hydrological data analysis, integrating DRR and climate change adaptation for resilient urban cities.</li> </ul>                                                            | Guwahati Municipal Corporation, Guwahati Metropolitan Development Authority, Fire department, District Disaster Management Authority, Kamrup (M) |
| Medium-term Recommendations (2-5 years)   |                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                  |
| Flood Early Warning                       | Currently, alerts are disseminated through messages based on FLEWS Hydro-Meteorological Analysis                            | <ul style="list-style-type: none"> <li>Establish a mechanism to disseminate alerts and warning of flood early warning systems to communities through volunteer groups and zonal DM committees. In addition, on-ground information on localized flooding can be acquired from the community through this channel.</li> <li>Make the Integrated Command and Control Centre the main centre for data monitoring with provisions of social media, SMS alerts and community radio forecasting.</li> <li>Cost-effective early warning systems installation like water batteries as shared in Subsection 2.3 on the nullahs that are in close proximity to residential areas and flood hotspots. This would be particularly helpful in areas around the Brahmaputra banks and periphery of the city.</li> </ul> | Guwahati Municipal Corporation, FREEMA, District Disaster Management Authority, Kamrup (M)                                                       |

| Components             | Existing Conditions                                                                                                                                                                                                                                                                                                                                                                           | Recommendations                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Potential Organisation for Action                                                                         |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| Solid waste Management | <ul style="list-style-type: none"> <li>The current practice of landfills at multiple sites with the primary site Boragaon pose a threat to contamination of soil and water. Expansion of city limits will expose more residents near the site to poisonous gases.</li> <li>Waste generated at present in the GMC area is 641 TPD which is expected to increase to 889 TPD by 2031.</li> </ul> | <ul style="list-style-type: none"> <li>Set up decentralized compost plants near market areas, like Paltan Bazar, Uzan Bazar. Assign responsibility to women's Self-help Groups for operations of these.</li> <li>Set up material recovery facilities with sufficient spaces for sorting recyclable materials in each ward or cluster.</li> <li>Induct SHGs, waste pickers, and recyclers for easy segregation of recyclable waste and management of material recovery facilities.</li> <li>Exercise a stringent ban on single-use plastics.</li> </ul>                                                                                                                                                                                                       | Guwahati Municipal Corporation – Engineering, Public Health and Sanitation, Public Works Department, NGOs |
| Wastewater Management  | <ul style="list-style-type: none"> <li>Wastewater treatment plants would be required considering an increase in water demand from 232.90 to 318.81 MLD in 2031 (as per draft Master Plan 2045)</li> <li>A sewerage network and facilities are proposed for South and East Guwahati by JICA.</li> </ul>                                                                                        | <ul style="list-style-type: none"> <li>GIS mapping of all sewerage networks being laid sewerage, including information on topographical features, and gradient information so limited pumping points are needed.</li> <li>Alignment considerations as to reduce the number of crossings with railway tracks and National Highways. Develop a database categorizing them as per their vulnerability (safe and unsafe).</li> <li>Information on the sewerage network is to be shared through various forms of media to ensure last-mile connectivity.</li> <li>Install small cost-effective and sustainable alternatives to wastewater treatment plants like DEWATS for disposing of wastewater from small communities, individual properties, etc.</li> </ul> | Guwahati Municipal Corporation – Engineering, Public Works, Sanitation department, Academia               |

| Components              | Existing Conditions                                                                                                                                                                                                                                                                                                                                                 | Recommendations                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Potential Organisation for Action                                                                     |
|-------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| Stormwater Drainage     | <ul style="list-style-type: none"> <li>▪ Unhygienic conditions due to open channels at over 46% of the total drains with the majority leading to foul odour and spread of diseases.</li> <li>▪ The issue of gradient leads to waterlogging at locations like Binoy Kumar Tamuli Path, Pub Sarania Main Road, Saikia Road Wireless, Gandhibasti area etc.</li> </ul> | <ul style="list-style-type: none"> <li>▪ Provision of new stormwater drainage network with consideration to key parameters of precipitation intensity, catchment delineation, percolation characteristics, surface runoff, elevation, etc. at areas like Sarumotoria, Saikia Road wireless.</li> <li>▪ Develop a Stormwater Management Strategy to increase retention capacities in line with the Sponge City Master Plan as taken up by GMDA in 2022</li> <li>▪ A detailed study to understand the gradient of the drain shall be taken up at these locations.</li> <li>▪ Use technology (IOT) to monitor the level of channels flowing through the city. This can be initiated under Smart Cities Mission, Guwahati.</li> <li>▪ Enhance sewer and drainage systems to handle higher water volumes, and develop flood barriers.</li> </ul> | Guwahati Municipal Corporation – Engineering, Public Works, Sanitation department, Academia           |
| High-resolution Mapping | <ul style="list-style-type: none"> <li>▪ Drone-based mapping of infrastructure and services is at a nascent stage in the city.</li> <li>▪ High resolution gradient maps are needed.</li> <li>▪ Currently, the drainage network maps are being updated by the GMC.</li> </ul>                                                                                        | <ul style="list-style-type: none"> <li>▪ A thorough topographical analysis needs to be done for the entire city drainage network planning. Sharing the GIS/GPS database to be integrated with all department works.</li> <li>▪ Prepare high-resolution (LIDAR/ UAV) based local area plans, drainage master plans integrating spatial and economic strategy.</li> <li>▪ Designing of stormwater drainage system considering the run-off coefficient, land use change from GIS and remote sensing information</li> <li>▪ Improve and expand drainage infrastructure to handle heavy rainfall and prevent waterlogging.</li> </ul>                                                                                                                                                                                                            | Guwahati Municipal Corporation – Engineering, GIS, NESAC, Science and Technology Department, Academia |



| Components                                       | Existing Conditions                                                                                                                                                                                                                                                                                                                                                                                                                                   | Recommendations                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Potential Organisation for Action                                                                                                 |
|--------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
| Planning for comprehensive Flood Risk Management | <ul style="list-style-type: none"> <li>Detailed scientific evaluation of the drainage system with consideration to climatic changes, projected population change, and demands needs to be considered. At present, Guwahati Metropolitan Area Storm Water Drainage Scheme has been implemented at with remedial action at some severe flooding locations.</li> <li>Mission Flood Free activities should incorporate detailed risk analysis.</li> </ul> | <ul style="list-style-type: none"> <li>Develop and implement projects to develop environment-sensitive urban systems.</li> <li>Address issues of informal housing in high-risk areas through urban poverty reduction and slum-upgrading projects.</li> <li>Mobilize ward officers and create ward-level committees along with volunteers to prepare ward-level flood risk reduction plans and develop green space/corridors in Guwahati.</li> <li>Constitution of expert committee including hydrologists, environmentalists, planners, and NGOs for developing of comprehensive flood risk management strategy.</li> <li>Establish inter-agency coordination centers and regular meetings.</li> </ul> | Guwahati Municipal Corporation (including Ward and Zone offices), Engineering, Environment, Housing Water Supply Department, NGOs |
| Long-term Recommendations (5-10 years)           |                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                   |
| Ecosystem Restoration                            | The Master Plan of Guwahati demarcates the eco-sensitive zones where development should be restricted. However, there is a need to completely prohibit further construction on the hill areas and hillocks that are being encroached upon.                                                                                                                                                                                                            | <ul style="list-style-type: none"> <li>Ensure multi-stakeholder committees including District Administration, Forestry department, and urban local body recommend solutions to the illegal encroachment of eco-sensitive zones like near water bodies and hill areas.</li> <li>Take up plantation, riparian buffer creation and bio-remedial measures to mitigate the impact of erosion and climate change in the Basishta River catchment and Deepor Beel areas.</li> <li>Formulate a plan for restoring damaged trees, agroforestry, and compensatory afforestation in landslide-prone areas of Division 3, especially wards 55, 56, 57</li> </ul>                                                   | Guwahati Municipal Corporation, District Administration, Forest Department, Soil Conservation Department                          |

| Components                     | Existing Conditions                                                                                                                                                                                                                                                                                                       | Recommendations                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Potential Organisation for Action                                                 |
|--------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
|                                |                                                                                                                                                                                                                                                                                                                           | <ul style="list-style-type: none"> <li>Spatial planning measures to be undertaken for nature conservation, recreation, and infrastructure as shared in Subsection 2.3. This should be considered on priority for Division 1, 2, 3 along waterbodies.</li> <li>A strategy for promoting construction incorporating blue-green features, particularly in high-risk areas could be developed.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                   |
| Dedicated Budgetary Allocation | <ul style="list-style-type: none"> <li>At the ward level, the allocation of the budget to flood management activities is not segregated.</li> <li>Gender Budget 2024-25 includes aspects of training for disaster risk management. However, aspects of livelihood continuity post-disaster are not considered.</li> </ul> | <ul style="list-style-type: none"> <li>Allocate at least 3-5% budget at the ward level for disaster risk management activities. This is in line with the 3% non-salary unique budget allocation mandated for line departments as the Resilience Budget for implementation of the Assam DRR Roadmap 2030.</li> <li>Study detailed flood impacts on vulnerable populations to devise a realistic relief package.</li> <li>Utilize the State Disaster Mitigation Fund (SDMF) for further capacity building.</li> <li>Involve communities in budgeting processes to ensure funds are allocated to the most needed flood resilience projects.</li> <li>Provide targeted subsidies for low-income groups and women-led businesses in order to build resilience against floods. This can help in further collaborations for flood risk management. Can be initiated through state and national government livelihood missions.</li> </ul> | Guwahati Municipal Corporation, Finance Department                                |
| Wastewater Management          | Sewage treatment plants or proper sewage network needed.                                                                                                                                                                                                                                                                  | <ul style="list-style-type: none"> <li>Set up decentralized sewage treatment plants and ensure restoration of water bodies in and around towns/cities.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Guwahati Municipal Corporation – Engineering, Public Works, Sanitation department |

| Components                              | Existing Conditions                                                                                                                                                                                                                                                         | Recommendations                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Potential Organisation for Action                                                                                 |
|-----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|
|                                         |                                                                                                                                                                                                                                                                             | <ul style="list-style-type: none"> <li>Establish solutions for on-site treatment of greywater effluent and reuse for gardening etc. under the Jal Jeevan Mission (Urban) context.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                   |
| Periodic update of Land use Information | <p>The interval between Master Plan preparation is more than 20 years with Draft Master Plan 2045 currently being prepared after the Master Plan 2021. In earlier plans zoning land for residential has not adequately considered the space needed for civic amenities.</p> | <ul style="list-style-type: none"> <li>Ensure appropriate land use planning using detailed zonation is undertaken guided by micro-zonation studies.</li> <li>With current rapid growth, it is necessary for intermediate updation and review of land use information every 3- 5 years.</li> <li>Local Area Plans should integrate land use information and update</li> <li>Formalise intermediate interventions for periodic EIA and SIA of all development projects.</li> <li>The master plan should be complemented by various sectoral plans for the environment, climate change, housing, etc, under an overall planning framework.</li> <li>Ensure all new constructions strictly comply with building codes, standards, and the latest techno-legal regime.</li> </ul> | Guwahati Municipal Corporation, Guwahati Metropolitan Development Authority, Town and Country Planning Department |

## 5 Conclusions and Way Forward

The increase in urbanization in Indian cities has fundamentally altered the risks faced by them. Urban flooding risks are increased due to more impermeable surfaces, fewer green areas, and insufficient drainage systems. At the same time, poor solid waste management makes these issues even more difficult. Uncollected waste, frequently choked drainage systems, increasing the danger of flooding during periods of heavy precipitation since storm water has nowhere to go. The detailed analysis of the primary and secondary data suggests that there is a vast scope for interventions with respect to the consideration of climate change and the need for planning and development. The analysis suggests an increase in water surface extents from a 10-year to 100-year scenario and in the future there will be a severe impact on critical infrastructures due to floods. This can also lead to cascading incidents such as a fire at industrial sites, landslides in hilly areas, etc. The absence of a detailed stormwater drainage plan with information on gradients and projected increases in stormwater flow can aggravate the impact of future floods. Based on the findings from the risk assessment and consultations there is a need for critical interventions in the flood resilience planning of the urban system of Guwahati.

