LAND USE PLANNING FOR INTEGRATED URBAN FLOOD RISK MANAGEMENT: A CASE OF NARMADAPURAM CITY

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by

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DEPARTMENT OF ARCHITECTURE AND PLANNING

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LIST OF ABBREVIATIONS

ADB – Asian Development Bank

AI – Artificial Intelligence

AR6 – Sixth Assessment Report (IPCC)

BDI – Blue-Green Infrastructure *(when used as BGI)*

BGI – Blue-Green Infrastructure

CPCB – Central Pollution Control Board

CRED – Centre for Research on the Epidemiology of Disasters

CDMP – City Disaster Management Plan

CIRIA – Construction Industry Research and Information Association

CLUP – Comprehensive Land Use Plan

CRZ – Coastal Regulation Zone

DP – Development Plan

DPR – Detailed Project Report

DRR – Disaster Risk Reduction

EEA – European Environment Agency

EIA – Environmental Impact Assessment

FEMA – Federal Emergency Management Agency

FRM – Flood Risk Management

FRA – Flood Risk Assessment

GFDRR – Global Facility for Disaster Reduction and Recovery

GHG – Greenhouse Gas

GIS – Geographic Information System

GLOF – Glacial Lake Outburst Flood

HFL – High Flood Level

HUDCO – Housing and Urban Development Corporation

ICT – Information and Communication Technology

IFM – Integrated Flood Management

IMD – India Meteorological Department

IPCC – Intergovernmental Panel on Climate Change

IUFM – Integrated Urban Flood Management

LID – Low Impact Development

LULC – Land Use Land Cover

MCGM – Municipal Corporation of Greater Mumbai

MCC – Municipal Corporation of Chennai

MoHUA – Ministry of Housing and Urban Affairs

NCMC – National Crisis Management Committee

NDMA – National Disaster Management Authority

NIDM – National Institute of Disaster Management

NOAA – National Oceanic and Atmospheric Administration

OECD – Organisation for Economic Co-operation and Development

PMP – Probable Maximum Precipitation

PPP – Public–Private Partnership

PMC – Patna Municipal Corporation

RTP – Regional Transport Plan

RS – Remote Sensing

SDG – Sustainable Development Goals

SOP – Standard Operating Procedure

SPP – Spatial Planning Policy

SuDS – Sustainable Drainage Systems

TDR – Transfer of Development Rights

TOD – Transit-Oriented Development

ULB – Urban Local Body

UNDRR – United Nations Office for Disaster Risk Reduction

UN-Habitat – United Nations Human Settlements Programme

USGCRP – U.S. Global Change Research Program

WMO – World Meteorological Organization

WRD – Water Resources Department

WSUD – Water Sensitive Urban Design

WTP – Water Treatment Plan

ABSTRACT

Due to the combined effects of climate change, intense rainfall, unchecked urbanization, and the deterioration of natural drainage systems, urban flooding has become a more serious issue globally. Impervious surface expansion, encroachment on wetlands and floodplains, and poorly designed or maintained drainage infrastructure are the main causes of frequent and highly impactful floods in Indian cities. Given that traditional structural measures by themselves are inadequate for long-term resilience, this dissertation explores the crucial role that land use planning plays in integrated urban flood risk management. Through an extensive review of international policies, Indian guidelines, technological tools, and case studies, Phase I provides a thorough conceptual foundation. It synthesizes thematic insights on blue-green solutions, climate-adaptive planning, infrastructure strategies, spatial planning tools, and governance integration. Phase II provides an empirical framework for utilizing GIS-based assessment and policy evaluation to analyze spatial patterns, built form features, and infrastructure performance. In order to incorporate risk-sensitive zoning, ecosystem restoration, sustainable drainage techniques, and better institutional coordination into urban development processes, the study intends to create an integrated land use and infrastructure-based planning framework. In rapidly urbanizing Indian contexts, the research advances flood-responsive and climate-resilient urban planning by bridging theoretical insights with practical planning approaches.

Keywords : Urban Flooding, Urban Flood Risk, Land Use Planning, Urban Flood Risk Management.

सारांश

जलवायु परिवर्तन, अत्यधिक वर्षा, अनियंत्रित शहरीकरण, और प्राकृतिक जलनिकासी प्रणालियों के क्षरण के संयुक्त प्रभावों के कारण विश्वभर में शहरी बाढ़ एक गंभीर समस्या बनती जा रही है। भारत के शहरों में अभेद्य सतहों का बढ़ना, आर्द्रभूमियों और बाढ़भूमि क्षेत्रों पर अतिक्रमण, तथा खराब रूप से डिज़ाइन या रखरखाव किए गए जलनिकासी तंत्र—ये सभी बार-बार होने वाली और अत्यधिक प्रभावी शहरी बाढ़ के मुख्य कारण हैं। परंपरागत संरचनात्मक उपाय दीर्घकालिक लचीलापन सुनिश्चित करने के लिए अब पर्याप्त नहीं माने जाते। इसी पृष्ठभूमि में, यह शोध प्रबंध समग्र शहरी बाढ़ जोखिम प्रबंधन में भूमि उपयोग नियोजन की महत्वपूर्ण भूमिका का अध्ययन करता है। अंतरराष्ट्रीय नीतियों, भारतीय दिशानिर्देशों, तकनीकी उपकरणों और केस-स्टडीज़ की विस्तृत समीक्षा के माध्यम से चरण-I मजबूत वैचारिक आधार प्रस्तुत करता है। यह ब्लू-ग्रीन इंफ्रास्ट्रक्चर, जलवायु-अनुकूल नियोजन, अवसंरचना रणनीतियों, स्थानिक नियोजन उपकरणों और सुशासन एकीकरण से संबंधित प्रमुख विषयों का समन्वित विश्लेषण प्रदान करता है। चरण-II में GIS आधारित मूल्यांकन और नीति विश्लेषण का ढांचा विकसित किया गया है, जिससे स्थानिक पैटर्न, निर्मित पर्यावरण (built form) की विशेषताओं, तथा अवसंरचनाओं के प्रदर्शन का अध्ययन किया जा सके।इस अध्ययन का उद्देश्य एक ऐसा समग्र भूमि उपयोग एवं अवसंरचना-आधारित नियोजन ढांचा तैयार करना है, जिसमें जोखिम-संवेदनशील ज़ोनिंग, पारिस्थितिक पुनर्स्थापन, सतत जलनिकासी तकनीकें (SuDS), और बेहतर संस्थागत समन्वय को शहरी विकास प्रक्रियाओं में प्रभावी रूप से शामिल किया जा सके।तेज़ी से शहरीकरण वाले भारतीय संदर्भों में, यह शोध सिद्धांतों और व्यावहारिक नियोजन दृष्टिकोणों के बीच की खाई को पाटते हुए, बाढ़-उत्तरदायी और जलवायु-लचीला शहरी नियोजन को आगे बढ़ाता है।

मुख्य शब्द : शहरी बाढ़, , शहरी बाढ़ जोखिम, भूमि उपयोग नियोजन, शहरी बाढ़ जोखिम प्रबंधन।

Chapter 1: Introduction

Urban flooding has become one of the biggest environmental and development issues of the twenty first century. It results from having too much rainfall, runoff or other water sources flowing more than the capacity of a city's drainage, sewerage and natural water-carrying systems can handle (Smith, 2020). Unlike traditional riverine or coastal floods, urban floods often occur in areas that are not in identified natural floodplains. Water accumulates quickly on the street, open areas, basement and on the built-up areas thus causing severe disruptions to the day to day life. Over the past two decades, the frequency, extent and socio - economic impact of urban flooding has increased across the globe. Between 2000 and 2019, floods impacted almost 1.6 billion people, or around 44 percent of the total number of disaster events during the same period (United Nations Office for Disaster Risk Reduction [UNDRR], 2020). This increasing phenomenon meant that cities are becoming the hotspot of hydrological hazards.

Urban floods today are caused even by moderate rainfalls events especially in densely built -up areas with low drainage capacity and rainwater infiltration capacity. For instance, a report released by the U.S. Government Accountability Office in 2018 in the United States identified urban flooding as a "major source of economic loss, social vulnerability, and housing inequality" (U.S. Government Accountability Office, 2018). Similar trends have been reported for some rapidly expanding cities in Asia, Africa and Latin America, where the increase in population, conversion of land and dominance of surfaces by concrete intensifies the vulnerability.

The economic impacts of urban floods are serious. Annual global losses are in the range of tens of billions of dollars, to say nothing of the indirect costs from supply chain disruption, health costs and long-term socio-economic losses (World Bank, 2021). In 2020 alone, extreme weather events, in which urban floods were part, incurred damages worth USD 210-268 billion in the United States, an average of nearly USD 0.7 billion per day (National Centers for Environmental Information, 2021). These numbers show that cities, and in particular, the 57% of the world population living in them today, and

the 68% expected to live there by 2050 (United Nations, 2019), will suffer from recurring flooding phenomena.

Urban floods not only have devastating effects on the physical infrastructure, but also create serious human and social consequences. Studies show that flood victims often experience psychological distress, and they are often displaced and value loss of their properties. In one evaluation, 84% of flood victims in urban areas reported stress and 13% had decreasing mental well-being following flood events (Thomas & Lopez, 2021). In addition, urban floods pollute water sources, propagate diseases, interrupt transportation, destroy utilities and negatively impact quality of life.

With this scale of impact, knowledge on the mechanisms, causes and impacts of urban flooding is crucial to the planning of resilient cities. This chapter gives a complete conceptual understanding by explaining the background of urban floods, major typologies, global and Indian context along with the natural and human induced underlying causes. These components form the analytical foundation for understanding land use planning for the integrated management of urban floods which is the focus of this dissertation.

1.1. Background of Urban Floods

Flooding is traditionally considered an inundation of land that is normally dry by an excess of water based on riverine overflows, precipitation or the other hydrological processes (Smith & Ward, 1998). In metropolitan context, flood events occur when precipitation or surface run-off exceeds the capacity of storm water and drainage infrastructure, consequently leading to occurrence of widespread water-logging on the streets, within residential premises and commercial districts (Butler et al., 2018). The Chicago Urban Studies Group has characterised urban flooding as a result of failure of the sewer system during periods of heavy rainfall, which in turn result in extensive inundation even in areas far removed from natural bodies of water (Chicago Urban Studies Group, 2015). Such manifestations often include seepage of building

envelopes, under doorways, backflow of sewage, and the formation of surface pools on roadways.

Over the last 20 years, the number of urban floods and their severity have increased significantly globally [Centre for Research on the Epidemiology of Disasters [CRED], 2020]. Rapid urban growth is one of the main causes of this trend. With the expansion of urban areas, natural areas with high permeability (such as wetlands, arable fields, and vegetated cover) give way to impervious substrates (concrete and asphalt) (Jacobson, 2011). These materials do not allow for infiltration which can mean an increased percentage of precipitation will be converted into fast flowing surface run-off which overwhelms existing drainage systems. Empirical evidence shows that conversion of natural land to constructed areas greatly increases run-off volumes and therefore increases the likelihood of urban flooding in high intensity rainfall events (Shuster et al., 2005). Consequently, every new building footprint, roadway or parking facility creates new hydrological stress in the urban environment.

The effects of climate change further increase such difficulties. In accordance with the Intergovernmental Panel on Climate Change (IPCC, 2021), global warming has intensified both the number of and the severity of extreme precipitation events as warmer air can hold and also release more moisture when a storm occurs. Numerous regions, including the United States, Europe, and South Asia, have been documenting significant increases in short duration, high intensity rainfall over the past decades (Westra et al., 2013). The South Asian monsoon has also become more erratic and unpredictable, a case in point being the 2005 Mumbai flood in which 944 mm of rainfall occurred in a 24 hour time frame, overwhelming the drainage infrastructure of the city (Government of Maharashtra, 2006). And because many cities are still built to a rather ancient design for their drainage systems, designed according to past precipitation patterns, they are increasingly ill-prepared for modern extremes.

Urban floods affect both developed and developing countries, although much variability is found in the nature of impacts. Developed nations are often better equipped with more developed infrastructural networks; but even then, ageing systems

and design implications make them vulnerable to such heavy downpours (Ashley et al., 2020). Conversely, many low- and middle-income countries are undergoing massive, often unplanned urban growth without proper drainage or planning structures. A global assessment finds that close to 89 per cent of people exposed to 1 in 100-year flood event live in developing countries (World Bank, 2018). These populations often live in informal settlements in areas prone to flooding in low lying locations with little access to resilient housing, insurance or municipal services (Douglas et al., 2008). As a result, Asia, Africa and Latin America cities have been suffering recurrent and devastating flood events throughout the 2000s and 2010s.

In sum, today's urban flooding is the result of coupled factors such as rapid urbanisation, an increase in impervious surfaces, poor drainage infrastructure and climate-induced increases in extreme rainfall. Economic analyses show that the total global weather related losses from urban flooding in 2020 were well over USD 200 billion (CRED, 2021). This growing burden identifies the need for integrated land-use planning, climate-resilient infrastructure, and sound flood-risk governance. A thorough insight into causal mechanisms and spatial dynamics of urban flooding is critical to design effective mechanisms to mitigate flooding which are elaborated upon in the ensuing sections.

1.2. Types of Urban Floods

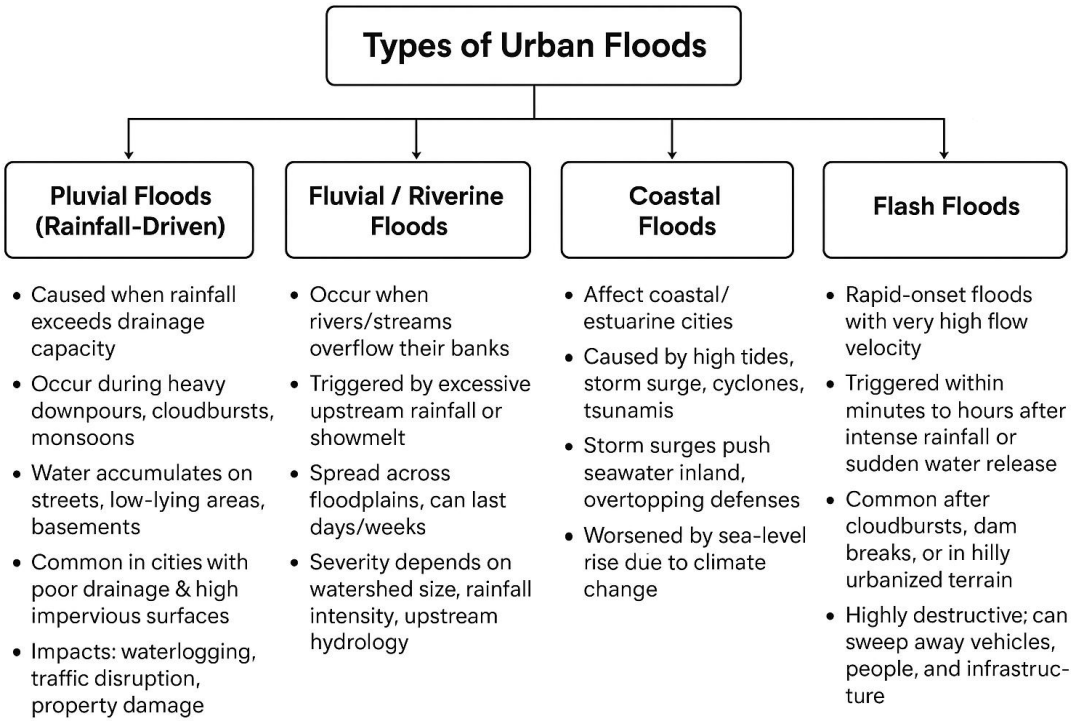


Figure 1: Types of Urban Floods *Source: Author*

Urban flooding can be categorized according to the mechanism that causes it. Coastal (sea inundation), fluvial/riverine (river overflow), pluvial (driven by rainfall), and flash floods are the most common types of urban floods. Each has unique dynamics. Knowing these kinds makes it clearer how urban floods occur and what needs to be done to mitigate them.

1.2.1. Pluvial Floods

When heavy rainfall exceeds urban areas' capacity for drainage and absorption, pluvial floods happen. Water ponds or flows over streets in this situation because heavy downpours produce large amounts of runoff that cannot enter or be transported by sewers. "Pluvial flooding occurs when rainfall exceeds the capacity of the local

drainage system or the ground," according to the Irish OPW, causing excess water to run off into streets, low-lying areas, or depressions. In reality, pluvial floods often occur during or right after storms. For instance, a cloudburst could quickly inundate an urban area by dumping more rain in an hour than roads and drains can manage. During monsoons or flash rainstorms, normally dry city blocks can be submerged by pluvial floods, which frequently happen without the assistance of rivers. These occurrences are particularly troublesome in areas with limited drainage and heavily sealed surfaces (roofs, asphalt). Water can build up on the surface and seep into basements during pluvial flooding, resulting in property damage, traffic jams, and the possibility of contracting waterborne illnesses.

1.2.2. Fluvial (Riverine) Floods

When watercourses overflow their banks, fluvial (riverine) floods occur. This indicates that a river or stream that runs alongside a city overflows its channel and into the floodplain in an urban setting. "Fluvial flooding occurs when rivers and streams break their banks," according to Ireland's flood management agency. This is usually the result of excessive upstream rainfall or snowmelt. An overflowing river has the potential to submerge infrastructure and neighborhoods in low-lying cities. Although they can cover large areas and last days or weeks, fluvial floods can build more slowly than pluvial floods, giving some warning. The size of the watershed, the amount of rainfall, and the upstream hydrology all affect the severity. For example, Patna (on the banks of the Ganges) may be completely submerged if the Ganges swells due to intense monsoon rains in the Himalayas. Levees may be breached by elevated flood stages, allowing floodwater to spread far into urban areas. Because they affect large river basins, fluvial floods frequently necessitate regional coordination (e.g., reservoir releases, embankment control).

1.2.3. Coastal and Flash Floods

Land near seas or estuaries is affected by coastal floods. High tides, storm surges, or tsunamis pushing seawater inland are the main causes of them. According to the Irish

OPW, coastal flooding happens "when sea levels along the coast exceed land levels or defenses." Extremely high tides or cyclonic storm surges can cause coastal cities, like Mumbai and Kolkata, to flood.

Since strong onshore winds and pressure changes push the ocean over sea walls and barrier islands, storm surge is a major cyclone risk in India. The frequency and severity of coastal floods are further exacerbated by rising sea levels brought on by climate change.

Rapid-onset floods known as "flash floods" are distinguished by extremely high flow rates and brief durations. "A flood of short duration with a relatively high peak discharge" is how the World Meteorological Organization (through UNDRR) describes a flash flood. Usually, flash floods happen minutes to several hours after a heavy downpour or unexpected water release. An intense cloudburst can almost instantly send torrents through valleys or streets in mountainous or urban areas. According to NOAA's definition, flash floods start within six hours—typically three hours—of intense rainfall, according to the UNDRR. They can sweep people and buildings away and carry debris. For instance, a flash flood could result from an hour of intense rain over a small portion of any urban area or any nearby hills; similarly, a small dam or embankment breaking could cause a flash flood. Beyond typical riverine or rainfall-driven events, flash floods and coastal floods both exacerbate the urban flood risk profile.

1.3. Urban Flooding in India



Figure 2: Urban Flooding in India *Source: AP News*

In the recent decades, urban flood occurrences and incidents have risen considerably in frequency and severity in rapidly growing Indian urban areas (as can be seen in Figure 2). National disaster assessments suggest the "growing trend of urban flooding" across the country, which is closely associated withshift in rainfall intensity, land-use pattern and infrastructural inadequacies (National Disaster Management Authority [NDMA], 2017). Major metropolitan centres like Hyderabad (2000, 2013), Ahmedabad (2001), Delhi (2002, 2003, 2009), Chennai (2004, 2015), Mumbai (2005), Kolkata (2007), Surat (2006), Jamshedpur (2008), Guwahati (2010) and Srinagar (2014) have been experiencing severe episodes of flooding in the last two decades (MoHUA, 2 These events caused large-scale destruction, considerable property damage, and the evacuation of hundreds to thousands of people. The 2015 Chennai floods, for instance, were triggered by extremely high amounts of rainfall which flooded entire neighbourhoods causing damages amounting to billions of rupees (Ramakrishnan & Kamal, 2016). Similarly, the massive Mumbai floods of 2005 overwhelmed the city's outdated drainage infrastructure which resulted in commuters being stranded and important transport corridors submerged (Gupta, 2007). While these large scale events

gain a great deal of attention, urban flooding has also become well common in small and medium sized towns in India (Singh & Kumar, 2021).

The particular susceptibility of India to urban flooding is due to a confluence of factors which include climatic, environmental, infrastructural, and socio-economic factors:

1. Monsoon Climate and Extreme Rainfall: The weather of India is monsoon-driven and thus the country is a major contributor to the flood risk. Short-duration, high-intensity rainfall is common during the monsoon season and based on the recent climate analyses, it seems that global warming has enhanced the frequency and intensity of these extreme precipitation events (Mukherjee et al., 2018). Studies published in the Journal of Environment and Bio-Sciences point to "extreme monsoon rainfall" as the preponderance of the natural component trigger of urban flooding across the Indian cities (Sharma & Patel, 2019). In coastal cities like Chennai and Kolkata, flooding is worsened by the effect of rain accompanied by strong winds and tide flow which pushes water to rivers, canal, and urban water drain system. The 2005 floods in Mumbai, where an unprecedented rainfall as dire as 944 millimeters over a 24-hour period was recorded, is one of the best examples of the inability of stormwater systems to handle such extreme events (Gupta, 2007).

2. Rapid and Unplanned Urbanisation: Over the last two decades Indian cities have grown at a rate that has outpaced the respective capacities of existing infrastructure. Between 2001 and 2011, there was about 32% increase in the urbanised land area of India which was mostly due to unregulated growth (MoHUA, 2020). Wetlands, natural drains, rivers, floodplains have been encroached upon and been taken up by new developments for residential, commercial and transport use. Chennai's Pallikaranai Marsh, which was highly natural sponges of monsoon runoff, has shrunk to less than 10% of its original area affecting the city's significantly higher susceptibility to floods (Ramakrishnan & Kamal, 2016). Similarly, studies show that over 70 percentile of Bengaluru's lakes have been lost or severely encroached by urban growth, with a consequent reduction in important storage and infiltration capacity (Srinivasan et al., 2019). According to the Ministry of Housing and Urban Affairs, "unplanned

development and encroachments along watercourses have disrupted the natural flow of water" and significantly increased water volumes in runoff (MoHUA, 2020, p. 12).

3. Ageing and Inadequate Drainage Infrastructure: Drainage systems in most Indian cities have been designed decades ago for much lower population and a lower rainfall intensity. Portions of drainage networks of cities like Delhi and Kolkata date back to the colonial era and have not been upgraded sufficiently to meet present hydrological needs (NDMA, 2017). As a result, even moderate rainfall often causes waterlogging, as well as overflowing of storm water drains. International research also supports this pattern; for example, research in Chicago shows that sewer systems designed in the early twentieth century are no longer interested to handle modern-severe rainfall events (City of Chicago Department of Water Management, 2019). In India, whether it is due to poor maintenance, solid waste accumulation or encroachment into natural water channels, further reduces the capacity of existing systems (Sharma & Patel, 2019).

4. Population Exposure and Socio- Economic Vulnerability: The rapid growth in the urban population (less than 10 per cent of India's total population in 1950 to more than 30 per cent of the total population today) has resulted in an increase in exposure to flood-Prone areas (United Nations, 2019). Those who are at the highest risk are informal settlements, often found along riverbanks, drainage channels or reclaimed wetlands. These communities usually do not have access to strong housing, flood protection, early-warning systems or financial resources for recovery. Recent analyses highlight that "marginalised communities are still not sufficiently addressed in urban flood risk planning," leading to disproportionate socio- economic consequences (Singh & Kumar, 2021, p. 45).

Collectively, these factors highlight the fact that urban flooding challenges in India result from the combination of extreme monsoon rainfall, increased impermeable surfaces, poor drainage infrastructure and increased socio- economic vulnerability. Government assessments reinforce the view that unregulated urban growth has "compounded flood risk" in major city centres and that in future, resilience will require floodplain management, sustainable drainage systems and risk sensitive land use

planning to be incorporated into urban development frameworks (NDMA, 2017; MoHUA, 2020). Understanding these compounding factors is critical to the development of effective strategies for integrated urban flood management in India.

1.4. Urban Flooding in Global Context

Urban Flooding is a significant global problem and is reflecting in exponential growth of urban areas, we are seeing in Indian cities and it is similar worldwide. Major metropolitan areas, such as Jakarta, Lagos, and New York have reported an increase in the frequency and extent of inundation events in the last two decades. Global assessments suggest that an increasing share of disaster-related losses are now occurring within the urban milieus (United Nations Office for Disaster Risk Reduction [UNDRR], 2022). A comprehensive international study of exposure to floods found that all continents experienced significant increases in the area built up and in people living in flood prone areas between 2000 and 2020 (Tellman et al., 2021). Africa showed the highest rate of augmentation in urban flood exposure, while East Asia (especially China) showed the greatest number of absolute impacts. Under high urban growth scenarios, it has been forecast that developing countries will experience massive increases in both the number of people and economic assets at risk of major floods, which will greatly exceed risks in developed countries (World Bank, 2023). These patterns highlight the disproportionate increase of urban flood risk in the Global South.

