Navsari City Action Plan for Flood Risk Management 2025

Prepared by: Council on Energy, Environment and Water

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DEV CHOUDHARY IAS
Municipal Commissioner

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Climate change–driven extreme rainfall is creating serious challenges for city administrations. With rapid urbanisation and reduced natural drainage, floods now occur faster and more intensely, threatening lives and infrastructure.

Navsari is not only an emerging hub for agro-processing, floriculture, and small-scale industries but is also positioning itself as one of the most livable cities of Gujarat. Blessed with cultural heritage, green landscapes, and strategic connectivity, the city is rapidly transforming into a center of balanced growth—where economic development and quality of life go hand in hand. Yet, its low-lying terrain along the River Purna makes it particularly vulnerable to urban floods, underlining the urgency of resilience planning.

The Navsari City Action Plan for Flood Risk Management 2025 is a landmark initiative that provides a practical framework to prepare for and respond to floods, reduce long-term risks, and strengthen the city's adaptive capacity. With clear seasonal strategies and defined departmental roles, it ensures systematic action across pre-monsoon, monsoon, and post-monsoon periods.

I am proud that many of the plan's priority measures were implemented before this year's monsoon, enabling timely response in high-risk areas. This reflects Navsari Municipal Corporation's commitment to evidence-based planning, citizen-first governance, and our vision of becoming Gujarat's most livable city. By integrating scientific data with local socio-economic realities, Navsari is setting a benchmark for other cities in the state and across India.

At a time when, taking inspiration from Hon'ble Prime Minister Shri Narendra Modi ji, Gujarat is celebrating Urban Development Year, I express my deep gratitude to the Hon'ble Chief Minister of Gujarat, the Hon'ble Minister for Jal Shakti, Government of India, and Hon'ble Member of Parliament from Navsari, Shri C.R. Paatil ji, for their constant encouragement and support. I also extend my thanks to Shri M. Thennarsan, IAS, Principal Secretary, Urban Development and Urban Housing Department, to Mrs. Kshipra Agre, IAS, Administrator of NMC, and to all officers of Navsari Municipal Corporation for their tireless efforts. I sincerely acknowledge the Council on Energy, Environment and Water (CEEW), whose scientific assessments, technical expertise, and policy insights were central to shaping this plan and strengthening Navsari's resilience strategy.

Together—with the vision of the nation's leadership, the commitment of the State, NMC's proactive governance, and CEEW's knowledge partnership—Navsari is charting the path to becoming not only flood-resilient but also the most livable city of Gujarat.

(Dev Choudhary)

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About the Navsari City Action Plan for Flood Risk Management

The Navsari City Action Plan for Flood Risk Management (APFRM) has been formulated using daily rainfall data from the Indian Meteorological Department (IMD) for the period 1970–2024. It combines climatic datasets with on–ground socioeconomic and satellite–derived data to map Navsari City's urban flood risk and provides recommendations on making the city resilient to floods.

This city action plan has been prepared as per the *National Disaster Management Plan 2019,* the National Disaster Management Authority *Guidelines on the Management of Urban Flooding, 2010,* and the standard operating procedures on urban flooding notified by the Ministry of Urban Development (now Ministry of Housing and Urban Affairs), 2020.

We sincerely acknowledge the substantial contributions of the expert team from the Council on Energy, Environment, and Water (CEEW). The plan was formulated under the supervision of Mr Nitin Bassi. The plan was drafted with the equal contribution of Ms. Pratha Mishra, Mr Kartikey Chaturvedi with the support of Ms Trisha Ravindranath. We also acknowledge the support of Mr Shravan Prabhu, Programme Associate, CEEW, for his internal review and providing valuable feedback.

Our heartfelt gratitude goes to the Government of Gujarat and Navsari Municipal Corporation. We would like to make special mention of Mr Ashwini Kumar, IAS (Principal Secretary, Urban development and Urban Housing Department, Government of Gujarat), Mr Dev Choudhary, IAS (Commissioner, Navsari Municipal Corporation), Mr Kiran Patel (Additional City Engineer, Navsari Municipal Corporation), Mr Rajesh Gandhi (Additional City Engineer, Navsari Municipal Corporation), Mr Alpesh Patel (Public Health department, Navsari Municipal Corporation), Mr Umesh Patel (Public Health department, Navsari Municipal Corporation), and Mr Ajay Wala (Fire and Emergency Services, Navsari Municipal Corporation) for their valuable feedback and review to enhance the robustness of the plan.

Further, we are thankful to all the officers at Navsari Municipal Corporation, including those from the Fire and emergency services Department, Drainage Department, Public Health Department, Road and Building Department, Town Planning Department, Water Supply Department, Electrical Department, IT Department and Disaster Shakha Navsari who were consulted on a regular basis for the preparation of the plan. We also thank the National Disaster Management Authority and the Central Public Health and Environmental Engineering Organisation for providing guidelines and frameworks used to develop this plan.

Contents

Improving design standards and expanding stormwater drainage network coverage can reduce the risk of urban flooding in cities.

Executive summary

India has more than 5,000 urban local bodies (ULBs) (MoHUA 2015), which together cater to over 31 per cent of the national population. Like with cities and metropolitan areas worldwide, Indian urban centres face multifaceted challenges that climate change is making increasingly complex. One growing concern is the rising frequency of high-intensity rainfall events over short periods, which significantly impacts the existing adaptive capacity (AC) of governments and communities. Vulnerable populations, especially senior citizens, children, persons with disabilities, and populations in informal settlements – often situated in hazard-prone, low-lying urban areas lacking formal infrastructure, adequate housing, and access to water, sanitation and hygiene (WASH) – are disproportionately impacted the most (UNDRR 2019). The social repercussions of such events intensify the risks associated with urban flooding.

With the number and intensity of urban flooding incidents increasing due to climate change, cities must take action to protect vulnerable communities by mitigating flood risks and maintaining or restoring ageing urban flood control infrastructure. A proactive and holistic approach begins with a flood risk assessment, as recommended by the 2019 *National Disaster Management Plan (NDMP)*. Such assessments should examine hazard, exposure, and vulnerability, and be followed by the development of effective risk mitigation, preparedness, and response mechanisms (NDMA 2019). Cities may also draw on global good practice guidelines, such as the World Bank's *Urban Flood Risk Handbook* (Ferguson et al. 2023).

Coastal cities are especially vulnerable to sudden and extreme storms and floods, as they are mostly located in low lying areas, and storm events combined with high tides make water evacuation difficult. Navsari in Gujarat is one such coastal city that regularly experiences recurrent floods. The city, situated at 20.94°N and 72.95°E, spans an area of approximately 43.63 sq km and is divided into 13 administrative wards.

To address these challenges, the Council on Energy, Environment and Water (CEEW) partnered with the Navsari city administration to prepare a city-level flood risk management action plan. This report presents the plan. First, it analyses historical rainfall data, which were used to update the intensity–duration–frequency (IDF) curve and estimate peak discharge. Second, it identifies hydrological, governance, social, and economic factors at the ward level that influence flood risk. Third, it maps urban flood hotspots. Fourth, it classifies wards into high and very high risk of urban flooding. Finally, it proposes recommendations to strengthen mitigation, preparedness, and response measures (Figure ES1).

Figure ES1: Key aspects of the urban flood risk action plan for the Navsari Municipal Corporation (NMC)

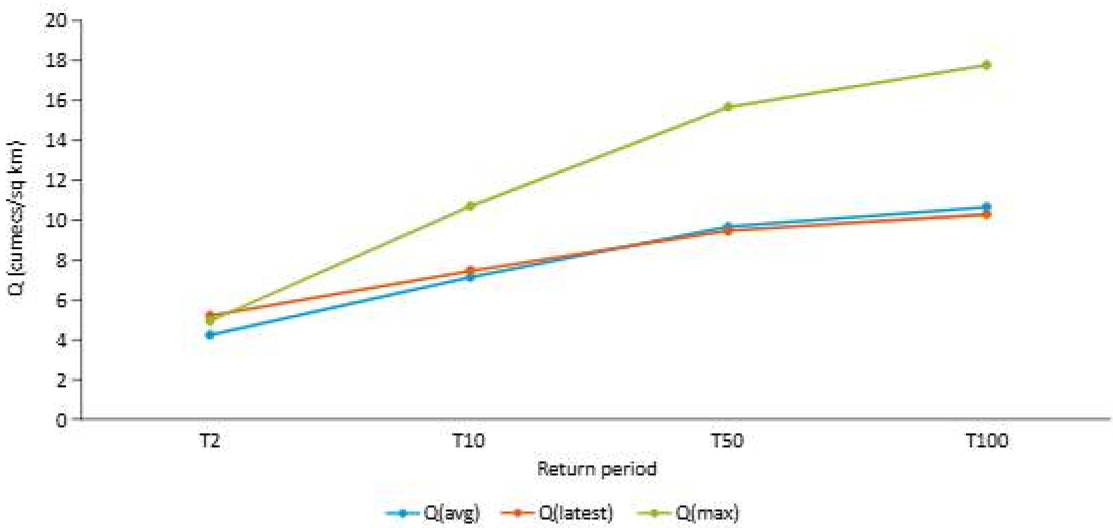
Source: Authors' compilation

Navsari City's Action Plan for Flood Risk Management (APFRM) comprises three specific components: why to take action, where to prioritise, and when to act.

Why to take action: This section involves tracing rainfall trends using historical rainfall data (1970–2024) and preparing the IDF curve. The 24-hour maximum precipitation during these 54 years ranged from 72 mm to 417 mm, with a coefficient of variation of 42 per cent, indicating high temporal variability. Such a high variation poses a challenge for the city administration, particularly in years with extreme rainfall that can potentially cause urban flooding. Over the same period, the peak discharge was 4.27 cubic metres per second (cumecs) per sq km for a two-year return period and 7.12 cumecs per sq km for a ten-year return period (Figure ES2). However, the primary concern for Navsari is the absence of data on the carrying capacity of its existing drainage network and the inadequate coverage of the stormwater network. Four of the thirteen wards (wards 4, 5, 9, and 13) lack a dedicated stormwater network. This highlights the need to inventorise the carrying capacity of stormwater network drains, while also upgrading the drainage network by expanding the network and maintaining the existing network.

Over the past 55 years, Navsari has recorded a daily maximum rainfall ranging from 72 mm to 417 mm, with a coefficient of variation of 42 per cent

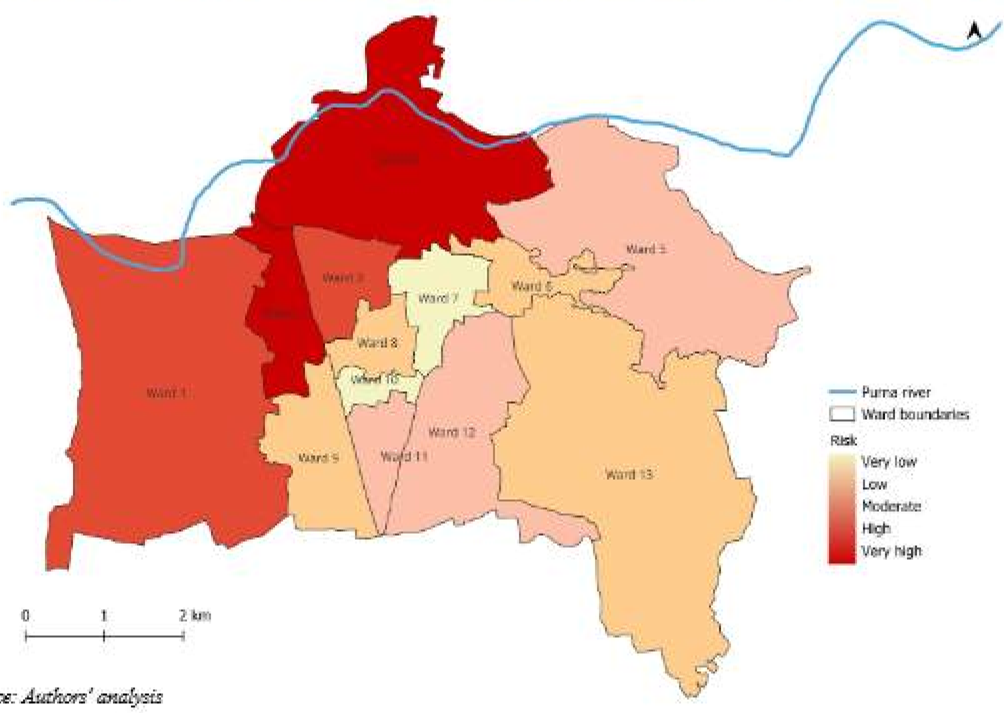
Figure ES2: Peak discharge estimation for areas under the NMC for different scenarios



Source: Authors' analysis using IMD gridded rainfall data
Note: Q (max) refers to the period of 1995–1999, when the maximum discharge was observed, and Q (latest) peak discharge refers to the period of 2020–2024.

Where to prioritise action: The urban flood risk index, developed and computed for Navsari (Figure ES3), identifies wards 4 and 2 as being at a very high risk of urban flooding. Wards 3 and 11 fall into the high-risk category, while ward 1 is classified as moderate to high risk, with its index value closer to the high-risk range. Wards 5, 12, and 8 fall into the moderate-risk category. Wards 13, 6, and 9 are categorised as low risk, while wards 7 and 10 face very low risk. The composite index–based risk assessment provides guidance to decision-makers to prioritise interventions and identify the most relevant stakeholders and types of interventions required in each administrative block.

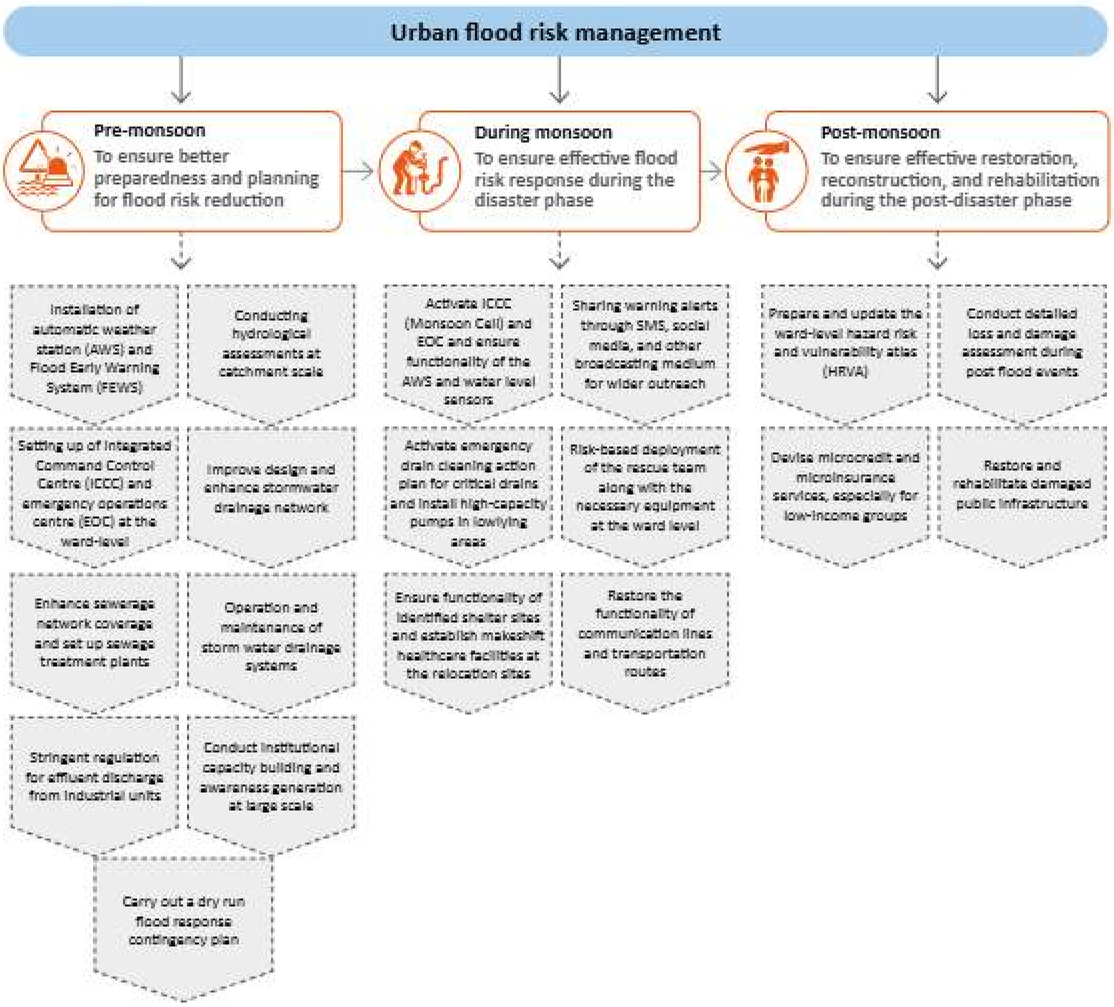
Figure ES3: Urban flood risk index for Navsari Municipal Corporation across different wards



Source: Authors' analysis

Who will (and how to) take action: Stakeholder involvement is crucial for validating the findings of the urban flood risk assessment, ensuring its uptake, and facilitating efficient coordination for implementation. The APFRM outlines a set of actionable recommendations for the NMC, which, once implemented, can play a pivotal role in mitigating the urban flood risks and strengthening city-level adaptation. The plan proposes a three-phase approach for the city administration, consisting of the pre-monsoon (December–May), monsoon (June-September), and post-monsoon (October–November) phases (Figure ES4). The pre-monsoon phase focuses on ensuring better preparedness and planning, the monsoon phase focuses on effective flood risk response, and the post-monsoon phase focuses on effective restoration, reconstruction, and rehabilitation post-disaster. For each phase, the plan provides a timeline for implementation and assigns responsibility to relevant departments, distinguishing between nodal and supporting roles.