Institutional conditions indicate Guwahati has significant lack of community participation in risk management activities, especially engagement of women networks, SHGs in flood risk management, training, etc. is negligible. Support from NGOs/CBOs/volunteer groups or religious organisations and private sector engagement for floods is mostly limited to relief activities. The lack of updated disaster management plans for infrastructures like schools, hospitals,

and electric substations indicates the need for mainstreaming of disaster risk management. Irregularities in solid waste collection and segregation as reported by the residents highlight the need for decentralized waste management systems. The rise in temperatures globally indicates that there could be a water shortage in the future which will need measures of rainwater harvesting, which is presently not followed in Guwahati. Allocation of dedicated resources, manpower, and budget for risk reduction is necessary, which is not emphasised at present. In addition, despite being frequently facing issues of flooding, nature-based solutions have not been explored to their full potential in Guwahati. These challenges may not be unique to Guwahati as many Indian cities are now at risk of flash floods that overwhelm existing infrastructure because of multiple hazards as well as unpredictable extreme weather conditions brought on by climate change.

Guwahati will face unsustainable pressures from the growing issues of urbanisation, if proper action is not done, increasing the danger of flooding and other environmental problems. To protect future urban living conditions, states must proactively establish mitigation and adaptation policies, risk-sensitive planning, and mechanisms that address urban floods. Some of the actions to guide the ambition of becoming disaster resilient in changing climatic conditions are preventing new risks, reducing existing ones, and managing residual risks. Potential national, state and local-level actions that can enhance the resilience of cities in India have been discussed in the following subsections.

## 5.1 Policy-level Interventions

Based on the systemic review of existing techno-legal frameworks as listed in Chapter 2 the following are the priority opportunities that need interventions from the perspective of policies and plans.:

- Even while disaster management plans are in place on paper, putting them into practice is still difficult. The majority of the plans approach disaster management from a relief-centric perspective rather than taking a proactive prevention, mitigation, and preparedness approach, despite the government's insistence on a paradigm change to a preparedness approach.
- A prominent aspect of preparedness measures for various flood typologies needs to be highlighted in disaster management plans. Area-specific challenges need to be addressed using localized solutions for which thorough flood risk assessments should be conducted.
- Cascading and compound risks are generally not considered a part of disaster management plans. The risks related to climate change have to be considered in a more holistic way along with the need for mainstreaming those with the current development planning policies.
- The plans at national, state, district, and city levels do not include aspects of regularizing or defining periodicity for the operation and maintenance of services such as drainage, water supply, and solid waste management which is integral to urban flood management.
- With respect to infrastructure, there is a need to strengthen resilient building practices for rapidly growing urban settlements which need to be made disaster-resilient.
- Inclusivity with respect to gender is limited to only capacity building in most of the disaster

management plans whereas it should be integral in all stages of DRR.

- Activities aimed at reducing risk are less visible in all of the plans. The accountability systems needed to guarantee that departments take DRM considerations into account when they aim to mainstream their initiatives which are not institutionalised in the existing frameworks. As a result, rather than being guided by the long-term strategies in State Disaster Management Plans, risk-reduction initiatives are led by external programmes and schemes.
- A prominent scope of collaborative strategy that recognises the roles of academia, corporations, government, civil society, and communities and encourages all parties to work together to achieve disaster resilience is lacking in bringing together the many stakeholders.

Thus, despite the existence of policies and guidelines, several anticipated outcomes, such as the incorporation of disaster risk reduction into development planning, remain unfulfilled. Therefore, in order to accomplish the integration of the identified aspects, it is essential to design policies and procedures within the pertinent context.

## 5.2 Institutional Mechanism

As is evident from the previous sections, mainstreaming of disaster risk management needs to be strengthened in policies at local as well as national, and state levels along with well-defined roles and responsibilities for the relevant stakeholders. Currently, methods to ascertain a suitable periodicity for maintenance of stormwater drainage, stringent implementation of building codes and standards, regular collection of waste from all areas and adequate and recurring workshops on awareness of

segregation of waste is yet to be undertaken. These factors can magnify urban flooding in the future due to siltation, deteriorated condition of RCC drains, and risk of contamination of water bodies would not be useful. The study highlights some key activities that should be undertaken by

the stakeholders to ensure the resilience of cities. Table 16 shares the roles and responsibilities of various government stakeholders which might be adapted in existing and new urban local bodies to streamline the flood risk management and overall resilience of cities.

**Table 16. Responsibility Matrix**

| Key Actions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Coordinating Departments                                                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>Implementation of strengthening and retrofitting activities for critical infrastructures as per the recommendation of safety audits.</li> <li>Restrict building permissions to the site within the limits of the highest watermark.</li> <li>Ensure flood-resistant rainwater harvesting features in the planning and construction of new residential, commercial, or industrial projects.</li> <li>Construction of shelters at safe zones.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                         | Municipal Corporation/<br>Municipality<br>– Engineering Department       |
| <ul style="list-style-type: none"> <li>Repair and monitor maintenance of damaged drain and drainage networks in the flood-affected wards/zones.</li> <li>Ensure periodicity in de-silting activities and make emergency desilting and drain cleaning action plan for critical drains.</li> <li>Prepare zone-wise detailed network maps, and flood action plan and submit them to the municipal office and disaster management authority.</li> <li>Install high-capacity pumps in all low-lying areas and regularly pump out submerged areas.</li> </ul>                                                                                                                                                                                                                                                                                                               | Municipal Corporation/<br>Municipality<br>— Stormwater Department        |
| <ul style="list-style-type: none"> <li>Ensure regular and proper desilting/dredging, cleaning and other suitable measures in water bodies of the wards.</li> <li>Ensure compliance is maintained when new infrastructure is built.</li> <li>Undertake studies on flood line mapping, vulnerability analysis, and risk mapping.</li> <li>Demarcation of low-lying, vulnerable settlements, and waterlogging areas in the ward.</li> <li>Discourage reclamation of low-lying land.</li> <li>Ensure proper functioning of communication networks.</li> <li>Ensure solid waste removal from open drains and regular de-silting procedures are undertaken.</li> <li>Ensure the flood-proofing of critical infrastructure, bridges, etc., within the ward.</li> <li>Provide emergency kits, and amenities to people residing in flood banks after early warning.</li> </ul> | Municipal Corporation/<br>Municipality –<br>Ward Office/<br>Zonal Office |



|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                  |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>▪ Strengthening up an emergency operation centre (EOC) to continuously monitor the flood situation, sending alerts to citizens.</li> <li>▪ Coordination with NDRF, SDRF and civil defense for check of the necessary equipment in each ward.</li> <li>▪ Strengthening and upgrading the current flood forecast and early warning system using devices based on IoT.</li> </ul>                                                                                                                                                            | Disaster Management Cell, District Disaster Management Authority |
| <ul style="list-style-type: none"> <li>▪ Coordinate with local task forces/volunteer groups to generate awareness for urban floods.</li> <li>▪ Design relief packages for vulnerable populations based on damage assessment and departmental action reports.</li> <li>▪ Organize capacity building, mock drills for flood, ensuring rescue material at the local level—awareness program.</li> </ul>                                                                                                                                                                             |                                                                  |
| <ul style="list-style-type: none"> <li>▪ Conduct training to doctors, psychologists, health educators, and ASHA workers on pre and post-disaster mental health care.</li> <li>▪ Issue health cards to vulnerable groups like women, elderly and disabled persons.</li> <li>▪ Coordinate with EOC for vector control and fogging.</li> <li>▪ Assign mobile hospital units in flood zones for safe delivery.</li> <li>▪ Provide alerts to private and public sector hospitals for support.</li> <li>▪ Undertake measures to disinfect zones that have got contaminated.</li> </ul> | Public Health Department, NGOs                                   |
| <ul style="list-style-type: none"> <li>▪ Undertake regular checks to confirm infrastructure remains in operational condition during flooding.</li> <li>▪ Demarcate proper evacuation routes to ensure accessibility of safe shelters.</li> <li>▪ Prepare emergency structures (levees etc.) to control flood risk.</li> <li>▪ Regularly monitor dilapidated structures and update it with municipal body.</li> </ul>                                                                                                                                                             | Public Works Department                                          |
| <ul style="list-style-type: none"> <li>▪ Install water supply outlets above flood level at identified hotspots.</li> <li>▪ Ensure adequate sources of alternate water supply, water tankers etc.</li> <li>▪ Map groundwater resources to identify areas resistant to disaster impacts.</li> <li>▪ Restoration of all water supply infrastructure after floods to a functional condition.</li> <li>▪ Identify specific points of contamination of drinking water and ensure measures to prevent it in the future.</li> </ul>                                                      | Water Supply Department                                          |
| <ul style="list-style-type: none"> <li>▪ Identification of extreme fire-prone areas, and industrial sites and ensure maintenance of equipment and vehicles nearby.</li> <li>▪ Evacuate stranded persons from the affected area.</li> <li>▪ Coordination with other agencies for rescue and relief.</li> </ul>                                                                                                                                                                                                                                                                    | Fire Department                                                  |

## 5.3 Implementation of Nature-Based Solutions

The International Union for Conservation of Nature (IUCN) defines NbS as “actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits.” These solutions can range from low human intervention, which involves less disruption to ecosystems, to high human intervention, which involves more intrusive

management of ecosystems, or even the creation of new ecosystems. NbS not only addresses immediate water management needs but also contributes to broader environmental and social benefits as evident from Figure 44. It shows that diverse NbS can be used in diverse landscapes to adapt to the threats of climate change. Consequently, it is critical to think about the main weaknesses and use NbS to its fullest capacity in order to strengthen community resilience.