The scale of the problem is underlined by a number of significant findings. A 2025 report from Nature estimates that some 89 percent of the global population, or 1.81 billion people, exposed to 1-in-100-year flood event live in low- and middle-income countries (Zhang et al., 2025). Practically it means that huge populations in cities in Africa, South Asia, SouthEast Asia and Latin America are at risk of catastrophic urban flooding within a century. The devastating consequences of flooding in Pakistan (especially the events of 2010 and 2022 that claimed 1,985 and 1,500 lives respectively) can be used to understand the scale of losses in the urban and peri-urban areas (Government of Pakistan, 2023). Numerous cities in South Asia such as Dhaka, Mumbai, Kolkata, Chennai, New Delhi, Karachi, and Lahore have been facing

recurrent urban floods in the last several decades. Many of these megacities are located on river deltas or low-lying coastal areas, where geographical factors also increase vulnerability (Asian Development Bank, 2020).

Urban flooding also brings about significant economical burdens at the global scale. According to the Intergovernmental Panel on Climate Change, extreme events occurred around the globe with estimated economic losses of between USD 210 billion and USD 268 billion in 2020, of which a considerable portion was due to floods (IPCC, 2021). In the United States, the National Flood Insurance Program works millions of claims a year, with many claims for urban flash floods outside officially designated flood zone areas (Federal Emergency Management Agency [FEMA], 2022). In developing countries, flood related losses are frequently of the same order of magnitude as local government budgets and have significant negative impacts on economic development and compound socio economic inequalities. One global assessment claims that over 90 per cent of all flood-related deaths occur in Asia, even though it has about one-third of the total population of the world, thereby expecting greater burdens on the densely populated urban centres (UNDRR, 2022).

The rising occurrences and spatial scale of urban floods around the world could be attributed to both climatic and socio -economic contributors. Climate-modelling studies show that precipitation extremes are increasing globally, with multi-day floods projected to become up to three- to sixfold more frequent under high-warming scenarios by the end of the century (IPCC, 2021). Concurrently, accelerated urbanisation is increasing the level of exposure: at current rates, by 2050, 68 per cent of the global population will live in urban areas, increasing the concentration of people and economic assets within flood prone locations (United Nations, 2019). Recent empirical research highlights the importance of urban development patterns; whilst uncontrolled urban sprawl may offer heightened flood risk by increasing the proportion of impervious surfaces and altering natural drainage systems, cities that implement an integrated stormwater management and green infrastructure approach are able to significantly reduce flood impacts (Bronstert et al., 2019).

Although local contexts may vary, there are several global trends such as extreme rainfall, built-up imperviousness, and increasing population exposure which are common across different regions. Urban flooding is also plaguing not just the tropical developing countries, but also temperate, industrialised nations. For instance, the U.S. National Climate Assessment notes that "heavy downpours are increasing nationally," which is fostering an increase in urban flash floods in cities such as Miami, New York and Houston (U.S. Global Change Research Program, 2018, p. 45). Likewise, European cities have reported increased occurrences of pluvial flooding caused by rain and combined sewer overflows in the last several decades (European Environment Agency [EEA], 2020). Even cities with more moderate or low historical flood risk (according to historical data) in Australia and the Pacific have experienced severe urban flooding in periods of heavy storm seasons (Queensland Government, 2021). The emerging consensus is clear: urban flooding is a global environmental and development challenge, based on climate change and rapid urbanisation, which requires both systemic planning for resilience, and context-specific local solutions.

Overall, the international geography of urban flooding has been characterised by increasing exposure and disproportionate impacts. While developed countries are facing problems associated with aging infrastructure, the large majority of flood-related victims are located in developing countries where urban growth is outpacing efforts to build resilience (UNDRR, 2022). Satellite-based assessments show a steady rise in the population and developed areas located in flood-prone areas of cities across the world (Tellman et al., 2021). These trends demonstrate the need for urgent action in diagnosing the root causes of urban flooding (land-use change, climate pressures and infrastructural limitations), and implementing the relevant interventions (improved drainage systems, early warning mechanisms and risk sensitive urban planning) (see Section 1.5: Causes of Urban Flooding).

1.5. Causes of Urban Flooding

Urban flooding happens when the combined impact of natural and anthropogenic processes exceeds the urban environment's ability to cope with the overflowing of

water. Extreme precipitation is the most important natural force in such events. With climate change, the hydrological cycle has been enhanced as a result of the warmer atmospheric conditions allowing more moisture to be powered into the air leading to an increase in the frequency and intensity of heavy rainfall events (Intergovernmental Panel on Climate Change, 2021). Storms that therefore had once been "100-year events" are occurring more often in many parts of the world. According to the IPCC, pluvial flood risk of cities with a long history of high levels of precipitation is on the rise as rainfall extremes increase under warming scenarios (IPCC, 2021). In South Asia, changing monsoon dynamics and tropical cyclones have solid impacts on the increased regional flood risk (Asian Development Bank, 2020). According to one modelling study, under high emmission pathways, the frequency of long period urban floods could increase significantly over the next few decades, exposing cities to much higher and more sudden volumes of stormwater (Zhang et al., 2024).

Human-initiated land-use patterns are equally influential. The expansion of impervious surfaces (e.g. concrete pavements, paved roads, rooftops) that leads to a reduction in natural infiltration and increase of surface runoff. Each square metre of additional sealed surface contributes to an increase in floods (due to higher flood peaks for the same rainfall intensity) Bronstert et al, 2019). Rapid and unplanned urbanisation accelerates these effects in concentrated development of the poorly drained low lying areas. As one global synthesis states, "urban flooding has become one of the most common and widely distributed disasters globally," and this has been mainly because of the effect of climate change and unregulated urban growth together (United Nations Office for Disaster Risk Reduction, 2022).

The ability of drainage infrastructure is what further determines the outcomes of floods. Many stormwater systems - including storm sewers, canals and open drains - were designed decades ago for smaller populations and lower rainfall intensities. When precipitation exceeds the design thresholds, drains overflow at rapid rates and cause flooding in the streets. Inadequate maintenance worsens this problem; clogged drains full of plastic waste, silt and debris greatly reduce the hydraulic capacity. Chicago is one case in point, where older sewer systems in some neighbourhoods have proven

unable to deal with the amount of water during today's stronger storms (U.S. Global Change Research Program, 2018). Similar trends are evident in rapidly growing Indian cities where trunk drainage networks have not been able to keep up with the growth of the cities - leading to even moderate rainfall overwhelming street level drainage (Ministry of Housing and Urban Affairs, 2025).

Another contributing factor is the loss of watercourses and ecological buffers in the natural environment. Historically, lakes, wetlands, marshes and stream networks served important functions of storing and gradually releasing rain water. Urban growth has filled in or covered over many of these systems, destroying natural floodplains and reducing nature's ability to absorb runoff. The encroachment of the lakes within Bengaluru has led to a dramatic increase of flooding of low-lying neighbourhoods (Srinivasan et al., 2019). Similarly, the large loss of wetland in Chennai decreased the buffering capacity during the 2015 floods leading to massive inundation over the entire city (Ramaswamy & Kumar, 2020). Reviews repeatedly single out wetland destruction and waterbody encroachment as key man-made drivers of urban flood risk (UNDRR, 2022).

Subsidence is another issue that is increasing. Land subsidence is when soils are compacted or groundwater is overly abstracted (excessive groundwater extraction) and will cause the elevation of the land surface to decrease and the drainage to be impeded. This phenomenon is especially bad in deltaic megacities. Jakarta, for instance, faces one of the highest rates of urban subsidence in the world, exacerbating pluvial and tidal flooding and making some areas of the city even more vulnerable to such storm surges (Abidin et al., 2015). In combination with sea-level rise, the subsidence can double or even treble fecundity inundation in coastal cities (IPCC, 2021).

Coastal cities are endangered with further threats of sea level rise and storm surge. Gradually rising sea levels means higher baseline water levels, so, increasing storm surges, as well as high tides, are more dangerous for storm surges and waves driven by cyclones. Heavy rainfall run-off can be pushed inland by these surge events, and result in compound floods. Cities like Kolkata and Chennai parts of it are especially

vulnerable in case of monsoon rains coinciding with the activity of the Bay of Bengal cyclone(s) (Chakraborty et al., 2025). A study in 2025 notes that both cities "are facing further risks from storm surges and sea - level rise, which will only increase the impacts of extreme weather events" (Chakraborty et al., 2025, p. 78).

The changes in urban planning and governance also heighten the impact of floods. Rapid urban growth frequently leaves proper regulatory implementation far behind and as a result, construction in floodplains, blocked drainage paths and inadequate stormwater provisions in new developments. There are many cities that do not have detailed urban flood maps, meaning that communities, developers, and decision-makers are not aware of the existing risks (FEMA, 2022). A national assessment in the United States found that many flood prone urban areas "are not identified by existing maps" prompting the need for better risk communication and new flood assessments (FEMA, 2022, p. 13). Weak institutional coordination, incoherent governance, and poor execution of policies can increase the natural tendencies of flooding in cities.

Socioeconomic factors also influence susceptibility. Informal settlements, which are usually situated in low-lying or poorly drained terrain where properties are cheapest to buy, are the first and worst to be flooded. These populations are often uninsured, have no savings, and live in vulnerable housing, and are therefore disproportionately affected both during and after a flood event. Public unawareness of flood risks is also a contributing factor in making matters worse; many people underestimate their exposure or do not know about some simple mitigation measures at a household level (UNDRR, 2022). The solution to these social and institutional vulnerabilities is critical to understanding why floods often upscale to become disasters in the urban setting.

Ultimately, urban flooding is the product of too much water going in, and too little water getting away. Climate-driven storm extremes result in larger pulses of water, yet the urban landscape, where impervious surfaces, poor drainage and fewer natural buffers are prevalent, provides fewer outlets to allow water to dissipate safely. Thus the major causes of urban flooding can be divided into two related categories:

- **Drainage capacity and infrastructure:** The capacity of urban drainage network including storm sewers, canals and drains is often limited. Many of these systems were initially designed for small precipitation events or were based on outmoded assumptions about land use. When rainfall intensity exceeds the design thresholds, that is when over -run occurs, and that possibility is made even greater by poor maintenance and physical obstructions, such as litter, silt and plastic debris, that reduce conveyance capability. Empirical studies from Chicago show that century-old sewers cannot sustain modern day, more intense rain storms and similar studies in many Indian metropolises confirm the fact that inadequate drainage infrastructure causes flooding again and again, with meager rainfall, in rapidly growing areas which lack trunk drainage.

- **Loss of natural watercourses and buffers:** In the past, lakes, ponds, streams and wetlands in and near cities served as important retention and attenuation areas. Contemporary development has resulted in the destruction or infilling of these natural features thereby eliminating floodplain storage capacity. For instance, encroachment on Bangalore's lake ecosystem has led to a significant increase in the flood submergence in low lying districts whereas remaining wetlands in Chennai failed to buffer a 2015 flood event. Such changes force stormwater to be piped through a smaller system of channeled pipes and gutters which can be quickly overloaded.

- **Subsidence of land:** Urban land subsidence originating from the compaction of soils and the withdrawal of ground water reduces the land surface level and increases the tendency of flooding, though the tender effect is restricted to a certain area. In the case of Jakarta and other urban settlements on the delta, subsidence has exacerbated the already inefficient drainage, and demonstrates the relationship between resources depletion in the ground and the risk of inundation above ground.

- **Sea- level rise and storm surge (in coastal cities):** Coastal metropolises are confronted with a further threat of inundation due to incremental sea level rise, which causes an increase in the base water levels and increases both high tide and storm surge impacts. Heavy precipitation run-off can be driven inland by cyclonic surge waves. Concurrent monsoon-led rainfall and cyclones of the Bay of Bengal, for example, has led to both riverine and tidal flooding in Kolkata and Chennai; according to a study to be released in 2025, the two cities face increased risk from sea level rise and storm surges, thereby increasing planners' difficulty in managing the impacts of extreme weather events. As a result, coastal urban flood risk is both affected by precipitation on land and at sea.

- **Problems of urban planning and governance:** Floods may be indirectly caused by a lack of responsibility and regulatory regimes. Rapid and unplanned urban development tends to lead to construction practices that ignore the role of drainage design and flood plain zoning requirements allowing infrastructure projects to proceed without adequate plans for storm water. Public officials and planners often have little overall urban flood mapping, resulting in the construction of commercial and residential areas in areas of high risk. National assessments in the United States have showed a tendency to forget flood-prone urban areas from cartographic representations; in this respect, a good risk communication and planning are necessary in order to counteract tendencies of natural disasters such as floods.

- **Socioeconomic factors:** The low cost of land in low-lying and vulnerable areas favours slums and informal settlements in such areas. These communities become the first to be affected by flooding due to the lack of access to adequate drainage facilities, and are disproportionately impacted after the flooding occurs due to low savings or insurance coverage. Public indifference - in the form of minimisation of flood risk by officials and developers - reduces the incentive for mitigation at the earliest opportunity Surveys show that many people living in urban areas are unaware that they can take measures to minimise damage to flooding. Addressing these social determinants is integral to the prevention of the escalation of flood events into urban catastrophe.

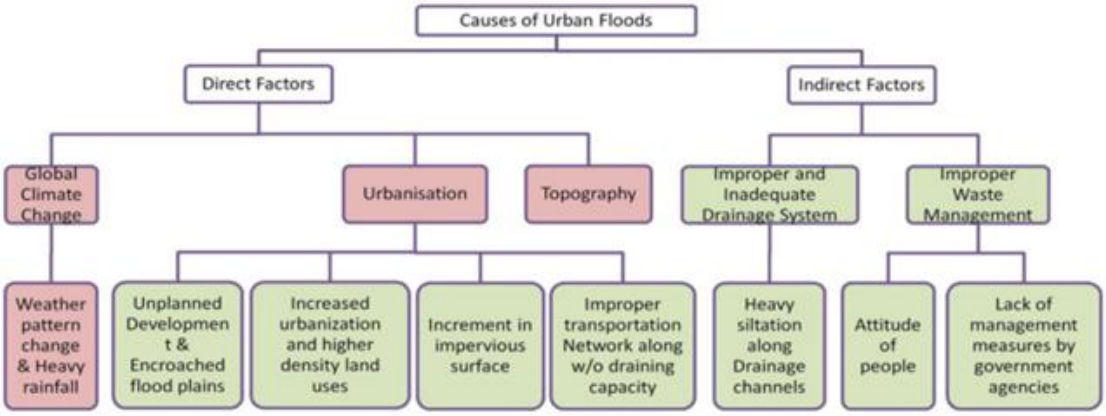


Figure 3: Causes of Urban Floods *Source: Author*

In conclusion, excessive water input combined with limited water removal causes urban flooding. Larger water bursts are brought about by climate-driven storms, but there are fewer outlets for that water in urban environments. As a result, the primary causes fall into two categories:

- **Natural drivers:** storm surges, riverine flood stages, heavy rainfall (pluvial flooding), and rising sea levels brought on by global warming.

- **Anthropogenic drivers:** Urban sprawl, impermeable surfaces, inadequate drainage, loss of natural buffers, subsidence, and poor planning and governance.

These elements work together. Extreme rainfall (natural) might not have caused flash flooding in a fully vegetated watershed, but it does so in a modern city due to anthropogenic changes in a matter of minutes. In a similar vein, a city block that would otherwise flood from a downpour can be lessened by having enough green spaces and wetlands (left intact). Developing targeted mitigation, a topic covered in other sections of flood research, requires an understanding of this interaction of causes.

Major causes of urban flooding include:

- **Climate change and excessive rainfall:** more powerful storms and unpredictable monsoons. Each rise in global temperature increases the likelihood of heavy downpours.

- **Impervious urban surfaces:** Urban surfaces that are impervious to natural infiltration, such as parking lots, roofs, and roads, significantly increase runoff.

- **Inadequate drainage infrastructure:** Overflows occur quickly when sewers and drains are too small or clogged.

- **Loss of natural channels:** Drained wetlands and filled streams remove buffers, forcing water into streets.

- **Urban expansion and encroachment:** Building on floodplains and riverbanks reduces conveyance and storage of floodwaters.

- **Sea-level rise and storm surge (coastal cities):** Rising ocean levels and coastal storms push seawater into cities, amplifying floods.

- **Socio-political factors:** Poor planning, insufficient flood mapping, and marginalized communities living in vulnerable zones amplify impacts.

These causes are not merely theoretical, numerous studies and reports have identified them in practice. For example, a 2018 U.S. study explicitly links suburban development and undersized infrastructure to increased urban flooding. A 2025 review of Indian cities points to "rapid and unplanned urbanization," with specific examples of marshlands and lakes being lost in Chennai and Bangalore, as key flood drivers. Likewise, global research emphasizes that without adaptation, continued urban growth under climate change will "substantially raise the likelihood of flooding" in cities worldwide.

1.6. Need for the Study

1. Urban Flooding as a Land-Use Challenge:

- Urban flooding is not only a hydrological issue but also a direct outcome of land-use decisions such as rapid urbanization, encroachment, and the reduction of natural drainage spaces (UN-Habitat, 2020).

- The conversion of permeable surfaces (wetlands, forests, agricultural land) into built-up areas disrupts the natural water cycle and increases runoff (Gupta & Nair, 2019).

- Integrating land-use planning with flood management helps ensure that urban expansion does not increase surface runoff or obstruct natural drainage.

2. Need for Integrated Urban Flood Management (IUFM):

- Integrated Urban Flood Management (IUFM) emphasizes a combined approach linking drainage systems, urban design, zoning, and environmental conservation (World Bank, 2021).

- Traditional engineering approaches alone cannot address modern urban flooding; instead, integrated land-use policies are key to climate-resilient cities (IPCC, 2021).

- IUFM promotes balanced development by aligning land-use decisions with hydrological functions.

3. Role of Land Use Planning in Minimizing Surface Runoff:

- Strategic land-use planning helps reduce the volume and speed of stormwater runoff by encouraging permeable surfaces, green infrastructure, and controlled development (Singh & Bhatt, 2018).

- Planners can designate low-impact zones, vegetated areas, and open spaces that naturally absorb rainfall.

- Urban development regulations should mandate green roofs, infiltration trenches, rain gardens, and permeable pavements to control pluvial flooding.

4. Zoning and Development Control for Flood Risk Reduction:

- Zoning tools help ensure that high-risk flood zones remain free from dense development (MoHUA, 2020).

- Building bylaws can regulate floor elevations, setbacks, and construction materials for structures in moderate-risk areas.

- Urban expansion should follow floodplain zoning maps, watershed boundaries, and hydrological assessments for sustainable growth.

5. Protection and Restoration of Natural Drainage Systems:

- Land-use planning must protect rivers, streams, ponds, wetlands, and natural depressions that serve as natural buffers during heavy rainfall (NIDM, 2018).

- Encroachment on drainage channels, lakes, and floodplains significantly increases urban flood vulnerability (Patel & Sharma, 2021).

- Restoration of these natural systems—through desiltation, boundary demarcation, and catchment management—is essential for integrated flood mitigation.

6. Addressing Urban Encroachments and Informal Settlements:

- Many urban flood hotspots emerge from informal settlements located in low-lying areas, riverbanks, and drainage corridors (World Bank, 2021).

- Land-use planning should incorporate inclusive strategies such as land readjustment, resettlement, and safe housing policies.

- Preventive regulations must restrict future encroachments in ecologically sensitive zones.

7. Policy and Governance Frameworks Supporting Integrated Flood Management:

- Effective implementation requires coordination between urban planners, municipal bodies, disaster management authorities, and environmental agencies (MoHUA, 2020).

- Policies such as Master Plans, Development Plans, City Disaster Management Plans (CDMP), and Climate Action Plans must be aligned.

- Integrated flood governance ensures that drainage, land use, housing, transportation, and infrastructure planning follow a unified vision.

8. Sustainable Urban Design for Flood Resilient Cities:

- Urban design strategies such as waterfront redevelopment, flood-resistant architecture, elevated walkways, and street-level water retention enhance safety during extreme rainfall.

- Compact and transit-oriented development (TOD) reduces large-scale land conversion, protecting natural hydrological systems (UN-Habitat, 2020).

- Mixed-use and compact forms minimize imperviousness and support efficient water management.

1.7. Aim of the Study

Land Use Planning for Integrated Urban Flood Risk Management.

1.8. Research Questions

1. How can land use planning reduce urban flood risk?

2. What planning strategies can improve urban flood resilience?

3. How can land use planning help in Integrated urban flood risk management.?

1.9. Objectives of the Study

Phase I:

- **Objective 1:** To understand key concepts, terminologies and frameworks of land use planning, flood risk management, and urban resilience.

- **Objective 2:** To examine how land use patterns and urban infrastructure affect flood vulnerability.

- **Objective 3:** To identify best practices from global and national case studies for integrated flood management.

Phase II:

- **Objective 1:** To analyze spatial factors linking land use, built form, and urban flood risk in the study area.

- **Objective 2:** To evaluate issues and existing planning measures for flood management in the study area.

- **Objective 3:** To develop an integrated land use-based planning framework with practical recommendations for urban flood risk management in the study area.

1.10. Research Methodology

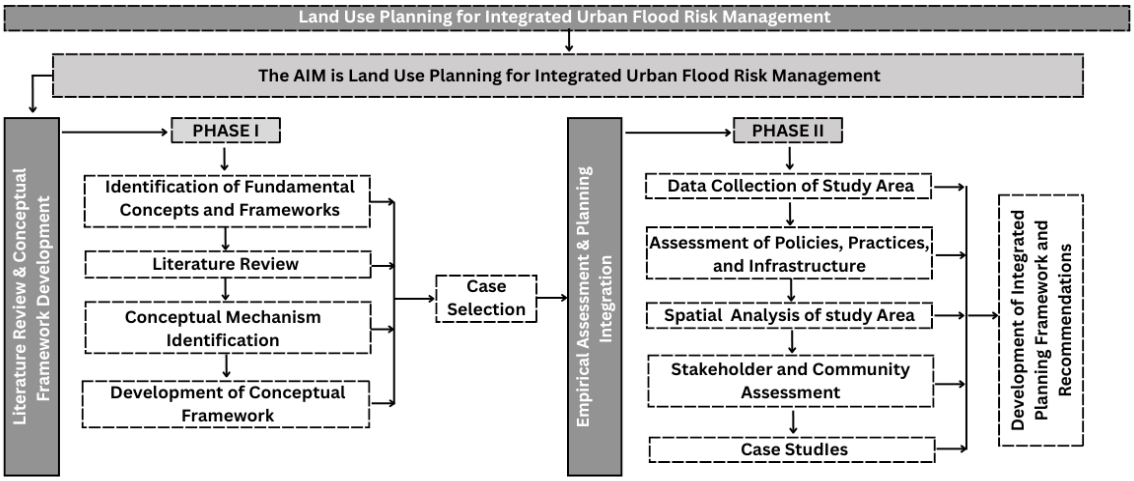


Figure 4: Research Methodology *Source: Author*

The methodology for this study has been designed to systematically examine the interrelationship between land use planning, urban infrastructure, and flood risk, with a specific focus on developing an integrated planning framework for enhanced urban flood resilience. The research design follows a two-phase structure, comprising (i) *Literature Review and Conceptual Framework Development* and (ii) *Empirical Assessment and Planning Integration*. These phases are interconnected and cumulatively guide the study toward the development of evidence-based recommendations and an integrated planning framework.

PHASE I: Literature Review and Conceptual Framework Development

Phase I forms the conceptual foundation of the study. It emphasizes theoretical understanding, synthesis of existing scholarship, and the construction of a comprehensive framework that informs empirical inquiry in Phase II.

1. Identification of Fundamental Concepts and Frameworks:

This stage involves identifying and defining the core theoretical constructs relevant to the study, including *land use planning*, *urban flood risk*, *resilience*, *blue–green infrastructure*, and *integrated risk management*. Standardized definitions and global frameworks (e.g., Sendai Framework, IPCC guidelines, UN-Habitat planning principles) are reviewed to establish conceptual clarity and ensure alignment with internationally recognized terminologies. This step ensures that the study is positioned within established academic and policy discourses.

2. Literature Review:

A systematic and thematic literature review is conducted to examine scholarly research, policy documents, institutional reports, and case studies published over the past two decades. The review analyses three major thematic domains: (i) the influence of land use dynamics on flood vulnerabilities, (ii) the role of urban infrastructure—including drainage, transport networks, and open spaces—in shaping flood outcomes, and (iii) the evolution of integrated urban flood management strategies globally and in India.

The literature review not only evaluates existing knowledge but also identifies research gaps, theoretical inconsistencies, and underexplored linkages. Insights gained here inform the design of Phase II and justify the selection of the study area.

3. Conceptual Mechanism Identification:

This step aims to identify the mechanisms through which land use patterns, infrastructural capacities, and planning approaches contribute to flood occurrence, exposure, and severity. Using conceptual mapping, the study identifies causal pathways, interactions between built form and hydrological processes, and the role of governance systems. These mechanisms form the basis for developing a framework that explains flood risk as a multidimensional phenomenon shaped by spatial, infrastructural, sociopolitical, and environmental variables.

4. Development of Conceptual Framework:

Based on the previous stages, a conceptual framework is developed to guide the empirical component of the research. This framework outlines a structured relationship among key variables, illustrating how land use planning, policy mechanisms, infrastructural provisions, community behaviour, and environmental conditions collectively influence flood vulnerability. The framework also guides data collection, analysis procedures, and the interpretation of results in Phase II.

5. Case Selection;

The final step of Phase I involves selecting a suitable case study area based on predefined criteria such as urbanisation pressure, historical flood occurrence, infrastructural gaps, and availability of data. The chosen study area represents a context where land use planning and flood risk challenges intersect, providing a relevant and empirical foundation for Phase II investigation.

PHASE II: Empirical Assessment and Planning Integration

Phase II translates the conceptual insights from Phase I into an empirical, spatial, and policy-oriented assessment. It investigates the study area's land use patterns, infrastructural characteristics, governance frameworks, and community-level responses related to urban flooding.