Figure ES4: An effective urban flood management underlines the importance of phase-wise strategies



Source: Authors' compilation

The Navsari APFRM provides a comprehensive framework by integrating scientific assessments with local governance and socio-economic conditions, and formulating ward-level risk profiles. With its three-phase strategy and clear departmental responsibilities, the plan equips the city administration to manage urban floods and build long-term resilience in Navsari effectively.

1. Introduction

Before 2005, flood disaster management in India primarily focused on riverine floods, which largely affected rural areas. In recent times, however, many Indian cities have experienced floods with increasing frequency. For some cities, flood peaks have risen by 1.8 to 8 times and flood volumes by up to 6 times, primarily due to higher levels of built-up area (NDMA 2019). As a result, flooding occurs very quickly. Although the nature of urban flooding differs significantly from that of rural areas, in the absence of a dedicated urban flood management strategy, it is often treated through the same lens as riverine floods.

The 2005 Mumbai floods marked a turning point. In 24 hours, the city received 944 mm of rainfall, a 100-year high, which brought it to a complete standstill. Nearly 500 lives were lost, and economic damages amounted to INR 28 billion (USD 322 million)(Singh 2018). The magnitude of the destruction resulting from these urban floods made the authorities realise that the causes of urban flooding are significantly different, requiring targeted strategies. In response, the National Disaster Management Authority (NDMA) released the *National Guidelines for the Management of Urban Flooding* in 2010 to enhance urban flood disaster management efforts and strengthen the national vision of transitioning towards a more proactive, pre-disaster preparedness and mitigation-centric approach.

In recent years, the recurrence of flooding events has increased in Indian cities. Notable examples include the floods in Hyderabad in 2020 and 2021, Chennai in November 2021, Bengaluru and Ahmedabad in 2022, parts of Delhi in July 2023 and June 2024, and Nagpur in September 2023 (Singh 2022). This rising urban flood risk is driven by changing precipitation patterns linked to climate change and by rapid, unplanned urbanisation. Built-up areas in cities have expanded dramatically, resulting in the creation of concrete jungles with extensive networks of impervious surfaces. Such developments lead to increased surface run-off, which results in frequent floods in very short periods during storm events. Encroachment on natural drainage lines, vegetation landscapes, floodplains, lakes, and other water bodies in urban areas has further reduced the capacity of natural green and blue systems to retain water, thereby compounding flood risks. For instance, in Bengaluru, the proportion of built-up area increased from 8 per cent in 1973 to 93 per cent in 2020 (Ramachandra et al. 2016). Due to this concretisation, 98 per cent of lakes in the city have been encroached upon. Moreover, drainage infrastructure bottlenecks, combined with issues in their operation and maintenance, are further making cities vulnerable to flooding. Addressing these challenges requires an optimum mix of adaptation strategies, including water-sensitive urban planning, localised forecasting, monitoring, and early warning systems. Furthermore, strengthening institutional capacity and developing effective awareness strategies are crucial for long-term resilience to urban floods.

According to an analysis by the Council on Energy, Environment and Water, 64 per cent of Indian tehsils have experienced an increase of 1 to 15 days in the frequency of heavy rainfall days, particularly in Maharashtra, Tamil Nadu, Gujarat, and Karnataka (CEEW 2023). The consequences for urban systems are severe, ranging from localised flooding to disruptions in essential services such as water supply and healthcare. Over the past two decades, floods have caused the most significant loss of life and property among natural disasters in India. Today, a single flood event can result in damages of INR 8,700 crore (approximately USD 1 billion), with such incidents becoming increasingly frequent (Kumar 2022).

In this context, the flood risk management plan developed with the Navsari Municipal Corporation (NMC) analyses trends in rainfall intensity, frequency, and duration; identifies factors that have the potential to cause or accentuate urban flood risk; computes a ward-level risk index, and presents strategies to mitigate impacts.

2. Profile of the Navsari district and municipal corporation

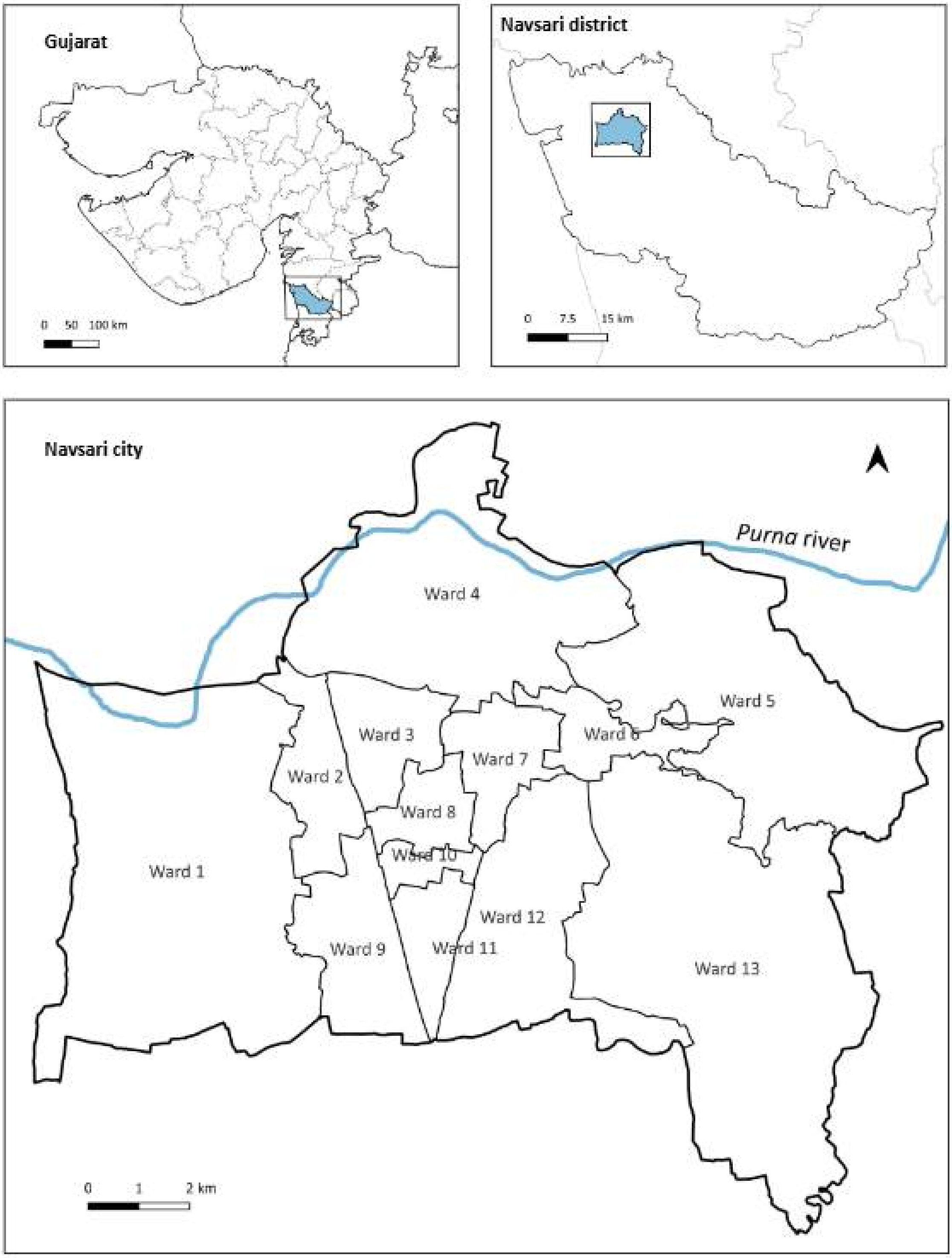
Navsari district, carved out of Valsad in 1997, spans approximately 2,211 sq km, making it the 31st largest district in Gujarat. Located along the coastal plains of southeastern Gujarat, it lies near the Purna River and stretches to the Arabian Sea. The district comprises six talukas: Navsari, Jalalpore, Gandevi, Chikhli, Vansda, and Khergam. Its geographical area is classified into three zones: the west coast region, characterised by rocky, shallow lands with pit mounds, and areas with medium to black soils. Irrigation is supported by canals, tubewells, open wells, and lift irrigation. Key crops include paddy, legumes such as pigeon pea *(toor dal)*, black gram *(urad dal)*, vegetables, and fodder (Digital India n.d.b).

The NMC, covering an estimated 43.63 sq km[1], was established in January 2025 after the former municipality was upgraded. It governs the city of Navsari, the semi-urban town of Adipur, and six nearby villages. The NMC is responsible for property tax collection, water supply, sanitation, waste management, urban planning, birth and death registration, and public health services. The corporation was established to enhance urban governance and improve civic service delivery across its expanded jurisdiction. At the same time, the state's urban development department redefined ward boundaries, with NMC now divided into 13 wards.

Navsari lies on coastal plains near the Arabian Sea, with the Purna River cutting across its northern end. Its elevation ranges from 5 to 28 m above mean sea level, and its soil is predominantly black clayey to loamy. The climate is hot and humid, with summer temperatures ranging from 35°C to 41°C. The city receives an average annual rainfall of 1,500 mm, most of which falls between June and September. Humidity levels range from 35 to 85 per cent, peaking during the monsoon and remaining moderate to low for the rest of the year, giving the city a predominantly humid seasonal character (Digital India n.d.a). The NMC is divided into 13 administrative wards, namely - ward 1, ward 2, ward 3, ward 4, ward 5, ward 6, ward 7, ward 8, ward 9, ward 10, ward 11, ward 12, and ward 13.

1 This information is based on data received from the Navsari Municipal Corporation and is subject to change if any administrative revisions are made.

Figure 1: Map of Navsari district highlighting the area of NMC



Source: Authors' compilation

3. Urban floods and the current scenario

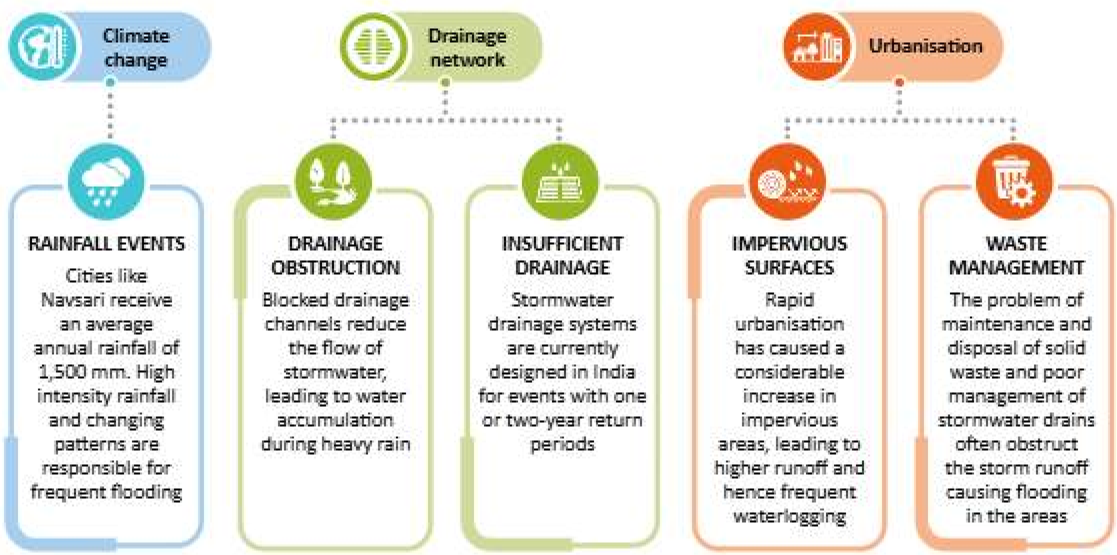
Urban floods occur when a city receives excessive volumes of water due to heavy rainfall, rapid snowmelt, storm surges caused by cyclones or tsunamis, or other causes. This water submerges parts or even the entirety of a city, overwhelming infrastructure and preventing drainage.

3.1 Causes of urban flooding

Urban flooding worldwide is a result of a combination of natural and anthropogenic factors (Figure 2), making it a complex challenge to manage. The Intergovernmental Panel on Climate Change (IPCC) highlights the dire consequences of human-induced climate change for the Indian subcontinent, including increased dry spells, a 20 per cent intensification of extreme rainfall, and an exponential surge in heatwaves and cyclonic events. These climate extremes have contributed directly to the growing frequency of flood hazards.

Insufficient drainage infrastructure in urban areas exacerbates flooding during storm events. The climate change–driven intensification of precipitation patterns is leading to more frequent and heavy downpour events that overwhelm the existing urban drainage systems (Wang, Li, and Zhang 2021). Ageing and poor maintenance of the existing drainage system further reduce the capacity of drains to manage rainwater efficiently (Andaroodi et al. 2020). The status of the drainage system in India is provided in Annexure 1.

Figure 2: Urban flooding is caused by multiple interlinked factors



Source: Authors' compilation

3.2 Status of the stormwater drainage system in Navsari

The NMC reports a total of 180 km of stormwater drains across the municipal area. However, ward-level records maintained by the drainage department account for only 8.9 km and indicate that no separate stormwater drainage exists in four wards. This suggests either the absence of records or inadequate infrastructure in those areas. Since the detailed distribution of the complete 180-km network is unavailable at the ward level, the existing length was proportionally allocated across the nine wards where data exists. The remaining four wards were considered to have no separate stormwater drainage infrastructure, reflecting the current data gaps. These include wards 4, 5, 9, and 13 (Table 1).

Table 1: Ward-wise length of stormwater drains in NMC

Ward	Stormwater network length (Original, km)	Stormwater network length (Re-scaled, km)
Ward 1	0.66	13
Ward 2	0.65	13
Ward 3	0.47	10
Ward 4	0	0
Ward 5	0	0
Ward 6	0.55	11
Ward 7	1.15	23
Ward 8	2.03	41
Ward 9	0	0
Ward 10	0.66	13
Ward 11	0.19	4
Ward 12	2.58	52
Ward 13	0	0
Total	**8.95**	**180**

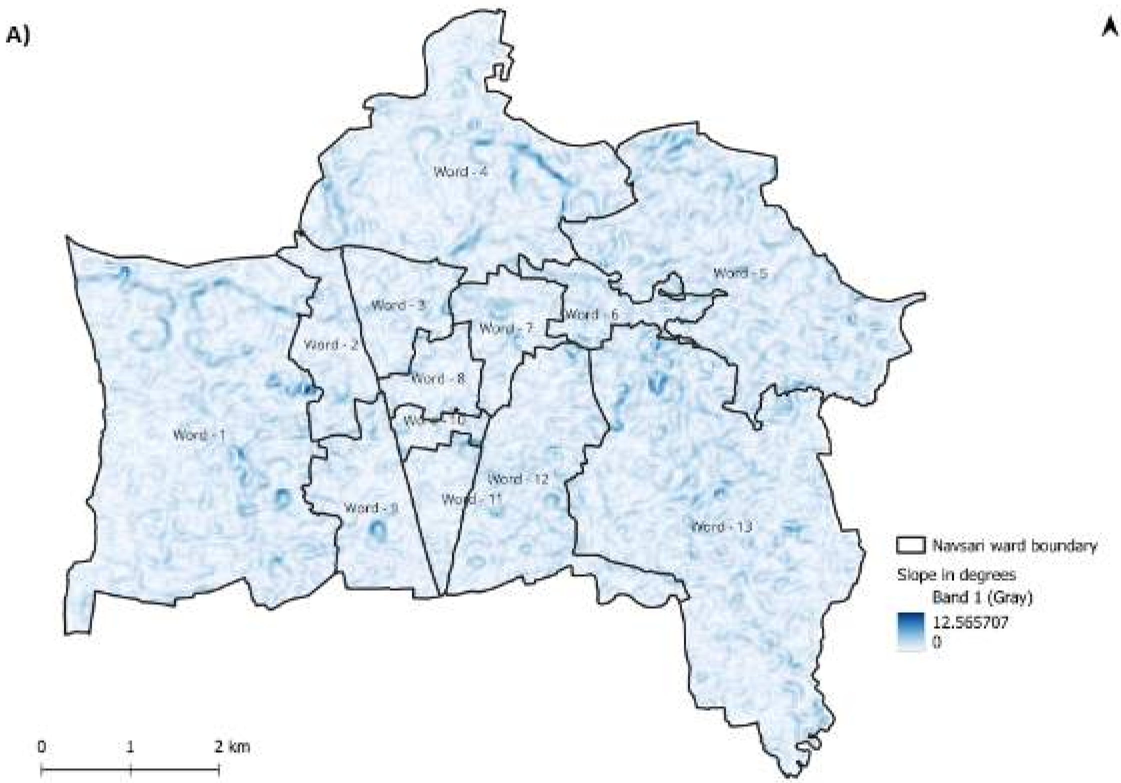
Source: Navsari Municipal Corporation. Data in column "Stormwater network length (Original, km)". Received from the Drainage Department, Navsari Municipal Corporation, 2015-2024.

Note: To achieve a fair ward-wise distribution of the 180 km of stormwater drains reported by the NMC, we employed a simple two-step method. First, in the initial data shared by the drainage department, any ward with a reported length of less than 1 km was rounded up to the nearest whole number (for example, 0.6 km was rounded up to 1 km). This was done to avoid minimal values from skewing the overall proportion. Then, to ensure that the total matched the full 180 km essentially reported by NMC, we scaled the original ward-wise values using the original ward length, multiplied by 180 km (the total stormwater drain length), divided by the sum of all the original ward lengths available in the ward-wise dataset. This approach helped us proportionally distribute the total length across the wards in a balanced manner. Importantly, wards that originally had 0 km of drains were left unchanged and kept as is. This was done to reflect the absence of reported infrastructure, rather than making assumptions where no data existed.