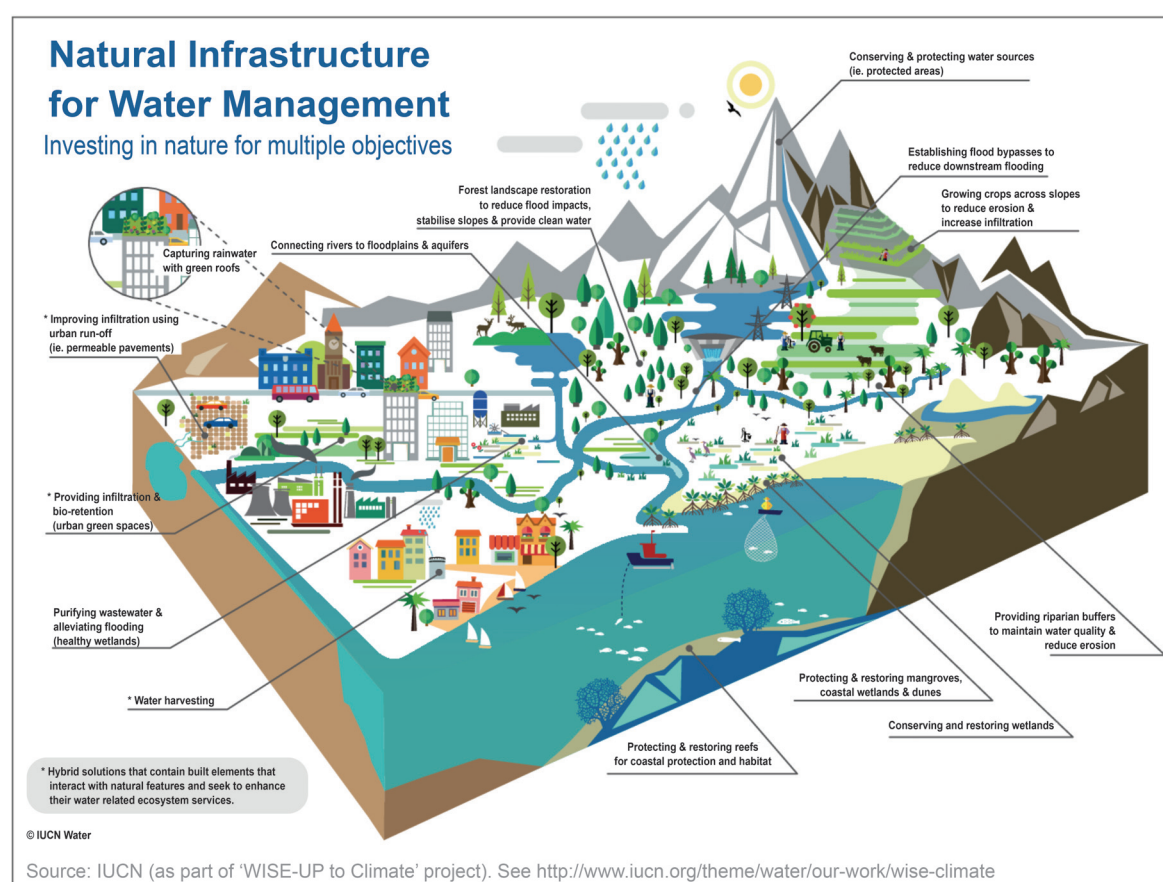


Figure 44. Nature-based Solutions for Water Management

Source: IUCN

Despite having implemented nature-based solutions for soil conservation (ecological management practices in Guwahati), these interventions are piecemeal in nature and have not been adopted throughout the city. Interventions such as practices like agroforestry to improve water infiltration and retention, riparian buffers, and urban green spaces have been highlighted as recommendations in

Subsections 5.4. Nature-based Solutions can be promoted to mitigate the rising temperature, soil erosion, and curb the effects of pollution caused by landfill sites in proximity to eco-sensitive zones. Table 17 highlights some of the NbS interventions that can be useful for newly formed municipalities or any old and bigger municipal corporations like Guwahati with larger populations.

**Table 17. Nature-based Solutions for the Management of Urban Floods in Cities**

| Focus Area of Nature-based Solution | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Reduce the Risk of Urban Flooding.  | <ul style="list-style-type: none"> <li>The capacity of traditional drainage infrastructure is usually exceeded by heavy rainfall events due to drainage networks being either too small or too old to handle the increasing urbanisation and changing patterns of precipitation. While traditional drainage systems typically rely on underground pipes and concrete channels, which can increase runoff and cause flooding, improved drainage systems <b>use natural components to manage stormwater</b> more sustainably.</li> <li><b>Permeable pavements, rain gardens, and vegetated swales</b> are a few examples of these elements. During times of heavy rainfall, natural features such as ponds, wetlands, and retention basins can be utilised to retain and hold excess runoff. These characteristics not only lessen flooding but also improve biodiversity, water quality, and recreational opportunities.</li> <li><b>River restoration systems</b> that eliminate invasive species, restore riparian vegetation, and implement erosion control measures by integrating <b>ecosystem-based approaches</b> into flood risk management plans, strengthening legal frameworks, and empowering communities allow for sustainable river management. The Namami Gange Programme in India rejuvenates the Ganga River and its ecosystem health through conservation, biodiversity park creation, decentralized planning, etc.</li> </ul> |
| Promote Biodiversity                | <ul style="list-style-type: none"> <li><b>Green roofs</b>, or the technique of growing vegetation on building rooftops, have various benefits, such as increased biodiversity, temperature control, and rainfall retention. Green roofs efficiently manage stormwater by collecting precipitation, lowering surface runoff, and keeping drainage systems from overloading during heavy rainfall events. On green roofs, rainwater is gathered and held by the vegetation, which acts as a natural sponge to release water gradually. Furthermore, the process of plant evapotranspiration helps to cool the surrounding area. E.g. Singapore's Green Roof initiative integrates policy support with an intervention that provides insights into stormwater retention, energy savings, and biodiversity enhancement.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Improve Water Quality               | <ul style="list-style-type: none"> <li>A number of factors, including inappropriate land use, changes in river shape brought on by natural processes or man-made operations like encroachments, quarrying, as well as the existence of buildings and communities in flood-prone areas, all increase the risk of flooding</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

| Focus Area of Nature-based Solution   | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|---------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                       | <p>along with the solid waste management techniques used today, which obstruct drainage systems. Creating a <b>green river-like connection between wetlands</b>, consists of improving biodiversity and natural assets, recreation, <b>sediment trapping</b>, and water purification. High-<b>biodiversity wetlands</b> offer organic water treatment capabilities. Before runoff from the land reaches open water, it filters out pollutants, excess nutrients, and silt.</p> <ul style="list-style-type: none"> <li>▪ The restoration and preservation of natural habitats through NbS bolster ecosystem resilience and biodiversity, sustaining diverse plant and animal communities that contribute to the preservation of water quality and natural filtration services. <b>Biofiltration systems</b> and vegetated areas further remove excess nutrients like nitrogen and phosphorus from runoff, curbing nutrient loading in aquatic ecosystems and averting eutrophication and algae blooms.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Mitigate the Effect of Climate Change | <ul style="list-style-type: none"> <li>▪ <b>Urban forests and green corridors</b> are examples of green infrastructure features that control microclimates, act as a buffer against climatic unpredictability, and lessen the impact of the urban heat island effect, all of which lessen the vulnerability of cities to flooding brought on by climate change.</li> <li>▪ <b>Constructed wetlands</b>, also referred to as engineered ecosystems, replicate the features of natural wetlands in order to effectively treat and regulate rainfall. These wetlands have been purposefully included in the urban environment of many cities in order to serve as buffers, slowing the flow of stormwater and reducing the risk of flooding. E.g. Constructed wetlands in Rotterdam, Netherlands.</li> <li>▪ Another initiative that has been useful in flood-prone cities is <b>Sponge City Initiative</b> which promotes modernising the current infrastructure while incorporating natural solutions into urban development initiatives, such as built wetlands, permeable pavements, and green roofs. Additionally, planning for sustainable land use and community involvement are crucial.</li> <li>▪ Stakeholders must encourage partnerships with the commercial sector, integrate nature-based solutions into urban planning procedures, and strengthen local implementation and maintenance capabilities. The accumulated findings highlight the need for expanding the initiative's reach, improving processes for monitoring and evaluating its effectiveness, and incorporating natural solutions into more all-encompassing climate adaption measures.</li> </ul> |

## 5.4 Way Forward

This study “Development of Flood Risk Assessment Framework and Roadmap for Resilient Cities” is the first document of its sort created for the city of Guwahati. A thorough analysis was conducted to recommend flood risk management strategies; however, there are certain nuances that should be detailed and taken into account while carrying out future risk assessment studies. Among them are:

- The urban landscapes of Guwahati is rapidly expanding, leading to notable shifts in land use and land cover. As the city’s built-up area grows, the natural drainage systems may become even more obstructed. There will be a greater demand for sewer infrastructure as the city expands in both area and population. Although it has been determined that stormwater drains and sewerage channels must be kept apart, other city-specific plans, such as a master plan for drainage, must also take these conclusions and recommendations into consideration.
- Urban flood hotspots in the divisions classified as high-risk have been discovered by this study. Floods in and around these areas are expected to submerge critical infrastructure, including roads, fire stations, hospitals and electrical substations. In order to safeguard these, a distinct spatial inventory must be created and implemented in accordance with the study recommendations.
- It is imperative that solid waste management strategies be implemented effectively in order to facilitate flood mitigation as suggested in the recommendations. The practices ought to emphasise the value of community involvement, especially among women, and contain measures to increase public awareness of the detrimental effects of solid waste.
- The study was stipulated to a short timeframe and could be further strengthened by detailed assessment using sufficient high-resolution data, detailed survey elevations, frequency for discharges, and rainfall at all rain gauge stations on the rivers along the city to support a more detailed hydrologic and hydraulic analysis.
- Detailed data collection at the household level of all wards in each city can ensure that community-level vulnerabilities are minutely assessed can lead to the development of a city-specific flood risk assessment framework that would be unique to the city’s identity. This would require periodic review and addition of components owing to changing climatic conditions and development parameters.
- Future studies can consider a detailed topographical survey to identify the present extent of natural drainage channels which may not be similar to the satellite imagery as the drainage channels visible in earlier years’ imagery may have since been obscured by encroachment.
- As a next step extensive validation of the obtained WSEL can be performed using High Flood Levels (HFL) for the respective critical locations, rivers, with elevations for multiple historic flood events, along with the rainfall intensities for those flood events, inundation depths, and daily discharge at river gauges at multiple locations are gathered through detailed field survey.
- To ascertain that the recommendations mentioned in the previous chapter can be easily implemented financially, a feasibility evaluation must be conducted. Determining the funding sources e.g. from the central, state, or municipal governments—is also necessary.

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## Annexures

### Annexure 1 – Data Collection Tools

**Stakeholder guiding questions - Consultations to understand the vulnerabilities of the city and wards.**

These are the list of guiding questions to support interaction with the key stakeholders at city-level. Consultant would collect information based on these questions.

Name and Designation of Official:

Date and Time of Interaction:

#### Physical

1. Which are the most flood affected wards in the city?  
Riverine Flood-  
Urban Flood-
2. Are there natural barriers (e.g., hills, wetlands) that provide protection from flooding to the city?
3. What types of provisions are available for flood defence (floodwalls, dams etc)? Are they effective?
4. What kind of changes in the landuse have occurred in past 20 years? Mention examples of specific issues related to encroachment and damage to urban forests and lakes?
5. What % of the city has well connected stormwater drainage system? Mention examples of urban flooding challenges and how are stormwater drains affected?

#### Social

1. What were the impacts of previous floods on the community, infrastructure, and economy?
2. What lessons have been learned from past flood events, and how have they influenced risk reduction measures?
3. Are there barriers to communication such as low access to mobile phones, network connectivity in the city that affect dissemination of early warning information? How do the women, LGBTQ+, elderly get affected due to such issues like language or limited access to technology?
4. Do women have access to resources such as education, healthcare, and economic opportunities prior to the disaster?
5. Are there specific risks or vulnerabilities that women face during flood situation or evacuation, such as increased risk of gender-based violence or separation from family members? Share with example from past incidents.

## Economic

1. What type of economic losses associated with flood events, including damage to property, crops, and livelihoods? Which wards have faced high economic losses due to flood?
2. What type of capacities available with local businesses and industries to recover from flood-related disruptions?
3. Are there any prominent schemes in city which support reconstruction and revival from damage caused by flood/other disasters? What % of population opts for govt. schemes, funding options to rebuild houses, business establishment etc. impacted by floods?