1. Data Collection of the Study Area:

Comprehensive data collection is undertaken through primary and secondary sources.

- Primary data include field observations, stakeholder interactions, interviews, and community assessments.

- Secondary data include satellite imagery, land use maps, census information, drainage network maps, municipal plans, hazard zonation maps, policy documents, and infrastructure inventories.

2. Assessment of Policies, Practices, and Infrastructure:

This step evaluates the effectiveness of existing policies, regulatory instruments, and planning practices that influence land use and flood risk management within the study area. Institutional reports, municipal development plans, drainage master plans, and disaster management guidelines are critically examined. Simultaneously, infrastructural assessments focus on drainage capacity, maintenance conditions, road networks, impervious surface coverage, encroachments, and the performance of flood mitigation systems. The assessment identifies strengths, gaps, and inconsistencies in existing urban planning and governance arrangements.

3. Spatial Analysis of the Study Area:

Spatial analysis is conducted using GIS tools to examine land use changes, urban expansion, hydrological pathways, drainage infrastructure, elevation variances, and flood-prone zones. Remote sensing data are processed to assess temporal transformation in land cover, built-up development, and encroachments in natural drainage channels. The spatial analysis helps quantify the relationship between land use configurations and flood vulnerability, thereby validating the conceptual mechanisms identified in Phase I.

4. Stakeholder and Community Assessment:

Understanding local perspectives is essential for developing feasible planning solutions. Stakeholder consultations include municipal officials, planners, engineers, disaster management authorities, and local community representatives. Community assessments focus on flood experiences, coping mechanisms, perceptions of governance, infrastructural deficiencies, and social vulnerabilities.

This step ensures that the analysis integrates institutional realities and community needs, making the final framework socially grounded and practically implementable.

5. Case Studies:

Relevant global and national case studies are analysed to extract best practices, lessons, and innovations in integrated urban flood management. These comparative insights help contextualise the findings from the study area, demonstrate successful models, and identify adaptable strategies suitable for urban areas similar to the selected case.

Integration and Framework Development

The final stage synthesizes the outputs of Phase I and Phase II to develop an Integrated Planning Framework for urban flood resilience. The proposed framework combines conceptual insights, empirical evidence, spatial analysis results, and stakeholder perspectives. It outlines actionable recommendations for land use planning, infrastructure development, policy reforms, and community-based approaches, thereby offering a comprehensive model to reduce urban flood risks and enhance long-term resilience.

1.11. Scope of the Study

The scope of this study covers the evaluation, analysis and formulation of an integrated framework of land use planning and urban flood risk management in the form of spatial and infrastructural aspects. The research investigates the dynamic relationship between land use change - such as urban sprawl, loss of green cover and densification of built-up areas - and changes in flood risk patterns in cities. Furthermore, it assesses how an urban area's infrastructure systems, especially drainage networks, road systems, and blue/green infrastructure affect the ability of urban areas to absorb and manage stormwater (World Bank, 2011; Chan et al., 2018). This study borrowed from both global structures and local contexts. Internationally recognised principles (Integrated Flood Management (IFM) framework by the World Meteorological Organization (WMO) and World Bank and the Climate Resilient Cities framework (World Bank, 2012) provide the conceptual basis. Nationally, guidelines of the National Disaster Management Authority (NDMA, 2010) and policy instruments from the Ministry of

Housing and Urban Affairs (MoHUA, 2017) are mentioned to place the Indian urban planning scenario in perspective.

Spatial analysis supported by secondary sources of data including remote sensing, flood hazard maps and urban land use data will be used to develop correlations between the built form, surface permeability and flood prone zones (Avashia and Garg, 2020; Tomar and Tiwari, 2021). The study is both diagnostic and prescriptive - in the sense that it is diagnostic in its assessment of the adequacies or otherwise of existing planning and infrastructural architectures that contribute to the problem of flooding, and prescriptive in prescribing planning based resilience architecture that integrates flood mitigation strategies into urban development processes. The results are supposed to provide for risk-insensitive land use planning, sustainable drainage design, and urban policy reform.

1.12. Limitations

Whilst the study takes a multidisciplinary and data - informed approach, several limitations are recognised. First, the analysis is mainly based on secondary data sets (e.g., remote sensing data, policies and government reports) which can differ in terms of spatial resolution, temporal coverage or data accuracy, especially for developing cities (IPCC, 2022). Second, time and resource constraints the research focuses on spatial and policy analysis rather than full scale hydrodynamic or predictive flood modelling approach, which may no quantitative validation of flood mitigation scenarios (Sun et al. 2022).

Third, the policy and institutional evaluation is dependent on the availability of current planning and flood management documents, which do not necessarily represent on- or post-flood revisions (NDMA, 2020). Furthermore, the contextual transferability of global case studies (e.g. Sponge City model in China or Rotterdam's resilience planning) may confront challenges, owing to India's unique governance, socio-economic and urban form characteristics (OECD, 2023; Chan et al., 2018).

Nevertheless, these limitations are addressed through cross-referencing multiple sources of data, triangulating information in the literature, and validating findings based on known theoretical and policy frameworks. The strength of the study is that it combines the spatial analysis, infrastructure evaluation and governance review to gain a well-rounded understanding of urban flood resilience.

1.13. Expected Outcomes

The work is expected to produce a holistic framework to how land use planning and infrastructure development are integrated in the dealing of urban flood risk. The expected results include:

1. A conceptual model showing the inter-relationship between land use dynamics, infrastructure system, and the flood hazard mechanism (Jha et al., 2011).

2. Policy and institutional evaluation identifying the gaps in the existing urban planning and flood management mechanisms in India (NDMA, 2010; MoHUA, 2017).

3. Integrated land use planning framework including practical suggestions on incorporating flood mitigation strategies such as sustainable drainage systems (SuDS), zoning controls, green infrastructure and blue-green networks into statutory master plans (World Bank, 2011; Avashia & Garg, 2020).

Chapter 2: Literature Review

Urban flooding is becoming an international issue caused by climatic change, population growth and uncontrolled urban growth. In this context, a risk-based land use planning paradigm has been widely accepted as a key to promoting resilience in the cities. Flood Risk Not only from extreme precipitation events and sea level rise, rapid, extensive, and often unplanned urban development is causing rapid flood risk, which exceeds existing stormwater infrastructure. Integrated planning is intended to balance competing philosophies, that is, maximize the waterfront economic and recreational values with the need to provide ecosystem services while at the same time minimizing damage through spatially secure siting, construction, and activity planning. Critical scholarship consistently argues that conventional structural defenses, such as those by levees, walls or drainage systems, are insufficient on their own and they must be supplemented by non-structural land use methods, such as zoning restrictions, development controls and active community engagement, if we hope to effectively control residual risk. This literature review traces the development of flood - management thought, synthesises some of the thematic frameworks prevalent today, which cover the planning instruments, infrastructural solutions, green and blue solutions, climate change adaptation strategies, governance mechanisms, and technological advancements, and evaluates some salient case studies, with a special focus on India and other developing countries. It eventually identifies convergences, evidences the gaps and also suggests the future research directions towards integrated urban flood resilience.

Table 1: List of Papers/Reports/Journals

No.	Name of Paper/Report/Journal	Year	Author(s)	Source/Publisher	Aim of the Study	Key Takeaways
1	Urban Flood Risk Management: A Tool for Integrated Land Use	2005	Jha, A.K.	World Bank	To examine the role of spatial planning in mitigating urban	Identifies zoning, building control, and infrastructure

	Planning				flood risk in developing cities.	integration as core planning tools for flood reduction.
2	Flood Risk Management: Global Practices	2007	Sayers, P. et al.	OECD	To review global approaches for managing flood risk in urban regions.	Integrates spatial planning and infrastructure investments for risk mitigation.
3	Climate Change and Urban Floods: A Review	2008	Ashley, R. & Balmforth, D.	Journal of Water Management	To analyze climate-induced urban flooding and its management through planning.	Highlights land use change and drainage system design as adaptation levers.
4	Integrated Urban Water Management: Managing Floods in Cities	2009	UN-Habitat	UN-Habitat Report	To promote holistic water and land management for resilient urban growth.	Emphasizes integration of drainage, zoning, and green areas in planning.
5	Flood Risk Management in the Context of Land Use Planning	2010	White, I. & Richards, J.	Planning Theory & Practice	To link flood risk reduction policies with spatial planning mechanisms.	Advocates planning controls over floodplain encroachment.
6	Urban Flood Management in India: Issues and Approaches	2010	NIDM	Government of India	To assess flood risks and mitigation in Indian cities.	Suggests policy reforms integrating planning, hydrology, and infrastructure.

7	NDMA Guidelines for Urban Flooding	2011	NDMA	Government of India	To define a national framework for urban flood management.	Prioritizes non-structural and planning-based measures alongside drainage.
8	Green Infrastructure in Urban Flood Mitigation	2012	Mell, I.C.	Landscape & Urban Planning	To evaluate green infrastructure as a mitigation strategy.	Shows ecological design reduces surface runoff and improves resilience.
9	Urban Flooding and Sustainable Drainage Systems (SuDS)	2012	Butler, D. & Digman, C.	CIRIA	To develop guidelines for sustainable drainage design.	Promotes permeable surfaces and decentralized stormwater systems.
10	Integrating Flood Risk Management with Spatial Planning	2013	Carter, J. & Lawson, N.	Environment & Planning B	To assess policy integration for flood resilience.	Recommends multi-sectoral collaboration and zoning reforms.
11	Urban Expansion and Flood Risk in Indian Cities	2013	Gupta, K. et al.	J. of Environmental Management	To link land use change and flood exposure in India.	Demonstrates high correlation between impervious growth and flood risk.
12	Mainstreaming Urban Resilience in Development	2014	UNDRR	UNDRR Report	To integrate resilience principles in planning frameworks.	Endorses resilient urban design and early-warning infrastructure.

13	Managing Flood Risk through Land Use Planning: Case of Jakarta	2015	Ward, P.J. et al.	Natural Hazards Journal	To analyze urban flood risk management in Jakarta.	Combines zoning, retention basins, and flood mapping.
14	Smart Cities and Flood Risk Management in India	2015	Bhat, G.K. et al.	TERI	To explore smart city strategies for flood mitigation.	Suggests ICT and GIS integration for spatial flood management.
15	Flood Risk and Urban Planning in the Global South	2016	Douglas, I. et al.	Progress in Physical Geography	To assess flood governance in rapidly urbanizing regions.	Calls for stronger institutional and planning coordination.
16	Building Urban Flood Resilience through Land Use Planning	2016	Sayers, P.	World Bank	To frame land use policies supporting flood resilience.	Combines spatial regulation, infrastructure, and social measures.
17	GIS-Based Assessment of Urban Flood Vulnerability	2017	Singh, R. et al.	Indian J. of Geography	To apply GIS in evaluating urban flood risks.	Identifies hotspots using land cover and drainage data.
18	The Role of Infrastructure in Urban Flood Resilience	2017	Ahern, J.	Urban Ecosystems	To explore multifunctional infrastructure for resilience.	Suggests adaptive design and redundancy in networks.
19	Integrated Flood Management: Concept Paper	2018	WMO	World Meteorological Organizati	To outline global integrated flood management (IFM) framework.	Advocates coordination among planning, engineering, and environmental

				on		sectors.
20	Urban Flood Resilience and Spatial Planning	2018	Porter, J. & Davoudi, S.	Cities Journal	To conceptualize spatial planning for resilient cities.	Emphasizes governance, community, and policy integration.
21	Flood Hazard Mapping for Urban Planning	2019	Shrestha, S. et al.	Natural Hazards Review	To develop GIS-based flood hazard maps.	Supports zoning decisions and infrastructure siting.
22	Role of Infrastructure in Climate Adaptation	2019	World Bank	GFDRR	To link infrastructure investment and climate resilience.	Promotes robust, adaptive, and flexible systems.
23	Urban Flooding and Policy Framework in India	2020	NIDM	Governme nt of India	To review urban flood policies and governance.	Identifies institutional fragmentation and reform needs.
24	Integrating Land Use and Flood Management Policies	2020	White, I. & O'Hare, P.	J. of Environme ntal Planning & Manageme nt	To combine spatial and environmental planning for flood management.	Recommends policy harmonization and spatial risk mapping.
25	Blue-Green Infrastructure for Flood	2021	Fletcher, T. et al.	Water Research	To evaluate ecosystem-based	Combines stormwater control with biodiversity

	Resilience				flood solutions.	enhancement.
26	Climate Resilient Cities: IPCC AR6	2021	IPCC	Intergovernmental Panel on Climate Change	To establish global adaptation frameworks for urban areas.	Recognizes spatial planning as a key adaptation tool.
27	Urban Flood Management in Developing Nations	2022	OECD	OECD Urban Policy Review	To evaluate flood governance in developing cities.	Encourages integrated land-water management frameworks.
28	Spatial Planning Tools for Flood Risk Reduction	2022	Ahmad, S. et al.	Sustainable Cities & Society	To review planning instruments for risk reduction.	Endorses GIS-based zoning and risk modeling tools.
29	Flood Resilience and Infrastructure Networks	2023	World Bank	Global Resilient Infrastructure Report	To study network interdependency in flood resilience.	Highlights cascading effects and redundancy design.
30	Integrated Land Use and Infrastructure-Based Framework for Flood Management	2024	NASA & NDMA	NDMA, India	To develop integrated spatial and infrastructure frameworks.	Applies remote sensing for urban resilience planning.
31	Sustainable Urban Drainage and Land Use Synergy	2019	CIRIA & DEFRA	UK Govt.	To link SuDS with urban land planning.	Encourages local planning guidelines for runoff reduction.
32	Floodplain Encroachment and Land	2018	Jain, V. et	Springer	To evaluate floodplain misuse	Calls for legal enforcement of

	Use Conflicts		al.	India	in Indian cities.	floodplain zoning.
33	Multi-Scale Planning for Flood Resilience	2020	Sayers, P. & Hall, J.	Elsevier	To identify planning scales in flood risk governance.	Supports integration of local and regional plans.
34	Urban Heat & Flood Nexus: Land Use Insights	2021	Singh, P. & Mishra, A.	Elsevier	To connect surface imperviousness with urban floods.	Advocates for porous materials and urban forestry.
35	Adaptive Infrastructure for Urban Flood Risk Reduction	2023	ADB	Asian Developm ent Bank	To propose adaptive design and financing models.	Promotes resilient infrastructure and flexible land-use policies.

2.1. Chronological Evolution of Urban Flood Risk Management Thinking and Policies

Early 2000s - Emergence of Integrated Planning 2005-2012: In the mid-2000s, there was explicit linking of spatial planning to flood risk mitigation by scholars and practitioners. For instance, Jha (2005) articulated urban flood risk management as an instrument for integrated land uses planning that emphasizes zoning and building codes and integration of infrastructure as key flood reduction measures including the designation of floodplains and control of development intensity. By 2007, coupling urban development and engineered solutions was recommended by global reviews of such issues (e.g., OECD/Sayers et al.), as neither land use policy nor infrastructure alone could deal with increased flood exposure. In 2008-2009, studies in (European) contexts and through United Nations agencies (e.g., Ashley & Balmforth 2008; UN-Habitat 2009) emphasized the role of climate change in increasing the flood hazard in cities; making adaptive planning an imperative. Early empirical studies observed the contribution of land-cover change (impervious growth) and outdated drainage design

for flood risk, therefore requiring planners to consider this in long-term urban design. UN-Habitat's guidance in 2009, for example, emphasized the importance of holistic urban water management that includes drainage, zoning and green spaces as part of planning (promoting a balance of "gray and green infrastructure" ecosystem).

2010 - 2015 - Policy Mainstreaming and Resilience Framing: The early parts of this century saw guidelines and case studies spread through to 'mainstream' flood risk management into urban policies. India's National Institute of Disaster Management (2010) and the National Disaster Management Authority (2011) issued urban flood management frameworks which recommended stringent land use regulation and emphasized on non-structural planning measures along with drainage works. Studies by White & Richards (2010) and Carter & Lawson (2013) directly implicated flood risk reduction policies to spatial planning mechanisms to promote control floodplain encroachment and promote multi-sectoral coordination. Concurrently, practical initiatives emerged, such as Jakarta's flood management programme that combined zoning and retention basins and hazard mapping (Ward et al. 2015), and the "100 Resilient Cities" programme undertaken that came with green infrastructure and community planning. By 2014-2015, ideas for "urban resilience" became commonplace (UNDRR 2014; Porter & Davoudi 2018), which emphasizes early-warning systems, emergency preparedness, and the incorporation of resiliency into city planning. Smart city initiatives in different countries, including India (Bhat et al. 2015), started in seeking information and communication technology and geographical information systems to manage floods in real time.

2016-2020 - Integrated Resilience and Technology Adoption: Over the past few years, integration at multiple scales and systems has increased further. Reviews, including Douglas et al. (2016), emphasised that rapidly urbanising areas in the Global South need better institutional frameworks. Multi-hazard planning, strong infrastructure networks and risk-informed finance were recommended by both the World Bank in 2016, 2019, and the Organization for Economic Cooperation and Development (OECD) in 2022. Spatial planning has evolved from two-dimensional static zoning to multiple dynamic tools (Sayers & Hall 2020) and is now multi-scale and more explicit

(Hess et al. 2009). Greater emphasis is placed on low-regret strategies that include a mix of gray infrastructure improvements and also ecosystem-based "blue-greens" infrastructure (e.g. bioswales, retention wetlands) to buffer intense storms. Urban infrastructure planning now tends to include adaptive design with redundancy (Ahern 2017), and multifunctional parks as flood water reservoirs. Simultaneously, developing new technologies have become indispensable: GIS-based hazard mapping (Shrestha et al. 2019) and satellite monitoring (NASA/NDMA 2024) are useful for evidence-based planning. The IPCC AR6 (2021) highlighted spatial planning as an important tool of climate adaptation in cities.

2021-Present - Toward Adaptive, Inclusive, Data-Driven Strategies: In the ongoing phase, the approach to integrated flood risk management is embedded in the context of climate resilient urban development. Recent research and policy frameworks (OECD 2022; Ahmad et al. 2022; World Bank 2023; Asian Development Bank 2023) have called the need for the harmonization of land use and water management policies. Blue-green infrastructure is now a key theme (Fletcher et al. 2021) based on a realisation that ecosystem solutions can jointly provide flood solutions and biodiversity benefits. There is more focus on social equity, including the need to ensure that vulnerable communities are protected, and on governance innovation, for example on risk informed insurance and land readjustment schemes. Technological advances, such as satellites, data supplemented with AI enhanced modelling of risk and real-time sensors are now integrated into planning processes. An example of this shift towards data-driven interventions is the Disaster Mapping Portal offered by the US space agency, that gives near real-time flood maps and forecasts. Overall, the stage has shifted from siloed approaches of structural fixes to holistic multi-dimensional approaches that include land use, infrastructure, ecology, governance, and technology.

2.2. Thematic Synthesis

2.2.1. Spatial Planning Tools

Spatial planning provides the foundation for managing flood risk. Key instruments include zoning regulations, development controls, and spatial plans at various scales. Common tools are:

- **Zoning and land-use restrictions:** Governments designate flood-prone zones (e.g. floodways, floodplains) as non-developable or for limited uses. Flood zoning may prohibit or severely limit development in high-risk areas, as seen in Switzerland where high-risk flood zones ("red zones") ban new construction entirely.

- **Setbacks and buffer zones:** Planning rules often require setbacks from rivers and coasts. Development controls can mandate elevated construction, flood-proofing, or increased setbacks to keep buildings out of flood swaths. For example, planning may require a freeboard above flood levels or designate green strips for overflow.
- **Impervious surface regulation:** Spatial plans may cap total impervious cover or require sustainable drainage features. This reduces runoff at the source. Some cities incentivize permeable pavements and green parking to absorb rainwater.

- **Land-readjustment and incentives:** Beyond bans, cities use incentives (higher floor-area ratios outside flood zones, transfer of development rights away from floodplains) to nudge development patterns.

- **Infrastructure siting in plans:** Urban plans now often incorporate flood hazard maps to guide critical facilities' location, and reserve open space (parks, detention basins) for stormwater retention. Participatory planning can engage communities in shaping these plans.

Collectively, these tools are employed in combination, since no single measure suffices. For instance, Dharmavaram *et al.* (2017) note that spatial plans must be backed by risk-based assessments and enforcement instruments, else compliance is weak. Land use policies can "minimize development in flood-prone zones" and guide safe urban expansion, but effective application requires community engagement and integrated governance. Thus, spatial planning is not just technical mapping but also regulatory and social processes that shape where and how cities grow.

2.2.2. Infrastructure Approaches

Infrastructure remains crucial, but the focus has broadened from solely hard defenses to resilient networks and multifunctional assets. Infrastructure measures include:

- **Gray (engineered) infrastructure:** Traditional measures such as levees, floodwalls, canals, and deep drainage tunnels are deployed to protect assets and channel floodwaters. However, planners now recognize their limits. For example, structural defenses are typically designed for a "finite" (often historic) flood event and may not account for uncertainties of climate change or urbanization. Moreover, levees may transfer risk downstream or foster false security (inducing more development behind them), leading to high residual risk.

- **Redundant and flexible networks:** To improve resilience, infrastructure design increasingly emphasizes redundancy and adaptability. This means having multiple flow paths (e.g. parallel storm sewers), space for flood storage (e.g. daylighting culverts), and plans for upgrades under higher standards if needed. For instance, New Jersey's state water infrastructure plan incorporates a "measurement system" for monitoring flooding, and promotes green-gray mixes like bioswales and pervious pavements alongside sewer upgrades.

- **Water-sensitive urban design (WSUD):** Following principles like Sustainable Drainage Systems (SuDS) or Low Impact Development, cities integrate engineering measures that mimic natural hydrology. Techniques include detention basins, swales, curb-cut gardens, and rainwater harvesting. Infrastructure codes now sometimes mandate on-site retention or infiltration; e.g. new codes may require capture of the first 15–20 mm of runoff on-site to reduce peak flows.

- **Multipurpose land-use:** Some infrastructure is dual-use. Parks, sports fields or green belts are designed to hold floodwater during storms (stormwater parks). Canals and drainage channels are landscaped as linear parks. This multifunctionality—advocated by Ahern (2017) and others—connects flood resilience with urban amenity.

However, numerous studies highlight that infrastructure investments must be coupled with land use and social measures. The World Bank notes that historically "cities have chosen structural measures" but these alone "have proven to be inadequate". The

limitations cited include climate uncertainty, downstream impacts, high costs, and induced risk-taking. Most structural defenses reduce but do not eliminate damage, leaving "residual risk" that land-use planning and emergency management must address. Consequently, modern strategies advocate a portfolio approach: robust (possibly nature-based) engineering, flexible zoning, and emergency preparedness in tandem.

2.2.3. Green and Blue Infrastructure

Ecosystem-based (green-blue) infrastructure has gained prominence as a complementary approach. It uses vegetation and natural processes to manage floodwaters and provide co-benefits (habitat, recreation, heat reduction). Key concepts include:

- **Green Infrastructure (GI):** Elements such as rain gardens, green roofs, street trees, and urban forests that intercept and absorb rainfall. Research indicates GI can significantly reduce stormwater runoff and lower peak flows. For example, case studies of Sustainable Urban Drainage Systems (SUDS) in the UK and Sponge City projects in China show that GI installations can measurably "reduce stormwater runoff and alleviate peak discharge in the drainage system". These measures also enhance social well-being (shade, beauty) and support climate adaptation (reducing heat, improving air quality).

- **Blue infrastructure:** Water-focused green assets like constructed wetlands, retention ponds, bioswales, and permeable channels. These features temporarily store or slow runoff. For instance, retaining floodwaters in wetlands can mimic lost floodplain storage, while bioswales along streets filter water before it enters sewers. Combined "blue-green corridors" along rivers serve as buffers and habitat.

- **Multi-functionality and synergy:** Modern planning emphasizes integrating blue and green networks. As Fletcher *et al.* (2021) note, "Blue-Green Infrastructure" is designed to manage stormwater (blue component) while supporting vegetation and biodiversity (green component). Examples include Dutch "water squares" and U.S. sponge pavement projects that temporarily pond water while blending into public spaces.

- **Greenbelt and floodplain restoration:** Protecting and restoring natural floodplains or upstream forests is another key strategy. These areas can absorb large flood volumes. Several case studies show that setting aside floodplain land (sometimes using tools like Transfer of Development Rights) provides long-term resilience.

Evidence suggests that well-designed GI not only mitigates floods but also encourages public support. However, barriers remain in implementation (costs, governance). The literature underscores that funding and institutional buy-in are critical for GI projects to reach sufficient scale. Nevertheless, GI is widely endorsed: it "can reduce stormwater runoff" and is being mainstreamed in resilience plans (e.g., New Jersey's plan and various 100RC cities). In combination with gray infrastructure, blue-green solutions make urban hydrology more balanced and sustainable.

2.2.4. Climate Change Adaptation

Climate change looms large over urban flood planning. Literature consistently argues that rising intensity and frequency of storms (plus sea-level rise) must be factored into land-use decisions and infrastructure design. Themes include:

- **Future-proof design standards:** Adapting floodplain maps and building codes for projected climate scenarios. For example, planners now often design drainage systems for higher rainfall depths, and restrict development in areas projected to flood under future climates. Some guidelines recommend "adaptive design" (Sayers 2016; ADB 2023) that allows iterative upgrades

- **Land-use flexibility:** Anticipating that some areas may become unsuitable, plans may identify relocation zones or "managed retreat" where development is phased out. This contrasts with older fix-it-at-all-costs approaches. It implies using zoning to discourage new investments in the most vulnerable spots.