Furthermore, the total drain length of 180 km yields a city-wide average drainage density of just 4.13 km per sq km. In contrast, the estimated natural drainage density across the municipal area, based on catchment characteristics such as natural streams, terrain slope, and existing surface flow patterns, is approximately 4.9 km per sq km. This indicates that natural drainage density is about 18.7 per cent higher than the constructed stormwater drainage density, underscoring a shortfall in engineered capacity to at least align with the area's hydrological behaviour (Figures 3 and 4).

Figure 3: Catchment characteristics influencing urban drainage patterns include A) slope, B) natural streams, and C) drainage density

A)



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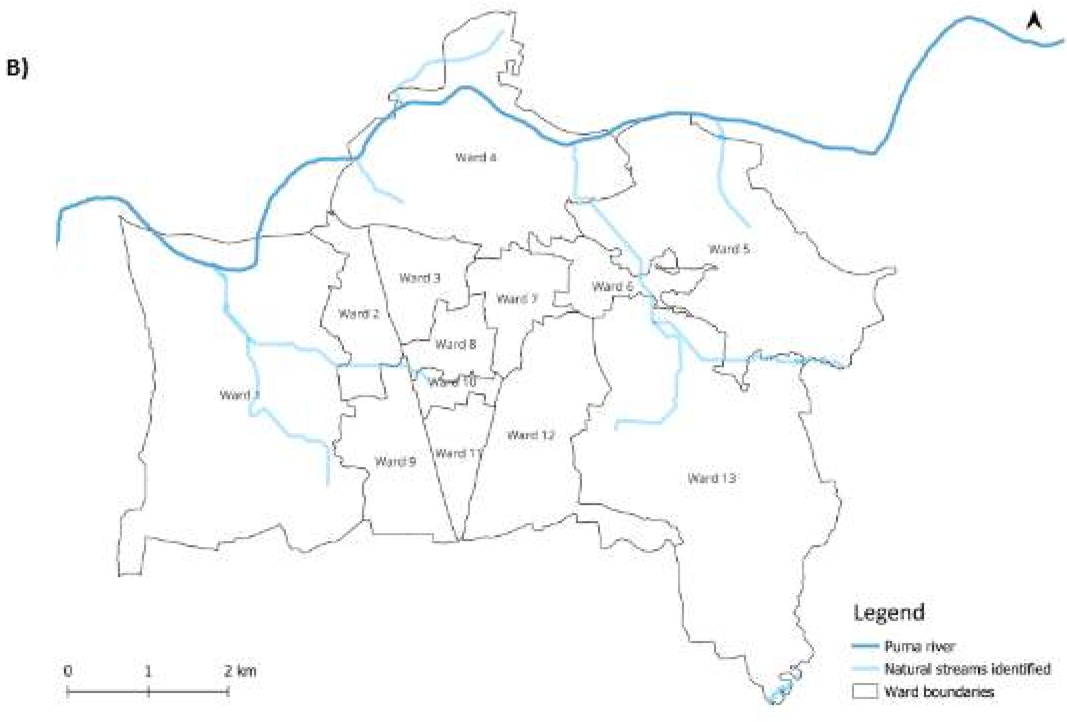


Source: Authors' compilation

C)

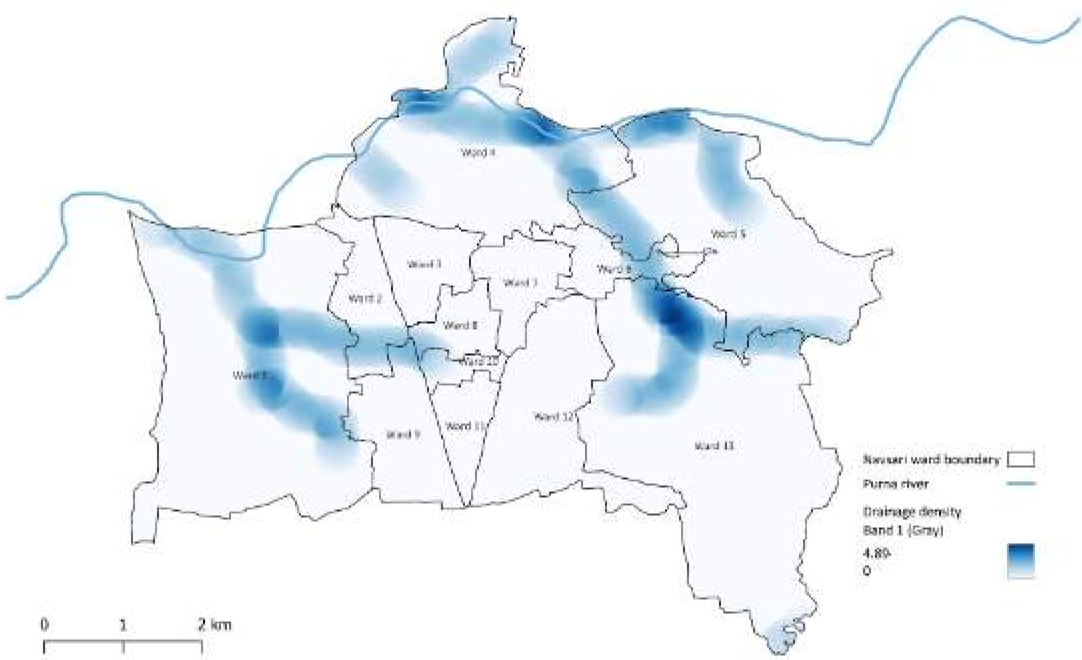


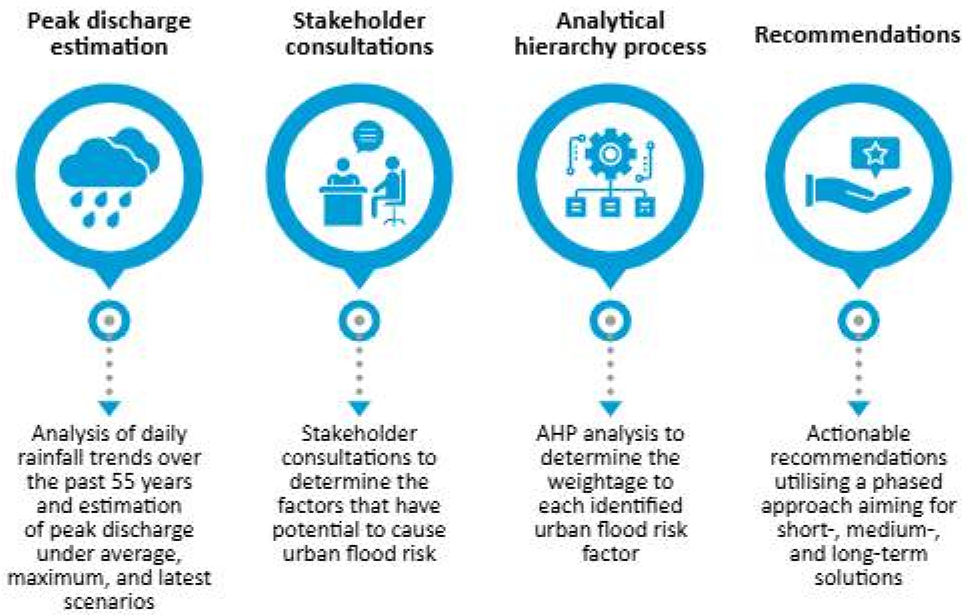
Figure 4: Emerging pressures revealed on the stormwater drainage network within NMC

Source: Authors' compilation

4. Methodology

First, a detailed analysis was performed to understand the past and current rainfall patterns in Navsari, accompanied by an IDF analysis of Navsari. The IDF analysis and peak discharge were estimated for a 55-year period (1970–2024), which helped to understand Navsari's hydrological and drainage dynamics, including inundation mapping. This was followed by the development of an urban flood risk index using the IPCC AR5 assessment framework. Finally, we identified the hotspot regions for urban floods and made recommendations with short-, medium-, and long-term targets (Figure 5).

Figure 5: A four-step approach was adopted to develop the urban flood management plan



Source: Authors' compilation

4.1 Intensity duration frequency (IDF)

To understand the rainfall trends, occurrence of storm events, and flood discharge in NMC, an IDF analysis was undertaken using the methodology presented by Kumar et al. (2022); the details are provided in Annexure 2.

4.2 Flood inundation mapping

Reliable flood extent data at high spatial resolution remains a critical gap in many regions, particularly for post-event assessments. To address this, we adopted the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) recommended practices, utilising Google Earth Engine (GEE) in conjunction with Sentinel-1 Synthetic Aperture Radar (SAR) data to map flood inundation (UN-SPIDER 2023). This approach has been validated in other contexts – for example, during the 2024 Chiang Rai flood, where change detection between pre- and post-flood SAR images achieved over 93 per cent accuracy in delineating flooded areas (Thammaboribal et al. 2025).

The steps we followed for flood inundation mapping are illustrated in Figure 6. A threshold of –20 decibels (dB) was applied to Sentinel-1 data to detect flooded areas. This value is slightly lower than the typical backscatter of dry land before flooding (–15 dB), which is automatically stored in the GEE platform.

Figure 6: Flood inundation mapping carried out through a series of systematic steps

Source: Authors' compilation

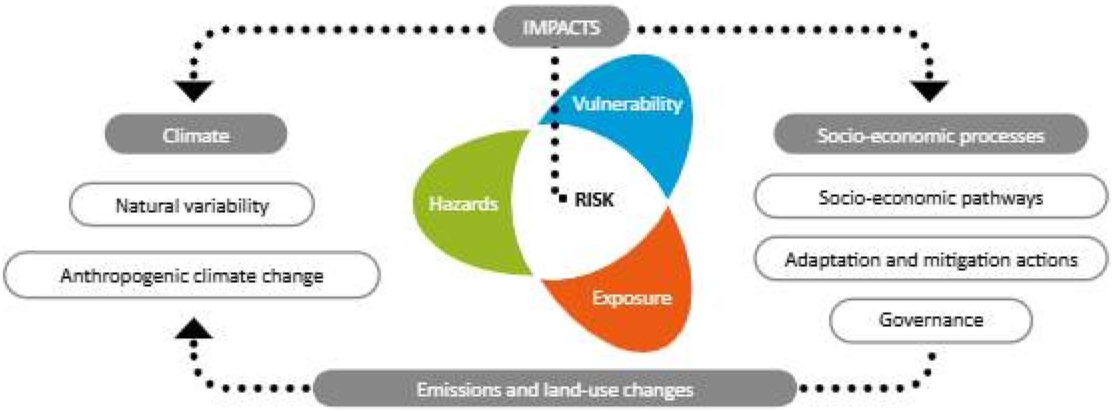
4.3 Development and computation of ward-level urban flood risk index

To assess the 'where to prioritise action' component of Navsari's APFRM, a ward-level urban flood risk index was developed. The index estimates the extent of risk associated with urban floods for each ward based on the computed scores.

The methodology for developing this index follows the framework of the IPCC Fifth Assessment Report (AR5), which defines risk as the interaction of three components: hazard, exposure, and vulnerability (Figure 7). 'Risk' is understood as "the potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from the potential impacts of climate change and human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and wellbeing, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species" (IPCC 2014). The components of risk are explained in Annexure 3.

The computation of the ward-level urban flood risk index followed a series of steps (Figure 8). Indicators were first selected under each component, informed by a detailed literature review and broad-based stakeholder consultations. Ward-level data for these indicators were then collected. The indicators were normalised using maxima–minima method to ensure comparability, after which they were reclassified based on their relation (direct or indirect) to the outcome. A detailed list of indicators under hazard, vulnerability, and exposure, along with their relationship to risk, is provided in Annexure 4. Indicators that could not be considered, or for which assumptions were made due to the absence of data or information, are listed in Annexure 4.1.

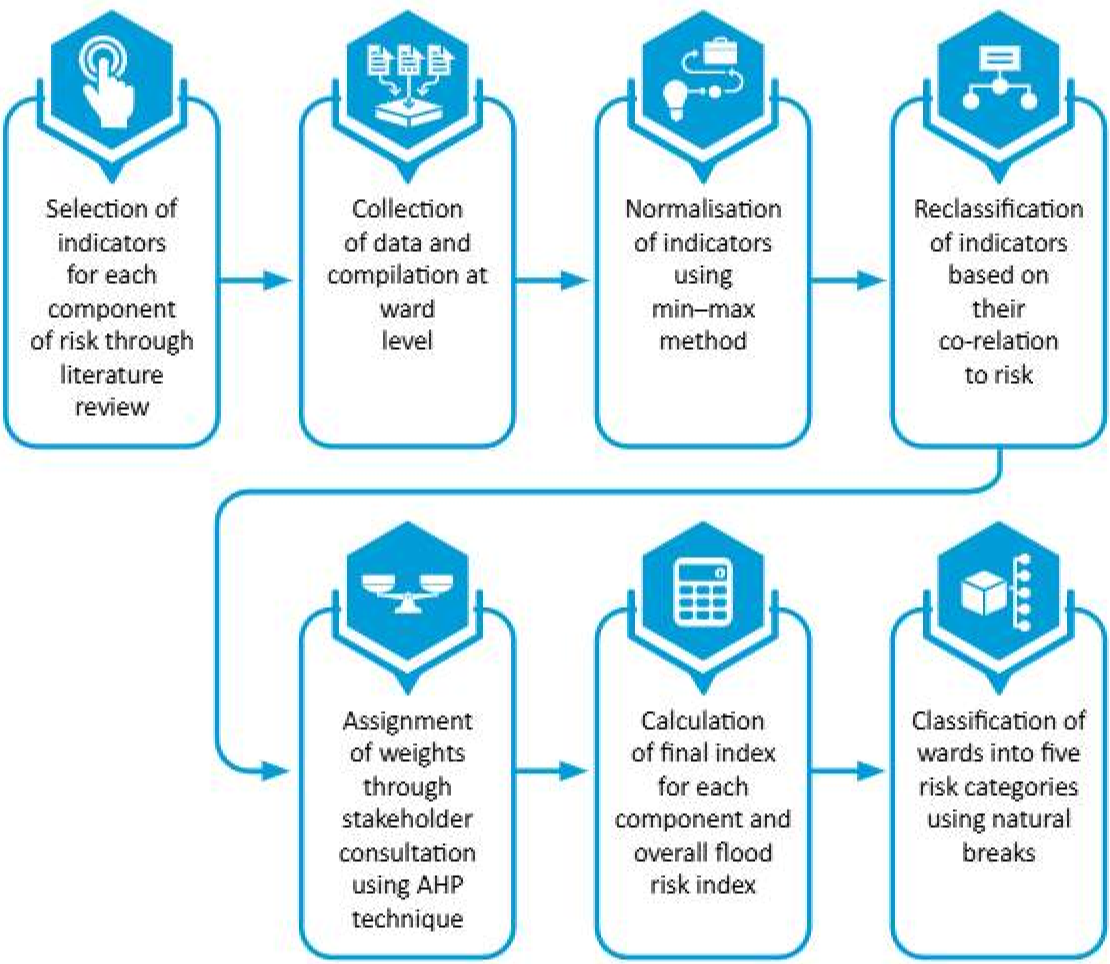
Figure 7: Components and sub-components of risk as outlined in the IPCC's AR5 framework



Source: IPCC 2014

Following this, the Analytical Hierarchy Process (AHP) was employed to assign weights to each indicator (Figure 8). The detailed process and assigned weights are presented in Annexure 5. Composite risk scores were then computed for each ward using the risk equation and classified into five categories: very high, high, medium, low, and very low (Figure 9).