## Institutional

1. Who are the key collaborators in flood risk management other than government. In what aspects do neighbouring cities, NGOs CBOs etc. collaborate?
2. How has the existing mechanisms strengthened resilience and promote gender equality in disaster risk reduction and response efforts?
3. What mechanisms are used to ensure trust in local authorities and response agencies in situations of flooding?
4. What measures are taken to promote gender-responsive planning and programming in disaster management initiatives? What more can be done?
5. What opportunities exist for enhancing capacity through investments in infrastructure, education, and livelihood diversification?

## Natural

1. What % of city area is vulnerable to floods of different types? What are the other prominent hazards?
2. What are the factors such as deforestation or urbanization exacerbating flood vulnerability of the city? How has climate change influenced the flooding patterns there?
3. What are the critical infrastructures (e.g. hospital, fire brigade, power lines, water treatment plant etc.) that have been severely affected by flooding? If possible, provide ward-wise information?
4. What are the prominent nature based solutions being implemented in the city to address issues of flooding like plantation, lake rejuvenation, watershed development etc. Have these solutions helped in curbing impact of floods. And how?
5. How are pollution levels influenced by the flooding? Are there recurrent patterns of water-borne diseases, change in water quality etc. after floods?
6. Are hazard maps considered during development planning in the city? What type of steps are taken to ensure the consideration?

## Stakeholder Guiding Questions – Capacity Component

Use these set of questions to understand the capacities available with the key departments (Municipal Corporation/Municipality, Metropolitan Development Authority, State Disaster Management Authority, Public Health Engineering Department (Phed), Water Resources and any other department important for Flood Risk Management

### A. Institutional Capacity

1. Key role of your department with regards to the following, if any, along with details of the role. Please include any other role with respect to any Emergency Support Functions, if not listed below.

|                                                                                   |  |
|-----------------------------------------------------------------------------------|--|
| Flood Risk Assessment                                                             |  |
| Early Warning Generation                                                          |  |
| Early Warning Dissemination                                                       |  |
| Flood Risk Mitigation (including those related to nature-based solutions, if any) |  |
| Preparedness & Capacity Building                                                  |  |
| Flood Response                                                                    |  |
| Flood Relief & Compensation                                                       |  |
| Damage and Loss Assessment                                                        |  |
| Flood Recovery                                                                    |  |

2. What are the existing institutional mechanism and instruments within your department that support fulfilling the above identified roles?  
(e.g. Task forces, Committees, etc. mandated to perform such a role or legal instruments backing such a role such as any SOP, manual, guidelines, plans, etc.)
3. Which are the key external stakeholders (outside your department) whose support is crucial to fulfill the above mentioned roles & responsibilities? List down and explain each of them to help develop a network of closely associated stakeholders.
4. How is the coordination and communication with these stakeholders undertaken? What are the associated gaps?
5. What is the mechanism of to and fro flow of information with the city/municipality EOC/Control Room/Command & Control Centre? Associated gaps? Key technologies leveraged?
6. Any reporting and documentation mechanism that are currently in place that smooth the functioning of department for flood related roles?



- 7 What are the key datasets available with the department such as maps, demographic data, climatic data, public utilities network data, spatial data, hazard monitoring software/technologies, record of past disasters that are utilised/ can be utilised for the above mentioned roles?

## B. Human Resources

- 1 Details of nodal officer, if any, designated for DRM or flood related roles (listed above).
- 2 List and details of officials and staff trained on different aspects of DRM, particularly, flood related.  
  
(e.g. EOC operator, GIS staff in dept, staff performing specific roles on flood mitigation and management such as pre-monsoon clearance of drainage, removing of vulnerable branches, trees, hoardings, O&M staff of different critical services, etc.)
- 3 Provide details of technical staff/skills available with the department that can be leveraged for any of the above mentioned roles with respect to flood risk assessment, mitigation and management.

## C. Physical Capacity

- 1 Key physical resources (infrastructure, assets) associated with your departments that are/can be utilised for flood risk mitigation and management (Particularly those help fulfilling the above roles). Do include the critical infrastructure associated with your departments.  
  
(E.g. Dewatering pumps, flood early warning systems, flood shelters, boats, life jackets, medicines, health facilities, drainage network, STP, etc.)  
  
What are the additional resources that can further enhance your functioning with respect to the above roles?
2. Are there any instances of disruption in continuity of services your provide or functioning of any of your critical infrastructure during past disasters, particularly floods? How were these cases managed at that time and what measures have been undertaken since then to prevent their re-occurrence in future or mitigating their impacts?
3. Share past examples where additional physical resources had to be deployed from your counterparts departments in neighbouring cities/districts/states?

## D. Financial Resources

1. What are the key sources of funds that support the fulfilling the above mentioned roles, procuring & maintaining the mapped resources and HR, etc. ? (Differentiate national, state and local sources or schemes/ initiatives which are leveraged for such funding)
2. Are there instances of CSR or philanthropy fundings for undertaking any flood risk mitigation or management measures?
3. What are the key challenges associated with existing financial mechanisms?
4. What more can be done to enhance the functioning of these mechanisms (in terms of timeliness, adequacy, reporting, etc.)?

Q1. What sources do you trust for information about Urban flooding and other disasters? How frequent do you use these sources?

Q2. Which measures have you taken to address issues of urban flooding?

Q3. How did you organize the staffing to address the urban flooding?

Q4. What actions were taken to mitigate flooding risks? Frequency of O&M

Q5. What actions did you take to address urban floods? Do you have SoPs and how frequently are they revised? Are there tasks beyond the SoPs that have to be addressed?

### Stakeholder Consultation-Ward/Zone Data Collection

*Use these set of questions to understand the capacities available with the ward/zone level officials. Specific information based on their assessment to be included.*

|                                          |  |
|------------------------------------------|--|
| Ward no. / name                          |  |
| Ward officer name                        |  |
| Total population of ward (disaggregated) |  |
| Area of ward                             |  |
| Date                                     |  |

|                                                                                                                                                                         |  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
| <b>Physical</b>                                                                                                                                                         |  |
| <b>1.1 Land use and housing</b>                                                                                                                                         |  |
| 1.1.1 % of building constructed following building code (1= less than 20%, 2= 20-40%, 3=40-60%, 4=60-80%, 5=80-100%)                                                    |  |
| 1.1.2 type % area of informal settlements (5= less than 20%, 4= 20-40%, 3=40-60%, 2=60-80%, 1=80-100%)                                                                  |  |
| 1.1.3 % of houses above normal/ flood water logging/low-lying areas (1= less than 20%, 2= 20-40%, 3=40-60%, 4=60-80%, 5=80-100%)                                        |  |
| 1.1.4 Total % of the ward's population living in proximity (less than 50m) to the river/ water body (1= more than 50%, 2=30%-50%, 3=20-30%, 4=10-20%, 5= less than 10%) |  |
| 1.1.5 % of house with ownership (1= less than 20%, 2= 20-40%, 3=40-60%, 4=60-80%, 5=80-100%)                                                                            |  |
| 1.1.6 Rate of increase in built-up area every 5 year in the ward (1=50% or more, 2=20-50%, 3=10-20%, 4= 5-10%, 5= less than 5%)                                         |  |
| 1.1.7 % area having temporary structures (5= less than 20%, 4= 20-40%, 3=40-60%, 2=60-80%, 1=80-100%)                                                                   |  |
| <b>Water and sanitation</b>                                                                                                                                             |  |
| 1.2.1 % levees, embankments, bunds, dams, and floodwalls in good condition (1= less than 20%, 2= 20-40%, 3=40-60%, 4=60-80%, 5=80-100%)                                 |  |
| 1.2.2 % of area frequently waterlogged (1= more than 40%, 2=30%-40%, 3=20-30%, 4=10-20%, 5= less than 10%)                                                              |  |
| 1.2.3 % of the population having access to drinking water - tap connection at the house (1= less than 50%, 2= 50-60%, 3=60-70%, 4=70-80%, 5=80% above)                  |  |
| 1.2.4 % population having access to sanitation (1= less than 20%, 2= 20-40%, 3=40-60%, 4=60-80%, 5=80-100%)                                                             |  |
| 1.2.5 % area from where solid waste is collected everyday (1= less than 20%, 2= 20-40%, 3=40-60%, 4=60-80%, 5=80-100%)                                                  |  |
| 1.2.6. % area affected by water supply disruption (1=more than 50%, 2=30-50%, 3=15-30%, 4=5-15%, 5=5% or less)                                                          |  |
| 1.2.7 % of solid waste collected 48 hours after a disaster (1=less than 10%, 2= 10-30%, 3=30-60%, 4=60-80%, 5=80-100%)                                                  |  |
| <b>Roads and accessibility</b>                                                                                                                                          |  |
| 1.3.1 % of roads are all weather road, RCC roads (1= less than 20%, 2= 20-40%, 3=40-60%, 4=60-80%, 5=80-100%)                                                           |  |

|                                                                                                                                                                                                      |  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
| <b>1.4 Critical infrastructure</b>                                                                                                                                                                   |  |
| 1.4.1 % of hospitals in the ward at risk of flooding (1= more than 40%, 2=30%-40%, 3=20-30%, 4=10-20%, 5= less than 10%)                                                                             |  |
| 1.4.2 % of bridges in flood prone/waterlogged area (1= more than 40%, 2=30%-40%, 3=20-30%, 4=10-20%, 5= less than 10%)                                                                               |  |
| 1.4.3 % of buildings more than 20 years old (1= more than 40%, 2=30%-40%, 3=20-30%, 4=10-20%, 5= less than 10%)                                                                                      |  |
| 1.4.4 % of public building structures use flood resistant designs (1=none, 2=less than 20%, 3=20-40%, 4=40-60%, 5= above 60%)                                                                        |  |
| 1.4.5 How many electric sub stations were affected in past floods (1= more than 8, 2=6-8, 3=4-6, 4=1-3, 5=none)                                                                                      |  |
| 1.4.6 % of schools at risk of flooding (1= more than 40%, 2=30%-40%, 3=20-30%, 4=10-20%, 5= less than 10%)                                                                                           |  |
| 1.4.7 How many high-value assets (industry, heritage) in the flood-prone area of ward (1= more than 8, 2=6-8, 3=4-6, 4=1-3, 5=none)                                                                  |  |
| <b>1.5 Drainage system</b>                                                                                                                                                                           |  |
| 1.5.1 How many bottlenecks or areas of insufficient capacity within the drainage network? (1 = more than 10 identified spots, 2=7-9, 3= 4-6, 4= 1-3, 5=none)                                         |  |
| 1.5.2 Frequency of maintenance of drainage pipelines (1= never, 2 = once in 5 years, 3= once every year pre-Monsoon, 4 = every 6 months, 5=every 3 months or more frequent)                          |  |
| 1.5.3 What is the capacity of the drainage system to handle high levels of rainfall(more than 65mm per day)? (1=very poor, 5= very good)                                                             |  |
| 1.5.4 What % of drainage system incorporating green infrastructure (e.g., rain gardens, permeable pavements) to enhance drainage capacity? (1= none, 2= 1-20%, 3=20-40%, 4=40-60%, 5= more than 60%) |  |
| 1.5.5. What % of construction in the ward is on drainage catchment and natural drainage channel that is prone to localized flooding? (1=more than 50%, 2=30-50%, 3=15-30%, 2=5-15%, 1=less than 5%)  |  |
| <b>Social</b>                                                                                                                                                                                        |  |
| <b>Population and demography</b>                                                                                                                                                                     |  |
| 2.1.1 % of population under 14 and over 64 (1= more than 40%, 2=30%-40%, 3=20-30%, 4=10-20%, 5= less than 10%)                                                                                       |  |
| 2.1.2 Literacy rate of population (1= less than 20%, 2= 20-40%, 3=40-60%, 4=60-80%, 5=80-100%)                                                                                                       |  |
| 2.1.3 % of population live in slum area/urban informal settlement /urban poor areas (1= more than 40%, 2=30%-40%, 3=20-30%, 4=10-20%, 5= less than 10%)                                              |  |
| 2.1.4 Population density per square kilometre (1= very high, 5= very low)                                                                                                                            |  |
| 2.1.5 % population living below poverty line (1= more than 40%, 2=30%-40%, 3=20-30%, 4=10-20%, 5= less than 10%)                                                                                     |  |
| <b>Awareness</b>                                                                                                                                                                                     |  |
| 2.2.1 % of ward officials aware of roles and responsibilities during flood, urban flood (1= less than 20%, 2= 20-40%, 3=40-60%, 4=60-80%, 5=80-100%)                                                 |  |
| 2.2.2 Awareness or knowledge of population about the threat and impacts of flooding (1= less than 20%, 2= 20-40%, 3=40-60%, 4=60-80%, 5=80-100%)                                                     |  |
| 2.2.3 How often does the city authority organize public awareness program/disaster drills (1= never, 2= no schedule, 3= once a year, 4= once every 6 months, 5= every 3 months or more frequent)     |  |
| 2.2.4 % Population has access to internet (1= less than 20%, 2= 20-40%, 3=40-60%, 4=60-80%, 5=80-100%)                                                                                               |  |