- **Integrated coastal adaptation:** In coastal cities, spatial planning involves coastal setbacks, dunes, mangrove conservation, and designing waterfront uses that tolerate intermittent flooding. Many cities include sea-level rise projections in their zoning maps and emergency plans.

- **Cross-sector climate integration:** IPCC (2021) and other sources emphasize embedding climate risk information into all stages of city planning, including

transport and housing. This means that land-use plans double as climate adaptation plans. For instance, New Orleans' post-Katrina master plan (2010) explicitly assigned agencies to climate-related actions, linking flood protections to housing and economic plans.

- **Early warning and insurance:** Climate adaptation in urban flooding also includes non-physical tools like early warning systems, risk transfer instruments (flood insurance), and emergency evacuation planning, which are often part of integrated risk strategies. These complement spatial adaptations.

In summary, climate adaptation has shifted flood risk management toward flexible, knowledge-driven approaches. Cities now consider long-term uncertainties in their planning processes. However, the literature notes a gap between recognizing climate risks and enacting protective measures – many regulations still rely on past data, and urban expansion often proceeds in flood-prone areas despite projections. This gap highlights the need for continuous updating of plans and stronger regulatory frameworks (a point underscored by synthesizing reports like IPCC AR6).

2.2.5. Governance and Policy Integration

- **Multi-level coordination:** Urban flooding crosses jurisdictions (national, regional, local). The Swiss example shows how integrated governance can work: hazard maps and responsibilities are aligned across federal, cantonal, and municipal levels. The federal government provides support, cantons delineate risks and enact controls, and municipalities implement local measures. This nested governance ensures policies are applied consistently.

- **Institutional integration:** Literature repeatedly highlights that institutional fragmentation hinders flood planning, especially in developing countries. Douglas *et al.* (2016) and others call for breaking silos between planners, engineers, and disaster agencies. Integrated management frameworks (WMO 2018) advocate coordinating urban planning departments with water authorities and environmental agencies. Without this, plans may conflict – for example, transportation expansions may block natural drainage if not coordinated.

- **Community participation and awareness:** Studies stress involving stakeholders in planning processes (Dharmavaram *et al.*, 2017; OECD 2022). Participatory mapping of flood-prone zones and community input on open-

space use can build public support. Risk communication is crucial, as public buy-in makes or breaks zoning restrictions.

- **Policy harmonization:** Researchers (White & O'Hare 2020; Carter & Lawson 2013) note that integrating flood risk into existing policies (land-use planning, environmental management, building codes) avoids fragmentation. For example, updating general land-use plans to include flood overlay zones or flood risk assessments is a current best practice. Case studies from around the world show that effective cities incorporate flood considerations into their master plans, investment programs, and budgets (e.g. New Orleans, Switzerland).

- **Legal and financial tools:** Governance also involves enacting legal instruments (mandating setbacks, rezoning floodplains, etc.) and financial mechanisms (risk-based flood insurance, development impact fees in high-risk areas). The literature suggests that incentives (or penalties) can encourage compliance where direct regulation is weak.

Overall, the literature converges on the view that "governance, community, and policy integration" are essential (Porter & Davoudi 2018). Yet gaps remain: many countries lack clear mandates for flood risk in planning laws, or lack cross-sectoral bodies to enforce holistic approaches. For example, an OECD review (2022) found that coordination is often weak, leading to parallel flood control projects and missed planning links. This points to a critical research and practice gap: building institutional capacity and accountability is as important as technical planning.

2.2.6. Technological Tools (GIS and Remote Sensing)

Modern urban flood planning increasingly exploits geospatial technology:

- **Hazard mapping and modeling:** GIS-based flood hazard maps are now standard inputs to plans. For instance, high-resolution flood maps (1-in-100-year extents) help identify no-build zones and design infrastructure placement. Shrestha *et al.* (2019) and others have developed GIS-based methods to support zoning decisions and drainage siting. These maps often combine hydrologic models with topography and land cover.

- **Remote sensing:** Satellite data provide synoptic views of floods. Platforms like NASA's Disasters Mapping Portal supply near real-time flood extent imagery (from MODIS, Sentinel, RADAR, etc.), along with soil moisture maps.

- **Decision support systems:** Software platforms (often cloud-based) integrate various data layers – rainfall forecasts, topography, urban layouts, demographic data – to model flood risk scenarios. These tools enable planners to run "what-if" analyses for different land-use or infrastructure options.

- **Smart sensors and IoT:** Some cities are piloting real-time monitoring networks (rain gauges, river gauges, even flood-detecting cameras) feeding data into city control centers. This aligns with "smart city" initiatives to improve early warning and adaptive management.

- **Remote sensing for land-use change:** Satellite imagery can also monitor urban expansion and impervious surface growth over time, providing quantitative inputs for flood risk assessment and long-term land planning.

In sum, technology enhances both the assessment and implementation phases of planning. NASA's own guidance emphasizes that "better data, better modeling and a deeper understanding of flood exposure" are needed globally. These tools do not replace policy, but they inform evidence-based planning and transparent communication of risk.

2.3. Case Studies and Regional Focus

2.3.1. Indian Context

India's fast-growing metropolises are a good example of the many-faceted nature of the urban flood risk. Empirical investigations (Gupta et al., 2013; Jain et al., 2018) have picked up on a strong correlation between uncontrolled proliferation of impervious surfaces and pavement and built-up areas, and the increasing episodes of floods in cities like Mumbai, Chennai and Delhi. Policy responses in India have been changing in the recent years. The National Institute of Disaster Management (2010) along with National Disaster Management Authority (2011) has promulgated guidelines, which advocates integration of land use planning with flood risk assessment. These directives explicitly promote the priority of measures non-structural, planning-centric such as the protection of natural drainage channels and wetlands, in conjunction with improvements of drainage capacity. Nevertheless, analytical reports (e.g. NIDM 2020) show institutional

fragmentation: development approvals often ignore floodplain restrictions, and a variety of agencies are operating in siloed arrangements e.g. urban planning, water resources, environmental bodies. Recent efforts by smart city initiatives have been to deploy GIS based risk mapping and monitoring systems in real time (Bhat et al., 2015), however, there is a huge gap in terms of enforcement of planning regulations such illegal constructions on flood plain. A critical need for the tight legal enforcement of the zoning law (Jain et al., 2018) and the adaptation of urban development to the hydrologic realities is underlined by Indian flood experience.

2.3.2. Other Developing Country Contexts

In rapidly urbanizing cities of the Global South, similar themes emerge. For example, Jakarta's land-use planning was updated after severe floods: Ward *et al.* (2015) report combining retention basins with revised zoning. In African cities, flood-prone informal settlements often lack infrastructure and are highly vulnerable; research (Douglas *et al.*, 2016) suggests tailored solutions are needed where government planning capacity is limited. Many emerging economies now experiment with nature-based solutions: China's "Sponge City" program (inspired by SuDS) has pilot cities reworking urban design to absorb rainwater (coastal wetlands, green roofs). Likewise, Latin American cities like Bogota have invested in parks that double as reservoirs. These examples illustrate that, even with resource constraints, governments increasingly seek integrated frameworks (often with international support from WB, ADB, etc.). Global institutions (e.g. OECD 2022 Urban Policy Reviews) note that lessons are starting to diffuse: enabling policies, international financing instruments, and transnational peer learning are helping developing nations adopt land-use planning for flood resilience.

2.3.3. Global Best Practices and Lessons

High-income cities are examples of models of integration. Switzerland is one example of the integration of hazard maps into land use that has been successfully applied with a federated strategy, where federal funds are used to support flood projects, cantons create risk maps of flood risks, and municipalities implement controls at the local level

in a move towards a whole-of-government approach to land use. Another example is New Jersey's water infrastructure initiative that intentionally blends the infrastructure improvements (sewer upgrades, etc.) of grey infrastructure with the green retrofits (permeable pavement, rain gardens, etc.) of a comprehensive state-level plan. In the United States, the post-2005 New Orleans Master Plan is another example: it involved explicit flood risk strategies, in a variety of sectors - infrastructure, housing, and land use - and clearly assigned responsibilities for agencies to ensure that different roles increased plan viability. Internationally there has been a significant number of countries with legislation for flood risk management (still EU Floods Directive, Japan National Resilience Act 2013 etc.) ensuring the enforcement of spatial planning tools. Overall, best practices focus on integration: the integration of regulatory zoning, engineered works, ecosystem restoration and community-based approaches into a coherent policy framework.

2.4. Integrative Analysis: Convergences, Gaps, and Future Directions

Convergences: There is near universal support for an integrated approach to flood risk across the literature based on the idea that no one sectoral solution is adequate. Consensus converges to the need of the coherence between spatial planning and infrastructural and ecosystem measures. Authors always make specific recommendations about the role of certain instruments - including: zoning of floodplains, building standards for resilience, economic incentives and disincentives, investment in green-blue infrastructure. Numerous studies (e.g. Porter & Davoudi 2018; Dharmavaram et al. 2017) stress cross-sectoral collaboration as well as the involvement of stakeholders, which are indispensable. A clear movement towards risk informed planning at all scales is evident along with an understanding that flood risk management is a continuous adaptive process instead of a one off project.

Research and Practice Gaps: Despite this consensus, there are vast gaps. Implementation difficulties remain, where planning provisions are often on paper, and are not enforced. Dharmavaram et al. (2017) point out that "enforcing compliance" with zoning and building codes is difficult. Empirical investigations in fast urbanizing cities

show that informal development encroaches upon floodways because of weak governance and socio- economic pressures. In addition, data and capacity constraints hinder appropriate planning in many municipalities; hazard maps are often incomplete or outdated and risk modelling often fails to account for future climate trends, which has been less than successful for many, and was the focus of criticism for a re-examination of conventional design paradigms. Tensions also arise between development aims on the one hand and flood safety on the other; literature contains accounts of "paradoxes" (e.g. Burby 2006) where flood protection efforts have actually promoted riskier development.

Integrated insights and contradictions: As debates change, so does the literature. Earlier studies of structural defenses contrasts to recent emphasis on non-structural measures demonstrates a learning curve as it is increasingly accepted by most authors that levees alone breed overconfidence. A tension lies between short-term (build now) economic incentives and long-term avoidance of risk (avoid flood zones). Equity is a theme that runs throughout as, while many papers emphasise the need to protect the urban poor, who are most vulnerable, there is often little implementation, suggesting a gap between policy ideals and reality. Regarding technology, there is much optimism about GIS and tools based on satellite technology, however some caution is due; data must be a tool for policy action there is a risk of analytical exercise.

Future directions: Moving forward, there are a number of priority areas where the review recommends further work. First, multi- hazard planning will become more and more important as climatic changes create compound risks (floods with heatwaves, drought, etc.). Researchers are calling for generalised frameworks to incorporate flood planning in wider urban resilience planning in which elements like heat, landslides and other hazards can be considered. Second, governance innovation is needed: the use of instruments such as regional basin planning, cross-municipal flood consortia and public-private partnerships for resilience financing are emerging topics. Third, the technological integration will increase: for example the integration of AI-driven flood forecasting into dynamic land use planning, the use of big data (mobile phone usage, social media) for real-time assessment of flood impact, and the improvement of digital

twin cities for simulating flood scenarios. Finally, there are the social dimensions, understanding community responses, justice in making relocation decisions and mainstreaming flood awareness into culture, which are under researched, but crucial.

In sum, the literature outlines a clear path towards holistic and adaptive flood management via land use. The "integrated flood management" paradigm promoted by the World Meteorological Organisation (2018), which integrates the planning, engineering and environmental areas, has been increasingly mirrored in practice. Nonetheless, actualization of this vision implies the need to cross institutional gaps and enforce regulations, finance for maintenance and an ongoing update of planning tools that allows for new types of risks. Future research must therefore seek interdisciplinary approaches, linking the physical and the policy, to help drive urban development that is both sustainable and flood resilient.

Chapter 3: Study Area

Narmadapuram, which was previously known as Hoshangabad, is a great city located on the southern bank of the Narmada River in Madhya Pradesh, the central Indian state. The city is the administrative headquarters of Narmadapuram District and also has cultural, historical and religious significance. One of the most sacred rivers of India, Narmada contributes to a major part of Narmadapuram's identity and has an important role in the social, economic and spiritual life of Narmadapuram. The city was officially changed to Narmadapuram from its old name Hoshangabad to highlight its historical and cultural links to the Narmada River. The agriculture sector is the backbone of the local economy and plays a significant role in agriculture. Agriculture crops are wheat, soybean and pulse crops. Itarsi Junction is one of the busiest rail junctions in India and Narmadapuram is an important area as it is close to the station. Sethani Ghat is the city's most prominent attraction that holds religious ceremonies, evening prayers and celebrations like Narmada Jayanti along the river's bank. Furthermore, Narmadapuram is a hub for nearby tourist sites, such as Pachmarhi, the ‘Queen of Satpura,' a hill station. Narmadapuram has an historical value, natural value and also a religious value and is an important urban centre in Madhya Pradesh (District Administration Narmadapuram, n.d.).

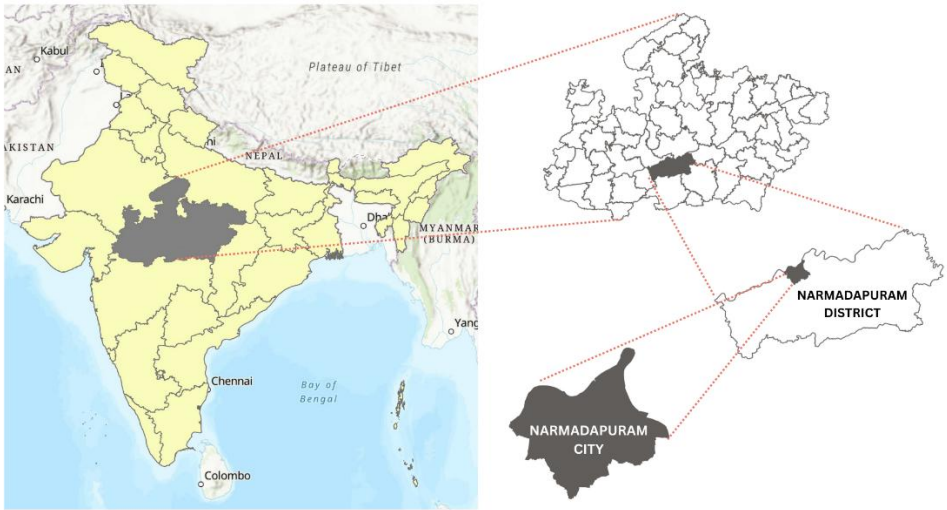


Figure 5: Location Map *Source: Author*

3.1. Regional Setting and Connectivity

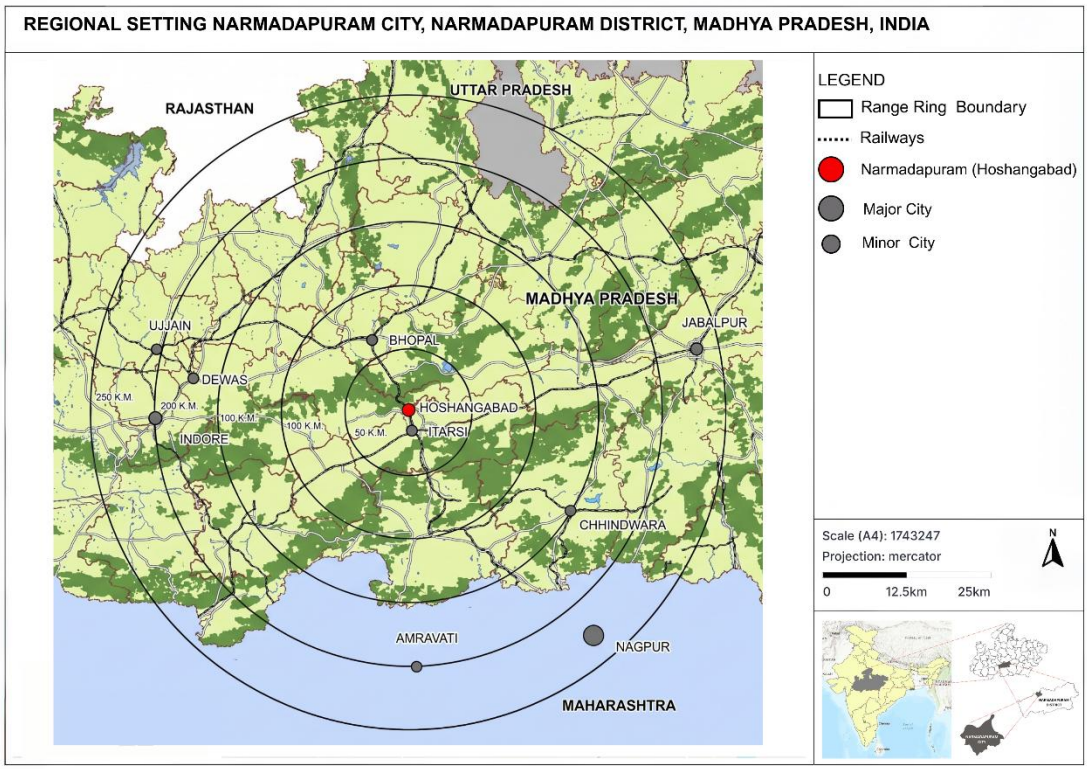


Figure 6: Regional Setting Map *Source: Author*

Figure 6 shows the regional contextual location of Narmadapuram (historically Hoshangabad) in a logical hierarchy, starting from the micro local core area of Narmadapuram. Narmadapuram is actually at the absolute center so as to make a dual node with Itarsi, which is on the innermost ring of 50 K.M. directly south of Narmadapuram. Internationally, Itarsi is a well known railway junction and indeed, this map shows many railway lines converging onto this immediate region. This confined environment makes Narmadapuram not only an urban island, but also a major gateway for vehicular transportation between its north-south and east-west routes in the Indian landscape. Moreover, its proximity to the 50 K.M. radial boundary of Bhopal, the state capital, makes it a key regional satellite that can tap directly into economic and administrative relations with the capital. It is evident from figure 6 that Narmadapuram acts as a pivot point linking the different sub-regions of Madhya Pradesh, moving outwards in the state level spatial dynamics between 50 km and 250 km rings. The

concentric circles are continuous along the western lane reaching towards Dewas and Indore the main commercial and industrial hub of the state. To the East and South East of the map, spatial trajectories are identified towards the judicial center of Jabalpur and Chhindwara. In the meantime, the historical and religious center of Ujjain is frozen at the outside northwestern edge at the 200 K.M.-250 K.M. mark. These major cities are arranged on an evenly spaced radius, thus helping to visualize the fact that Narmadapuram is ideally situated at a relatively equal distance from all the major economic hot-spots of Madhya Pradesh.

The map at higher level of hierarchy (macro-regional level) puts Narmadapuram in larger region of Central India, showing its relationship with adjacent states of Rajasthan (to the North West region) and Uttar Pradesh (to the North region). The most important inter-state relationship that is exhibited is to the south where the 250 K.M. boundary runs completely through the Madhya Pradesh state boundary and deep into the Maharashtra state. The major urban centres Amravati and Nagpur are clearly marked in this outer ring. This underlines that the region of Narmadapuram is not only a political entity and its historical role is not limited to political boundaries but also serves as an important geographical and logistical nexus between the central Indian heartland and the industrial networks of western and southern India.

Lastly, the map offers valuable environmental and topographical background by using green choropleth shading to indicate different levels of terrain and vegetation density. There is significant amount of green cover around Narmadapuram and extending to the south and east, indicating the forested areas of the Satpuras, a dense forest area. This means Narmadapuram is an exceptionally well connected transit and urban node whose physical growth and regional context is within and constrained by very sensitive ecological zones and rugged natural topography.

3.2. Administrative and Planning Units

Spatial development and territorial governance in Narmadapuram City is organized within a dual functioning system of vertical block-civic governance and horizontal

regional planning. The system of governance and spatial development of Narmadapuram City can be described in terms of a two-layered jurisdictional system; one at the micro-level of civic governance within the blocks; the other at the macro-level of regional planning. There is an urban administration core that is managed using a municipal ward structure within the defined City Boundary.

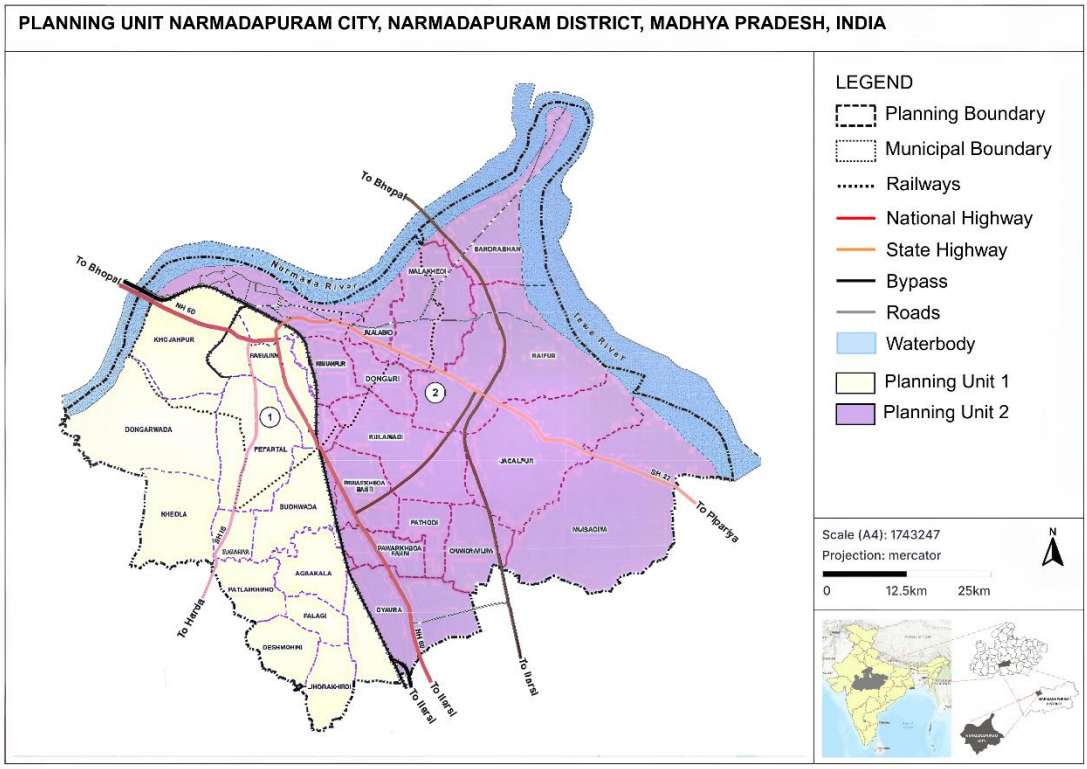


Figure 7: Planning Units *Source: TNCP*

This administrative nucleus consists of 33 distinct municipal wards, grouped mainly on the southern bank of Narmada River, as shown in Figure 8. These wards form the urban core, where the population density is high and a dense network of municipal infrastructure exists, and where complex socioeconomic activities exist. These wards are well integrated with and divided from the regional transportation corridor, comprising major railway lines, local arterial roads and a National Highway which provide link to regional centres like Bhopal, Harda and Itarsi. A well-designed Planning Boundary with a regional jurisdiction for structured peripheral growth and long term

planning for land use is defined, well exceeding municipal boundaries. The large planning area is divided into two main macro-development zones Figure 7 that are intended to manage transitions from rural to urban and expand infrastructure. Planning Unit 1 is located in the western and south western quadrant of the peri-urban fringe of the city encompassing a series of rural hinterlands and developing settlements.

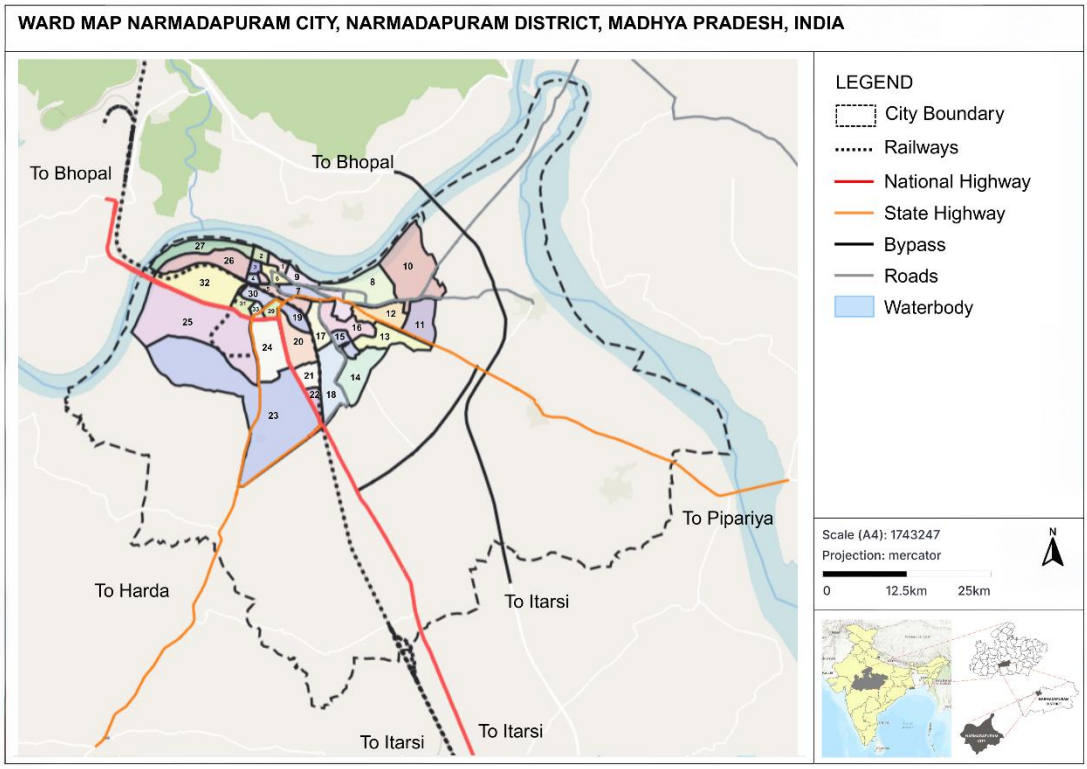


Figure 8: Ward Map *Source: Author*

The spatial orientation of Planning Unit 1 is defining by structurally limiting the impact of National Highway 46 and the central railway line to its eastern boundary and the main longitudinal east-west transportation corridor is State Highway 15 that is driving growth towards Harda. In contrast, Planning Unit 2 is the larger, eastern and north-eastern part of the regional planning area, which looks more like a pattern of expansion affects by the natural geographical characteristics. Geographically, this macro-unit is limited by Narmada River in the north and Tawa River in the east meeting at an ecologically important Bandrabhan confluence. The key revenue villages and special

areas like Malakhedi, Raipur, Dongri, Kulana-di, Jagatpur, Pathodi, Misrodya and Pawarkheda Farm agricultural areas are +egh\connected into planning unit 2. The Planning Unit 2, from a logistical view, becomes an important logistics link as it gets cut by the north-south alignment of N.H-46 passing towards Itarsi and the east-side alignment of S.H-22 passing towards Pipariya. These two different types of planning models can help officials consider trade-offs among environmental concerns and agriculture conservation, industrial development, or residential growth in the context of Narmadapuram's growing urban footprint.