Figure 8: Computing the urban flood risk index via a seven-step process

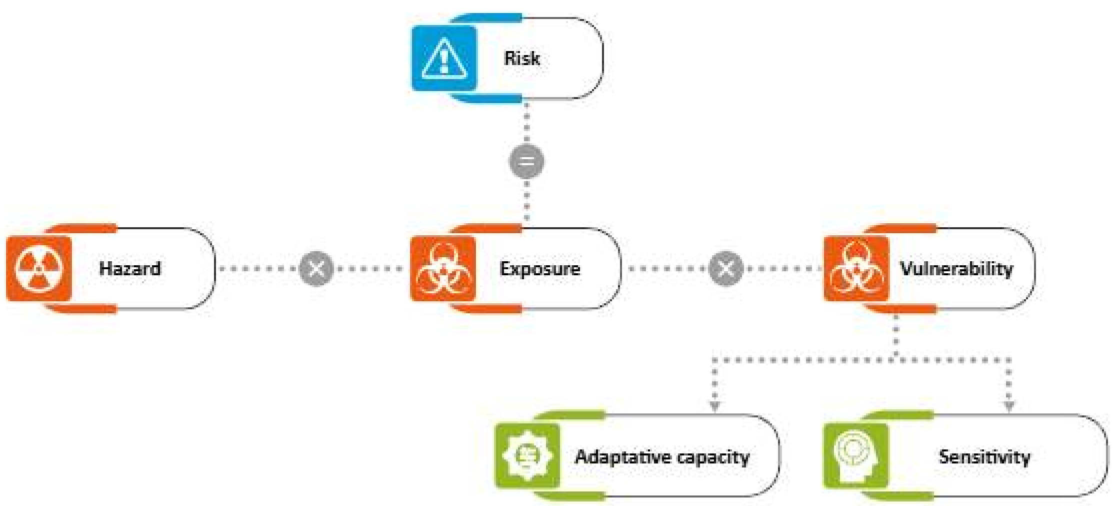


Source: Authors' analysis

Figure 9: Consultation workshop and meeting with NMC officials

Images: CEEW

Figure 10: Risk assessment equation



Source: Authors' compilation using data from IPCC 2014

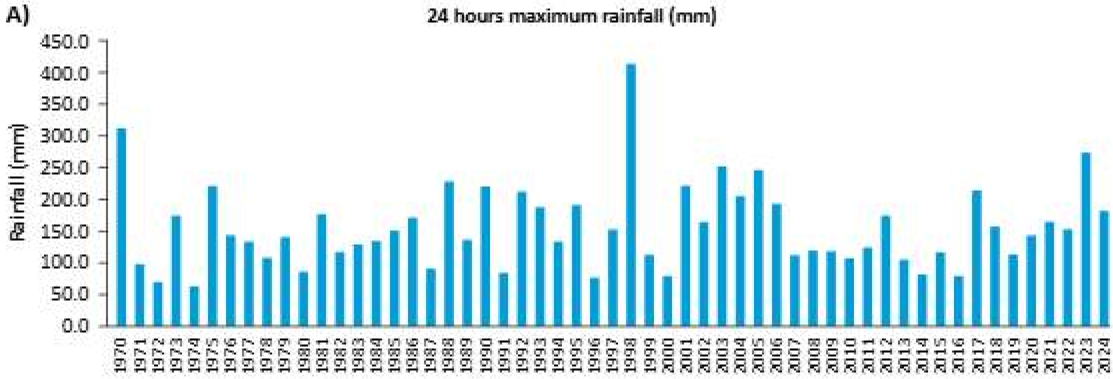
5. Results

5.1 Intensity–duration–frequency curves

Rainfall in Navsari shows high inter-annual variability. Between 1970 and 2024, the maximum one-day rainfall ranged from 72 mm to 417 mm (Figure 11). The variability in daily maximum rainfall, as indicated by the coefficient of variation in rainfall, was estimated to be 42 per cent of daily rainfall. In July 2024, Navsari recorded a total rainfall of 1,335 mm, which is 43 per cent above the normal July average of 561 mm. About 48 per cent of this total fell within a consecutive five-day period, with daily rainfall amounts of 124.92 mm, 102.35 mm, 184.95 mm, 93.09 mm, and 118.22 mm. For a low-lying coastal city, such variability in rainfall is substantial. Hence, there is a need to better prepare for such extreme events.

Figure 11: A) Variations in daily maximum precipitation for Navsari from 1970 to 2024
B) Monthly rainfall distribution for Navsari in 2024

A)



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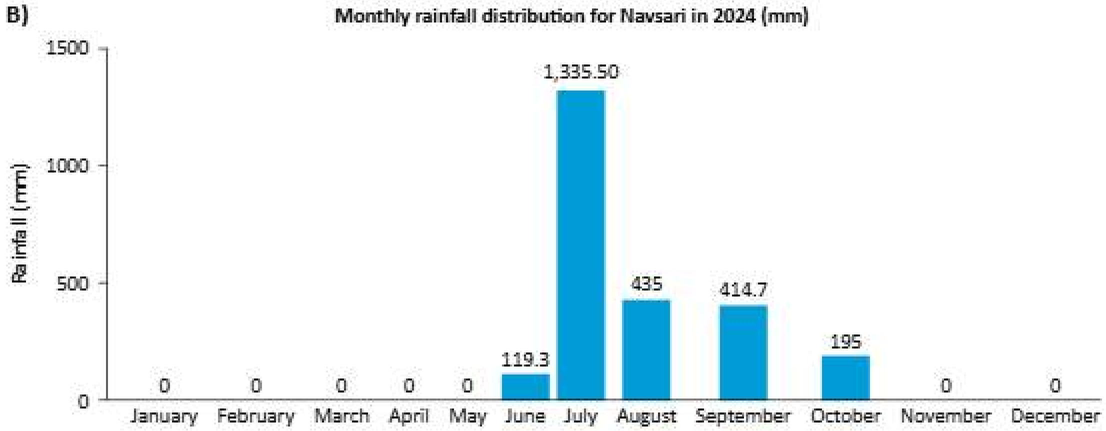


Source: Authors' analysis using IMD gridded rainfall data

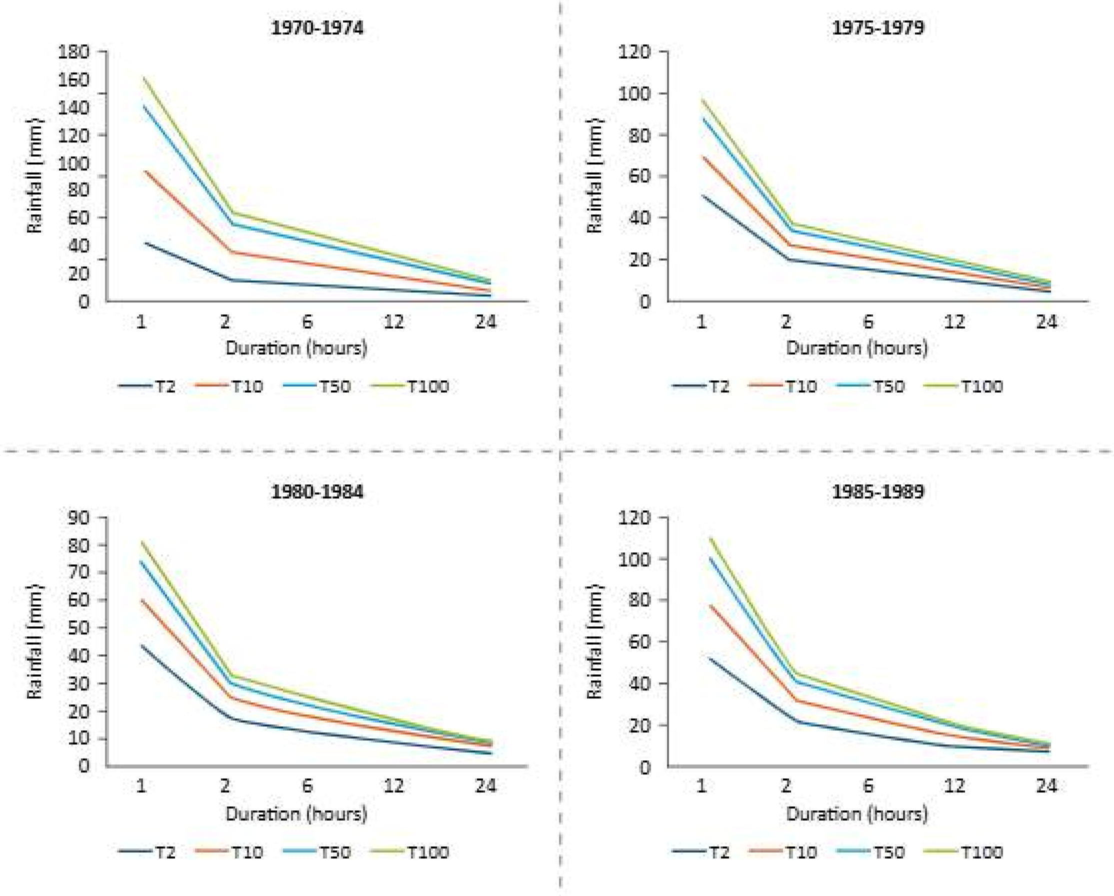
The IDF curves for the analysed period are presented in Figure 12. The IDF curve was prepared for 1970–2024 as a whole and for five-year blocks of daily maximum rainfall. On average, rainfall intensity was about 51 mm/hr for a one-hour duration with a two-year return period, and 85 mm/hr for a one-hour duration with a ten-year return period.

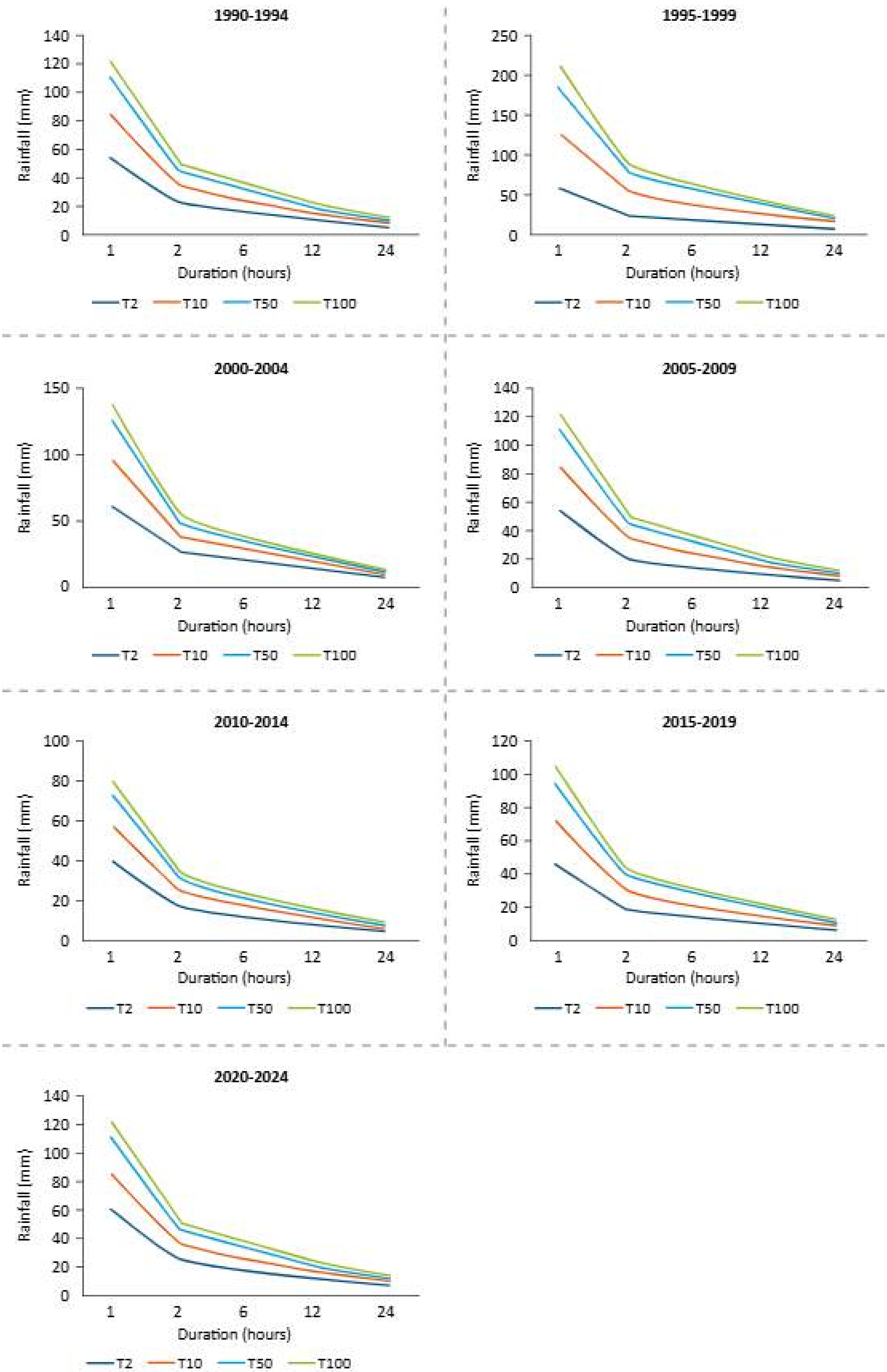
Figure 12 shows that each five-year block displays different behaviour, with some periods recording lower rainfall intensities and others markedly higher. The maximum rainfall intensity was 58.74 mm/hr for a one-hour duration with a two-year return period in 1995–1999. For the same block, the one-hour intensity with a ten-year return period reached 126.53 mm/hr. This reflects the impact of the 1998 historical flood caused by Cyclone 03A (Joint Typhoon Warning Center 1998).

For the last five years of the analysis (2020–2024), rainfall intensity was 61.53 mm/hr for a one-hour duration with a two-year return period, and 88.72 mm/hr for a one-hour duration with a ten-year return period.

Over the past 50 years, rainfall intensities for short and moderate durations have shown a consistent upward trend in every alternate year, indicating that even frequently occurring rainfall events have become more severe. For instance, the one-hour intensity rose from 44.18 mm in 1970–1974 to 61.53 mm in 2020–2024 – an increase of 17.35 mm. Similarly, the two-hour value increased from 18.55 mm to 25.84 mm, the six-hour value from 13.38 mm to 18.64 mm, the twelve-hour value from 8.43 mm to 11.74 mm, and the twenty-four-hour value from 5.31 mm to 7.40 mm.

Figure 12: Intensity duration frequency (IDF) curves highlight that rainfall intensities have risen across all durations over the past five decades





Source: Authors' analysis using IMD gridded rainfall data

5.2 Peak discharge estimation

Following the IDF analysis, peak discharge was estimated to understand the amount of discharge generated during different events and return periods.

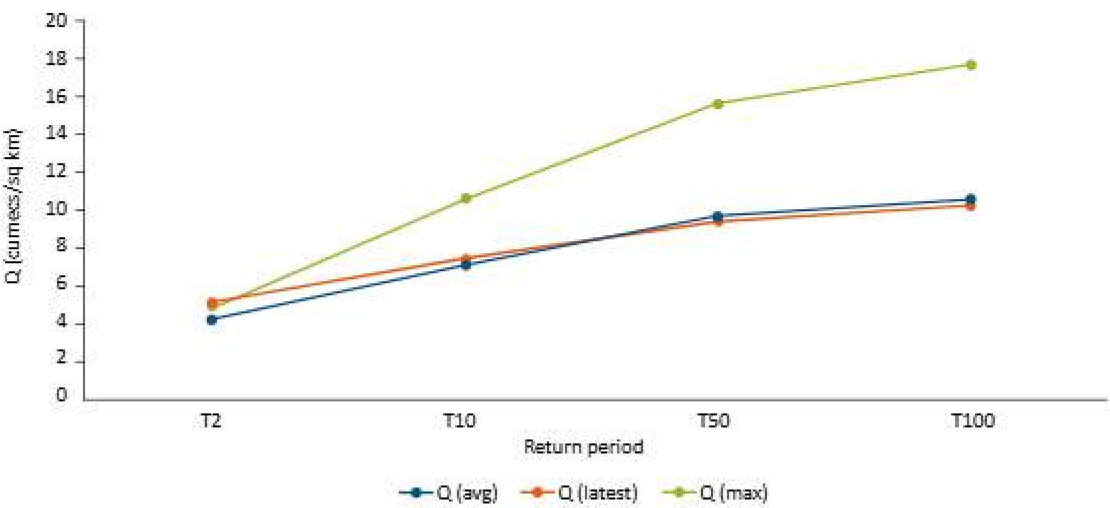
The concentration time was estimated as 1.97 hours (approximated to 2 hours), which is the time needed for water to flow from the most remote point in a watershed to its outlet. Based on this, the rainfall intensity corresponding to 2 hours and a return period of 2, 10, 50, and 100 years was considered for estimating the peak flood flow from the total area. For estimation, the entire area under the NMC was considered a watershed. The coefficient of runoff was considered to be 0.72.

The estimated peak discharge for the entire NMC area was about 185 cubic metres per second (cumecs) for a storm with a two-year return period and about 308 cumecs for a storm with a ten-year return period. To provide a more nuanced understanding, peak discharge per unit area (in sq km) was compared for different scenarios:

- Q (avg): peak discharge estimated using the entire period of analysis (1970–2024)
- Q (max): peak discharge for 1995–1999 when maximum discharge was observed
- Q (latest): peak discharge for 2020–2024, the last five years of the analysis

Results are presented in Figure 13 and Table 2.

