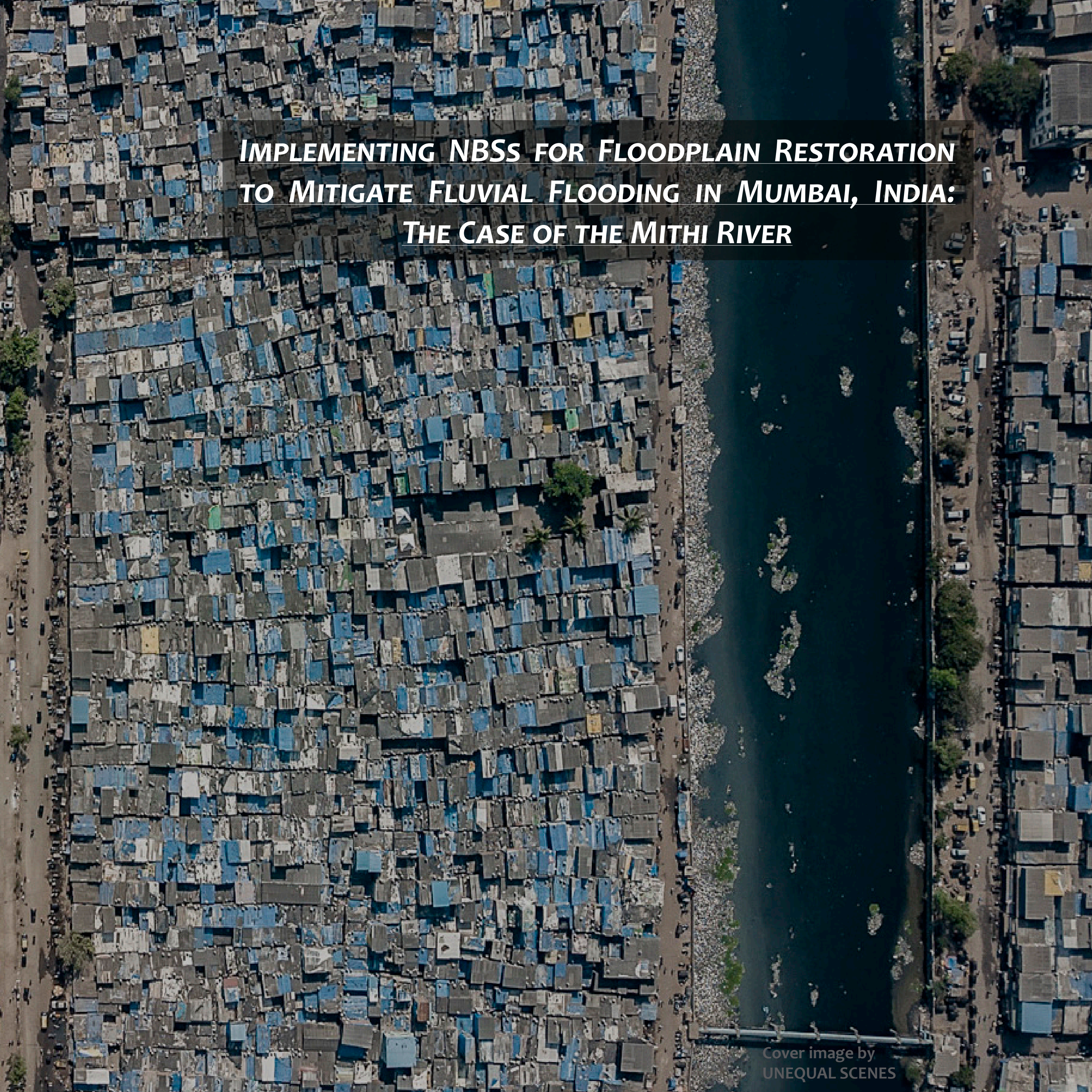
Implementing NBSs for Floodplain Restoration to Mitigate Fluvial Flooding in Mumbai, India: The Case of the Mithi River



Cover image by UNEQUAL SCENES

Mumbai Samachar | By Ashwin Vaswani

Implementing NBSs for Floodplain Restoration to Mitigate Fluvial Flooding in Mumbai, India: The Case of the Mithi River

Candidate: Kharwar Anjali Ketankumar

LM-48 (DM270): Master of Science program in Territorial, Urban, Environmental and Landscape Planning

A.Y. 2024/ 2025W

Cohort 2022/ 2023

Tutor: Prof. Giaimo Carolina

Co-tutor: Prof. Ricardo Pollo

December 2025

ACKNOWLEDEMENTS

I would like to express my deepest gratitude to my professors and supervisors - Professor Pollo, Professor Giaimo Carolina and, PhD. Anja Pejovic- for their constant support , guidance and patience throughout the course of my thesis. Their support has shaped not only this work, but also my growth as a student.