3.3. Demographic Profile

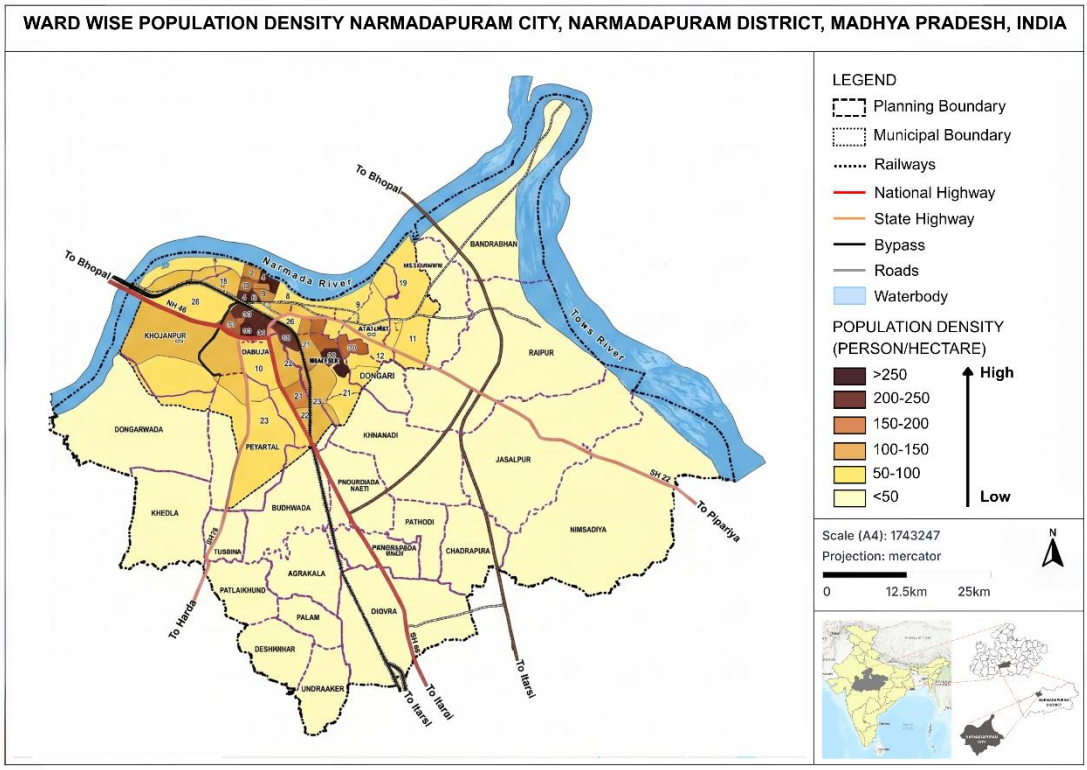


Figure 9: Ward Wise Population Density Map *Source: TNCP*

This map shows the concentration of residential development at a spatial level: the number of persons per hectare in the planning area. The highest population density (more than 250 persons/ha) are found in the core municipal wards located immediately south of Narmada River which is the historical and commercial heart of the city. The

density decreases as one moves further from this dense core to adjoining regions such as Dabuja and Khojanpur (100 – 250 persons/hectare). The peripheral/outer planning boundary areas (including Dongarwada, Khedla, Budhwada, Jasalpur and Raipur) on the other hand, are characterized by very low population density (less than 50 persons per hectare), indicating the predominant rural, agricultural and developing nature of these areas.

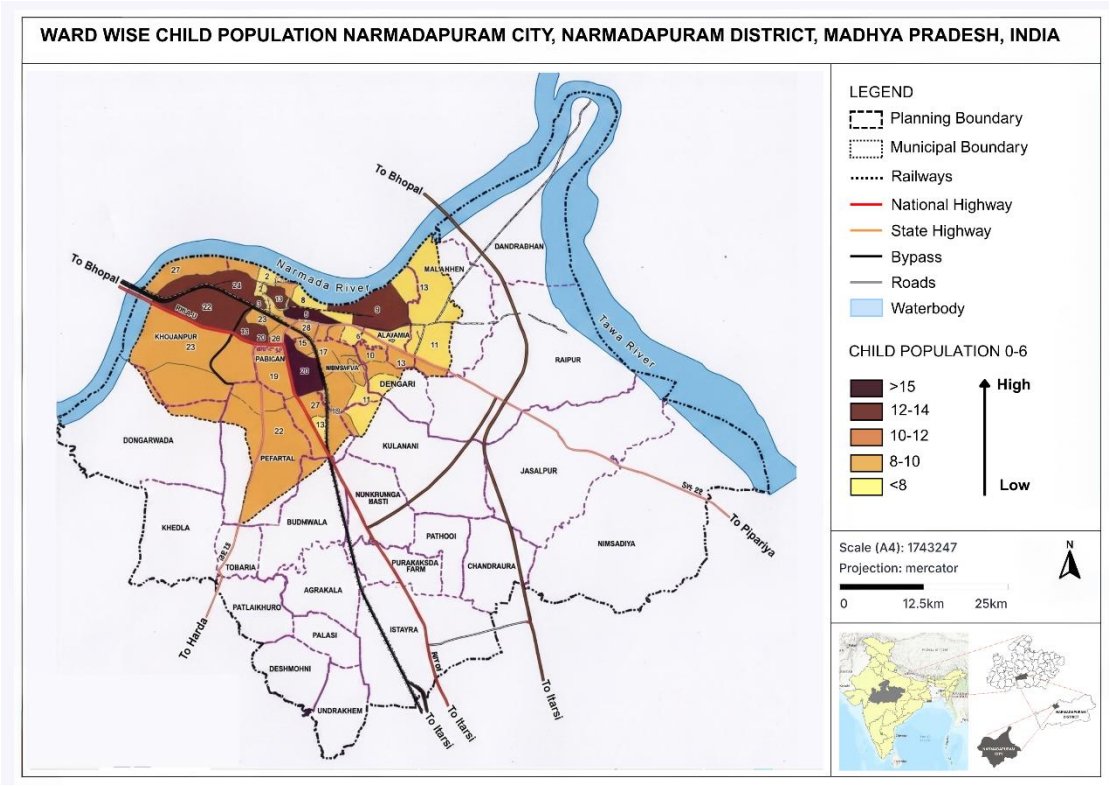


Figure 10: Ward Wise Child Population Density Map *Source: TNCP*

This map shows the percentage of 0 to 6 year children in each ward. Larger percentages of young children (above 15%) are mainly located in the inner and north-western urban areas including the vicinity of Khojanpur and other central wards. This means that there are either a higher rate of births or older families in the more established municipal sectors. The proportion gradually decreases as the person goes east and south, in outer planning villages such as Malanhen, Dongari, Jasalpur, Nimsadia etc, where the

minimum percentage is less than 8%, spinning an older age group or less dense families in these out-territories.

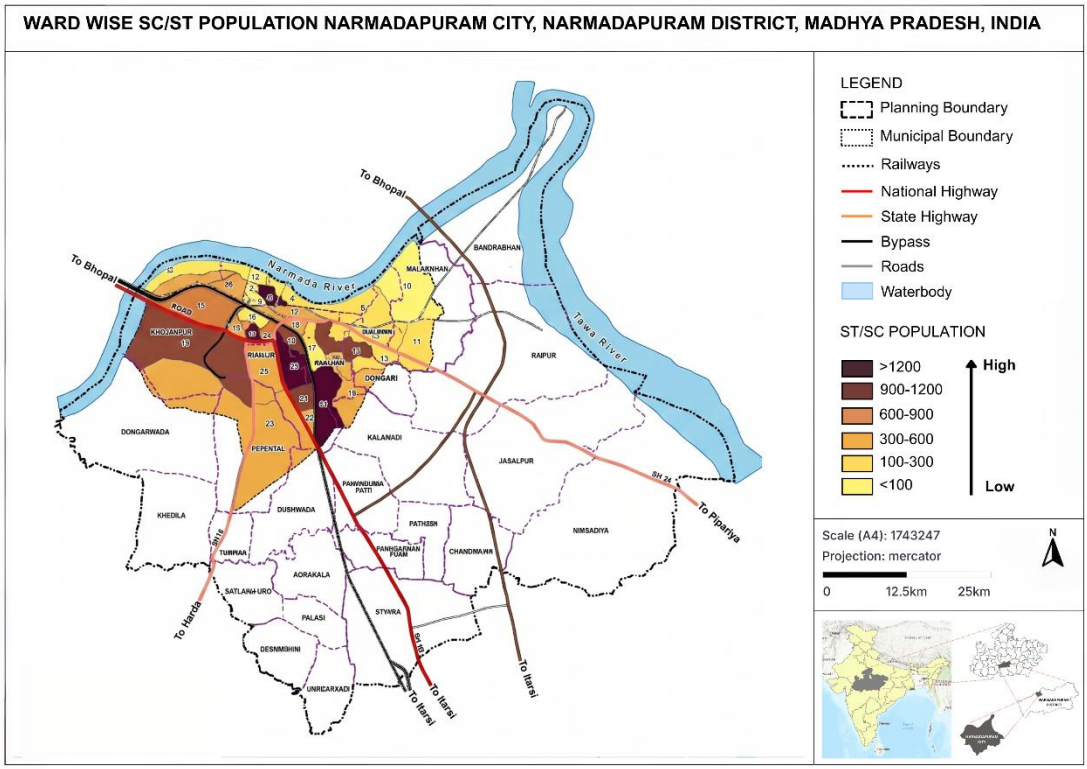


Figure 11: Ward Wise SC/ST Population Density Map *Source: TNCP*

This map shows absolute distribution of the SC and ST communities. The distribution by population is separate in the dark shaded areas creating a distinct corridor running through the centre-west of the city from north to south, with populations reaching their peak of more than 1200 people per ward in these dark shaded areas. On either side of this main path, there are moderate numbers (300-900 people) who run down towards Pepartal. In contrast, the eastern plains and the extreme north-western areas (in the planning boundary) have very low numbers (less than 100) of SC/ST people, reflecting a very segregated SC/ST residential pattern.

Figure 12 shows the percentage of people being literate by region, providing a snapshot of the education infrastructure available to most people. The highest literacy rates (exceeding 85%) stand out as a striking feature in a clearly delineated northeast 'pocket'

along the Narmada River (marked near Seawaneex) and a few inner urban areas of towns. Most of the central municipality wards have a consistent literacy rate of 75-85%. Large chunks of the peripheral regions in the south and south eastern side of the city that extend down to Budhwada, Panjshada basti and Jasalpur are in the lower education categories (65% to 75% or below 65%) and bring out the stark differences between urban and rural education access and literacy results.

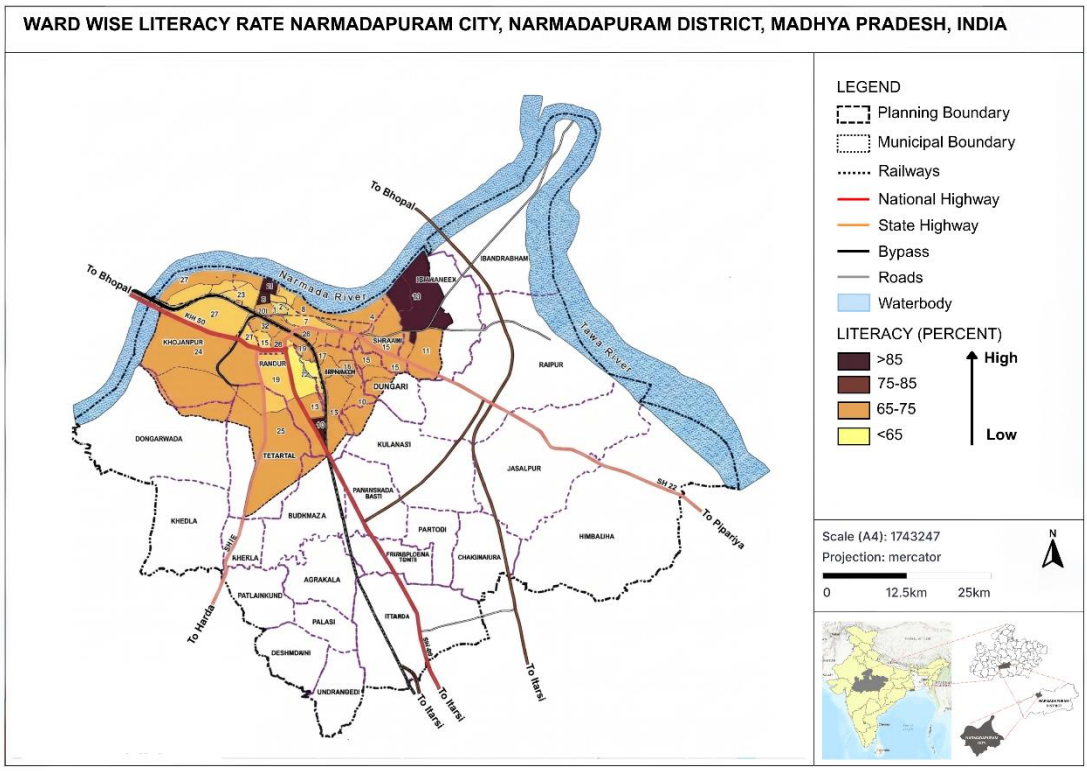


Figure 12: Ward Wise Literacy Rate Map *Source: TNCP*

Figure 13 shows the numbers of females per 100 males. The highest sex ratios (more than 1000) are in ward groups, concentrated in the centre of the north in highly urban wards alongside the riverbank, which show a high proportion of females. The urbanised wards around the parish area have a relatively even sex ratio (900-1000), with a significant proportion. On the contrary, the uneven distribution of gender appears clearly in the outer rural fr+eghinges where the ratio of women to men moves below

850 - in problem areas such as Khedla in eastern and southern parts such as Raipur, Nimsadiya, Jasalpur etc.

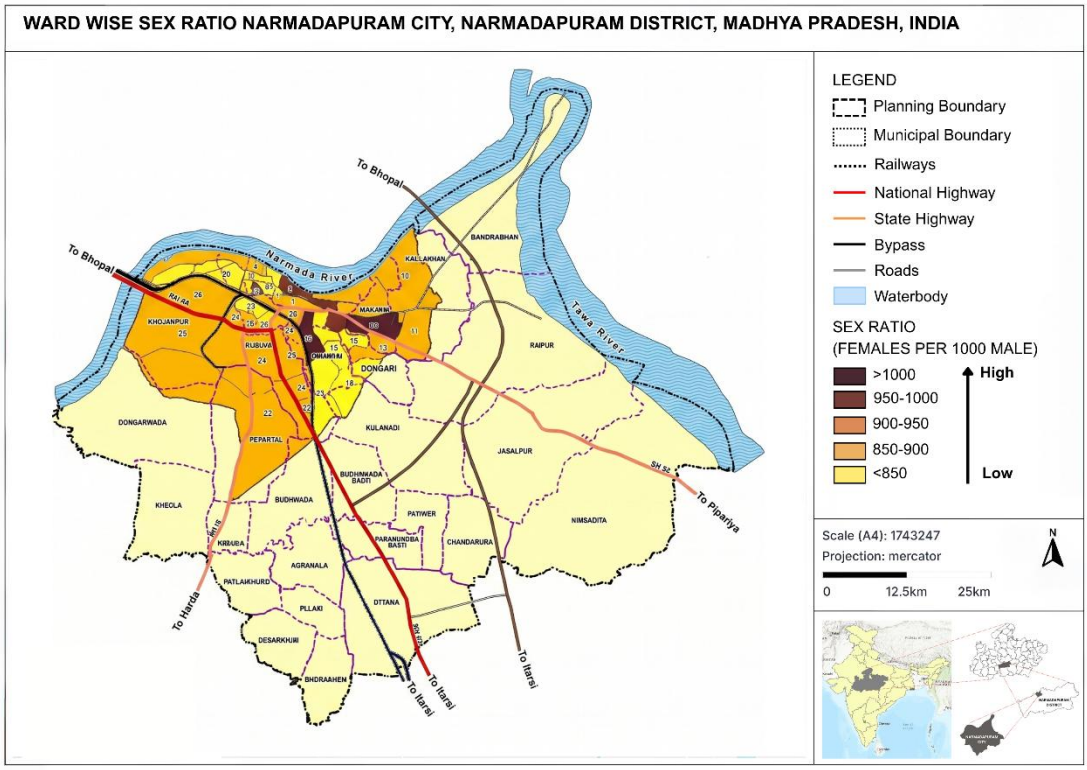


Figure 13: Ward Wise Sex Ratio Map *Source: TNCP*

3.4. Physical and Environmental Characteristics

Slope Map shows Narmadapuram (City of Narmadapuram) with variations of terrain in percent. The topography is divided into 5 slope intervals: slopes less than 3.51% (vibrant green), 3.51% to 7.01% (light green), 7.01% to 10.52% (yellow), 10.51% to 14.03% (orange) and gradients of 14.03% and more than 14.03% (red). Most of the area (green - low slope class) is a flat or gently rolling plain, very suited for agriculture and urbanisation. Yellow (slightly steep), orange (steeper) and red (steeper) slopes are sparsely scattered and are mainly confined along the northern and NE margin along the river banks which represent the natural incisions and steep banks cut through by the waterbodies.

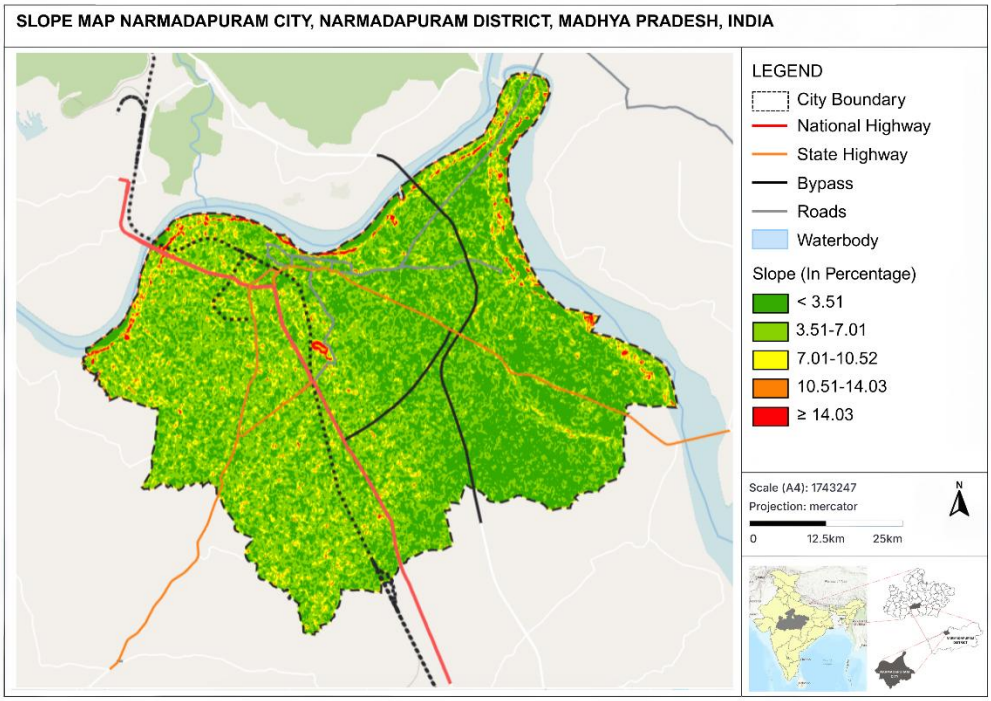


Figure 14: Slope Map *Source: Author*

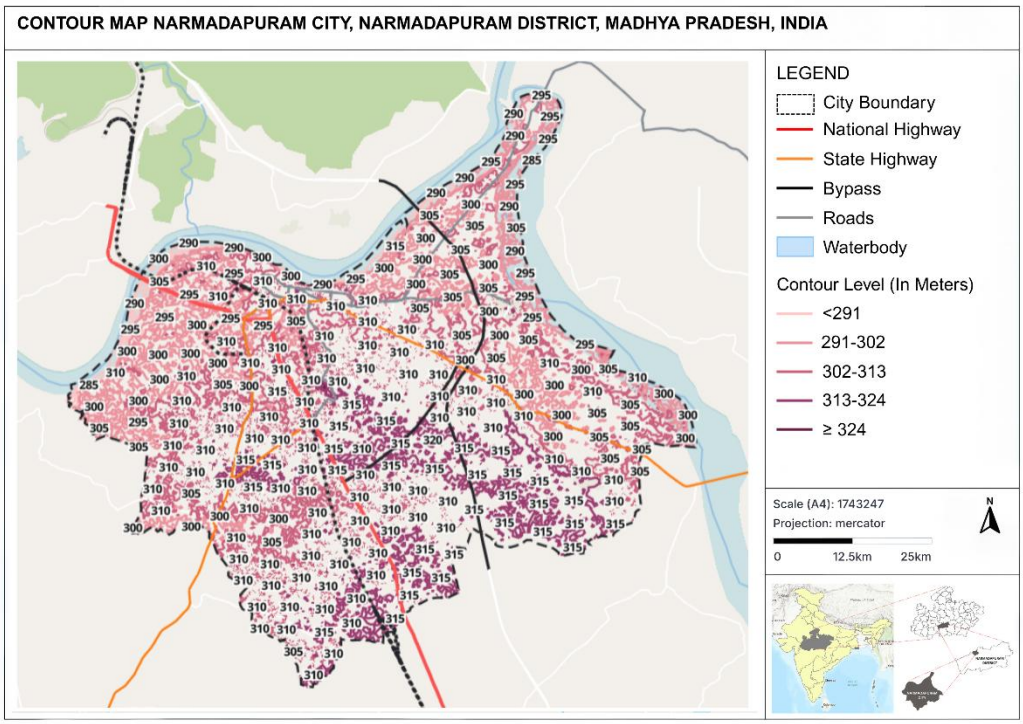


Figure 15: Contour Map *Source: Author*

Contour Map shows a detailed topographic map of the Narmadapuram City with contour lines indicating absolute elevation in metres above sea level. The relief is divided into five elevation zones, from light pink (low-lying), to dark purple/maroon (high elevated). The contour lines are closely spaced (mainly 290m, 300m, 310m and 315m) indicating a gentle topographic slope from the northern riverbank to the south and west of the area. The highest elevations are localized along the southernmost city boundary in accordance with the natural drainage system, which is to the south and which flows into the Narmada River channel.

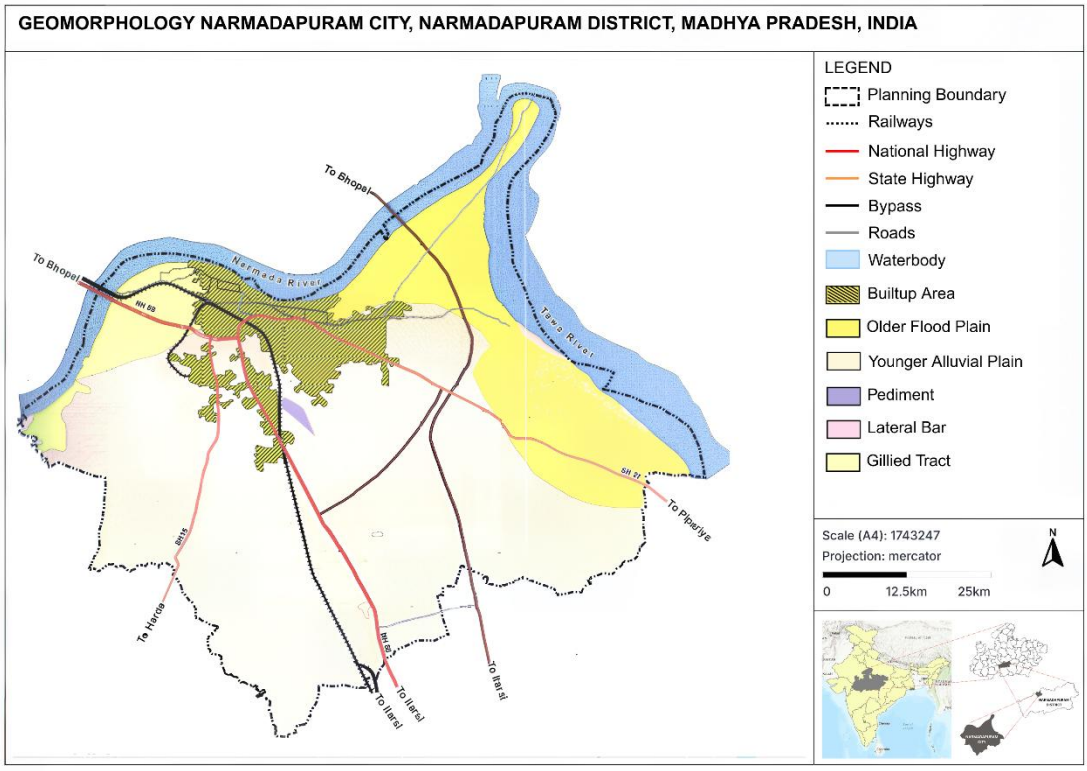


Figure 16: Geomorphology Map *Source: TNCP*

This map outlines the landforms/land cover that have been formed under surface processes and significantly influenced by the fluvial dynamics of the Narmada and the Tawa river systems in Narmadapuram. Three types of landscape are distinguished along the margins of the Olde Flood Plaine (largely in yellow), the Younger Alluvial Plain

(largely indicated in cream/off white) and the Pediment (purple) and the Lateral Bar (pink) formations and the Gullied Tracts (small patches). The hatched "Builtup Area" is located mostly on the stable surface of the younger alluvial plain and areas of the older flood plain and shows how the relatively level, river-cut topography has historically supported human habitation and how the hydrological imprint of the basin is closely associated with it.