|                                                                                                                                                                                                                        |  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
| 2.2.5 % population affected by water-borne diseases every year (1= More than 30%, 2= 20-30%, 3=10-20%, 4=5-10%, 5=5%or less)                                                                                           |  |
| <b>Preparedness</b>                                                                                                                                                                                                    |  |
| 2.3.1 How often is community participation in monitoring and reporting drainage issues, such as localized flooding or blocked drains? (1= never, 2= rarely, 3= during specific season, 4= most of the times, 5=always) |  |
| 2.3.2 Extent of engagement of women networks, SHGs in flood risk management, training etc. (1= never, 2= rarely, 3=once every year, 4=once every 6 months, 5= regularly or 3 months)                                   |  |
| 2.3.3 % of population needing shelter after recent floods (1= More than 30%, 2= 20-30%, 3=10-20%, 4=5-10%, 5=5%or less)                                                                                                |  |
| 2.3.4 Availability of sufficient dewatering pumps and equipment                                                                                                                                                        |  |
| 2.3.5 Extent of support from NGOs/ CBOs/volunteer groups or religious organisations for floods                                                                                                                         |  |
| <b>Economic</b>                                                                                                                                                                                                        |  |
| <b>3.1 Employment &amp; income</b>                                                                                                                                                                                     |  |
| 3.1.1 % of population having employment (1= less than 20%, 2= 20-40%, 3=40-60%, 4=60-80%, 5=80% above)                                                                                                                 |  |
| 3.1.2 % of women in workforce (1= less than 20%, 2=30-40%, 3=40-50%, 4= 50-60%, 5= more than 60%)                                                                                                                      |  |
| 3.1.3 % of households depending on only one income source (1= more than 80%, 2=60-80%, 3=40-60%, 4=20-40%, 5=less than 20%)                                                                                            |  |
| 3.1.4 % of business activities (informal sector) affected due to floods in the ward (1= above 50%, 2= 20-50%, 3=10-20%, 4=1-10%, 5= none)                                                                              |  |
| 3.1.5 % of affected households required govt. incentives to rebuild after flood (1= more than 80%, 2=60-80%, 3=40-60%, 4=20-40%, 5=less than 20%)                                                                      |  |
| <b>3.2 Funds and budget allocation</b>                                                                                                                                                                                 |  |
| 3.2.1 Availability of sufficient funds with ward offices to prevent floods (1=very low, 2= low, 3= moderate, 4= good, 5=very good)                                                                                     |  |
| 3.2.2 Access of credit facility with ward office to face/prevent floods (1=very low, 2= low, 3= moderate, 4= good, 5=very good)                                                                                        |  |
| 3.2.3 Effectiveness of funding/subsidies for urban poor or low -income groups during floods (1=very low, 2= low, 3= moderate, 4= good, 5=very good)                                                                    |  |
| 3.2.4 Availability of funds for women and women led businesses affected by flood (1=very low, 2= low, 3= moderate, 4= good, 5=very good)                                                                               |  |
| 3.2.5 % of residential units under any sort of insurance scheme (1= less than 20%, 2=20-40%, 3=40-60%, 4=60-80%, 5=80% above)                                                                                          |  |
| <b>Institutional</b>                                                                                                                                                                                                   |  |
| <b>4.1 Effectiveness of flood risk management (1=poor, 5=good)</b>                                                                                                                                                     |  |
| 4.1.1 Existence of sufficient members in emergency team during a flood (1=poor, 5=good)                                                                                                                                |  |
| 4.1.2 Effectiveness of emergency team during a disaster (leadership /competence) (1= poor, 5 = good)                                                                                                                   |  |
| 4.1.3 Availability of sufficient evacuation centres (e.g community centres, school)                                                                                                                                    |  |
| 4.1.4 regularity in testing and updation of disaster management plans                                                                                                                                                  |  |
| 4.1.5 Existence and readiness of multiple channels of early warning dissemination for vulnerable communities like elderly, women, children who may not have mobile phones                                              |  |
| <b>4.2 knowledge sharing</b>                                                                                                                                                                                           |  |

|                |                                                                                                                                                                                               |  |
|----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
| 4.2.1          | Effectiveness of staff in learning from previous disasters (1=poor, 5=very good)                                                                                                              |  |
| 4.2.2          | Availability of regular disaster training programmes for staff (1= never, 2= once in 5 years, 3= once every 2 year, 4=every year, 5= every 6 months or more frequent)                         |  |
| 4.2.3          | Frequency of flood risk awareness programmes (disaster education) for communities (1= never, 2= once in 5 years, 3= once every 2 year, 4=every year, 5= every 6 months or more frequent)      |  |
| 4.2.4          | Capacity for ward office for sharing of flood awareness (books, leaflets. Manpower, campaigns) (1=very poor, 2=poor, 3=moderate, 4=good, 5=very good)                                         |  |
| 4.2.5          | Interconnectedness and cooperation for transfer of information between key stakeholder, NGOs, nearby city etc. (1=poor, 5=very good)                                                          |  |
| <b>Natural</b> |                                                                                                                                                                                               |  |
| 5.1.1          | Intensity of riverine flood (1=very high, 2=high, 3=moderate, 4=low, 5=very low)                                                                                                              |  |
| 5.1.2          | Intensity of urban flood (1=very high, 2=high, 3=moderate, 4=low, 5=very low)                                                                                                                 |  |
| 5.1.3          | Frequency of riverine flood (1=every 6 months, 2=every year, 3= every 2year, 4= every 5 year, 5 = every 10 year or less)                                                                      |  |
| 5.1.4          | Frequency of waterlogging/urban flood (1=every month, 2=every 3 months, 3= every year, 4= every alternate year, 5 = once every 3 year or less)                                                |  |
| 5.1.5          | Loss of urban water bodies (encroachment on lakes ponds drainage etc) due to development of infrastructure, housing etc. over the last 10 years (1=more than 10, 2=7-9, 3=4-6, 4=1-3, 5=none) |  |



## Household Survey

### Use in Locations that are Frequently inundated in the City

|                                                                                                                                                                 |  |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
| 1. Name                                                                                                                                                         |  |
| 2. Gender and Age                                                                                                                                               |  |
| 3. Total Members in HH                                                                                                                                          |  |
| 4. Age Group (<5 yrs, 5-18 yrs, 18-60 yrs, >60 yrs)                                                                                                             |  |
| 5. Education (Illiterate = 1, Primary (1 to 7 Grade) = 2, Secondary (8-10 Grade) = 3, Higher Secondary (10-12 Grade) = 4, University or Higher = 5, Others = 6) |  |
| 6. Health status (Pregnant/Lactating = 1, Differently Abled = 2, Bedridden/Special Care = 3, Others = 4)                                                        |  |
| 7. Employment Status (Salaried = 1, Daily Wager = 2, Self-employed = 3, Pension = 4, Unemployed = 5, Students = 6, Others = 7)                                  |  |
| 8. Do you live in your own house with title or in rented accommodation (Own House with Title = 1, Rented Accommodation = 2, Friends/Relatives = 3, Others = 4)  |  |
| 9. Who is the service provider for solid waste disposal and collection system? (Government = 1, Private Agency = 2, Community-driven = 3, Others = 4)           |  |
| 10. How many floors are there in the house? (Ground Floor Only = 1, Ground+1 = 2, Ground+2 = 3, More than ground+2 = 4)                                         |  |
| 11. Does the house have a water connection? (Yes = 1, No = 2)                                                                                                   |  |
| 12. Does the house have a toilet and washroom? (Only Washroom = 1, Both Washroom and Toilet = 2, None = 3)                                                      |  |
| 13. Distance from low lying area in metres (<300 = 1, 300-500 = 2, 500-1000 = 3, >1000=4)                                                                       |  |
| 14. Near open area of waste disposal (4) in metres (<300=1, 300-500=2, 500-1000=3, >1000 = 4)                                                                   |  |
| 15. Do the key sources of water get polluted/flooded during rainfall, floods? (Yes = 1, No = 2)                                                                 |  |
| 16. What is the strength of community cooperation during urban floods? (Very Poor = 1, Poor = 2, Moderate = 3, Good = 4, Very Good = 5)                         |  |
| 17. Did you have to shift to safe shelters during floods?                                                                                                       |  |
| 18. Do you have regular community meetings to discuss local issues, challenges, etc.? (Yes = 1, No = 2, Not Aware = 3)                                          |  |
| 19. Does your family discuss preparedness measures and plan of action for disasters? (Yes = 1, No = 2)                                                          |  |
| 20. What do you discuss about-safe shelters, how to strengthen housing, emergency stock, evacuation plan etc.                                                   |  |
| 21. How was your family/household affected by past urban floods?                                                                                                |  |
| 22. What all key disruptions in critical services were faced during past urban floods?                                                                          |  |
| 23. How do you protect your houses/assets from being flooded/cyclone?                                                                                           |  |

## Baseline for Public Awareness (Y/N/Na Type Questions)

|                                                                                                                   |  |
|-------------------------------------------------------------------------------------------------------------------|--|
| 1. Has there been damages in the area (human/asset etc.) due to urban flooding in the past?                       |  |
| 2. Were you informed about the precautions to take during urban flooding by the municipality?                     |  |
| 3. Were you aware of when waterlogging issues will occur?                                                         |  |
| 4. Do you get information on urban flooding from: TV, Social Medial, Whatsapp?                                    |  |
| 5. Did you find any advisory posters in the community regarding the same?                                         |  |
| 6. Were the posters posted in accessible places in the area?                                                      |  |
| 7. Did elderly of your household read the posters?                                                                |  |
| 8. Did the municipality convey information on what to do next and in case of emergency?                           |  |
| 9. Did they inform whom to contact in case of emergency?                                                          |  |
| 10. Did you convey the message you gathered from the officials to other residents of the area?                    |  |
| 11. Do all residents of community adhere to guidelines as mentioned?                                              |  |
| 12. Do organisation/officials working in area guide you related to waste segregation?                             |  |
| 13. Do organisation/officials working in area guide you related to rain water harvesting?                         |  |
| 14. Do you wish to invest time in the workshops/trainings for disaster and urban flood related capacity building? |  |
| 15. What government initiative should be taken in the area so as to increase awareness of the public?             |  |

## Annexure 2 - Methodology for Risk Analysis

### Hydrological and Hydraulic

The hydrological analysis, conducted following the methodology detailed in the Storm Water Drainage Systems Manual, Volume 1 by the Central Public Health & Environmental Engineering Organisation (CPHEEO), utilized a DEM developed using the terrain information obtained from Bhuvan. This analysis elucidates surface runoff patterns directed toward the project site, delineating drainage areas, flow directions, and pathways for both the onsite and the offsite.