My heartfelt thanks to my colleagues, who made Torino feel like a home away from home. A special thanks to Nishith, my closest, most steadiest source of strength throughout my master's journey. From shared meals to learning new things, his presence has been a blessing.

I am profoundly grateful to my family - especially my parents and my brother - for their unconditional love and unwavering belief in me. Their constant check-ins and reassurance sustained me through every challenge of this thesis and beyond.

I am also sincerely grateful for my in-laws, who provided a peaceful and supportive environment to focus wholeheartedly on my work. And to our little Aadhya, as bright as a sun, thank you for bringing joy into even the most stressful days.

Lastly, and most importantly, i owe my deepest appreciation to my fiance, Vardhan. His patience, understanding, and constant support carried me through the toughest moments. This thesis would not have been possible without him. Thankyou, Vardhan, for standing by me in every way.

ABSTRACT

Mumbai, once an archipelago of seven islands, is today the sixth most populous metropolitan area in the world, with a population of over 23 million. Mumbai's

unprecedented recurrent urban flooding crises are a direct consequence of a stressed ecological environment exacerbated by its history of land reclamation and climate change impacts. Mumbai's River Mithi is a natural stormwater drain for the city. While much research has focused on the water quality of the Mithi River, the depletion of its integral floodplain ecosystem remains underexplored. This research addresses this gap by exploring the potential of Nature-based Solutions (NbS) in restoring the river floodplains to mitigate urban flooding risks and generate opportunities for recreational activities along the Mithi River.

This study employed a mixed-method approach. It synthesizes topographical and land-use data via GIS mapping with a critical review of ambivalent governance and land-use policies. The analysis revealed that Mithi's flooding is primarily influenced by long-term anthropogenic pressures, spe cifically land reclamation over the decades, unregulated encroachments by slums and their waste disposal in the river, and the detrimental implications of hard-engineered flood control structures. These factors have reduced the natural space for water to flow, making the city highly vulnerable.

The findings clearly suggest the need to shift from conventional hard-engineered grey infrastructure to a more nature-based planning paradigm. The research concludes with a site-specific masterplan for flood mitigation using NbS as a multi-faceted strategy for floodplain restoration along the banks of the Mithi River, offering a requisite pathway for enhancing flood resilience in Mumbai.

KEYWORDS

Urbanization; Mithi River; Urban Fluvial Floods; Floodplain Restoration; Nature-based Solutions (NbS); Flood mitigation actions; Flood Resilience

CONTENTS

01

INRODUCTION

1. INTRODUCTION

1.1. RESEARCH BACKGROUND

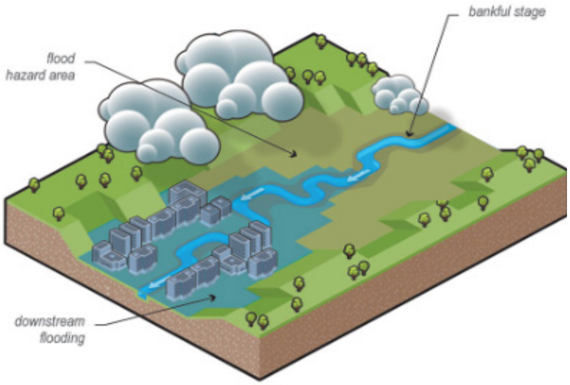


Figure 01:
The phenomenon of Fluvial flooding (Rosenzweig et al., 2024).
source: New York City Panel on Climate Change 4 (NPCC4)

Urban fluvial flooding, also commonly referred to as riverine flooding, has emerged as one of the most rapidly escalating challenges affecting metropolitan areas worldwide. This phenomenon happens when rivers or streams exceed the capacity of their natural or engineered channels, causing them to overflow into ounding low-lying urban areas - the natural floodplains (Jha et al.,2012). Cities where natural watercourses have historically shaped the urban landscapes are specifically vulnerable. The onset of such events is particularly acute in such cities leading to inundated floodplains and widespread disruptions of urban infrastructure (Sayers et al.,2013).

Due to the complex interplay of natural and anthropogenic factors, urban fluvial floods have intensified and become more frequent worldwide. Peak river discharges are overwhelming the existing drainage systems as unusually variable and extreme rainfall events occur owing to the impacts of climate change (IPCC, 2021). At the same time, land-use patterns have constantly been altered by rapid urbanization. The extensive replacement of permeable surfaces with impervious materials like concrete and asphalt drastically increased surface run-off into rivers and reduced the natural infiltration, thereby exacerbating the risk of flooding (Miller & Hutchins, 2017).