Figure 13: Peak discharge patterns outlined for NMC area across scenarios



Source: Authors' analysis using IMD rainfall data

Table 2: Scenario-wise peak discharge per sq km derived for the area within Navsari Municipal Corporation

Return period	Q (max) 1995-1999	Q (average) 1970-2024	Q (latest) 2020-2024
T2	4.93	4.27	5.17
T10	10.63	7.12	7.45
T50	15.63	9.61	9.46
T100	17.74	10.66	10.30

Source: Authors' analysis using IMD gridded rainfall data

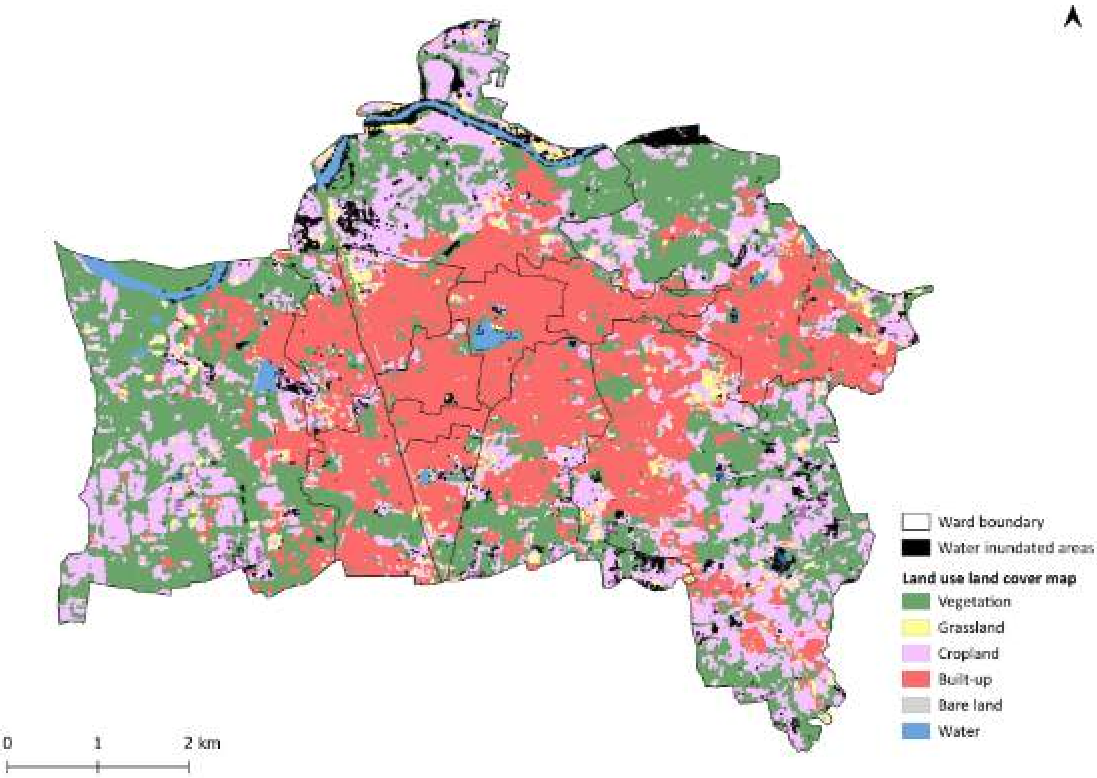
The existing stormwater drain capacity of Navsari remains uncertain, as the city's recent transition from *nagar palika* to a municipal corporation necessitates restructuring and detailed capacity audits. As indicated in Table 4, the drainage system needs to be upgraded to accommodate at least a 10-year return period scenario from Q (max), ensuring resilience under both average conditions and latest discharge (Q) trends. For upgrading and expanding the existing stormwater drainage system, we recommend adopting a capacity of 10 cumecs per sq km, which corresponds to the peak discharge in the Q (max) scenario expected once every 10 years.

5.3 Extent of flood inundation in Navsari Municipal Corporation

The total inundated area within NMC was estimated using the highest rainfall events of the past two years, for which data were available. Additionally, the major flood event of 24 July 2024 was mapped, during which, nearly 20 per cent of the total NMC area – about 8.725 sq km – was flooded (Figure 14).

In this event, ward 4 recorded the highest flood inundation extent at 4.6 sq km, accounting for 52 per cent of the total inundated area, followed by ward 13 with 1.6 sq km, representing around 20 per cent of the total.

Figure 14: Waterlogging observed across NMC after the 24 July 2024 rainfall event



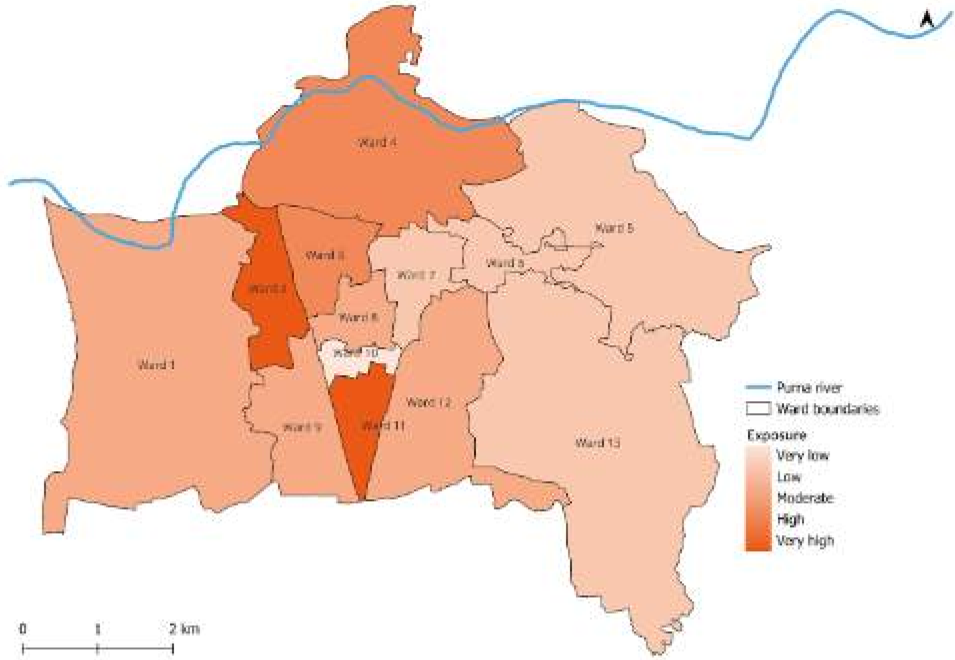
Source: Authors' analysis using satellite imagery

5.4 Urban flood risk index

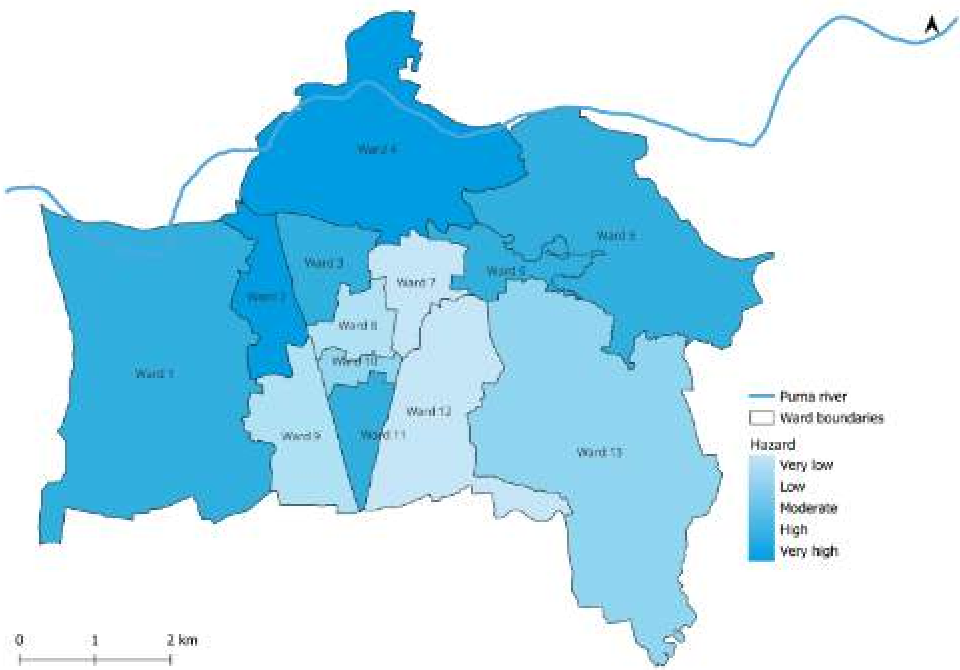
The urban flood risk index was computed at the administrative ward level for NMC. Based on scores, five categories were created using natural breaks: very high, high, medium, low, and very low risk. The range of values from 0 to 1 was classified as follows: very low (0–0.18) and very high (0.57–1). The risk maps and the sub-indices maps are presented in Figure 15.

Figure 15: Urban flood risk mapping for Navsari showcasing: A) hazard sub-index, B) exposure sub-index, C) vulnerability sub-index, D) overall risk index, and E) integrated findings from all components

A)

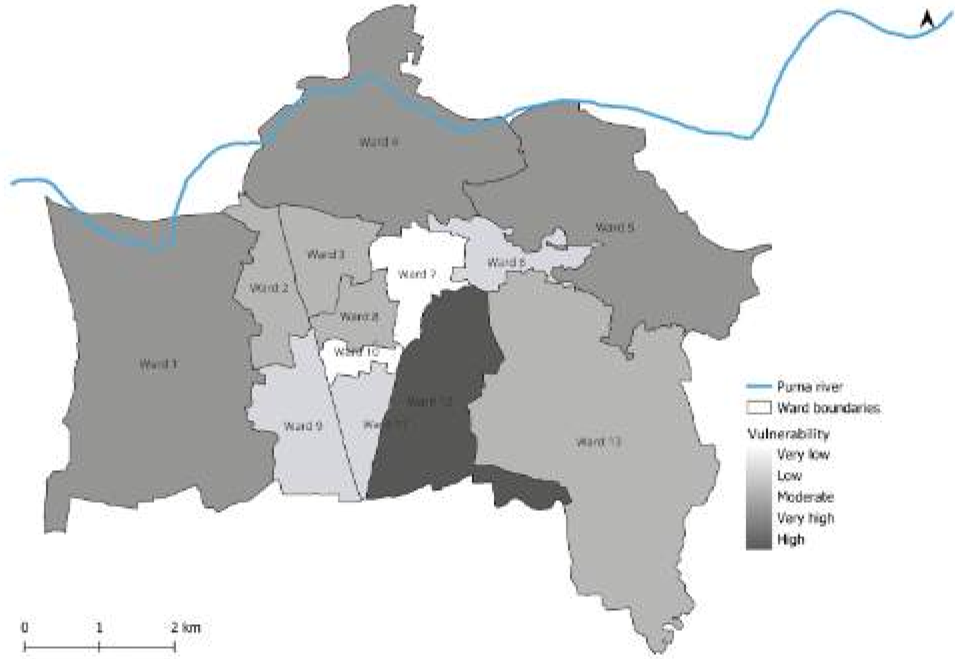


B)

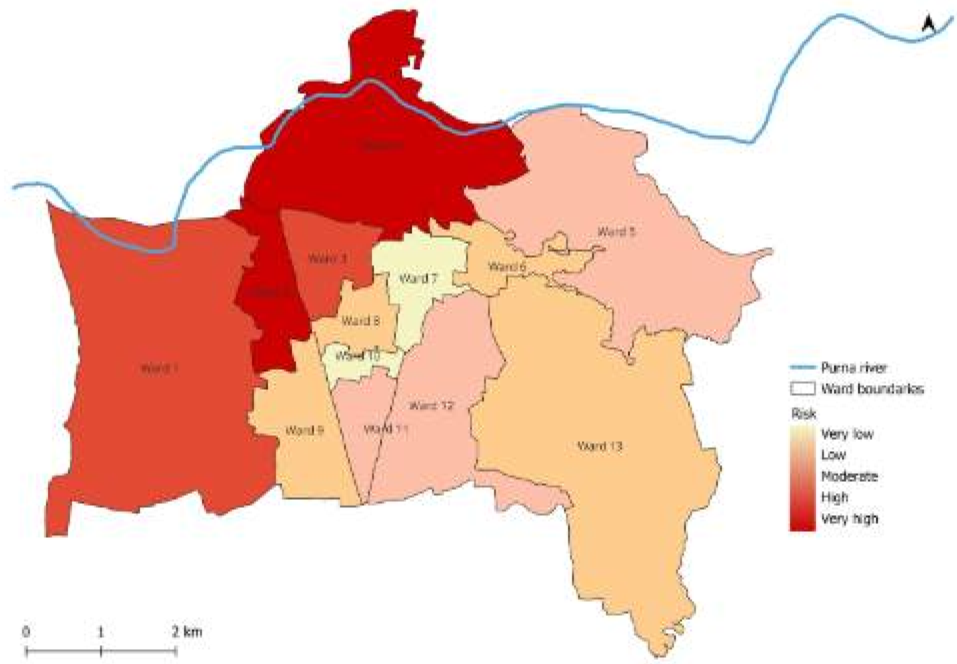


The computations reveal that wards 2 and 4 fall into the very-high-risk category, followed by wards 3 and 11, which are classified as high risk. Ward 1 is classified as moderate to high risk, with a risk score closer to the high-risk category. This is followed by wards 5, 12, and 8. Wards 6, 9, and 13 are in the low-risk category, while wards 7 and 10 exhibit very low risk. Ward-level urban flood risk profiling will enable NMC to prioritise interventions, identify the relevant stakeholders, and determine the types of interventions required for effective flood management.

C)



D)



Source: Authors' analysis

E)

Source: Authors' analysis

Further, we identified the factors (indicators) responsible for high hazard, exposure, and vulnerability scores for each ward (see Table 3). Hazard levels across wards are primarily determined by the proportion of the area affected by flood inundation. Exposure is closely linked to the absence of upgraded and functional stormwater drainage systems, which increases the likelihood of water accumulation during extreme rainfall. Meanwhile, vulnerability is compounded by several systemic gaps, such as the lack of hazard, risk, and vulnerability assessments (HRVA); limited rainfall monitoring due to missing gauges; the absence of Integrated Command and Control Centres (ICCCs) and emergency operations centres (EOCs), as well as insufficient or under-capacitated emergency shelters. This information provides NMC with the necessary data to identify potential causes of urban flood risks in wards and implement targeted actions to enhance urban flood resilience.

Table 3: Underlying factors shaping the urban flood risk index across Navsari's wards

Indicators	Ward 1	Ward 2	Ward 3	Ward 4	Ward 5	Ward 6	Ward 7	Ward 8	Ward 9	Ward 10	Ward 11	Ward 12	Ward 13
Hazard													
The proportion of flood inundated area (the highest annual flood event in the last five years) (2020–2024)				■									
Instances of waterlogging events or frequency of flooding (in the last five years) (2020–2024)		■	■	■									
Exposure													
Population density			■			■							■
Stormwater network coverage				■	■				■				■
Sewerage network coverage								■		■	■		
Slope					■	■							■
Built-up area to the geographical area		■										■	■
Vulnerability													
Distance from the river	■	■		■	■								
Households (HHs) with access to a water supply within the premises					■			■		■			
Proportion of population with special needs/ disabilities	■		■		■								■
Proportion of slum areas							■						■

Source: Authors' compilation

Note: The shaded boxes indicate wards with the highest risk with respect to that particular indicator.

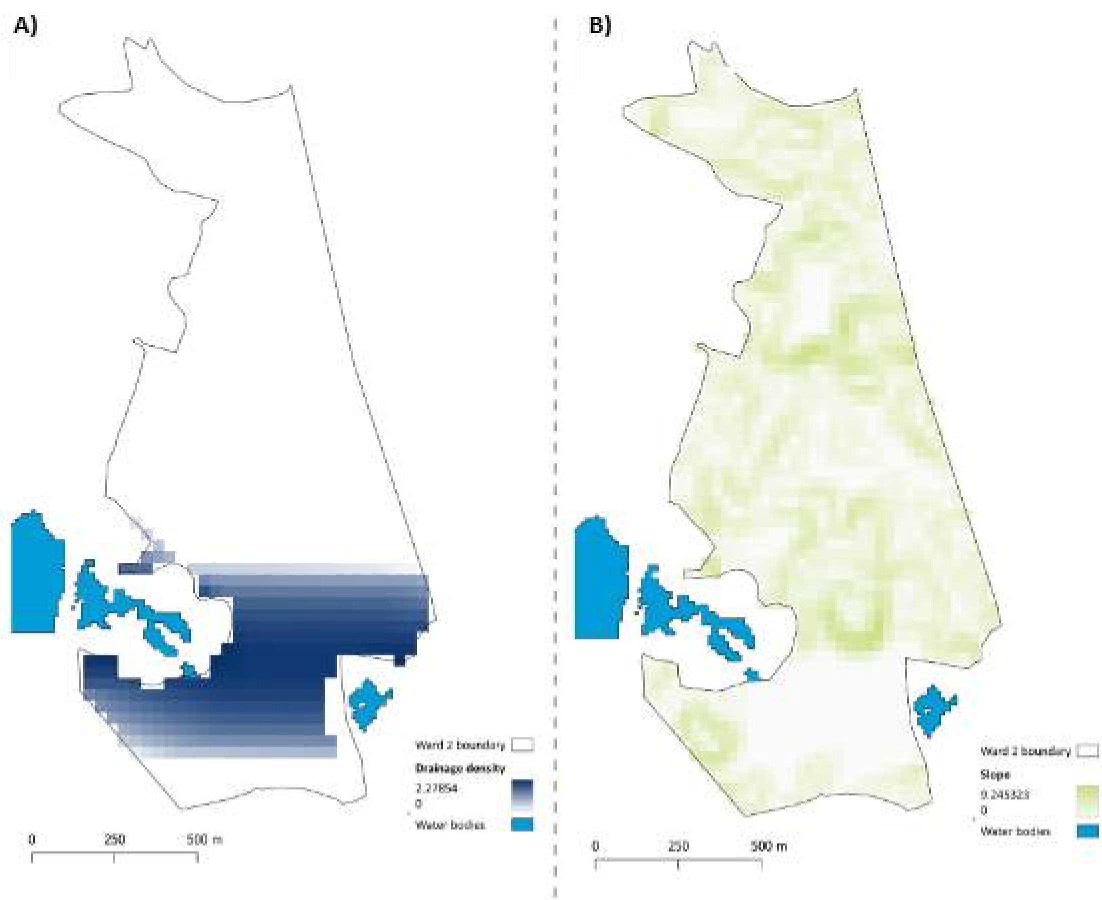
5.5 Hotspot analysis

Hotspot analysis was conducted for wards classified as very high flood risk, namely, wards 2 and 4. Waterlogging hotspots were identified using historical flood event data provided by NMC officials. To examine the factors contributing to these hotspots, several maps were generated. These include: natural drainage density; slope; waterlogged/water-innundated areas; water logging hotspots for ward 2 (A-D) and ward 4 (E-H) (Figure 16).