The time of concentration (TC) is when rainwater travels from the farthest point of the drainage area to the outfall. The time of concentration was determined for the drainage area using a combination of the equation developed by the Corps of Engineers and Manning's equation to obtain the time of travel in surface flow ( $T_o$ ) and conduit flow ( $T_f$ ), respectively. As shown in equation 1, the time of concentration is a summation of  $T_o$  and  $T_f$ .

$$T_c = T_o + T_f \quad \text{Eq. (1)}$$

The time of travel for surface flow ( $T_o$ ) was calculated by an equation developed by the Corps of Engineers:

$$T_o = \frac{0.994(1.1-C)L^{0.5}}{S^{0.333}} \quad \text{Eq. (2)}$$

Where,

$T_o$  = Time of Surface flow (min)

$C$  = Runoff Coefficient

$L$  = Length of Sheet Flow (m)

$S$  = Surface Slope (%)

The time of travel for the conduit ( $T_f$ ) was calculated by Manning's Equation:

$$V = \frac{1}{n} R^{0.67} S^{0.5} \quad \text{Eq. (3)}$$

$$T_f = \frac{L_{ch}}{60 \times v} \quad \text{Eq. (4)}$$

Where,

$V$  = Velocity in the channel (m/sec)

$n$  = Manning's roughness coefficient of the channel

$R$  = Hydraulic radius (m)

$S$  = Slope of the channel

$L_{ch}$  = Length of the channel (m)

Utilizing the aforementioned equations, the time of concentration is computed as the sum of the time required for surface and conduit flow.

The resulting time of concentration ( $T_c$ ) for Guwahati is estimated to be 89.07 min (1.48 hr) for DA Bharalu, and 48.80 min (0.81 hr) for DA Morabharalu under existing conditions.

## Rational Method

Detailed data for applying the Soil Conservation Service (SCS) unit hydrograph method was not available, and the available soil data was too coarse and insufficient for thorough analysis. Given the time constraints, the Rational method emerged as the most suitable option. The Rational method can be applied with limited data, and can quickly provide estimates of peak discharge. Additionally, it accounts for various types of losses beyond just soil-related losses.

The peak flow from the offsite drainage area is estimated using the Rational Method. The methodology is based on the Storm Water Drainage Systems Manual, Volume 1 by the Central Public Health and Environment Engineering Organisation (CPHEEO). The Runoff Coefficient 'C' depends on the surface type of a catchment. The C value is obtained from the CPHEEO manual. The Runoff Coefficients 'C' for the DA Bharalu and DA Morabharalu in Guwahati are used as 0.70 and 0.75 respectively, considering the areas as a high-density residential catchment. The peak flow for 10-year, 25-year and 100-year events are calculated using the Rational Method Formula:

$$\text{Peak Runoff } Q = C \times \text{Intensity} \times \text{Drainage Area} \quad \text{Eq. (5)}$$

## Hydraulic Analysis

Hydraulic analysis encompasses the study of fluid flow behavior in rivers, channels and other hydraulic structures (culverts, bridges, etc.). It involves predicting water surface elevations, flow velocities and other hydraulic parameters under various conditions, including flood events and channel modifications.

The Hydrologic Engineering Center's River Analysis System (HEC-RAS), developed by the US Army Corps of Engineers is a powerful software tool widely used for the hydraulic analysis of open channels. HEC-RAS employs various computational methods, including one-dimensional (1D) steady flow, 1D unsteady flow, and two-dimensional flow simulations, to accurately model complex hydraulic processes. The software facilitates the setup of detailed geometric models, including river channels, floodplains, and other hydraulic structures, using GIS data or manual input. By defining boundary conditions such as flow rates, and water surface elevations, users can simulate different flood scenarios and analyse their impacts on the surrounding environment. HEC-RAS provides comprehensive output data, including water surface profiles, flow velocities, inundation maps, and floodplain delineations, enabling engineers to assess flood risk, evaluate the performance of existing infrastructure, and design effective flood control measures. Overall, HEC-RAS is a valuable tool for hydraulic analysis and plays a crucial role in flood risk management.

Hydraulic analysis is used to determine the flood risk to the project site by understanding the water surface elevation, depth, and extent of the inundation. A (1D) steady-state hydraulic analysis is performed using the HEC-RAS software, version 6.4.1, to derive the flood level in the nallahs/ rivers. The objective of the hydraulic model is to understand the flood extent and the water surface elevation (WSEL), for the area within and around the city for different return period storm events. To account for the above characteristics of the site and determine the risk, a 1D modelling approach is used.

## One-Dimensional Hydraulic Modelling

In HEC-RAS, 1D hydraulic modelling involves dividing the river or channel into a series of cross-sections and computing the flow properties along the length of the channel. Each cross-section is characterized by its geometry, including channel width, depth, and slope, as well as hydraulic properties such as roughness coefficients. The software solves the 1D Saint-Venant equations, which govern the flow of water in open channels, to calculate water surface elevations, flow velocities, and other hydraulic parameters. This allows engineers to simulate various scenarios, such as different flow rates or channel configurations, and assess the impact on flood risk, water levels, and flow velocities within the river system.

A 1D HEC-RAS model is developed considering a stretch of nallahs/river covering the extent of the city. The peak flows obtained from the rational flow method are used as input to the upstream cross-section of the HEC-RAS model. The Bhuvan terrain is used to obtain the elevation information for all cross-sections of the river. The details of the structures (Bridge and culverts) are requested to the client, which are required for modelling on the river to understand their impact on the water surface elevation. However, due to insufficient information obtained for the client, the structures are excluded from the hydraulic analysis, also with an assumption that the major and new structures on the rivers and nallahs are already designed for more than a 100-year return period rainfall events. As a result of the hydraulic analysis, the WSEL and extent of inundation for 10-yr, 25-yr, and 100-yr return period rainfall events are obtained at each of the considered cross-sections.

Steady flow describes conditions in which depth and velocity at a given channel location do not change with time. Basic computational procedure is based on an iterative solution of the energy equation: The Energy equation and Manning's equation are written as follows:

$$Z_1 + Y_1 + \frac{\alpha_1 V_1^2}{2g} = Z_2 + Y_2 + \frac{\alpha_2 V_2^2}{2g} + h_e \quad \text{Eq. (6)}$$

Where,

$\alpha_1$  = Velocity weighting coefficients

$h_e$  = Energy head loss (m)

$Z_1, Z_2$  = Elevation of the main channel inverts (m)

$Y_1, Y_2$  = Depth of water at cross-section (m)

$V_1, V_2$  = Average velocity (m/s)

$g$  = Gravitational acceleration (m/s<sup>2</sup>)

$$Q = \frac{1}{n} R^{0.67} S^{0.5} A \quad \text{Eq. (7)}$$

Where,

$V$  = Velocity in the channel (m/sec)

$n$  = Manning's roughness coefficient of the channel

$R$  = Hydraulic radius (m)

$S$  = Slope of the channel

$L_{ch}$  = Length of the channel (m)

$Q$  = Flows (m<sup>3</sup>/s)

Water surface elevation (WSE) was computed at the cross-section by solving the Energy equation with an iterative procedure called the standard step method.

## Hazard, Vulnerability and Exposure Calculations

The degree of risk induced by floods depends on various social, physical, institutional, natural and economic factors that vary from one ward or division to another. So, the degree of risk induced by flooding is expected to vary significantly as identified from consultations. Following a series of consultations and discussions were held with various officials within Guwahati Municipal Corporation and other relevant departments. Hazard indicators were based on the rainfall and storm events, the final indicator list of exposure and vulnerability were reflected in the final data collection tools using the SPINE framework (described in Subsection 4.3.2) to include the aspects of socioeconomic, physical, institutional and behavioural indicators among others that are impacting the risk directly or inversely. All the indicators were normalised by bringing them to a common scale of 1-5. For this, the min-max normalisation technique was used where where risk was classified such that with an increase in the value of the indicator the risk is reduced.

This was followed by a semi-quantitative approach for assigning weights that allowed for stakeholder engagement in determining the relative weights of the indicators being compared. Multi-criteria decision modelling tools were reviewed that are widely applied within vulnerability and flood risk assessment studies (Hoque et al. 2019, Hasanuzzaman et. al. 2022) Although for this study, responses suggested that most of the indicators have equal importance i.e. indicators are equally significant with respect to the project objective.

### Risk Calculation Components

| Hazard                                                                               | Exposure                                                                      | Vulnerability                                                                                       |
|--------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>Flood Inundated Areas/ Hotspots</li> </ul>    | <ul style="list-style-type: none"> <li>Land Cover Characteristics</li> </ul>  | <ul style="list-style-type: none"> <li>SPINE Framework Indicators (Data Collection Tool)</li> </ul> |
| <ul style="list-style-type: none"> <li>Projected Water Surface Elevations</li> </ul> | <ul style="list-style-type: none"> <li>Slope</li> </ul>                       | <ul style="list-style-type: none"> <li>Research &amp; Documentation</li> </ul>                      |
| <ul style="list-style-type: none"> <li>Frequency of Waterlogging</li> </ul>          | <ul style="list-style-type: none"> <li>Population Density</li> </ul>          |                                                                                                     |
|                                                                                      | <ul style="list-style-type: none"> <li>Stormwater Network Coverage</li> </ul> |                                                                                                     |