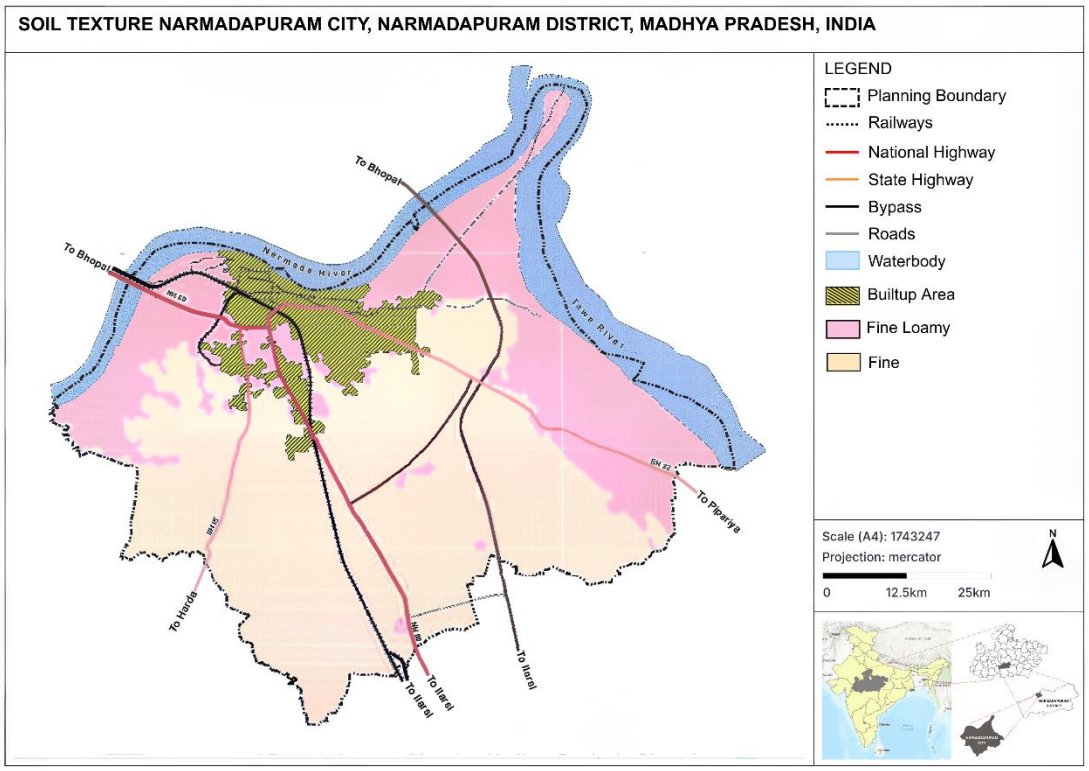


Figure 17: Soil Texture Map *Source: TNCP*

These map show the spatial distribution of surface soil textures in the planning boundary, which gives information about the ag suitability and drainage conditions of the area. The area is fairly uniform and contains two main texture classes: "Fine Loamy" and "Fine. The "Fine Loamy" soils (shaded pink) are present in large areas of the southern, south-western and north eastern corridors and are well balanced with sand, silt and clay which helps with permeability. The west and north central areas are mostly the "Fine" soils (light beige with shading). The "Builtup Area" covered with hatched

pattern is lying on top of transitional zone between both soil types, which is an indicator of urban development that has been happening directly over the good and cohesive soil matrix typical of the fertile Narmada basin.

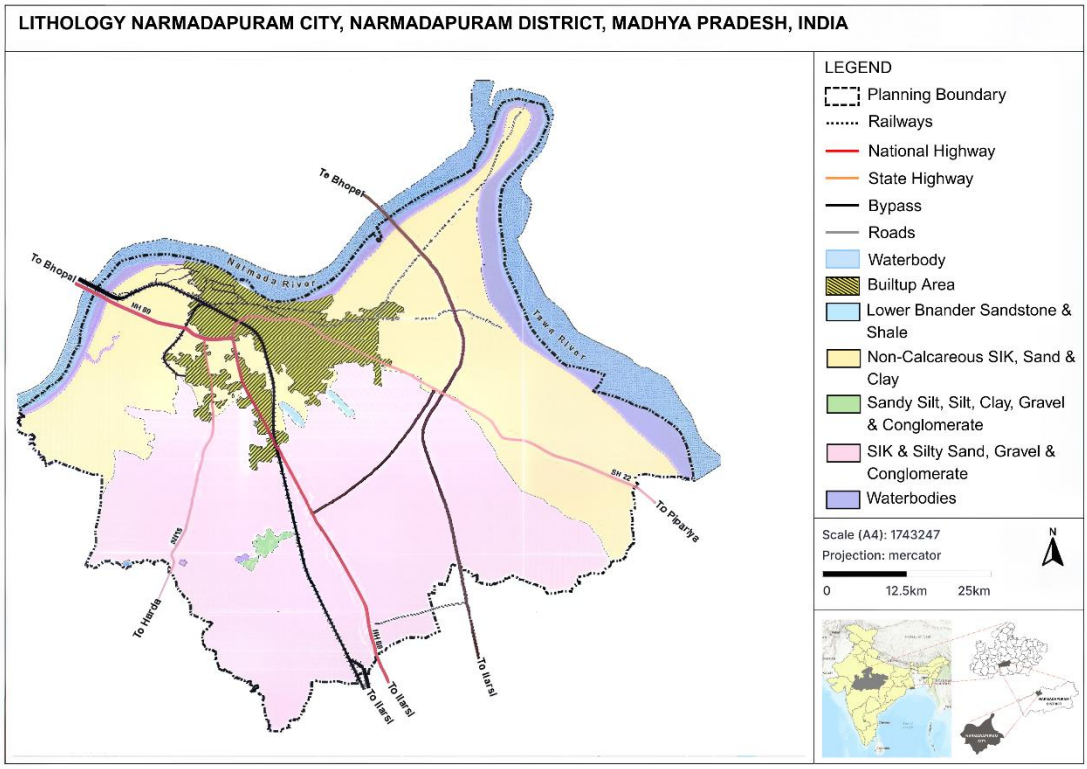


Figure 18: Lithology Map *Source: TNCP*

This map shows the geology underlying the Narmadapuram planning area, the type of rocks and sediments present. The lithology of this area is broken up into the major lithological units: Lower Bhander Sandstone & Shale at the northern and northeast borders along Narmada River and Tawa River, and Sandy Silt, Silt, Clay, Gravel & Conglomerate. Much of the central to eastern region is covered by "Non-Calcareous SIK, Sand & Clay" (colored beige), and much of the extensive southern and southwesterly areas are covered by "SIK & Silty Sand, Gravel & Conglomerate" (colored pink). The map also maps the hatched olive-green "Builtup Area" in a shape corresponding to the historical urban core of Narmadapuram, which is located on stable

alluvial and sedimentary foundations on the southern bank of the Narmada River, with a density of builtup area that is tight.

3.5. Climate and Rainfall

The climate of Narmadapuram district (earlier Hoshangabad) of Madhya Pradesh, India is considered as a typical Central Indian tropical wet-and dry climate with its influence of proximity to the Tropic of Cancer (District Administration Narmadapuram n.d.). The region has three distinct seasons with a very hot and hyper-arid summer (March to June) with peak afternoon temperatures from 40°C to 42°C, humid monsoon season (mid-June to September) with days having comfortable highs of 25°C to 27°C and nights reaching 10°C to 12°C, and mild and dry winter (November to February) with moderate afternoon highs of 25°C to 27°C and low temperatures of around 10°C to 12°C (India Meteorological Department (IMD), as cited in Wikipedia (2026); District Administration Narmadapuram (n.d.). It has heavy and highly seasonal rainfall, about 1314 mm/annum (IMD as cited in Wikipedia, 2026) with July and August being the wettest months of the year. This unique weather cycle results in low relative humidity in April, with average relative humidity below 19%, and on reaching the monsoonal rainfall season, which usually occurs in August, the air becomes saturated and the average humidity increases to 83% (IMD, as per Wikipedia, 2026).

The data collected over this 16-year period from 2009 to 2024, show a dynamic and cyclical nature of the annual precipitation, and the total for this period is 18,172 mm and the calculated long term mean is 1135.75 mm. There was significant variability in the first few years, reaching a healthy 1,449 mm in 2011, and then a sharp 43% drop in 2012 to 819 mm, the driest year in the records. After a big bounce back in 2013 to 1,208 mm, the region went through a four-year period of below-average rainfall between 2014 and 2017, with the lowest rainfall recorded in 2015 (841 mm). However, during the long stretch of wet weather from 2018 to 2021 stability was restored with each year exceeding the 1,100 mm water supply level by a comfortable margin. The most dramatic change, however, was in the last few years: a gap of 969 mm in 2022 followed by an unprecedented 1,617 mm in 2023 (the highest in the series) and then a

stabilization back down to 1,039 mm in 2024. The high value of 798 mm difference between the maximum and minimum values is indicative of the climate's extreme inter-annual variability, which stresses the importance of effective water resources management to cope with the high magnitude of the fluctuations from wetter to drier years.

Table 2: Rainfall Data

Year	Rainfall (mm)
2009	1,178
2010	1,115
2011	1,449
2012	819
2013	1,208
2014	970
2015	841
2016	1,042
2017	994
2018	1,210
2019	1,310
2020	1,181
2021	1,153
2022	969
2023	1,617
2024	1,039

Source: IMD: Annual & Custom District Rainfall Report

Chapter 4: Data Collection and Analysis

4.1. Events of Flood Occurrence

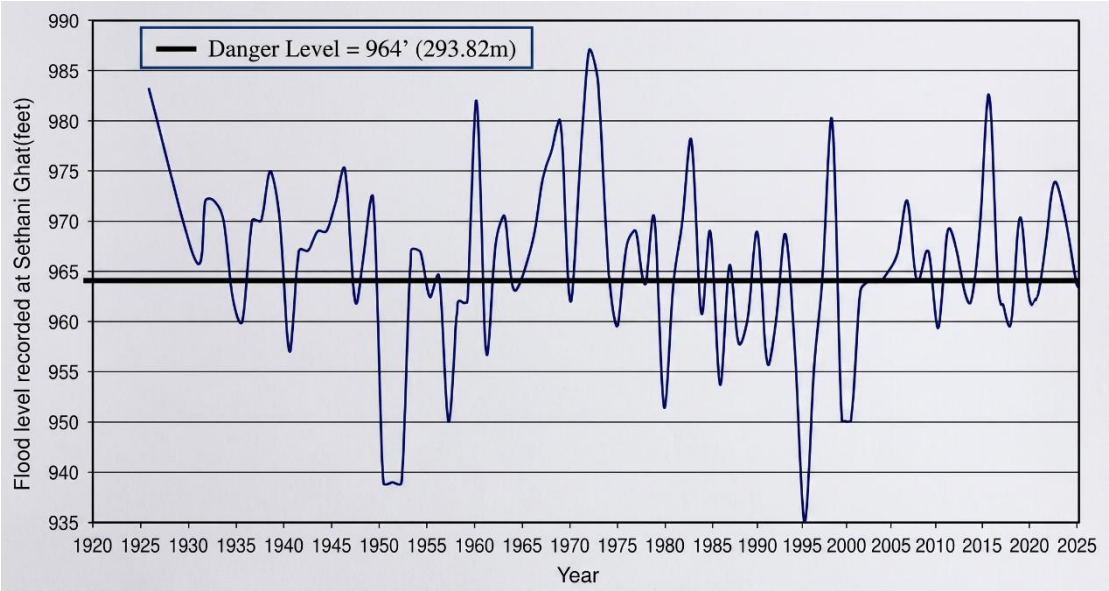


Figure 19: Events of Flood Occurrence *Source: MPWRD & CWC*

A detailed analysis of the data presented across both documents for flood levels recorded at Sethani Ghat on the Narmada River from 1926 to 2025 shows a high level of variability and clear long-term trends. The critical monitoring benchmark for these floods is not obtained from a flood stage but is the officially published flood danger threshold, which is clearly defined as 964 feet (293.82 meters). The annual maximums on this river have often exceeded this threshold value over the last 100 years and are important monitoring parameters for severe flood events in the region. The past record includes several exceptional high crest levels at which flood waters became significantly higher than the danger mark.

The highest recorded flood was in 1950 when the water level was at 988 feet above sea level. High on the scale of the event come major floods in 1971 and 1973, both reaching 987 feet, which are the most conspicuous visual upswings on the middle of the century. Entry in the data collection itself started during a period of high water with 1926 having the remarkable water level of 983 feet. The lowest maximums on the other hand indicate

times of relatively dry or low water periods when the water levels have not even reached the danger stage annually.

Table 3: Events of Flood Occurrence

SUMMARY TABLE: FLOOD LEVELS AT SETHANI GHAT (1926-2025)

[Danger Level = 964' (293.82m)]

Year	Maximum (feet)	Year	Maximum (feet)	Year	Maximum (feet)
1926	983	1971	987	2006	911
1933	972	1972	978	2008	960
1947	975	1973	977	2010	961
1950	988	1974	982	2012	978
1961	982	1985	983	2016	954
1973	987	1984	978	2017	976
1928	962	1987	978	2018	971
1930	972	1998	980	2013	970*
1954	956	1999	980	2020	972
1951	944	1996	940	2021	974*
1961	944	2001	940	2023	974*
1961	982	2003	941	2024	972*
1970	987	2005	942	2025	974*

Source: MPWRD & CWC

The most pronounced decrease was from 1951 to 1952 when the water level dropped to nearly 938 feet, and in 1995–96 when water levels in another large valley dropped to about 935 to 940 feet. When the decades are considered as a whole, some patterns of the frequency of these breaches emerge. The river used to routinely and aggressively exceed the danger level every several years before 1980, with large cyclical surges. This is a highly volatile period followed by a clear 20 year period (1985 to 2005) with noticeably lower low points and longer spells where the river was sufficiently low to not pose a danger despite occasional peaks such as in 1998. In the modern era (2010-2025), the data shows more high consistency, with the river frequently exceeding the danger level each year. The last four years (2021, 2023, 2024 and 2025) all have high water levels that are sustained between 972 and 974 ft. The recent entries are especially indicated by the asterisks in the data set, indicating the modern trend of high-water conditions at Sethani Ghat.

4.2. Drainage System Analysis

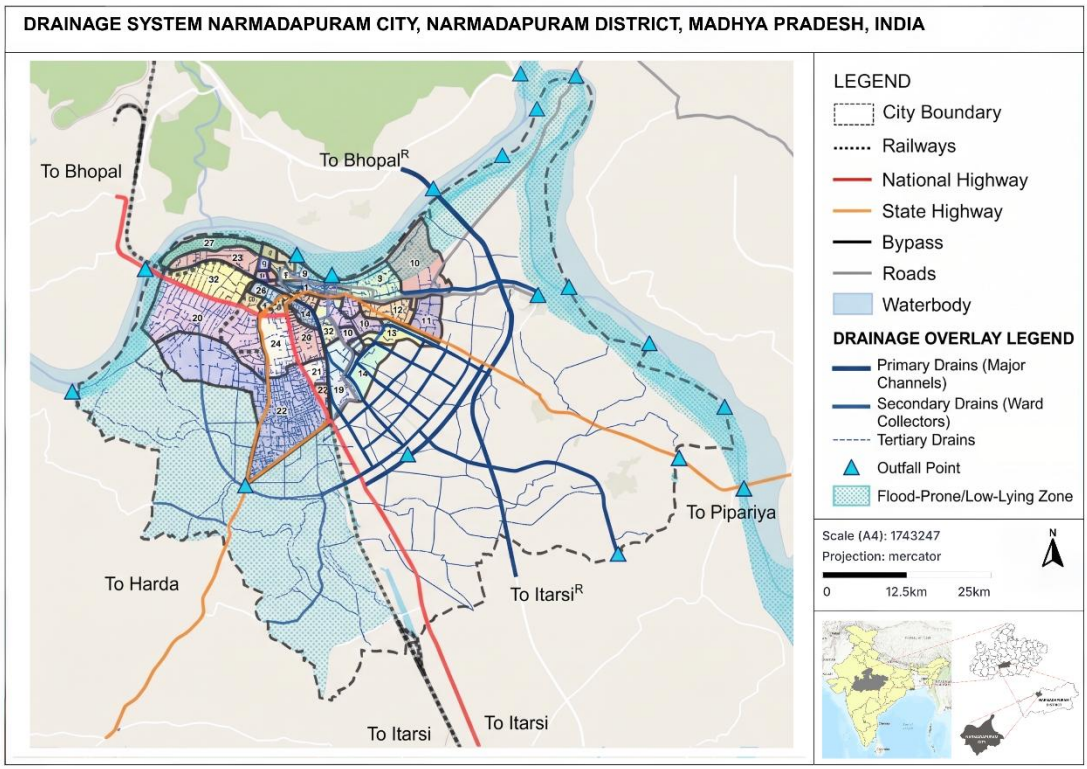


Figure 20: Drainage System Map *Source: Author*

The map is a structured three-tier hierarchical drainage network for managing the city's storm and wastewater. The main infrastructure provided is by major channels which are shown with prominent dark blue lines, and these are the main arterial trunks of the urban drainage system. These are large channels designed ahead, to which runoff from a large secondary network of ward collector channels is directed. Secondary drains (shown in a medium blue color) collect wastewater and rainwater discharged from smaller portions of the community. A dense micro-drainage network of tertiary drains is connected to these ward collectors, and uses fine, dashed blue lines to indicate the presence of localized streets and blocks for surface drainage. The network is concentrated and very well developed in the central and north-western areas of the city, particularly the extremely parceled wards, 20, 24 and 32 while the eastern and southern peripheries show a much less dense hydrological footprint.

The overall topography and flow pattern in the city are generally towards the north and north-east with higher proportions of urban runoff towards the primary waterbody boundary. Blue triangles indicate the systematic distribution of outfall points in the area of the collective drainage network. The large number of such outfalls around the north boundary suggests that the city's sewer is primarily dependent on the outfall of wastewater directly into the nearby river system. Apart from this main discharge area there are peripheral outfalls which are located on the eastern side towards Pipariya and western side towards Harda. The inclusion of these outlying outfall points as critical discharge areas of the fringes help to keep the peripheral runoff from being excessive in the central urban network.

Much of the city's land is shaded with a textured light blue layer to mark it as a flood prone or low-lying area. The most important vulnerability is the continuous wide belt that runs down the entire northern riverfront. This spatial alignment suggests that there is a high risk of riverine floods and backflow problems: when the river level rises high in certain periods of time within the monsoon season, outfall points may be inundated, and flow may be reversed to the urban core. Moreover, extensive flat lowlands are located along the west border to Harda and parts of the border on the south. In these peripheral lowlands the relative low density of primary arterial channels (channels of fifth order and higher) serving these particular sectors combined with their low elevation render these lowlands very susceptible to prolonged waterlogging.

The efficiency of the drainage system is correlated with the linear transport infrastructure system, especially the large-scale linear transport system. National highways, state highways, a bypass road and important railway lines running towards Bhopal (regional centre) and Itarsi, Pipariya, etc run through the city. These transport corridors are often intersected by the main and secondary drainage channels. These intersections are engineering nodes in case the culverts, bridges, and underpasses don't get scaled properly, they can become artificial dams and hydrological barriers. The railway tracks towards Itarsi and highway routes towards Bhopal are therefore critical bottlenecks, and are at high risk of urban pooling and flash floods during heavy rainfall, and require routine maintenance.

4.3. Flood Vulnerability

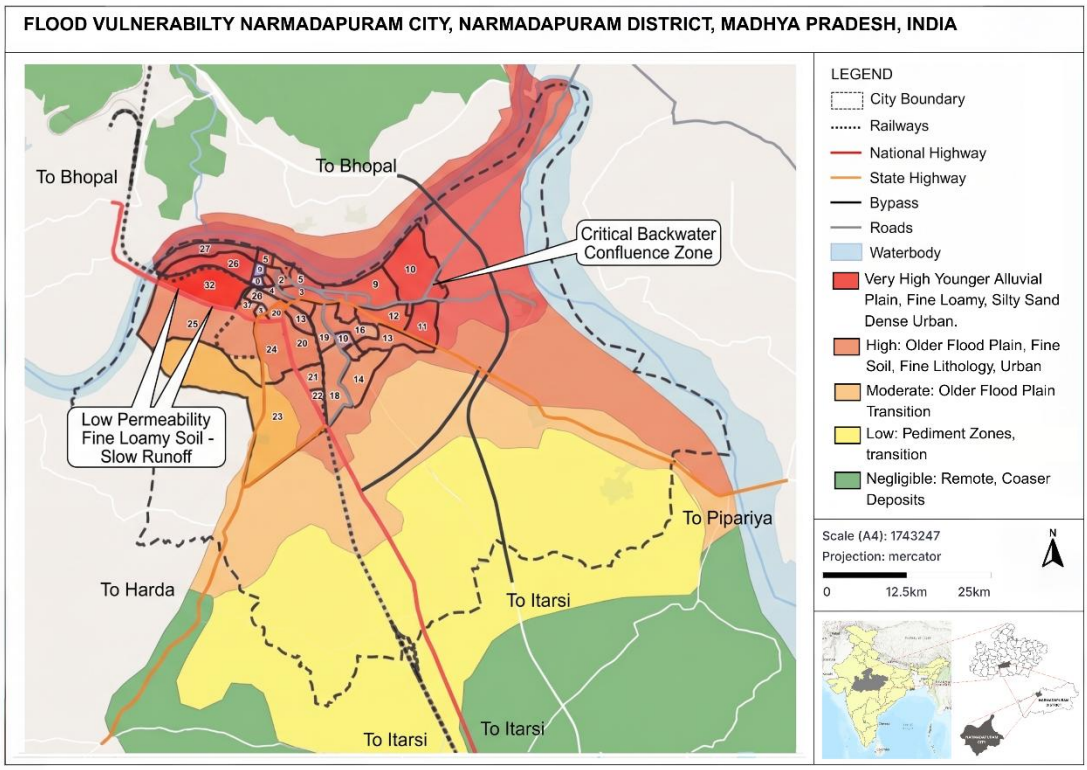


Figure 21: Flood Vulnerability Map *Source: Author*

The flood vulnerability analysis shows a good correlation between the hydrological characteristics of this area, soil lithology and the distribution of urban settlements. The northern and north eastern boundary regions of the city, lying directly adjacent to the main river system are the areas most strongly threatened. This zone has a geologically very high younger alluvial plain profile, with fine loamy, silty sand. Population exposure is very high, as this is the same area as the densely-built central urban core of the city. This high-risk profile is largely due to a prime backwater confluence zone along the river loop, where merging flows are extremely vulnerable to backing up and flooding nearby urban wards during periods of high flow.

The secondary zone around this immediate riverfront is also a zone of high vulnerability, this involving the older flood plain with fine soil and fine lithology. One of the key environmental issues in this high risk area is the presence of fine loam soils

that have low permeability. This soil type leads to a low surface run-off which has significant adverse impacts on natural drainage and causes long-term waterlogging problems during prolonged heavy rain. The terrain progresses further southwards and away from the active river channels, but first an intermediate zone of moderate vulnerability but older flood plain transition soils, eventually evolving into a zone of low vulnerability pediment transition soils. This is a large area of low risk in the yellow sector, rising to Itarsi, that gets better natural drainage and a higher elevation. Areas of negligible vulnerability zone are set at the remote southern peripheries where coarser deposits permit water to easily move through the deposits and are effectively separated from fluvial dynamics.

Transportation systems are extremely vulnerable to these hydrological hazards from an infrastructure standpoint, in the sense that they are vital to the city. The main national highway and the railway line leading north to Bhopal both traverse the very high risk alluvial plains, and pass close to the critical backwater confluence area where there is a threat of loss of regional connectivity during major floods. Likewise, the transport pathways that extend Southwest to Harda cross the low permeable, slow runoff areas and are quite vulnerable to seasonality disruptions as well as structural destruction due to standing water. The urban layout has an extremely worrisome feature: that the highest density areas within municipalities and key transit corridors fall along the line of greatest flood risk.