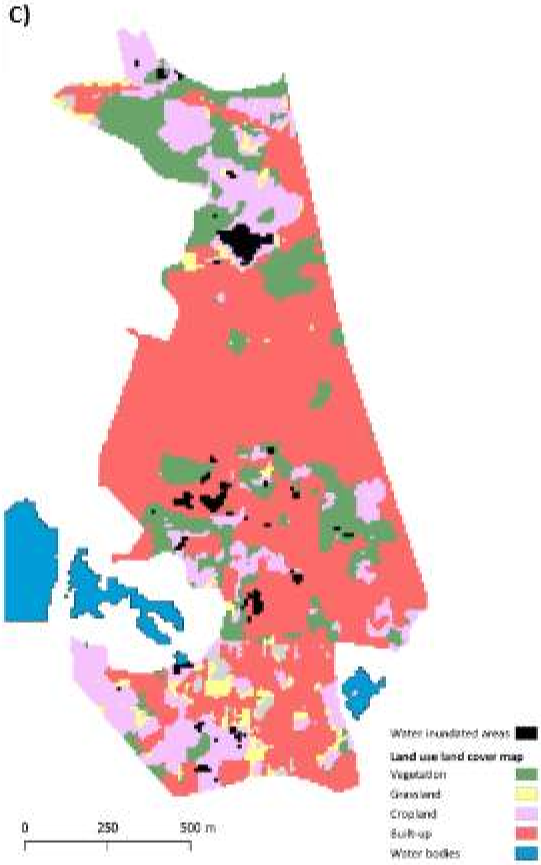
Each spatial layer provides distinct insights. Slope maps identify areas where water is likely to stagnate due to flat terrain, drainage density maps highlight natural flow paths that may cause water buildup, and SAR-based inundation maps depict flooding extents recorded during past events. When combined, these maps enable officials to understand the causes of recurrent flooding in certain areas and guide interventions such as drainage upgrades, desilting, or preventive works (Nardi et al. 2006; Schumann et al. 2009; Zhou et al. 2019a). The analysis could be further strengthened by overlaying stormwater drainage infrastructure, as constructed drainage systems with sufficient capacity are critical to reducing urban flood risk in identified hotspots. These networks function as water-carrying channels that divert excess runoff from an area, underscoring the importance of maintaining an updated repository of such data.

Figure 16: Navsari's very high urban flood risk wards

Ward 2



C)

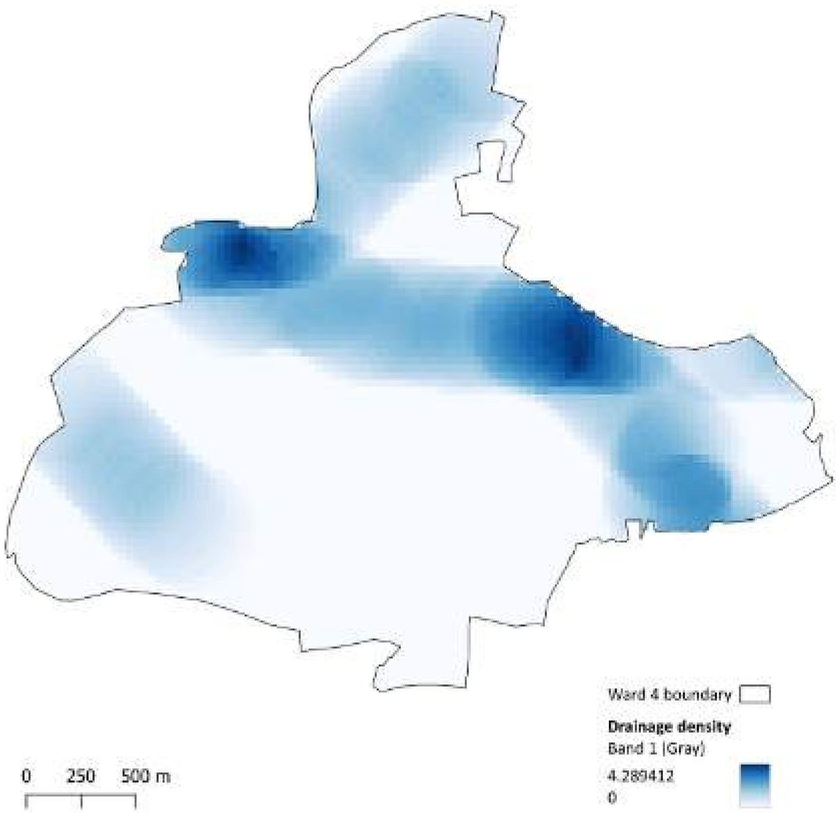

Water inundated areas
Land use land cover map
Vegetation
Grassland
Cropland
Built-up
Water bodies
0
250
500 m

D)

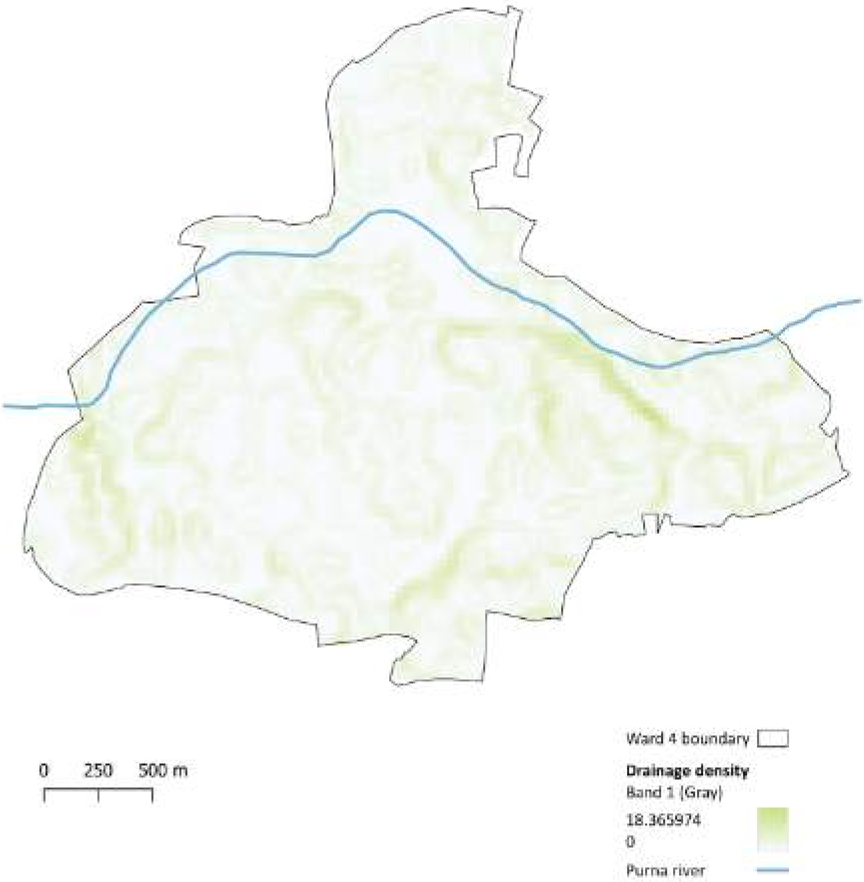

Bandar Road
Bandar Road Area
Taskar Nagar
Raychand Road
Ward 2 boundary
Waterlogging hotspots
Water bodies
0
250
500 m

Ward 4

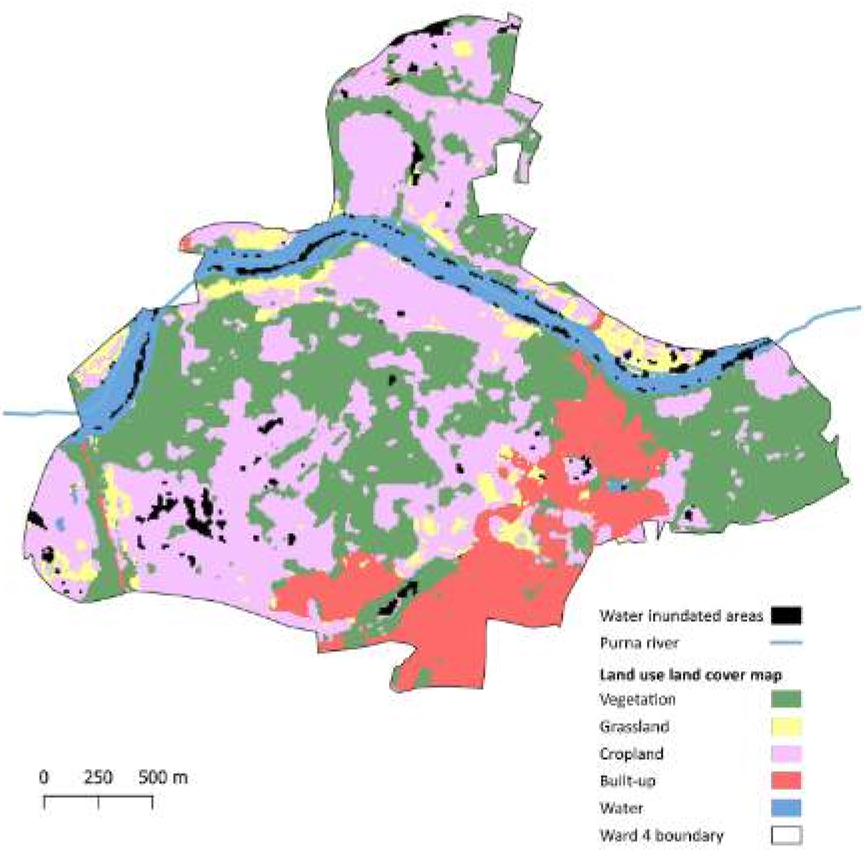
E)


Ward 4 boundary
Drainage density
Band 1 (Gray)
4.289412
0
0
250
500 m

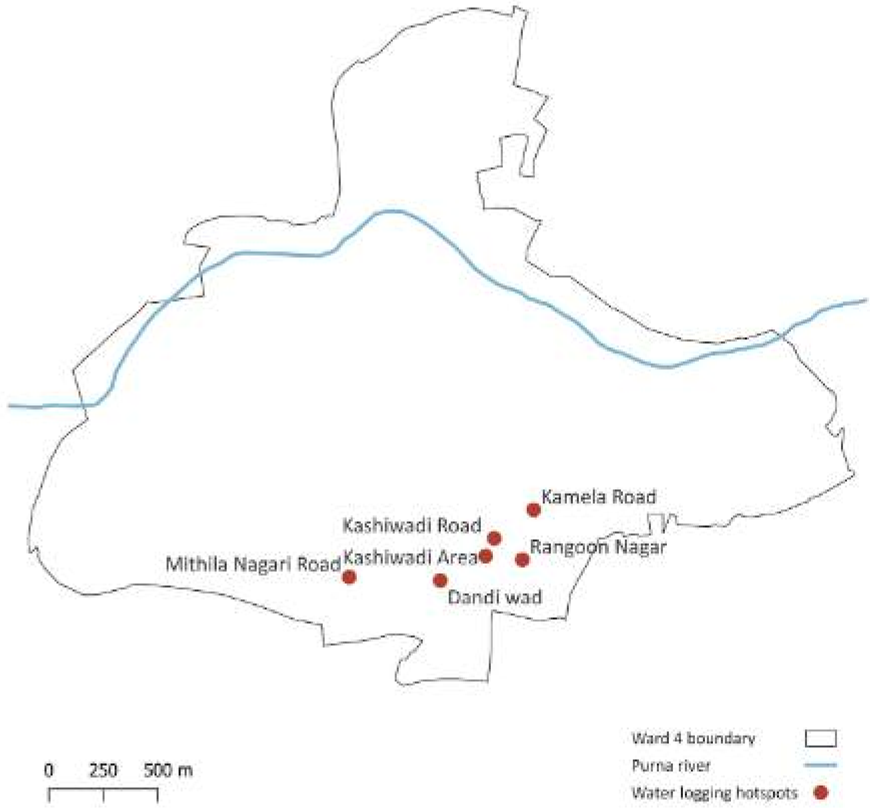
F)


Ward 4 boundary
0 250 500 m
Drainage density
Band 1 (Gray)
18.365974
0
Purna river

G)


Water inundated areas
Purna river
Land use land cover map
Vegetation
Grassland
Cropland
Built-up
Water
Ward 4 boundary
0 250 500 m

H)



Source: Authors' analysis using satellite imagery and data received from NMC

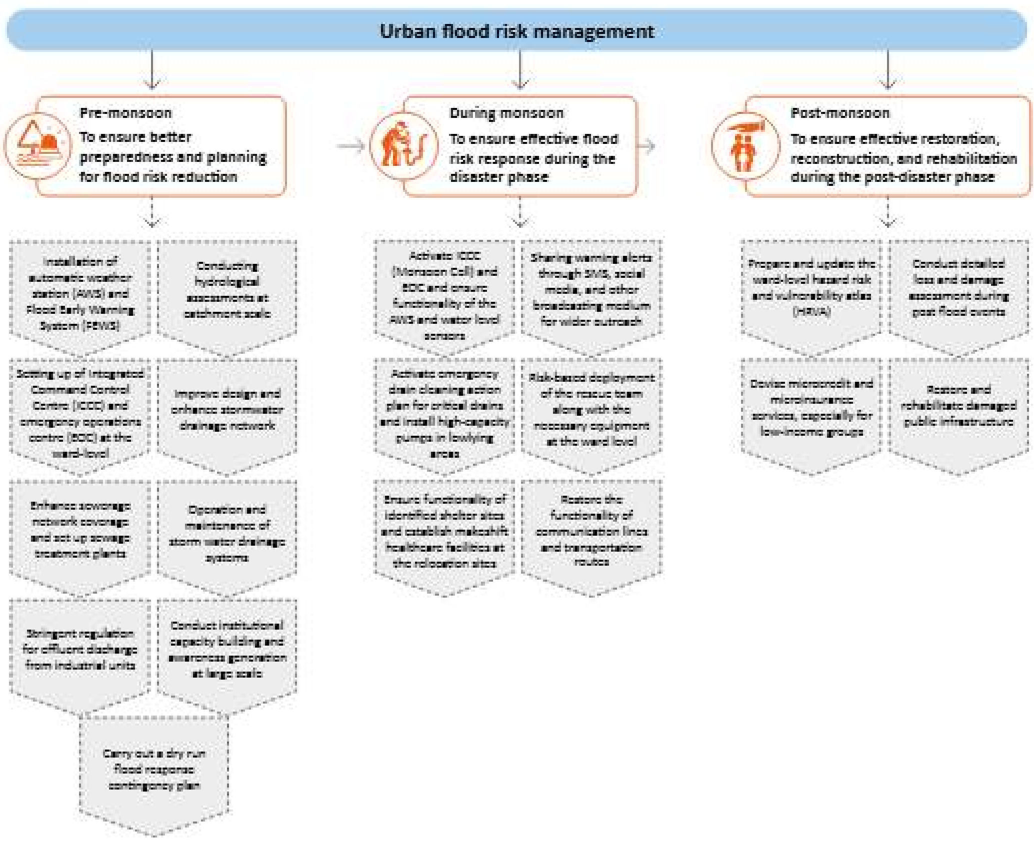
Regular training and capacity building for women's groups, youth organisations, and RWAs can enable swift, coordinated responses—cutting response times and reducing potential losses.

6. Urban flood risk management plan

This section of the action plan presents a set of actionable recommendations, which, once implemented, can play a pivotal role in strategising risk mitigation and adaptation at the ward level. The plan follows a three-phase approach, with recommendations specific to each phase. The pre-monsoon phase (December–May) emphasises better planning and preparedness for flood risk reduction. The monsoon phase (June–September) emphasises the importance of an effective flood risk response during a disaster. The post-monsoon phase (October–November) underscores the importance of ensuring effective restoration, reconstruction, and rehabilitation following a disaster.

Each recommendation elaborates on the existing situation within the city, the standards or design guidelines for the interventions, the spatial prioritisation of the interventions, responsibility allocation, and the expected impact of the suggested intervention over the short term (0–2 years), medium term (3–5 years), and long term (more than 5 years).

Figure 17: An effective urban flood management underlines the importance of phase-wise strategies



Source: Authors' compilation.

6.1 Phase 1: Pre-monsoon phase

This phase is crucial for preparedness and planning purposes. Both structural and non-structural measures must be implemented to mitigate and adapt to flood risks effectively. The details are presented in Table 4.

Table 4: Enhanced planning and preparedness during the pre-monsoon phase can play a pivotal role in flood risk reduction

Ensure better planning and preparedness for flood risk reduction			
Suggested intervention	**Current status, standards, and spatial prioritisation for action**	**Suggested timeline for implementation and responsibility allocation**	**Likely impacts**
Install automatic weather stations (AWS) and flood early warning systems (FEWS)	**Existing situation** None **Design guidelines/standard** • As per the World Meteorological Organization (WMO) norms, there should be at least one AWS for 10–20 sq km. **Spatial prioritisation** • Install AWS in high-risk and very-high-risk wards (wards 1, 2, 3, 4, and 11). • Implement FEWS by deploying automatic water-level sensors at appropriate locations, such as: • On River Purna flowing through wards 1, 4, and 5. • Critical drains and creeks in very-high-risk and high-risk wards (wards 2, 3, 4, and 11).	**Time-bound implementation** Short to medium term **Nodal department** Municipal commissioner office	• This will enable hyperlocal data generation. • AWS and FEWS can aid real-time monitoring of weather parameters. • They can help strengthen early warning systems and flood forecasting.
Conduct hydrological assessments at the catchment scale	**Existing situation** None **Design guidelines/standard** • Planning must begin with a hydrological assessment at the watershed or catchment level, particularly in urbanising zones. • This involves mapping catchment boundaries, flow paths, and outfalls and calculating runoff using rational or unit hydrograph methods. • Design discharge should reflect 2–10 year return periods based on land use and include climate-adjusted rainfall.	**Time-bound implementation** Short to medium term **Nodal department** Drainage department **Supporting department** • Information technology (IT) cell • District disaster management authority • State water resource department	• Catchment-scale hydrological assessments enable accurate, climate-resilient drainage design by mapping runoff paths and sizing infrastructure based on real flow conditions, reducing flooding in vulnerable wards. • This can ensure efficient investment by prioritising high-risk zones, and foster cross-departmental coordination, strengthening the city's long-term flood preparedness and infrastructure resilience.