## Annexure 3- Existing and Proposed Land Use Distribution Guwahati

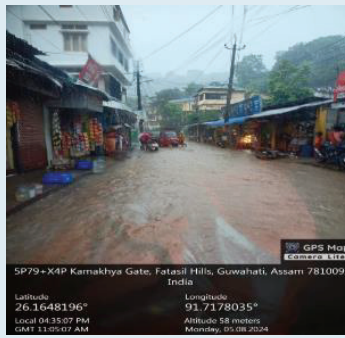
| Existing - 2020               |                         |               |                         |                        | Proposed - 2045 |                           |                        |
|-------------------------------|-------------------------|---------------|-------------------------|------------------------|-----------------|---------------------------|------------------------|
| Sr. No.                       | Landuse Category        | Area (Sq Km)  | % Age of Developed Area | % Age of Planning Area | Area (Sq Km)    | % Age of Developable Area | % Age of Planning Area |
| 1                             | Residential             | 86.40         | 63.97                   | 25.61                  | 99.71           | 41.02                     | 30.40                  |
| 2                             | Commercial              | 6.40          | 4.87                    | 1.95                   | 6.87            | 2.83                      | 2.09                   |
| 3                             | Industrial              | 5.75          | 4.38                    | 1.75                   | 6.11            | 2.51                      | 1.86                   |
| 4                             | Mixed                   | 2.72          | 2.07                    | 0.83                   | 24.82           | 10.21                     | 7.57                   |
| 5                             | Public and Semi Public  | 22.98         | 16.85                   | 6.75                   | 32.53           | 13.38                     | 9.92                   |
| 7                             | Recreational            | 2.22          | 1.69                    | 0.68                   | 38.37           | 15.78                     | 11.70                  |
| 8                             | Transportation          | 17.64         | 5.59                    | 2.24                   | 34.68           | 14.27                     | 10.57                  |
| <b>Total (Developed Land)</b> |                         | <b>144.87</b> | <b>100</b>              | <b>44.16</b>           | <b>243.09</b>   | <b>100</b>                | <b>74.11</b>           |
|                               | Conservation-1          |               |                         |                        | 64.9            |                           | 19.78                  |
| 9                             | Reserved Forest         |               |                         |                        | 24.08           |                           | 7.34                   |
| 10                            | Landslide Prone Area    |               |                         |                        | 3.59            |                           | 1.09                   |
| 11                            | Waterbody               |               |                         |                        | 16.13           |                           | 4.92                   |
| 12                            | Active Flood Plain Area | 183.13        |                         | 55.83                  | 13.6            |                           | 4.15                   |
| 13                            | Wetlands                |               |                         |                        | 7.5             |                           | 2.29                   |
|                               | Conservation-2          |               |                         |                        | 20.01           |                           | 6.12                   |
| 14                            | Hills                   |               |                         |                        | 20.1            |                           | 6.12                   |
| <b>Total (Protected Land)</b> |                         | <b>183.13</b> |                         | <b>55.83</b>           | <b>84.91</b>    |                           | <b>25.89</b>           |
| <b>Grand Total</b>            |                         | <b>328.00</b> |                         | <b>100</b>             | <b>328.00</b>   |                           | <b>100</b>             |

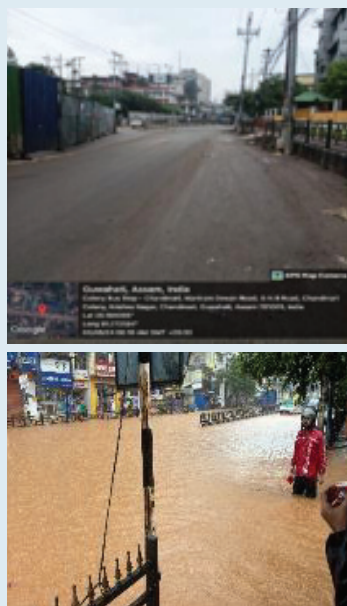
Source: Draft Master Plan 2045

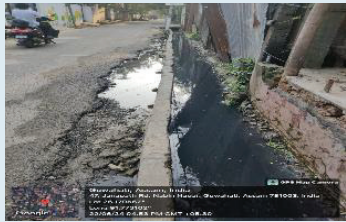
## Annexure 4 - Field Data Collection

**Table 18. Flood Location Information of Guwahati — Household and Community Interview**

| Area Name                                                              | Profile of the Area                                                                                                                                                                                               | Key Challenges                                                                                                          | Supporting Photographs                                                                |
|------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| <b>Division 1</b>                                                      |                                                                                                                                                                                                                   |                                                                                                                         |                                                                                       |
| Jalukbari, Guwahati University Bhupen Hazarika Samaddhi. Ward-1        | This is university area close to NH 17 and NH 27, mostly public buildings and university employees live here. High literacy rates, with many residents holding secondary and tertiary educational qualifications. | Waterlogging is a recurrent issue. Drain outlet is very narrow and needs to be maintained frequently to avoid blockage. |    |
| Bino Kumar Tamuli Path, near NH 27 opposite Radisson Blu Hotel. Ward-2 | This is a residential area with construction at many places going on. Primarily middle-class families with a mix of small business owners, salaried employees, and professionals live here.                       | Inlets for storm water to pass through are not sufficient and properly maintained.                                      |  |
| BBC Colony. Ward-6                                                     | People living mostly single-story Assam style house with GI sheet roofs.                                                                                                                                          | No proper drainage facility or storm water drains identified in the area.                                               |  |

| Area Name                                 | Profile of the Area                                                                                                                                                                     | Key Challenges                                                                                                                                                                                                                                                                              | Supporting Photographs                                                                                                                                                                                                                                                                                 |
|-------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Maligaon Chariali, Ward No. 7             | Commercial area, densely populated with small shops and market place and multi-storey buildings. The area has a mix of railway quarters, standalone houses, and residential apartments. | Heavy siltation of drains reduces the capacity also large volume of water coming from Nilachal hills leads to waterlogging. Dividers were constructed by PWD below the Nilachal flyover due to which water cannot drain out towards PNGB road to Kamakhya station and water logging occurs. | Nilachal Flyover, Maligaon Chariali<br>                                                                                                                                                                             |
| Durgasarobar, Kamakhya Gate., Ward No. 13 | Foothill of Kamakhya with shops and residential buildings.                                                                                                                              | Heavy silt, muddy sand coming from hill side and block the drain frequently.                                                                                                                                                                                                                | <br>GPS Map<br>5P79+X4P Kamakhya Gate, Fatasil Hills, Guwahati, Assam 781009, India<br>Latitude: 26.1648196° Longitude: 91.7178035°<br>Local 04:55:07 AM Altitude: 58 meters<br>GMT 11:25:07 AM Monday, 05/08/2024 |
| Agmark Gali, Ward No. 14                  | Multi storey houses and residential apartments in the area.                                                                                                                             | Low size drains with insufficient capacity. Solid waste clogs the drains at many spots as observed.                                                                                                                                                                                         |                                                                                                                                                                                                                   |
| Kedar Road, Ward No. 15                   | Wholesale and warehouse area.                                                                                                                                                           | Low laying area. Whole sellers and shops have to face difficulty in storage and transportation of goods. Flooding disrupts transportation systems, making it challenging for residents to commute.                                                                                          | In front of GST Bhawan<br>                                                                                                                                                                                        |

| Area Name                                                                         | Profile of the Area                                                                                                                                                                                                      | Key Challenges                                                                                                                                                                                               | Supporting Photographs                                                                |
|-----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| <b>Division 2</b>                                                                 |                                                                                                                                                                                                                          |                                                                                                                                                                                                              |                                                                                       |
| B. Baruah Road<br>(From B.Baruah College To Near Ulubari Fly Over)<br>Ward No. 31 | The area is characterized by a diverse socio-economic profile, encompassing both middle-class and lower-middle-class residents. A mix of commercial, retail, residential, public and semi-public buildings.              | Improper inner drain from Baruah Road to Borsala Beel with poor gradient. Stagnant floodwaters create a breeding ground for pathogens, leading to an increase in waterborne diseases and infections.         |    |
| GNB Road<br>(Chandmari To Silpukhuri)<br>Ward No. 33/35                           | One side of the road is Public and semi-public space, other side is the line of retail shops. The buildings of Chandmari colony are relatively well-maintained, reflecting the stable economic status of most residents. | Dilapidated cross culverts. Poor drain outlets. Encroachment on drains. Inundation level is higher than footpaths, shops had to raise their floor.                                                           |   |
| Rajgarh, Pub Sarania<br>(Byelane No. 1, 2, 3 & 4)<br>Ward No. 36                  | Residential area comprising of 2 to 3 storey houses.                                                                                                                                                                     | Poor drain conditions. Improper gradient of drains. Low elevation of road. Silt from Sarania hills overwhelm drain capacity and leading to water entering the houses. Transportation is seriously disrupted. |  |

| Area Name                                                            | Profile of the Area                                                                                                                 | Key Challenges                                                                                                                                                                                                                                                                                                     | Supporting Photographs                                                                                                                                                      |
|----------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| AGP Goli<br>(Liladhar Baruah Road)<br>Ward No. 31                    | Residential area with multi storey houses.                                                                                          | Road at low elevation.<br>Narrow outlet near railway track.<br>Water would enter homes.<br>Almost everyone in the lane had to raise their floors again.                                                                                                                                                            |      |
| <b>Division 3</b>                                                    |                                                                                                                                     |                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                             |
| Anil Nagar,<br>Nabin Nagar<br>and Tarun Nagar.<br>Ward No. 38,<br>39 | Residential Area with primarily lower-middle-class families with a significant portion engaged in informal and service sector jobs. | These areas lie on the lower elevation side of ward 38.<br>Drains are narrow and have poor gradient.<br>The deposition of trash in the area adds to the unclean environment, promoting the spread of diseases.<br>Roads and other critical infrastructure are often damaged further complicating recovery efforts. |   |

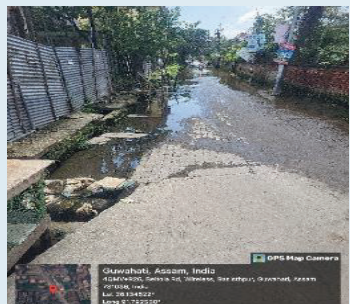
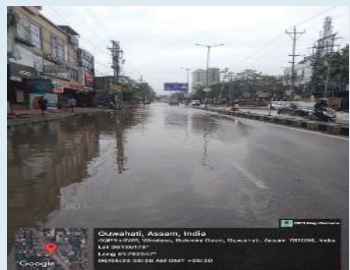


| Area Name                                                            | Profile of the Area                                                                                                                                                                                                                                                                   | Key Challenges                                                                                                                                                      | Supporting Photographs                                                                                                                                                      |
|----------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Noonmati, Salbari, Bhabanipur, Gopal Nagar Ward No. 55               | Residential area in the hill zone.                                                                                                                                                                                                                                                    | Silt from Noonmati, Sunsali hill flow down with storm water and overwhelm the drains so much that it overflows on the roads. Transportation is seriously disrupted. |                                                                                          |
| <b>Division 4</b>                                                    |                                                                                                                                                                                                                                                                                       |                                                                                                                                                                     |                                                                                                                                                                             |
| Assam Trunk Road (Vishal Mega Mart to Vishwaratna Hotel) Ward No. 18 | Commercial area on both sides of road.                                                                                                                                                                                                                                                | A linearly depressed low-lying area along the road leads to waterlogging whenever it rains.                                                                         |                                                                                         |
| Lachit Nagar Area, Ward No. 28                                       | It is residential area with education levels of residents generally high, and a significant portion of the population having completed secondary and tertiary education. There are educational institutions nearby, contributing to the community's overall awareness and engagement. | Overflow of Bharalu river leads to waterlogging in the area. Water inundates the streets and homes. Unhygienic condition of the roads and drains.                   |   |