4.4. Land Use Analysis

1. Geographical Context and Hydro-Vulnerability

The urban planning space of the city has a well-defined geographical definition, marked by two very salient and dynamic river systems: the large river system that runs along the northern and western boundaries and the large tributary that flows from the eastern side of the city. This exceptional spatial arrangement engorge the urban environment into a natural floodplain basin. The layout as it currently stands is quite compact and the old city centre is located on the south bank of the main river. The surrounding

landscape is mostly left in its natural state and acts as a naturally large agricultural field where large amounts of monsoon rainfall water can enter, be absorbed and slowly permeated.

The proposed master plan, however, suggests an aggressive expansion outwards, radially changing this relationship. The city's evolution from a small riverside town to a large city is changing their natural drainage basin. Infilling agricultural land around the periphery of the area modifies the topography and disrupts the natural flow of water to the riverside channels, making the entire area more vulnerable to catastrophic flooding during the rainy season.

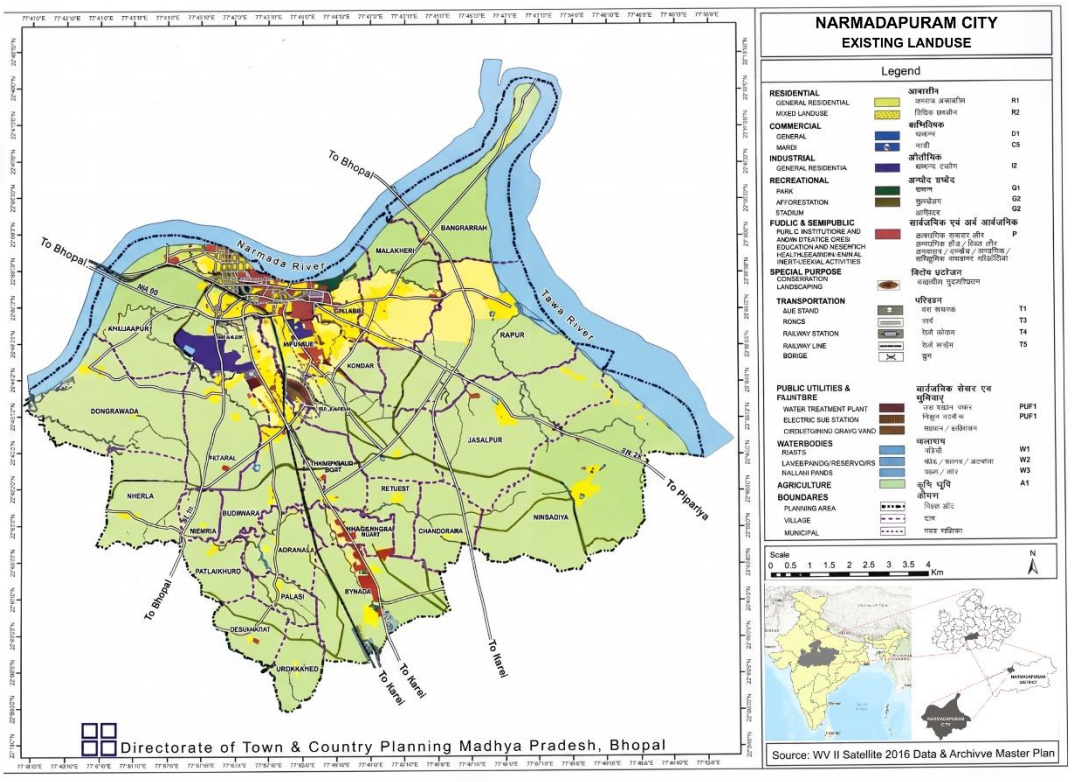


Figure 22: Existing Land Use Map *Source: TNCP*

2. The increasing impervious surfaces and runoff coefficient

The most dramatic changes between the two planning stages are the substantial changes in the light yellow general residential areas, and green agricultural fields, and their

conversion to very high density, bright orange proposed residential areas. This structural change involves the use of the non-porous roofing, non-porous topsoil, and asphalt roads instead of permeable roofing, topsoil, and natural fields.

On a hydrological perspective, this rapid urbanization results in a dramatic run-off increase. Any rainwater that percolated down before is instantaneously turned into overland surface-runoff. This process significantly shortens the "time of concentration"—the amount of time it takes for stormwater that falls across the basin of the watershed to collect and peak. The lack of buffer ground will cause existing stormwater infrastructure systems in the city to experience a sudden, large influx of water during higher intensity precipitation events resulting in very localized street waterlogging and residential low-lying areas becoming flooded.

3. Inappropriate development within Natural Drainage Corridors

The topography is seen in depth and features a complex network of natural streams, drainage lines and seasonal channels cutting through agriculture fields to flow into main river systems. The extensive orange scale extension plan that proposes residential and commercial expansion would essentially cover many of these natural blue coded drainage pathways.

Without a strict separation and protection of these secondary and tertiary channels in the urban master plan, development is sure to become choked, narrowed or completely eliminated. When natural, naturally meandering streams are narrowed into a concrete storm drain, there are significant hydraulic issues. These limited conduits are unable to contain the amount of water when high intensity precipitation occurs, resulting in immediate backwater conditions, where storm water backs up or flows over, placing adjacent residential pockets which were built directly over historical pathways of the water under water.

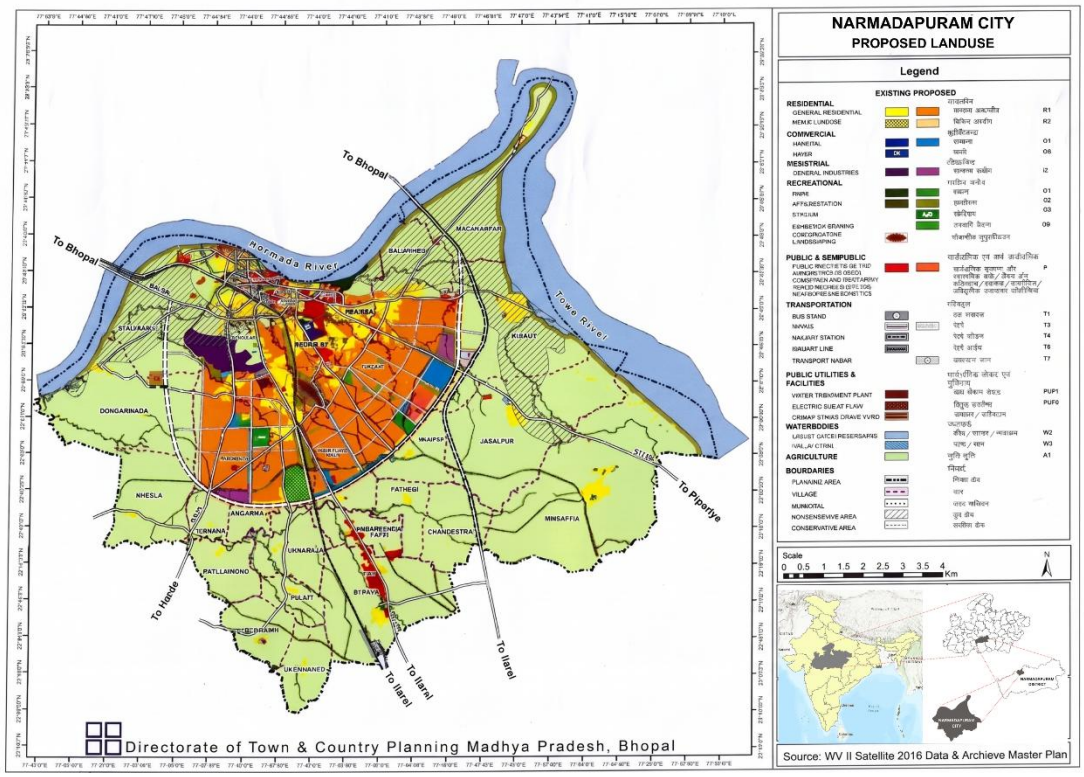


Figure 23: Proposed Land Use Map *Source: TNCP*

4. The Riverfront Buffer Strategy is a Mitigation Measure

Though risk elements are added through expansion, the proposed master plan has the main water bodies embedded with a hyper-recommended, future-oriented climate resilience plan. The plan puts in place an extensive and dedicated green buffer and conservation zone (a thickly hatched diagonal zone) that runs continuously on the immediate banks of both major rivers.

The plan aims to establish these highly vulnerable areas as permanent conservation areas by preventing or regulating the most damaging types of development in the active, high hazard floodplain. These green spaces help to act as an 'oxbow' during high discharges of the monsoon season in the region, stopping the main river or its tributary from causing harm to human health or to key urban infrastructure. Maintaining such zones is crucial to making the city resilient to the devastating floods that could occur along the rivers throughout the region.

5. Transport Infrastructure and Anthropogenic Damming Risks

The proposed master plan proposes to connect the city with the new network of ring roads and existing and enlarged transportation corridors, while integrating it into the wider economic landscape of the city and to its main economic external centres. These major works of infrastructure are crucial for the region's connectivity but can be a serious challenge for urban drainage if they are poorly planned and carried out.

Generally, large highways and rail lines are built up on earthen embankments. When these linear structures cross either across or against the natural slope of the land, but do not create a detailed network of underlying culverts and cross-drainage systems, then they are artificial dams. When the rain is heavy, the rain water is forced to tumble down the gradient and get trapped within these embankments. This causes significant, long-term flooding on the downstream side of the transportation corridors and degrades the city's major transportation corridors right when they are most needed.

4.5. Ward Wise Household Survey Data and Analysis

Data collection was focused on all the 33 wards, with 10 households surveyed per ward (Total 330 Households) to assess the localized impact of urban flooding across Narmadapuram.

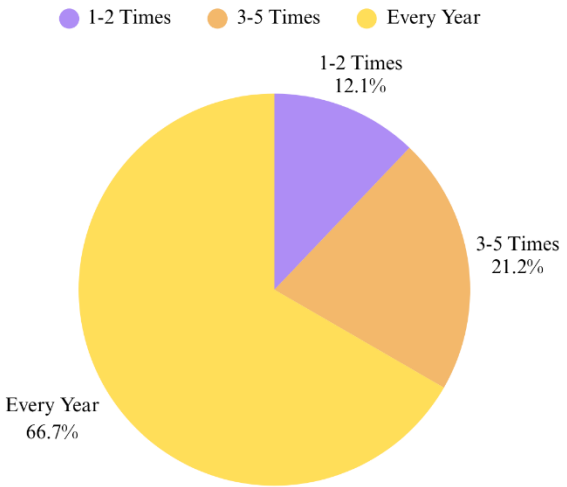
Question 1. In the last 5 years, how many times has water entered your premises?

A. Never

B. 1–2 times

C. 3–5 times

D. Every year



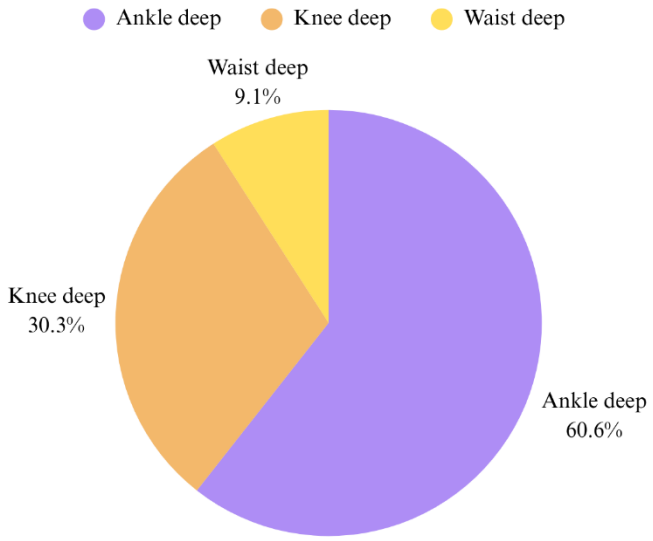
Question 2. What was the highest level of water inside your home?

A. Ankle deep

B. Knee deep

C. Waist deep

D. Above head level



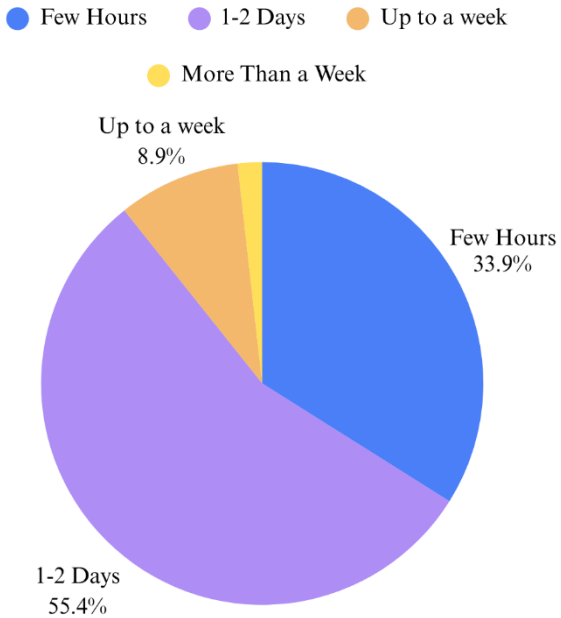
Question 3. What is the typical duration of waterlogging in your area?

A. Few hours

B. 1–2 days

C. Up to a week

D. More than a week



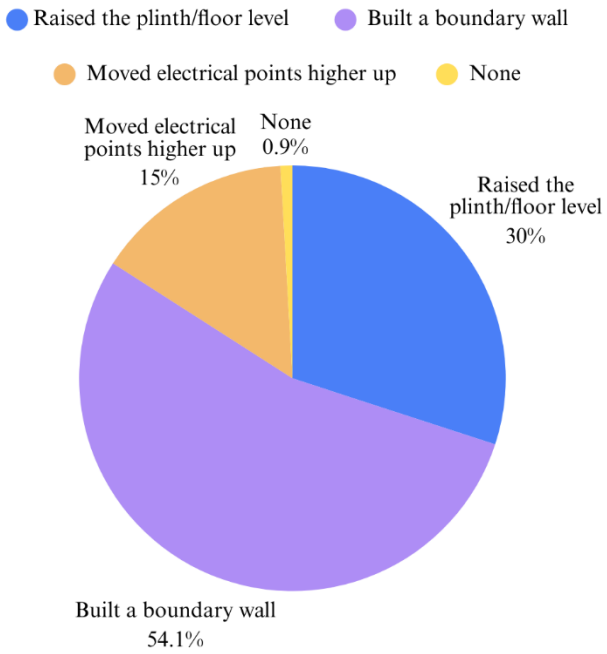
Question 4. Have you made any structural changes to your house to prevent flood damage?

A. Raised the plinth/floor level

B. Built a boundary wall

C. Moved electrical points higher up

D. None



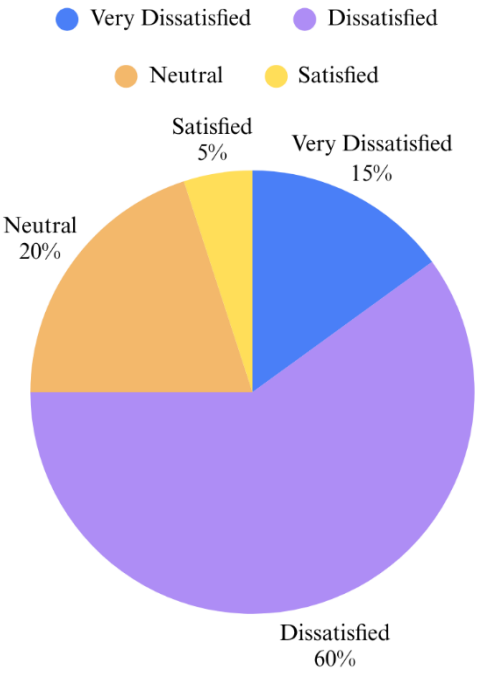
Question 5. How satisfied are you with the government's flood protection measures (embankments, drainage cleaning)?

A. Very Dissatisfied

B. Dissatisfied

C. Neutral

D. Satisfied



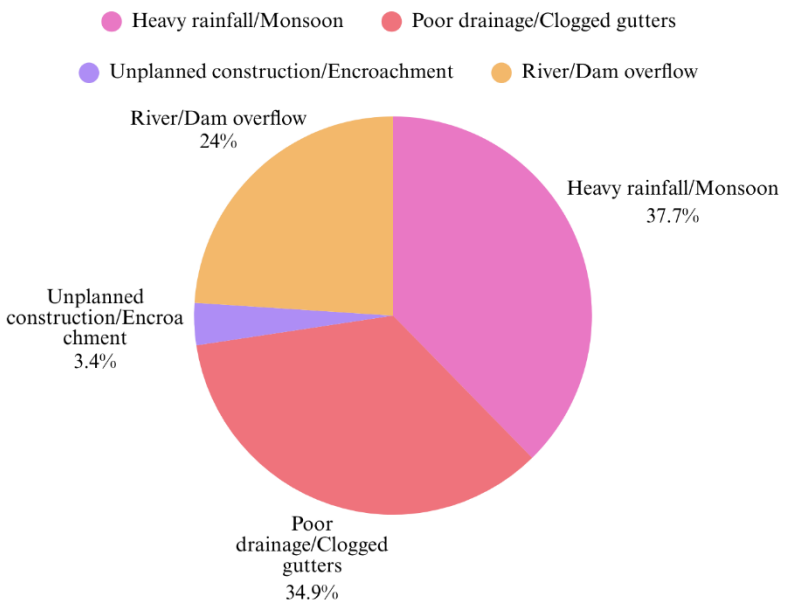
Question 6. What do you believe is the primary cause of flooding in your area?

A. Heavy rainfall/Monsoon

B. Poor drainage/Clogged gutters

C. River/Dam overflow

D. Unplanned construction/Encroachment



Question 7. Do you Face the problem of Urban Flooding in your Neighbourhood?

A. Yes

B. No

The Ward Wise Flood Vulnerability map categorizes and displays the urban wards of Narmadapuram City according to their flood vulnerability, which was determined through this qualitative survey responses.

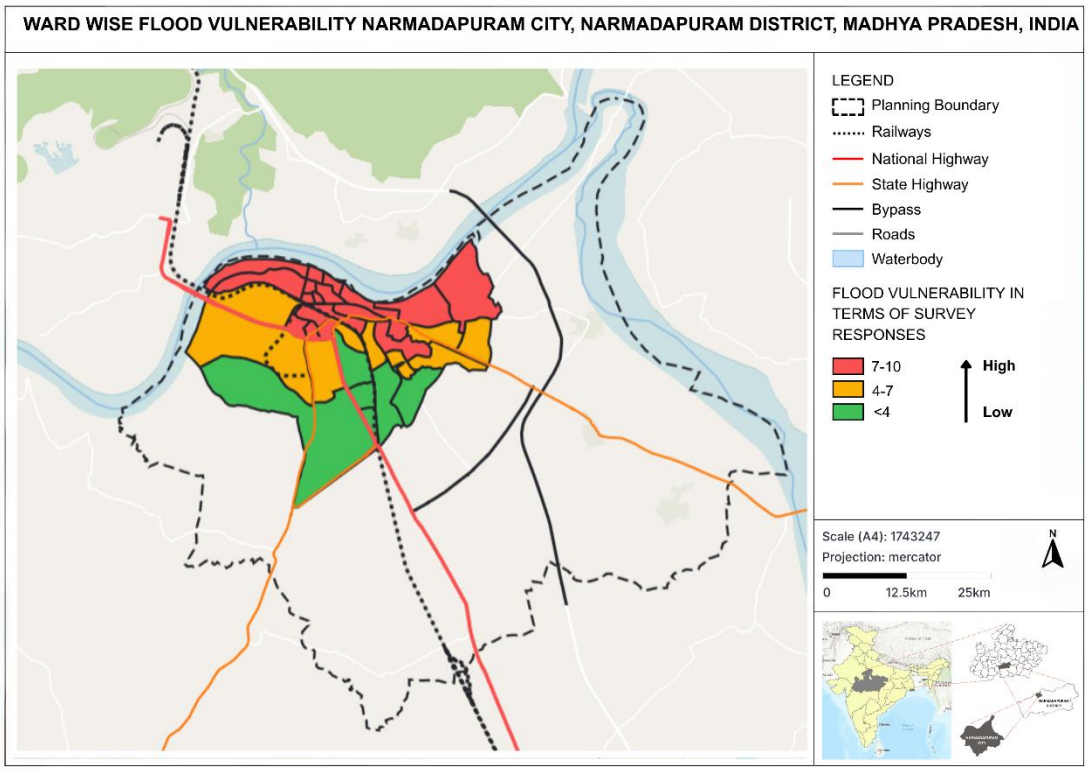


Figure 24: Ward Wise Flood Vulnerability *Source: Author*

Key Survey Take Aways

The survey results conclude that urban flood is not just a seasonal occurrence but is a regular problem in Narmadapuram City. One in three respondents – a startling 66.7% – are experiencing floodwater infiltration on a yearly basis into their home premises, indicating a serious lack of basic urban resilience. These floods are not "skin deep," with almost 40 percent of those surveyed having water in their homes at knee or waist depth. It is a significant issue of recurring water intrusion, which jeopardizes the integrity of residential buildings, results in the loss of citizens' property, and results in long-term risks for public health.

The situation is also worsened by an inadequate drainage system that does not adequately flush the water after a storm. More than half of the surveyed population

(55.4%) reports the presence of water at their neighborhood for 1 to 2 days for typical water logging. This slow recovery rate means that local drainage channels are severely backed up, insufficient or blocked. Water causes an economic and social impact by slowing down local traffic for days, blocking commerce and disseminating waterborne illnesses throughout the community.

Given the limited protection from the institutions, residents have had to make these measures themselves at a cost to themselves. More than 99.1% of households that were surveyed have made structural changes to protect their property with private funds. In particular, building walls to protect their home's boundaries is an activity that 54.1% of the population have carried out, and 30% have done so by elevating their home's plinth or floor level. Such extensive, compulsory investment in private remodeling is an everyday reflection of the vulnerability and financial pressures on local families.

This costly and sentimental burden has caused an overwhelming loss of faith in political leadership by the municipality. Almost 75% of respondents report being completely unhappy with the government's program of flood protection, such as dams, embankments and cleaning drainage works. Though residents recognize that heavy monsoon rainfall is a natural force, they also believe that anthropogenic failures are equally to blame (37.7%). The most regular operational triggers for the reported damage are poorly maintained infrastructure, clogged gutters (34.9%) and river or dam overflows (24%).

The results of the survey show that the location and topography of the city have a significant influence on the increase in flood risk in the city, which is reflected in the answers provided. The ward wise vulnerability mapping identifies a "High Vulnerability" zone which is very localized both along the river frontage to the north and northeast and in the dense urban core. Immediate river backups and critical back water confluence issues for these areas. Risk, on the other hand, decreases slowly between moderate and lower thresholds in the higher elevation wards on the south and southwest, providing a clear spatial picture of where municipal interventions need to be focused.

Chapter 5: Proposals and Recommendations

5.1. Land Use Zoning and control strategy

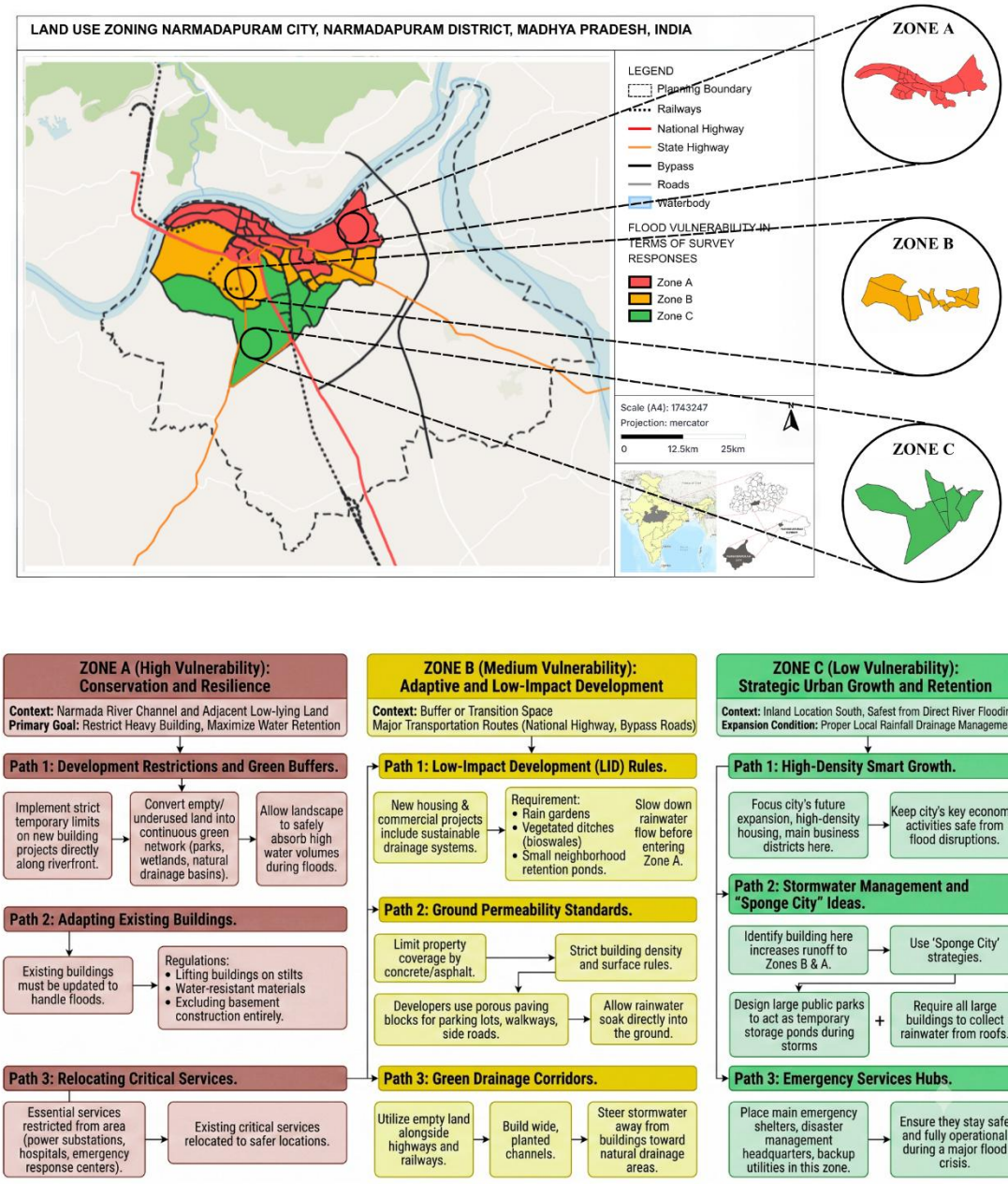


Figure 25: Land Use Zoning and Control Strategy *Source: Author*

The proposal proposes a complete urban planning strategy that embeds flood risk management into a city's master plan through a climate-resilient approach. This approach starts with two main analytical and environment inputs that go into a central revision module. In first step, hazard mapping and zoning is based on historical and predictive modeled data, which provides scientific floors for 10-, 25- and 100-year flood levels. Second, riparian buffers and restoration programs clearly establish an ecological setback zone of 50 to 100 meters along waterfronts and target priority sites of wetland and pond restoration for better natural water retention.