Ensure better planning and preparedness for flood risk reduction			
Suggested intervention	**Current status, standards, and spatial prioritisation for action**	**Suggested timeline for implementation and responsibility allocation**	**Likely impacts**
	Spatial prioritisation All wards across the components of risk.		
Set up an integrated command control centre (ICCC) at the city level and an emergency operation centre (EOC) at the ward level	**Existing situation** There is no dedicated ICCC at the city level; the corporation depends on data and information received from the district disaster management authority. **Spatial prioritisation** An ICCC needs to be established at the city level, and an EOC at the ward level, in suitable locations.	**Time-bound implementation** Short to medium term **Nodal department** Municipal commissioner office **Supporting department** • Information technology (IT) cell	• The ICCC acts as the master station and receives data from different sources and analyses it. • During the pre-monsoon phase, it provides evidence-based data and analysis for improving preparedness and planning for flood risk mitigation. The EOC can use the same to take action in different wards.
Improve design and enhance the stormwater drainage network	**Existing situation** • The total length of the stormwater drainage network is 180 km. • 30% of wards do not have a separate stormwater drainage network. **Design guidelines/standard** The design capacity should consider a runoff coefficient of up to C = 0.95 and the estimated peak flood flow volume for at least every alternate year. **Spatial prioritisation** • Expand the coverage of the existing stormwater network in very-high-risk (wards 2 and 4) and high-risk wards (wards 1, 3, and 11). • Construct a separate stormwater network in wards 4, 9, and 13 where it is absent.	**Time-bound implementation** Medium to long term **Nodal department** Drainage department **Supporting department** • Town planning department • Road and transport department	• This will increase system efficiency of the drainage network. • This can help mitigate waterlogging and reduce urban flood risks by accommodating high-intensity rainfall.
Proper operation and maintenance of stormwater drainage systems	**Existing situation** • Drain cleaning exercises were carried out 2–3 times annually, but they were limited to 30% of the total drainage network length. • The concretisation of drains at some places in the city has made its maintenance difficult.		

Ensure better planning and preparedness for flood risk reduction			
Suggested intervention	**Current status, standards, and spatial prioritisation for action**	**Suggested timeline for implementation and responsibility allocation**	**Likely impacts**
	Design guidelines/standard • The NIDM recommends at least two desilting cycles before the monsoons, covering 100% of the stormwater network. It also advises against fully sealed concrete drains without access. • It recommends manholes every 30–50 m and at all bends or junctions for proper inspection and cleaning. **Spatial prioritisation** • De-concretise drains and create manholes at appropriate sites. • Develop an annual maintenance calendar. • Construct detention ponds (storage volumes should match a design storm of 1-in-2 or 1-in-5 years) with a previous bottom with proximity to waterlogging hotspots in very-high-risk and high-risk wards.	**Time-bound implementation** Short to medium term **Nodal department** Drainage department	• This will help ensure unobstructed flow and prevent capacity reduction due to silt and waste accumulation. • It can also significantly lower the risk of waterlogging, especially in low-lying areas.
Enhance sewerage network coverage and set up sewage treatment plants	**Existing situation** • The sewerage network length is 290 km, but only 66% of HHs are connected to the sewerage network. • Only 6% of HHs in ward 5, and 50% of HHs in wards 1 and 3, are connected to the sewerage network, making them highly exposed to urban flooding. **Spatial prioritisation** • Prioritise the construction of sewerage networks in wards where they are absent. • HHs in ward 5 need to be prioritised to provide access to the centralised sewerage network. • All new urban sewerage extensions are to be linked with functional sewage treatment plants (STPs), with designed treatment capacity based on per capita flow estimates of 135 litres per person per day (LPCD), accounting for peak flow factors.	**Time-bound implementation** Medium to long term **Nodal department** Drainage department	• This can help prevent waterlogging in open areas and the discharge of used water into stormwater drains, thereby not overwhelming their capacity. • It can also reduce the risk of health hazards during heavy rainfall.

Ensure better planning and preparedness for flood risk reduction			
Suggested intervention	**Current status, standards, and spatial prioritisation for action**	**Suggested timeline for implementation and responsibility allocation**	**Likely impacts**
Ensure industrial units' compliance with the effluent discharge standards	**Existing situation** • There was observed laxity in the implementation of effluent discharge norms, where hazardous waste from the pharmaceutical industry was being directly dumped into open drains that finally merge into the river. • Location observed during field visit: 20°56'33.0"N 72°57'37.0"E (Address: Behind Hotel Fun City) **Spatial prioritisation** Coordinate with Gujarat Industrial Development Corporation (GIDC) and GPCB and conduct regular audits to ensure compliance with effluent discharge regulations.	**Time-bound implementation** Short term **Nodal department** Regional office (Navsari), Gujarat Pollution Control Board	• It can help maintain water quality during flood events when there are high chances of water coming in contact with the community and spiralling into a public health emergency. • It can also help maintain the carrying capacity of open drains and creeks within limits.
Conduct institutional capacity building and awareness generation at a large scale	**Existing situation** • The present institutional approach is directed more towards response and relief measures rather than preparedness and planning. • The NMC has developed a monsoon action plan, which highlights department-wise interventions that need to be undertaken as flood response and relief measures. **Spatial prioritisation** • Prepare a comprehensive training module with well-defined roles and responsibilities for each department, involving experts from SDMA and NDMA. • Carry out a behavioural change campaign involving social media influencers, local leaders, Resident Welfare Association (RWAs), and civil defence to make citizens aware of their responsibilities to mitigate and respond during floods.	**Time-bound implementation** Short to medium term **Nodal department** Municipal commissioner office **Supporting department** • Fire and emergency services • State Disaster Response Force and National Disaster Response Force	This will enable the NMC to test emergency preparedness, identify operational gaps, and ensure swift, coordinated actions during actual flood events, thereby minimising response time and potential losses.

Ensure better planning and preparedness for flood risk reduction			
Suggested intervention	**Current status, standards, and spatial prioritisation for action**	**Suggested timeline for implementation and responsibility allocation**	**Likely impacts**
	• Conduct mock drills before the onset of the monsoons to test flood contingency plans at both the city and ward levels with all relevant key stakeholders.		
Carry out a dry run of the flood response contingency plan	**Existing situation** This is yet to be mainstreamed. **Spatial prioritisation** Conduct regular or periodic pre-monsoon mock drills involving all relevant stakeholders for better preparedness, planning, and response during the disaster phase.	**Time-bound implementation** Short to medium term **Nodal department** Municipal commissioner office	• This will shift the institutional approach towards preparedness, planning, and promoting community participation. • It will also ensure effective and inclusive implementation of flood risk reduction measures at all levels.

Source: Author's analysis using information from NDMA. 2019. National Disaster Management Plan. New Delhi: National Disaster Management Authority, NDMA. 2010. National Disaster Management Guidelines: Management of Urban Flooding. New Delhi: National Disaster Management Authority and consultation with NMC departments.

6.2 Phase 2: Monsoon phase

In the monsoon phase (June–September), prompt action is required for effective flood response. The details are presented in Table 5.

Table 5: Adopting multi-pronged strategy is a key for effective flood response during the monsoon phase

Ensure effective flood risk response during the monsoon phase			
Suggested intervention	**Current status, standards, and spatial prioritisation for action**	**Likely timeline for implementation and responsibility allocation**	**Potential impacts**
Activate ICCC (monsoon cell) and EOC, and ensure functionality of the AWS and water-level sensors	**Existing situation** - None **Spatial prioritisation** Active command control at the city level and EOC at ward levels.	**Time-bound implementation** Short term **Nodal department** Municipal commissioner office **Supporting department** IT cell	This will bring city-level flood forecasting and alert systems into mission mode, ensuring a coordinated response and the timely deployment of response and relief measures.
Share warning alerts through SMS, social media, and other broadcasting media for wider outreach	**Existing situation** - None **Spatial prioritisation** Embed ICCC with social media and other broadcast mediums such as SMS alerts and community radio for wider outreach, in line with the 'Dos and Don'ts' guidelines.	**Time-bound implementation** Short term **Nodal department** ICCC under the municipal commissioner office	This would enhance community preparedness and enables timely evacuation and risk reduction, especially in very-high-risk and high-risk wards.

Ensure effective flood risk response during the monsoon phase			
Suggested intervention	**Current status, standards, and spatial prioritisation for action**	**Likely timeline for implementation and responsibility allocation**	**Potential impacts**
Activate emergency drain cleaning action plan for critical drains and install high-capacity pumps in low-lying areas	**Existing situation** The engineering department is responsible for gutter and pothole cleaning under the *Monsoon Action Plan*. **Design guidelines/standard** • The Ministry of Housing and Urban Affairs (MoHUA) recommends that urban drains should be designed for rainfall intensities of 12–20 mm/hr. However, in practice, these systems frequently experience overflow due to debris-induced blockages, particularly in cities with stormwater network coverage as low as 20%. • High-capacity pumps are essential where runoff cannot be drained by gravity, with sizing based on peak hydrograph detention and net positive suction head (NPSH) curve requirements. **Spatial prioritisation** • Emergency drain cleaning action plan for critical drains in wards 1, 2, 3, 4, and 11. • Installation of high-capacity pumps near eight waterlogging points in wards 1, 2, 3, 4, and 11.	**Time-bound implementation** Short term **Nodal department** Drainage department **Supporting department** • Public health department	• Emergency drain cleaning restores the designed flow by clearing solid waste and silt, even at moderate rainfall. • High-capacity pumps at low-lying sites can overcome terrain limitations in flat urban areas.
Risk-based deployment of the rescue team, along with the necessary equipment, at the ward level	**Existing situation** The fire department is mandated to ensure the functionality of boats, assign staff, and demarcate waterlogging hotspots with ropes under the *Monsoon Action Plan*. **Spatial prioritisation** • Deployment of additional staff at EOCs in very-high-risk and high-risk wards. • Maintain additional inventory of necessary equipment such as dewatering pumps, boats, life jackets, ropes, and emergency vehicles and ambulances on standby in very-high-risk and high-risk wards.	**Time-bound implementation** Short term **Nodal department** Fire and emergency services **Supporting department** • District disaster management authority (DDMA) • Police • Public health • Civil defence	• As per the NIDM, the decentralised deployment of rescue teams, aligned with ward-level risk maps, enables an immediate response, especially in densely populated or low-lying areas where external teams may face access delays. • Localised presence is critical to reduce dependence on centralised command during fast-onset events.

Ensure effective flood risk response during the monsoon phase			
Suggested intervention	**Current status, standards, and spatial prioritisation for action**	**Likely timeline for implementation and responsibility allocation**	**Potential impacts**
			• Many urban flood casualties are preventable if critical equipment (boats, ropes, life jackets, and dewatering units) are pre-positioned at identified hotspots.
Ensure the functionality of the identified shelter sites and establish makeshift healthcare facilities at relocation sites	**Existing situation** The drainage department is responsible for maintaining schools and other critical infrastructure under the *Monsoon Action Plan*. **Spatial prioritisation** • Along with very- high- and high-risk wards, prioritise the functionality of shelter sites in wards 5 , 6 and 12 due to the presence of a large number of slum settlements and persons with disabilities (PwD), thus being highly sensitive. • Ensure that the shelter sites are hygienic, with access to safe drinking water, food packets, and essential medicines. • Shelter sites should be equipped with first-aid care, deploy medical staff, provide ambulance services, and have an adequate supply of medicines, disinfectants, and equipment.	**Time-bound implementation** Short term **Nodal department** District disaster management authority (DDMA) **Supporting department** • Fire and emergency services • Public health • Urban community department • Urban development department	• This will ensure safe evacuation, immediate medical support, and continuity of essential services for displaced populations, especially in high-sensitive wards. • Makeshift healthcare facilities at relocation sites are crucial for preventing secondary health crises. • A pre-flood stockpile of medical supplies, as well as mobile health teams that can be deployed in coordination with urban health missions, must be maintained.
Restore the functionality of communication lines and transportation routes	**Existing situation** The light department is mandated to survey and maintain electric poles and growing trees near schools and flood-prone areas under the *Monsoon Action Plan*. **Spatial prioritisation** • There is a need to set up an integrated flood relief helpline service (immediate rescue information/ fire/ambulance/ police, and others), which is coordinated through the ICCC. • Prioritise the repair and restoration of critical infrastructure, such as roads, hospitals, and railway lines, to ensure the effective mobilisation and execution of flood response services.	**Time-bound implementation** Short term **Nodal department** • Road and transport department • Telecommunication department	This will ensure the immediate restoration of key mobility corridors, particularly roads to hospitals, railway stations, and relief centres.

Source: Authors' analysis using information from NDMA. 2019. National Disaster Management Plan. New Delhi: National Disaster Management Authority, NDMA. 2010. National Disaster Management Guidelines: Management of Urban Flooding. New Delhi: National Disaster Management Authority, and consultation with NMC departments.

6.3 Phase 3: Post-monsoon phase

In this phase, the focus is on recovery, rehabilitation, and reconstruction to restore affected communities and improve resilience. The details are presented in Table 6.

Table 6: Post-monsoon efforts should prioritise strategic restoration, reconstruction, and rehabilitation planning

Ensure effective restoration, reconstruction, and rehabilitation during the post-monsoon phase			
Suggested intervention	**Current status, standards, and spatial prioritisation for action**	**Likely timeline for implementation and responsibility allocation**	**Potential impacts**
Prepare and update the ward-level hazard risk and vulnerability atlas (HRVA)	**Existing situation** • NMC updates the *City Disaster Management Plan annually*. **Design guidelines/standard** • Risk assessment based on the IPCC AR5 framework. **Spatial prioritisation** • Prepare and document micro-scale hazard vulnerability and zoning maps, especially for high and very-high-risk wards (wards 1, 2, 3, 4, and 11) to prioritise the development of appropriate mitigation plans. • Update urban flood risk assessment on a pre-determined schedule.	**Time-bound implementation** Short term **Nodal department** Municipal commissioner office	• This will enable targeted flood mitigation planning and ensure efficient resource allocation and response strategies tailored to local vulnerabilities.
Conduct a detailed loss and damage assessment during post-flood events	**Existing situation** • This is yet to be mainstreamed. **Design guidelines/standard** • The values of the indicators adopted in the risk assessment framework (hazard, exposure, and vulnerability), which are based on past flooding events, can guide the development of the baseline for the loss and damage assessment. **Spatial prioritisation** • Prepare a damage assessment baseline from past flooding events, which should include damage to public property, loss of lives, and population affected. • Based on the baseline prepared, demarcate very-high-risk and high-risk wards in terms of the extent of damage.	**Time-bound implementation** Short to medium **Nodal department** Revenue department **Supporting department** • District disaster management authority • Urban community department • Fire and emergency services • Urban development department	• This would guide compensation and rehabilitation measures, and support improvements in future flood preparedness and infrastructure resilience.

Ensure effective restoration, reconstruction, and rehabilitation during the post-monsoon phase			
Suggested intervention	**Current status, standards, and spatial prioritisation for action**	**Likely timeline for implementation and responsibility allocation**	**Potential impacts**
Devise microcredit and micro-insurance services, especially for low-income groups	**Existing situation** This is yet to be mainstreamed. **Spatial prioritisation** • Map ward-wise vulnerable urban populations using the urban flood risk index (UFRI) developed by CEEW for Navsari. • Explore appropriate PPP models for delivering micro-insurance and micro-credit services.	**Time-bound implementation** Medium to long term **Nodal department** Revenue department **Supporting department** • Urban community department	• This will help in building the adaptive capacity of low-income communities by providing a financial buffer against flood-related shocks. • It would further support livelihood recovery and promote long-term resilience against recurring urban flood risks.
Restore and rehabilitate damaged public infrastructure	**Existing situation** This is yet to be mainstreamed. **Spatial prioritisation** • Develop a time-bound plan for flood-proofing of strategy and public utility services, especially in high-risk and very-high-risk wards (wards 1, 2, 3, 4, and 11) and high-risk and very- high-risk wards (wards 1, 4, 5, 12, and 13).	**Time-bound implementation** Short to medium term **Nodal department** Public works department **Supporting department** • Road and transport department • Town planning department • Public health department	• This will ensure the continuity of essential services, reduce long-term disruptions, and strengthen the resilience of urban systems against future flood events.

Source: Authors' analysis using information from NDMA. 2019. National Disaster Management Plan. New Delhi: National Disaster Management Authority, NDMA. 2010. National Disaster Management Guidelines: Management of Urban Flooding. New Delhi: National Disaster Management Authority, and consultation with NMC departments.

6.4 Cost estimation of structural intervention for flood risk management

The interventions recommended across each phase of the flood risk management plan are categorised into hard and soft measures. Efforts have been made to quantify specific complex interventions and provide tentative cost estimates (Table 7) to support the NMC in assessing the level of investment likely required for implementing key recommendations in the plan.