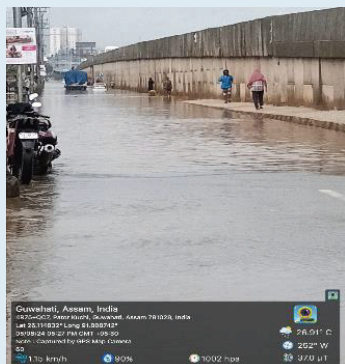


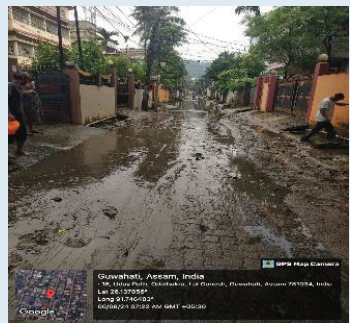
| Area Name                                     | Profile of the Area                | Key Challenges                                                                                                                                                                                                                                               | Supporting Photographs                                                                |
|-----------------------------------------------|------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Srimantapur<br>Main Road<br>Ward 28           | Public and residential area.       | The waterlogging issues in this region are primarily due to the flow of water from uphill, which overwhelms drainage and leads to overflow. Further low elevation of streets exacerbates the problem. Water enters people's home and disrupt transportation. |    |
| Srimantapur<br>LP School bye Lanes<br>Ward 28 | Residential area                   | Poor drain condition, clogged drains due to solid waste. Low elevation of lanes. Waterlogging in compounds. New drains are being constructed.                                                                                                                |  |
| Thana Goli<br>Ward No. 29                     | Old unplanned informal settlement. | Poor drainage system. Not much attention from government agencies, kuchha roads filled with muds, poor living condition.                                                                                                                                     |  |

| Area Name                                                                          | Profile of the Area                                                  | Key Challenges                                                                                                                                                                                                                                                                                                                                                                      | Supporting Photographs                                                                                                                                                      |
|------------------------------------------------------------------------------------|----------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Harbala Path<br>Ward No. 29                                                        | Residential area                                                     | Low elevation roads, poor drainage system, water enters people home, many have to raise floors.                                                                                                                                                                                                                                                                                     |                                                                                          |
| AM Road<br>from GS Road<br>to<br>Namghar Path<br>Suagpur PB<br>Road<br>Ward No. 30 | Residential area.                                                    | Waterlogged streets disrupt transportation and curtails people movement.                                                                                                                                                                                                                                                                                                            |                                                                                         |
| <b>Division 5</b>                                                                  |                                                                      |                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                             |
| G.S Road<br>(Rukminigaon,<br>Boromatoria)<br>Ward No. 48,<br>49                    | Commercial, retail shops along GS road and residential areas inside. | Low gradient, which impairs natural drainage, and the influence of the Bahini River, which exacerbates the problem during high-water events causing backflow of water. Water enters many houses and apartments with low parking areas. Disruption of services such as banks, hospitals etc. Movements of residents are restricted. Taxi and car rentals refuse service in the area. |   |

| Area Name                                            | Profile of the Area                                                                                                                                                                        | Key Challenges                                                                                                                                                                                                                                   | Supporting Photographs                                                                                                                                                      |
|------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Hatigaon Ward No. 42                                 | Hatigaon is a mixed-income locality in Guwahati, encompassing both middle-class and lower-middle-class households. Majority of residents having completed primary and secondary education. | Nutan Path is a low laying area compared to Hatigaon main road. Commuters face severe delays due to traffic congestion caused by flooded roads. The lack of alternative routes and the poor condition of existing roads exacerbate these delays. |                                                                                          |
| Beltola Road-Basisthapur Area (Wireless) Ward No. 41 | Residential area in Ward 41 and on the other side in Ward 48 its public and semi-public area.                                                                                              | Low lying area (low elevation), water flows very slowly because the slope is insufficient to drive water away effectively. Some parts of the storm water drains are damaged and overflow on roads causing damage to road infrastructure.         |    |
| Panjabari Ward No. 60                                | Pubic and semi-public area                                                                                                                                                                 | The volume capacity of the present drain is less than the amount of water running through. The drain is encroached in multiple point decreasing the flow and capacity. Transportation problem, taxi services refuse to go the area.              |   |



| Area Name                                         | Profile of the Area                                                             | Key Challenges                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Supporting Photographs                                                                                                                                                   |
|---------------------------------------------------|---------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sarumotoria<br>- Down Town<br>Area<br>Ward No. 49 | Residential area                                                                | <p>Back flow of water from oil pipeline which is used as outlet of drains in the area. The oil pipe line is not a designated drain and could not be desilted. It has not been cleaned for last 3 to 4 years and silt has reduced its capacity leading to overflow.</p> <p>Storm water enters many houses, a few months back a pregnant lady had to be evacuated from home during floods and faced challenges. After receiving severe backlash and pressure from Sarumotoria Unnyan society a few roads have been raised and new drains are being constructed sluice gates to prevent back flow of water from oil pipeline drainage channel. Still the waterlogging continues due to the overflow of the drain.</p> |   |
| NH near<br>Basistha<br>Chariali<br>Ward No. 45    | The area has a mix of standalone houses, apartments, and rented accommodations. | <p>During heavy rainfall, the volume of stormwater coming from Patorkuchi through Hindustan tower exceeds the capacity of existing drainage systems, leading to overflow and waterlogging on highways.</p> <p>This area is low laying and no proper gradient of Basisthapur inner drain.</p>                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                     |

| Area Name                                | Profile of the Area                                                                                      | Key Challenges                                                                                                                                                                   | Supporting Photographs                                                                                                                                                      |
|------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Division 6</b>                        |                                                                                                          |                                                                                                                                                                                  |                                                                                                                                                                             |
| Odalbakra Ward No. 22 & 25               | Residential area at foot of hills of Kalapahar.                                                          | The inner drain is very narrow and has bottle-neck at various location by constructing permanent structure.<br>Severe disruption in transport services and movement restriction. |                                                                                          |
| National Highway Ward No. 10             | Composite area with a mix of factories, mills, warehouses, retails and houses.                           | During heavy rainfall, the volume of stormwater coming from Boragaon hill exceeds the capacity of existing drainage systems, leading to overflow and waterlogging on highways.   |    |
| Bank of Morabharalu Ward No. 20, 21 & 23 | Mostly residential areas except to some length there is Public and semi-public areas around ACA stadium. | Fatashil sluice gate is closed to reduce water load of Bharalu and water comes from catchment area of Morbharalu overloaded the river leading to overflow.                       |   |

Source: Authors' analysis based on field data

## Annexure 5 – List of Officials Contacted

**Table 19. Key Government Officials Consulted in Guwahati**

| S. No. | Official Designation                                                                                          | Official Name                                                                                                          | Meeting Date             | Data Provided                                                                                                                      |
|--------|---------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|--------------------------|------------------------------------------------------------------------------------------------------------------------------------|
| 1      | Secretary to the Govt. of Assam, Department of Housing & Urban Affairs                                        | Shri Pabitra Ram Khaund                                                                                                | 29-05-2024               | Given permission to provide data and consultation.                                                                                 |
| 2      | Jt Municipal Commissioner                                                                                     | Sri. Mrinal Borah, ACS                                                                                                 | 27-06-2024, 24-07-2024   | Allotted Dy. Executive Engineer for data collection.                                                                               |
| 3      | Chief Engineer GMC                                                                                            | Sri Deepankar Kakati                                                                                                   | 25-07-2024               | Shared details pertaining to SWM, ongoing work, allotted engineers to provide necessary data.                                      |
| 4      | DC, Division I<br>DC, Division IV<br>DC, Division II<br>DC, Division III<br>DC, Division V<br>DC, Division VI | Sri Anil Deka<br>Sri Ramen Talukdar<br>Sri Dwigen Patowary<br>Sri Girin Deka<br>Sri Sayedur Rahman<br>Sri Golok Ch Das | 24-07-2024 to 30-08-2024 | Provided information for stakeholder questionnaire. Provided all Wards information and support for interaction at household level. |
| 5      | Executive Engineer, Office of the Director, Town & Country Planning                                           | Sri P.K Gogoi                                                                                                          | 30-05-2024               | Shared ward boundary, drainage network shapefiles for analysis Stormwater drainage network details.                                |
| 6      | Project Officer, Kamrup Metro                                                                                 | Sri Kaustav Talukdar                                                                                                   | 29-05-2024               | Shared disaster management plan, inputs on gaps in addressing floods.                                                              |
| 7      | Engg. Consultant (Earthquake Risk Mitigation) SDMA                                                            | Sri Rajesh Dutta                                                                                                       | 29-05-2024               | Provided information on capacity related to disaster management and ongoing programmes.                                            |



|    |                                                                            |                          |                           |                                                                                                                                                                                      |
|----|----------------------------------------------------------------------------|--------------------------|---------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 8  | Deputy Chief Executive Officer, FREMAA                                     | Sri Rupak Kumar Mazumdar | 23-07-2024                | Provided information on flood early warning systems in Guwahati and neighbouring areas.                                                                                              |
| 9  | Town Planner Guwahati Metropolitan Development Authority                   | Sri Debaraj Kalita       | 30-05-2024                | Shared master plan information and specific activities of GMDA in waterlogged areas.                                                                                                 |
| 10 | System Engineer/ Officer, GMDA                                             | Kirti Talukdar           | 26-07-2024                | Shared master plan information and specific maps.                                                                                                                                    |
| 11 | Assistant Commissioner, GMC                                                | Sri Ambarish Borah       | 30-05-2024, 23-08-2024    | Shared information on Mission Flood Free, capacity of GMC and other programmes in city.                                                                                              |
| 12 | Assistant Executive Engineer, (I/c) Div I, Bhutnath, GMC-Division I Office | Deepak Talukdar          | Throughout project tenure | Provided information for stakeholder questionnaire. Provided all division-level information, cross-verification of flooding hotspots and support for interaction at household level. |
| 13 | JTO, GMC, Div I, Bhutnath                                                  | Gyan Bezbaruah           |                           |                                                                                                                                                                                      |
| 14 | JTO, GMC, Div I, Bhutnath                                                  | Masud                    |                           |                                                                                                                                                                                      |
| 15 | Assistant Executive Engineer, GMC, Div-II, Uzanbazar                       | Bubul Bora               |                           |                                                                                                                                                                                      |
| 16 | Assistant Engineer, GMC, Div-II, Uzanbazar.                                | Bhupan Bodo              |                           |                                                                                                                                                                                      |
| 17 | JTO GMC, Div-II, Uzanbazar                                                 | Bubul Boro               |                           |                                                                                                                                                                                      |

|    |                                                                                  |                    |  |                                                  |
|----|----------------------------------------------------------------------------------|--------------------|--|--------------------------------------------------|
| 18 | Executive Engineer, GMC Div-III, Zoo Road                                        | Dipak Sarmah       |  |                                                  |
| 19 | JTO, GMC Div-III, Zoo Road                                                       | JP Mahanta         |  |                                                  |
| 20 | Assistant Executive Engineer, GMC-Div-IV, Fancy Bazar                            | Bandana Ojah       |  |                                                  |
| 21 | JTO, GMC-Div-IV, Fancy Bazar                                                     | M Pathak           |  |                                                  |
| 22 | JTO, GMC-Div-IV, Fancy Bazar                                                     | Pinki              |  |                                                  |
| 23 | Executive Engineer, GMC Div-V, Dispur                                            | Hiranya Hazarika   |  |                                                  |
| 24 | JTO, GMC Div-V, Dispur                                                           | Sankalp            |  |                                                  |
| 25 | Executive Engineer, GMC, Div-VI, Lakhara                                         | Pankaj Choudhury   |  |                                                  |
| 26 | JTO, GMC                                                                         | Shri Dheeraj Patel |  |                                                  |
| 27 | Tech. Office, GMC, Div-VI, Lakhara                                               | Laksheswer         |  |                                                  |
| 28 | Senior Research Officer, Directorate of Economics and Statistics Assam, Beltola. | Mukul Sarma        |  | Shared statistical data and demographic details. |



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