It is based on a three-tier spatial zoning system that controls land use according to flood risk. The risky areas are regarded as green corridors (mostly Zone A - High-Risk Basins / Waterfront Corridors). In this zone, subdivisions that add impervious cover are prohibited, floor area ratios and building heights are strictly limited and development is restricted to avoid an overall footprint that harms the natural infiltration of water while converting land into development.

Zone B (Prohibited Floodplain) is the secondary zone that will be built up as 100% open space. No new construction or permanent structures are allowed in this area, and the property is intended for community uses that will have low impact, including parks, playgrounds and rain water gardens. This approach is in accordance with the URDPFI and Ministry of Housing and Urban Affairs guidelines which are solely based on non-structural uses to safely accommodate excess floodwater.

Zone C is the more protected areas along the border where limited development is allowed but subject to strict adaptive construction regulations, further inland. Raised plinths or Stilts must be used on buildings within this zone to provide a platform for the primary structure and buildings cannot have basements within this zone. In addition, developers will also need to create double story ground floors that are only designed for uses that resist flooding, such as parking or public open space. Furthermore, having double stories grounds designed for flood-resistant purposes, such as parking or public open space. All of these aggregate into effective disaster risk reduction and a balanced

urban water cycle that is in line with the global land-use policy in the Sendai Framework.

5.2. Drainage Updates and Blue-Green Infrastructure

1. Drainage Capacity and Backflow Protection

The biggest threat for Narmadapuram is the city's internal drainage system where it intersects with the river Narmada. A significant backflow from river through the urban channels is observed during the high monsoon causing flooding of low lying areas and the historical ghat sectors. Non return (or check) valves will need to be installed at all principal river outfalls to ensure that the river will not flow back into the city. At the same time, the municipal corporation needs to upgrade the sizes of existing pipes and culverts to accommodate higher stormwater intensities(12, 20 mm/hr) and pump stations in areas of chronic water logging which are located in pockets with lower elevation need to be retrofitted so that they actively pump during the rainy hours when gravity-fed drainage is not possible.

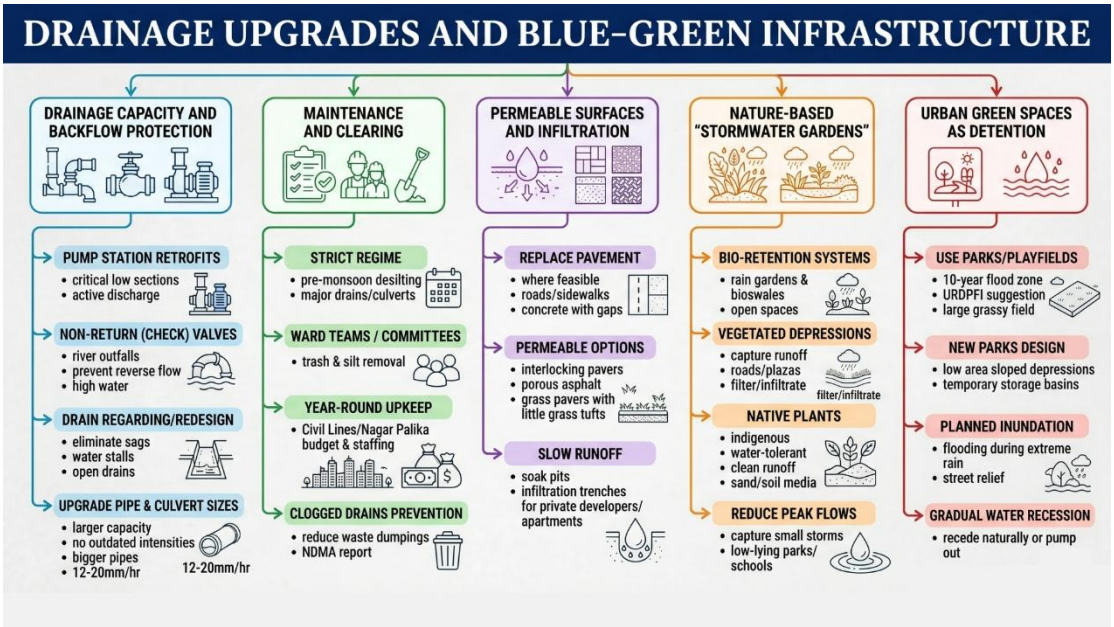


Figure 26: Drainage Updates and Blue-Green Infrastructure *Source: Author*

2. Maintenance and Governance Regimes

The infrastructure in a city such as Narmadapuram, which is located near a river, is only as good as the level of maintenance. Nagar Palika should have a well-defined and institutionalized pre-monsoon desilting schedule to be implemented before the onset of the monsoon rains targeting major trunk drains and culverts. De-centralized committees at ward level can be put in place for daily collection of trash and silt in dense commercial districts and market areas with limited access by municipalities. Having a year-round budget and coordination between local authorities and the National Disaster Management Authority (NDMA) will help reduce dumping of solid waste in open drains and will keep the existing network at peak capacity all year.

3. Permeable Surfaces and Infiltration

Due to the rapid urbanization in Narmadapuram, the ground absorption decreases with the increase of concrete covering, leading to urban floods. To address this, the City should systematically exchange traditional inlets and sidewalks and remove secondary roads with systems that allow them to absorb water like interlocking pavers, porous asphalt, and grass pavers. Building bylaws should require the use of soak pits and infiltration trenches for newer residential development and new residential complexes built out from the core. This creates an indirect “sink-or-swim” situation for the private sector to address and moderate runoff at the source, rather than having the municipal stormwater system overwhelmed.

4. Nature-Based Stormwater Gardens

The benefits of incorporating ecological landscape design into the public spaces of Narmadapuram's public space could be a promising sustainable approach to manage stormwater, mitigating the impact of flash floods. The inclusion of ecological landscape design in the public space design of Narmadapuram could be a viable solution for managing stormwater and reducing the severity of flash floods. Bio-retention systems (bioswales, engineered rain gardens) may be retrofitted to urban open spaces, road side placement and institutional campuses. These vegetated ponds are intended to capture initial surface runoff and to filter it through a designed sand and soil mixture with water-

tolerant native plants. Small to medium storm events are captured at the local level and these nature-based installations markedly reduce peak flow curves and enhance water quality prior to the runoff ever reaching local water bodies.

5. Urban Green Spaces as Temporary Detention

Narmadapuram can have recreational spaces and public parks as temporary flood mitigation infrastructure throughout the municipality. Large grassy areas, playfields and parks located close to 10-year flood zones can be modified to a low area sloped depression according to the recommendations of the Urban and Regional Development Plans Formulation and Guidelines (URDPFI). These areas are for designed and controlled floodwater inundation conditions for instances of extreme cloudburst, and are designed to store large amounts of water, to provide immediate relief to surrounding inundated streets. After the storm's highest surge, or when river levels fall, the "catchment" water is returned to the ground naturally or is evacuated through pumping.

5.3. Sustainable Urban Growth and Flood Resilience Strategy

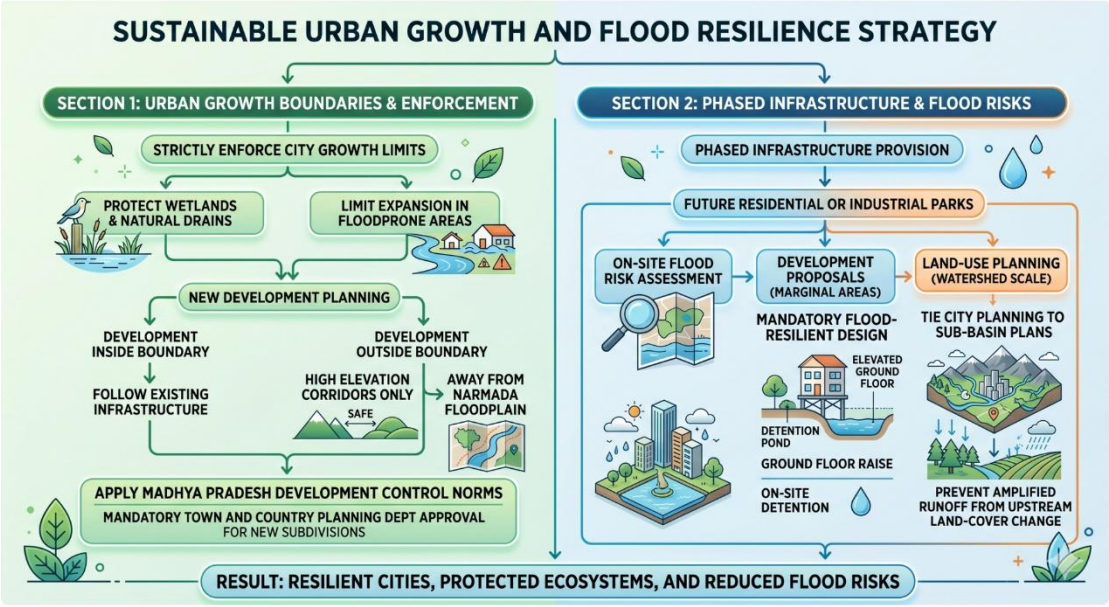


Figure 27: Sustainable Urban Growth & Flood Resilience Strategy *Source: Author*

The Sustainable Urban Growth and Flood Resilience Strategy is a detailed plan that considers both urban development and the protection of crucial environmental areas. The strategy is designed for climate-smart development and directly responds to the challenges that growing riverfront ecosystems encounter, through the imposition of strict regulatory parameters and through a phased, risk-aware approach to developing infrastructure. The idea includes embedding environmental protection in the municipal growth plan, ensuring a balance between protecting the environment and future socio-economic development.

Section 1: Urban Growth Boundaries & Enforcement

This is especially possible in a specific context of Narmadapuram, a city historically exposed to swelling during monsoons and sudden water releases along the Narmada River belt, which has a firm requirement to limit the growth of the city. The plan actively aims to preserve local natural drains and wetlands to eliminate blockages in the natural hydrological network and capacity to absorb surplus runoff, thus mitigating the risk of severe seasonal inundations. Most importantly, the strategy restricts development on identified flood prone areas, to protect sensitive floodplains from the encroachment of residential buildings.

In assessing new spatial developments, the strategy breaks up the future planning into distinct geographical areas according to their vicinity to safety risks. Planned development within the defined urban boundary must closely meet pre-existing infrastructure to maximise the efficient use of infrastructure and reduce the spread of development. On the other hand, any expansion outside the boundary is very constrained. This exterior growth is only allowed with certain approved corridors at high levels where it is naturally safe from the flooding water and will specifically be prevented from entering the vulnerable Narmada Floodplain. For absolute statutory compliance all new subdivisions must get approval from the Town and Country Planning Department before any construction can take off and must comply with the norms given in Madhya Pradesh Development Control Norms.

Section 2: Phased Infrastructure & Flood Risks

The second element in the core pillars of the strategy is a sequential approach based on risk principles in the planning of future residential zones or industrial parks. Infrastructure provision is carefully timed and only provided in relation to the ecological carrying capacity of the land and not permitted to be built in a speculative manner. The first priority will be to carry out an on-site flood risk assessment study, which will use scientific methods to map out flood risk on site, and identify where terrain is weak and where historic high flood lines are occurring, before any new ground is broken in these potential growth areas.

In "border-line safe" and "marginal safe" areas, the proposal requires a Flood Resilient Design framework. Developers in these areas need to design local engineering mitigations (such as raising the ground floor of buildings to keep living and working places out of floodwaters) and also consider on-site stormwater detention features (such as providing a dedicated retention pond) to control localized cloudbursts. In addition, the scale of land use planning is raised to a watershed level, and the planning work of the municipalities is deliberate and issues are directly linked to sub-basin planning. This comprehensive measure will stop the unmanageable high magnitude of the runoff from happening in the downstream area due to the land cover change in the upstream areas, thus preventing strong compound flooding in Narmadapuram.

Ultimate Strategic Result

This approach brings together strict spatial growth boundaries and site-specific control of engineering operations, shifting the paradigm from response to disaster to proactive planning in a resilient manner. Both components are executed synchronously to secure a safe and sustainable future, by implementing the concept of resilient cities, fully protected riverine ecosystems and substantially reduced flood risks.

5.4. Flood Proofing through best practices in Building Code Regulations

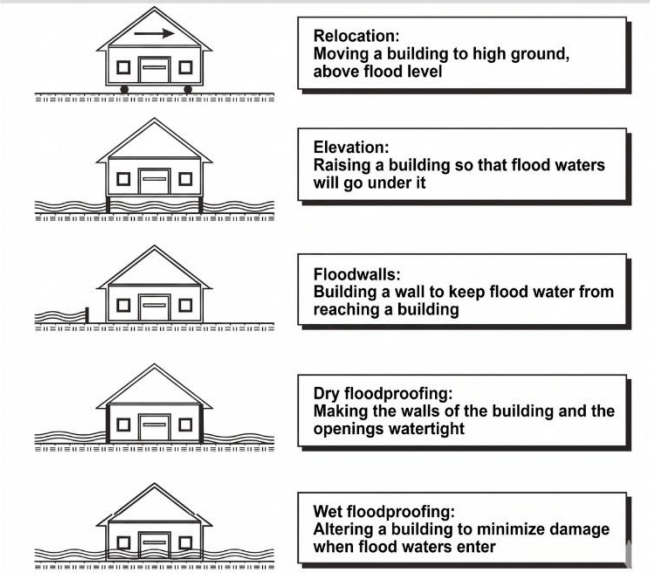


Figure 28: Building Code Regulations *Source: Author*

1. Relocation and Elevation Strategies

In the most problematic informal settlements and low lying residential pockets in the Narmada flood plains, Relocation is a long term, high priority measure. The city has the opportunity to completely remove the hazard to human lives and property from the high-risk communities and move them to safer heights further inland, thereby eliminating the risk forever when it rains the heaviest. When relocating buildings is not possible, Elevation is a highly practical option for new construction and retrofits in proximity to the riverfront. Building on stilt and sturdy pillars ensures that during sea surges the water from the Narmada can safely flow under the buildings while ensuring that living areas remain safe, without disrupting the natural flow of water in the flood plain.

2. Floodwalls and Barriers

If there is no way to relocate or elevate an area of dense urban infrastructure or culturally valuable features, such as the ghats that form the city's historic circuit, then Floodwall construction becomes necessary. Having reinforced perimeters along the most vulnerable parts of the river bank can protect inner urban areas from water encroaching on them from the side. These created walls are a defence system to prevent the river from flowing too far into the Narmadapuram commercial and residential areas when dam releases are high.

3. Dry and Wet Floodproofing

Localized proofing strategies are crucial for individual commercial buildings and homes located in the City's close flood-fringe areas. Waterproofing products are capable of being used in commercial zones along river banks to create an effective watertight barrier to the entry of water into buildings during short, shallow flood events, with temporary flood barriers, reinforced doors, and watertight sealants being used. In turn, if these structures are exposed to long-term flooding or in deep waters where sealing the building would result in the building's collapse under hydrostatic pressures, Wet Floodproofing is a more sustainable solution. This includes making the lower levels of buildings watertight with water resistant material, raising electrical utilities, and allowing water to flow through buildings on purpose during the flood to minimise structural damage and aid in subsequent flood recovery.

Chapter 6: Conclusion

This in-depth two-phase investigation proves in this dissertation that urban flooding is no longer just a natural disaster caused by the unpredictability of meteorological conditions, but rather an urban consequence of structural land use modification, surface changes, and planning deficits. During Phase I, a strong conceptual starting point was established, which examined international guidelines and national policy frameworks and revealed a clear consensus in the current literature: traditional gray infrastructure and engineered structural defenses are by themselves generally inadequate to deal with contemporary urban inundations. The theoretical findings of the research were successfully encapsulated in a spatial and empirical analysis of the city of Narmadapuram, an important urban-cultural node in the fertile Narmada River basin, during the Phase II of the research. The geomorphological, topographical and lithological mapping identified that the quick outward radial expansion offered by the master planning guidelines of the city is threatening to encroach directly on highly vulnerable younger alluvium plains and low lying riverfront basins.

The spatial analysis revealed an acute hydrological reality in the study area: the vast, and highly permeable, agricultural fields and natural ecological buffers are being replaced by dense impervious built-up structures, which are significantly reducing the watershed time of concentration. Historically, the fine loamy soils were known to absorb a lot of rainwater, which has now turned into a high rate of surface run-off causing a high volumetric burst that drowns stormwater channels. The external river dynamics are an additional factor that leads to a critical backwater confluence zone on the northern river loop which results in massive back-flow of water during high monsoon. The present structure of the city has positioned its most critical linear transport infrastructure (rail lines and state highways to Bhopal and Itarsi) and the densest population across these high hazard zones, making the city highly vulnerable to cascading physical and economic disruption.

The lessons learnt from the household survey in all 33 municipal wards confirmed the deeply social and psychological impact of these persistent hydrological shortcomings

and uncovered a significant disconnect between the performance of municipalities and the citizens' demands. The survey indicated that urban flooding in Narmadapuram is also a recurring seasonal problem as 66.7% of the households surveyed reported that flood water has entered their homes once a year. In addition, these events are quite intense, with almost 40% of the communities affected experiencing internal water logging on a regular basis on a knee-deep or waist-deep basis, causing significant damage to individual property, undermining building foundations and creating long-term public health risks. Problems that are systemic in the drainage network are reflected by the proportion of population experiencing prolonged post-storm waterlogging of one to two days, which is 55.4%. This highlights that the ward collectors and tertiary drains are badly clogged, under-designed or structurally backed up.

One of the most noteworthy results of this social evaluation is the extent to which structural adaptation has become autonomous and is now funded by citizens, rather than by corporate services to municipalities, following the complete collapse of the public trust in the ability of the public to be served by the corporate. Nearly 75% of respondents said they were extremely dissatisfied with the institutional flood protection programs, with poor condition of drains, clogged gutters and uncoordinated dam releases being the main causes of damage, demonstrating a huge outlay of private funds to protect homes proactively by 99.1% of households. The population of 54.1% also constructed a wide variety of private modifications, primarily protective boundary walls and physical elevation of floor plinths, by 30% of the property owners. These reactive retrofits are impressive examples of community resilience, but they impose devastating and compounding financial strain on families living in informal settlements, many of which are on the low lying drainage fringes, making systemic and institutionalized planning changes of paramount importance.

This dissertation proposes a multi-scalar, integrated planning and engineering framework linking spatial zoning, urban growth management and nature-based infrastructure, to make Narmadapuram more sustainable and resilient in the longer-term. The principle recommendation is to implement immediately a three-tier system

of spatial zoning using the 10-, 25- and 100-year predictive flood hazard maps, which are to be legally binding.The main recommendation is that a three-tier approach to spatial zoning based on the 10-, 25- and 100-year predictive flood hazard maps be implemented immediately and remain legally binding. Basin and waterfront corridors (Zone A) shall be tightly managed as green waterfront and basin corridors and no new subdivisions shall be allowed to add impervious surfaces, floor area ratio (FAR), or building heights. The entire active floodplain (Zone B) should be a totally restricted development zone with 100% reserved for non-structural community open spaces, such as public parks, playgrounds, and unpaved wetlands that can absorb and store excess monsoonal volumes as per the URDPFI and MoHUA guidelines. Permitting some urban development in adjoining transition sectors (Zone C), provided that they have to implement bylaws that will make the structures more resilient (such as building on elevated stilts; no basement buildings; uplift of plinths; and the use of ground floors for open public parking – one of the least resilient uses).

The municipal corporation needs to carry out target-specific structural and maintenance measures to reduce localized flashflooding and riverine backflow. Heavy duty non-return check valves (NRCVs) need to be retrofitted at all major river outfalls to effectively dam back the tidal inrushes, while dedicated pumping stations need to be installed at long-term low lying sags to provide a permanent provision for drainage pumping when gravity flow is not adequate. In addition, a well-defined pre-monsoon desilting schedule, with decentralised committees for solid wastes at the ward level, needs to be in place to completely eradicate the regular dumping of plastic filled silt in the urban water drains.

The engineering codes should ensure that sustainable drainage options are available which limit the catchment of water at source to restore the natural urban water cycle. Use of Interlocking Permeable Pavers and Porous Asphalt should be gradually increased throughout the City along traditional concrete sidewalks and pavements to allow infiltration of the ground. Soak pits, infiltration trenches and vegetated bio-retention swales must be a legal requirement for private developers to install on new multi-family campuses in residential areas in order to capture and filter initial storm

runoff. At the same time, large civic parks and playgrounds close to extremely vulnerable areas, should be restructured to include shallow sloped depressions that will temporarily collect water as storm clouds hurl toward the area, adding life-saving relief to adjacent streets.

Finally, urban planning needs to go beyond the territorial municipal boundaries and incorporate the concept of dynamic watershed. Strict adherence of town and country planning boundaries protecting sensitive ecological areas from speculative development and an integration of future master plans directly to the sub-basins hydro maps is necessary, as this is a major critical point in the Town and Country Planning Department's work. This regional coordination is very crucial in order to prevent the downstream urban areas from compound flooding because of the huge land cover alterations occurring in the upstream peri-urban fringes of the city.

To conclude, urban flood resilience in fast-growing urban contexts of India, such as Narmadapuram, demands for a paradigm shift from building single-line defenses to a full spectrum of risk-sensitive spatial governance. Urban flooding is very clearly an issue of land-use organization: Where a city has eliminated its natural watercourses, has choked its wetlands, and has paved its floodplains, disaster is all but assured. Initiatives that cut across institutional boundaries and make way for cooperation between town planners, municipal engineers and disaster management officials enable cities to effectively make socioeconomic development meet natural constraints. Describing regulatory barriers, safeguarding natural catchments and integrating Nature-based Drainage solutions into the statutory Masterplan provides a clear route toward a safer future. The strategies for land use and infrastructure developed in this dissertation can help urbanizing areas along rivers keep their populations well protected from flooding and minimize environmental impacts, while meeting the Sendai Framework global targets for disaster risk reduction.

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Annexure

Que No.	Questions	Options / Response Format
Part 1	**Respondent Profile**	
1	Location	*[Open text: Village/Ward, Block/Zone, District, State]*
2	Housing Type	A. Kucha (Mud/Thatch) B. Semi-Pucca C. Pucca (Brick/Concrete)
3	Number of floors in the building	A. 1 B. 2 C. 3 D. 4+
4	Primary Occupation	*[Open text: Agriculture, Daily Wage Labor, Business, Salaried, Other]*

5	Is your house near a water body? (River, Nallah, Lake, Coastal area)	A. Yes B. No
Part 2	**Historical Flood Experience**	
6	In the last 5 years, how many times has water entered your premises?	A. Never B. 1-2 times C. 3-5 times D. Every year
7	What was the highest level of water inside your home?	A. Ankle deep B. Knee deep C. Waist deep D. Above head level
8	What is the typical duration of waterlogging in your area?	A. Few hours B. 1-2 days C. Up to a week

		D. More than a week
Part 3	**Perception of Risk**	
9	On a scale of 1-5, how likely do you think a major flood will occur in the next 12 months?	1 (Very Unlikely) to 5 (Highly Likely)
10	What do you believe is the primary cause of flooding in your area?	A. Heavy rainfall/Monsoon B. Poor drainage/Clogged gutters C. River/Dam overflow D. Unplanned construction/Encroachment
Part 4	**Early Warning & Preparedness**	
11	Do you receive early warning alerts before a flood?	A. Yes B. No
12	If yes, what is the primary source?	A. SMS/Mobile Apps B. TV/Radio

		C. Loudspeakers announcements D. Neighbours/Word of mouth
13	Are you aware of the nearest government-designated flood shelter?	A. Yes B. No
Part 5	**Mitigation & Adaptation**	
14	Have you made any structural changes to your house to prevent flood damage?	A. Raised the plinth/floor level B. Built a boundary wall C. Moved electrical points higher up D. None
15	How satisfied are you with the government's flood protection measures (dams, embankments, drainage cleaning)?	A. Very Dissatisfied B. Dissatisfied C. Neutral D. Satisfied E. Very Satisfied

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