Table 7: Effective flood risk management plan underlines the need for dedicated investment plan

Intervention	Phase of intervention	Duration	Present unit cost	Estimated present cost (Requirement based on recommendations)	Assumptions (if any)
Installation of automatic weather stations (AWS) and flood early warning systems (FEWS)	Pre-monsoon	Short to medium term	**Automatic weather station (AWS)** INR 8–10 lakh	**Automatic weather stations (AWS)** INR 64 lakh–1 crore	**Automatic weather stations (AWS)** • Total number of units: 2

Intervention	Phase of intervention	Duration	Present unit cost	Estimated present cost (Requirement based on recommendations)	Assumptions (if any)
			Flood early warning system (FEWS) INR 88,000–1 Lakhs	**Flood early warning system (FEWS)** INR 4,40,000–5 lakhs	• Installation of one AWS in each very-high-risk ward zone (wards 2 and 4). **Flood early warning systems (FEWS)** • Total number of units: 5 • Installation of each (FEWS) in critical drains of wards 2, 3, 4, and 11 and one on River Purna (border between wards 4 and 5).
Improve design and enhance the stormwater drainage network	Pre-monsoon	Medium to long term	**Cost of laying down the drainage line** INR 15,000–18,000 per metre	**Total cost of laying down the drainage network** INR 315–378 crore (approx) **Assumption and calculation** Total drainage network = Total road length = 390 km (approx) Existing drainage network = 180 km Remaining = 390-180 = 210 km Unit cost = INR 2,350–2,950 per metre Total estimated cost = (210*10^3*2, 350) to (210*10^3*2, 950)	Pipe specification is suggested to handle the peak discharge (Q) of 10 cumecs per sq km (Section 5.2) for a 1.82-degree average slope. The following assumptions were considered for laying down the drainage line. Pipe diameter: 1,400 mm Material: RCC NP3 (reinforced cement concrete, non-pressure class 3): Standard for underground stormwater/sewer drains Depth of trench: 1.5 to 2.0 m (moderate depth typical for city drainage) Bedding material: Sand bedding Location type: Urban area (includes bituminous road cutting and restoration)

Intervention	Phase of intervention	Duration	Present unit cost	Estimated present cost (Requirement based on recommendations)	Assumptions (if any)
					Includes: Excavation, pipe cost, laying, jointing, backfilling, and road reinstatement
Enhance sewerage network coverage and set up a sewage treatment plant	Pre-monsoon		**Capital expenditure (CAPEX)** INR 1.56 crore per MLD **Operation and maintenance (O&M) cost** INR 18–20 lakh per MLD per year	**Capital expenditure (CAPEX)** INR 10 crore **Operation and maintenance (O&M) cost** INR 5.2–5.8 crore per year	**Capital expenditure (CAPEX)** • Estimated sewerage generation: 54 MLD • Gap between installed treatment capacity and sewerage generation: 7 MLD • CAPEX estimated for 7 MLD **Operation and maintenance (O&M) cost** • Operational capacity: 18 MLD • Installed capacity: 47 MLD • Gap between installed and operational capacity: 29 MLD • OPEX estimated for 29 MLD Note: • Water supply: 150 MLD • Design period: 30 years • Inflation adjusted: 5% • Technology considered: SBR (secondary)

Source: Authors' analysis using data and information from NMCG. 2010. "Sewage Treatment in Class I Towns: Recommendations and Guidelines." New Delhi: National Mission of Clean Ganga (NMCG), Ministry of Jal Shakti (MoJS), GWSSB. 2022. "Schedule of Rates 2022-23." Gandhinagar, Gujarat: Gujarat Water Supply and Sewerage Board, Mumbai live. 2024. "60 New Automatic Weather Stations Installed across Mumbai - Here's All You Need to Know." Mumbai Live. April 2024.

7. Financing for effective flood risk management

This section reviews funding provisions in existing national missions, explores various public–private partnership (PPP) models essential for developing flood-resilient infrastructure, and outlines a framework for integrating climate and disaster risk to build resilient PPP infrastructure.

7.1 Funding provision for flood risk management

Ongoing programmes of the Indian government that can fund flood-resilient infrastructure projects include *Atal Mission for Rejuvenation and Urban Transformation* 2.0 (AMRUT 2.0), *Flood Management* and the *Border Area Programme* (Table 8). Additionally, we recommend incorporating flood-proofing measures in all critical infrastructure projects and mainstreaming them into state-level programmes to ensure adequate budgetary allocations at the ULB level. We also recommend the creation of special-purpose vehicles for the development of flood-resilient infrastructure. ULBs should also explore PPP-based financial models to implement flood-resilient infrastructure projects, which can enable effective risk sharing, distributed responsibility, and optimum utilisation of limited financial resources.

Table 8: Fund allocation and fund-sharing arrangements of national schemes for flood risk response and mitigation

Schemes	Objectives and targets (if any)	Fund allocation	Fund sharing arrangement (centre: state)
Flood Management and Border Area Programme (FMBAP)	FMBAP enables the state/UT governments to provide a reasonable degree of protection against floods/ erosion by adopting structural measures in critical flood-/ erosion-prone areas.	• Total outlay of INR 4,100 crore for a period of 5 years from 2021–22 to 2025–26. • Under the *Flood Management Programme* (FMP), a component of FMBAP, an outlay of INR 2,940 crore for the following activities: a. flood control b. anti-erosion c. drainage development d. anti-sea erosion	60:40

Schemes	Objectives and targets (if any)	Fund allocation	Fund sharing arrangement (centre: state)
AMRUT 2.0	• 100% coverage of sewerage/ septage management in 500 AMRUT cities by 2025–26. • Creation or strengthening of stormwater drains around the water body. • Development of the community green spaces linked to a clean water body.	• Total indicative outlay is INR 2,99,000 crore, including the central share of INR 76,760 crore over 5 years.	25:75 (except for projects under PPP mode)
15th Finance Commission	• The 15th FC has recommended the creation of the National Disaster Risk Management Fund (NDRMF) and the State Disaster Risk Management Funds (SDRMF), going beyond disaster response.	**SDRMF** • Allocation of INR 1,60,153 crore in the SDRMF for the period 2021–26: • Of which, 80% of SDRMF is for disaster response (SDRF) and 20% for disaster mitigation. **NDRMF** • INR 68,463 crore has been allocated for NDRMF for the period of 2021–22 to 2025–26: • Of which, 80% is for disaster response and 20 per cent% for disaster mitigation.	For both SDRF and SDMF, 75:25

Source: Authors' analysis using data from MoHUA. 2021. "Atal Mission for Rejuvenation and Urban Transformation 2.0 AMRUT 2.0 Making Cities Water Secure Operational Guidelines." New Delhi: Ministry of Housing and Urban Affairs (MoHUA), Government of India (GoI); NDMA. 2021. "National Disaster Risk Management Fund (NDRMF) and State Disaster Risk Management Fund (SDRMF)." Disaster Management Division, Ministry of Home Affairs, Government of India.

7.2 Financial models

Alongside conventional funding mechanisms, innovative financing tools for flood-resilient infrastructure projects can be highly beneficial. The *National Green Credit Programme* (MoEFCC 2023) offers credits for voluntarily adopting environmentally friendly practices, including wastewater treatment and reuse. The private sector can also be approached to invest in the projects under their corporate social responsibility (CSR) obligations. For instance, Hindustan Zinc Limited (HZL) contributed to Udaipur's water management by establishing a 60 MLD STP as part of its CSR obligation. The treated used water (TUW) from this plant is mainly reused in HZL's industries.

Other innovative financial models are also crucial for effective implementation. The hybrid annuity model (HAM), introduced by the *National Mission for Clean Ganga* (NMCG), encourages private-sector investment in used water treatment infrastructure. Under this model, government payback is linked to the plant's performance in terms of adherence to pre-defined key performance indicators. Similarly, different PPP models can be leveraged by ULBs to develop flood-resilient infrastructure, such as TUW reuse projects, stormwater drainage infrastructure, and hydrological observation and flood forecasting systems. The PPP models can also be utilised to flood-proof critical infrastructure, including transport, healthcare, urban housing, allied infrastructure, and other urban systems. Table 9 provides various PPP models, highlighting the roles and responsibilities of public and private sector, risk-sharing arrangements, and their tentative applications in flood-resilient infrastructure.

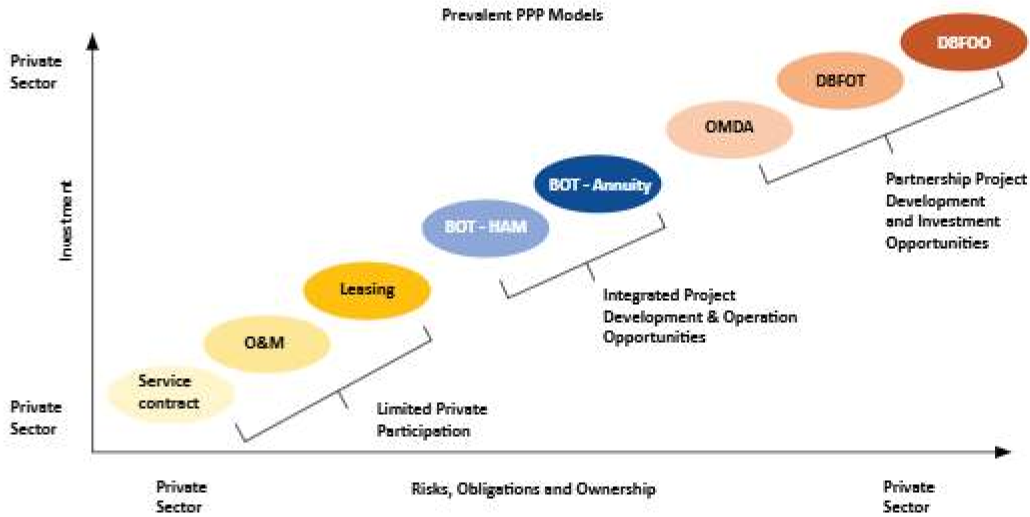
Table 9: Catalogue of public–private partnership (PPP) models that can be leveraged for developing flood-resilient infrastructure with active private-sector participation

PPP model	Role of the public sector	Role of the private sector	Risk-sharing arrangement	Applicability in flood risk management
Service contract	• Define service scope • Provide existing infrastructure • Pay fixed service fee • Monitor performance	• Provide operation and management (O&M) services • Supply/install equipment • Maintain service standards	Public sector: • Ownership, finance, and CAPEX risk • Private sector • Limited O&M performance risk	Short-term services like: • Drain cleaning • AWS installation and maintenance • Pump operations during monsoon
O&M contract	• Provide necessary infrastructure and fulfil data requirements • Pay fixed/incentive-based O&M fees • Monitor the key performance indicators (KPIs)	• Operate and maintain existing assets • Meet performance KPIs • Carry out innovation to improve efficiency	Public sector: • Retains all financial and design risks Private sector • O&M and minor service risks	Medium-term contracts for: • Operating stormwater pumps • Supervising green infrastructure • Early warning dissemination
DBFOT (Design–Build–Finance–Operate–Transfer)	• Facilitate land acquisition and regulatory clearances • Regulate service tariffs (if user-pay model) • Provide annuity/VGF if needed • Monitor through an independent engineer (IE)	• Design and construct an asset • Raise capital for the project • Operate and maintain over the concession period • Transfer asset at the end	Public sector: • Bears demand risk (if annuity) and force majeure risk to a degree Private sector: • Bears design, construction, finance, and O&M risk	End-to-end delivery of extensive flood infrastructure, such as: • Stormwater infrastructure • Flood retention parks • Integrated drainage corridors
BOT (Build–Operate–Transfer) HAM (Hybrid Annuity Model)	• Fund 40% upfront; 60% via annuity • Approve designs • Monitor compliance and disburse payments	• Build infrastructure with partial upfront finance • O&M for a fixed term	Public sector: • Partial financial risk and demand risk Private sector: • Construction and O&M risk	Suitable for flood control infrastructure and flood proofing of critical assets, where partial public funding is feasible
DBFOO (Design–Build–Finance–Own–Operate)	• Facilitate permits • Procure as a service (cloud/software)	• Build and own digital infrastructure • Charge ULBs for services • Maintain the platform and provide upgrades	Public sector: • Integration and payment risk Private sector: • Bears all the risk, including tech obsolescence	Emerging AI and machine learning models for digital flood monitoring systems and flood-risk analytics platforms, where ownership may remain private

Source: Authors' analysis using information from Department of Economic Affairs. 2023. "Reference Guide for PPP Project Appraisal." New Delhi: Infrastructure Finance Secretariat, Ministry of Finance, Government of India.

The PPP model mentioned in Table 9 falls under different PPP categories, depending on the extent of private-sector participation and the sharing of risk, obligation, and ownership (ROO) between the public and private sectors.

Figure 17: Categorisation of PPP models based on the extent of private-sector participation



Source: Department of Economic Affairs. 2023. "Reference Guide for PPP Project Appraisal." New Delhi: Infrastructure Finance Secretariat, Ministry of Finance, Government of India.

This would serve as a reference for NMC to enter PPP arrangements for flood-resilient infrastructure projects, depending on their local context and the ability to share ROOs.

8. Areas of future work

The *Navsari City Action Plan for Flood Risk Management* is the first of its kind for the city. While a comprehensive assessment was undertaken to recommend flood management interventions, specific nuances require further detailing and should be considered in future revisions of the plan. These include:

- **Integrating climate projections:** Climate change is expected to alter rainfall intensity and patterns in Navsari, increasing flood risk. While this plan relies on past and present trends, future updates should incorporate climate projections to ensure accuracy and relevance. In addition to daily rainfall, sub-daily rainfall should be recorded and factored into drainage system design, operations, and flood response. Automatic rain gauges (ARGs) and AWS should be installed across the city in line with NDMA guidelines.

- **Managing rapid urban expansion:** With Navsari's recent upgrade from a municipality to a municipal corporation, the city will undergo rapid urban expansion, leading to substantial land-use changes. As the built-up area increases, there is a growing risk of obstructing natural drainage channels. These natural streams (*nullahs*) not only form an integral part of the city's ecology, but they also serve as vital conduits for carrying stormwater runoff. Sewerage infrastructure must be developed alongside urban growth, but natural drainage systems must be preserved. In addition to prioritising the separation of stormwater and sewerage networks, city-specific initiatives, such as a drainage master plan, must align with the recommendations of this action plan. This ensures that natural drainage channels are preserved, cleaned regularly, and safeguarded against encroachment and degradation.

- **Protecting critical infrastructure:** This action plan has identified urban flood hotspots across administrative wards falling within the very-high-risk category. Critical infrastructures, such as hospitals, schools, fire stations, major roads, and electrical substations located within these zones are vulnerable to inundation during flood events. Therefore, it is essential to map these critical infrastructures spatially and prepare a dedicated inventory. This will enable targeted protection measures to be implemented in line with the recommendations outlined in the plan.

- **Strengthening solid waste management:** Effective implementation of an urban solid waste management policy in Navsari is crucial to support flood-mitigating activities identified under the plan. The policy should emphasise community involvement and awareness of the adverse impacts of solid waste accumulation in drains, which causes blockages and worsens local flooding. Additionally, precise coordination mechanisms must be established between the municipal solid waste department and the stormwater drainage division to ensure that cleaning schedules are aligned, and responsibilities are not fragmented across departments.

- **Ensuring financial feasibility:** An economic feasibility assessment is necessary to determine the practicality of implementing the suggested recommendations. Further, the sources of funds, whether from the central, state, or local administration, must be determined. Potential funding streams include the National Mission on Sustainable Habitat (NMSH), AMRUT 2.0, and various NDMA initiatives.

Strengthening sewerage infrastructure along with urban growth, and preserving natural drainage systems, is critical to long-term flood resilience in Navsari.

Acronyms

AC	adaptive capacity
AHP	analytic hierarchy process
AI	artificial intelligence
ARG	automatic rain gauge
AWS	automated weather stations
BOT	Build–operate–transfer
BPL	below poverty line
CPHEEO	Central Public Health and Environmental Engineering Organisation
CR	consistency ratio
CSR	corporate social responsibility
dB	decibel
DBFOO	Design–build–finance–own–operate
DBFOT	Design–build–finance–operate–transfer
DDMA	district disaster management authority
EOC	emergency operations centre
FEWS	flood early warning systems
FMBAP	Flood Management and Border Area Programme
FMP	Flood Management Programme
GEE	Google Earth Engine
GIDC	Gujarat Industrial Development Corporation
GIS	geographic information system
GPCB	Gujarat Pollution Control Board
HAM	hybrid annuity model
HH	household
HRVA	hazard risk vulnerability analysis
HZL	Hindustan Zinc Limited
ICCC	Integrated Command and Control Centre
IDF	intensity–duration–frequency
IMD	Indian Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
KPI	key performance indicators
LULC	land use and land cover
LPCD	litres per person per day
MLD	million litres per day
MoHUA	Ministry of Housing and Urban Affairs
NbS	nature-based solutions

NDMA	National Disaster Management Authority
NDRF	National Disaster Response Force
NDRMF	National Disaster Risk Management Fund
NGO	non-governmental organisation
NMCG	*National Mission for Clean Ganga*
NMSH	*National Mission on Sustainable Habitat*
NMC	Navsari Municipal Corporation
NPSH	net positive suction head
O&M	operations and maintenance
PPP	public-private partnership
PWD	public works department
R&R	response and relief
ROO	risk, obligation, and ownership
RWA	resident welfare association
SAR	Synthetic aperture radar
SDRF	State Disaster Response Force
SDRMF	State Disaster Risk Management Funds
STP	sewage treatment plant
TUW	treated used water
UFRI	urban flood risk index
UN-SPIDER	United Nations Platform for Space-Based Information for Disaster Management and Emergency Response
ULB	urban local body
WASH	water, sanitation and hygiene
WMO	World Meteorological Organization

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