The natural floodplains surrounding the river which traditionally act as natural buffers for absorption and storage of excess waters during flood events, are often encroached upon by urban expansion. The loss of these critical buffers not only also reduces the carrying capacity of the river but also places these urban settlements in a high-risk zone (Tucci et al., 2007). In many cities, informal and unregulated settlements on the natural floodplains further disrupt the natural flow of water. Besides, inadequate waste management results in accumulation of waste disposal in the river clogging the waterways and aggravating flood levels (Zope et al., 2016).

Conventionally, “grey infrastructure” has been widely used to keep rivers within designated corridors as a flood management technique. These techniques mostly rely on hard-engineered solutions such as embankments, levees, and concrete channels. However, these buildings may exacerbate flooding by limiting river dynamics and diminishing the floodplains’ natural storage and conveyance capabilities (Sayers et al., 2013). Furthermore, grey infrastructure is static and often doesn’t adapt to the unprecedented extreme flood events (World Bank, 2017).

In addition to physically damaging homes, infrastructure, and public utilities, floods can disrupt social and economic activity by disrupting trade and transportation, uprooting people, and incurring large financial losses (Hallegatte et al., 2013). Contaminated water supplies and waterborne diseases exacerbate the risk to public health during floods (World Health Organisation, 2021).

Urban resilience of cities is weakening as their sustainability and liveability are at risk due to the cumulative effect of such consequences. As urban population increases and climate change intensifies, integrated and adaptable flood management solutions become essential. Therefore, Experts are increasingly favouring the use of nature-based solutions (NbS) – such as – constructed wetlands, re-naturalisation of rivers to restore and maintain natural floodplain functions and to provide more effective and sustainable ways to reduce urban fluvial floods (Kabisch et al., 2017). These tactics emphasise utilising natural processes to increase flood storage, improve water quality, and deliver co-benefits such as urban cooling, green spaces, biodiversity conservation and recreational activities for resilient and healthy urban environments (Cohen-Shacham et al., 2016).

This research particularly focuses on the Mithi River of Mumbai in India to examine the site-specific challenges associated with urban fluvial flooding. The synopsis above provides a background for analysing these challenges by examining how ungovernable urban encroachments and agglomerations, in conjunction with hydrological changes, exacerbate susceptibility to extreme events and how nature-based solutions (NbS) might help enhance flood resilience in these rapidly urbanising areas.

1.1.1. CLIMATE VULNERABILITY AND URBAN FLOODING RISK IN MUMBAI

Indian was ranked among the top 10 most-affected countries in 2019 by the Climate Risk Index (CRI) 2021 (Eckstein, Künzel, 7 Schäfer, 2021). India has been struck by deadly heat waves, cyclones, and floods. The country suffered 430 events between 1995 and 2024, leaving USD 170 billion in losses, 1.3 billion affected, and 80,000 dead (Adil et al., 2025). The CRI 2026 classifies India among the most affected countries by recurring extreme eventsin the long-term index. for 1995-2024 (Adil et al., 2025).

Mumbai city is an estuary connecting the mainland with the Arabaian sea and home to over 12 million people (Municipal Corporation of Greater Mumbai [BMC], 2022). Several ecosystems related to its natural terrain have been altered due to years of reclamation (BMC,2022). Paul (2024) cites Mumbai as the "sinking city" due to its geography and built land reclaimed from the sea, making it one of the most vulnerable cities to climate change. Studies at IIT-Bombay reveal that Mumbai is sinking at a rate of 2mm per year (Paul, 2024). History of land reclamation, Rapid population growth, urbanisation, housing crisis and traffic congestion also make it more vulnerable to the adverse impacts of climate change (Paul, 2024).

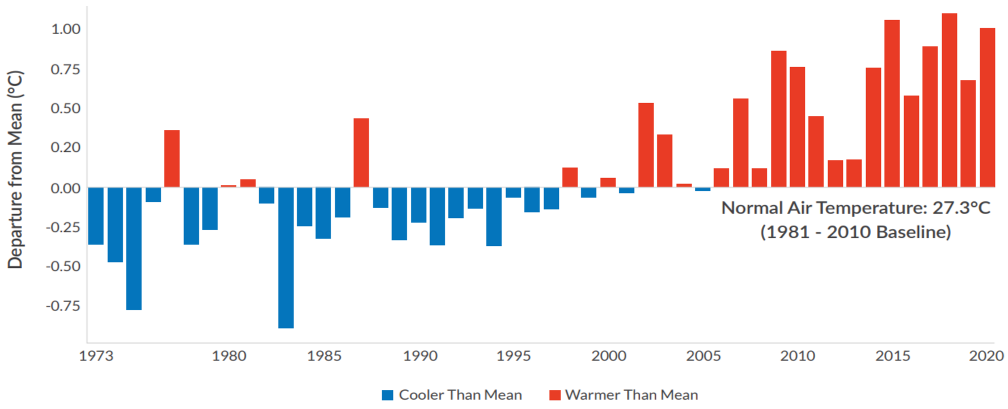


Figure 02: Urban Heat
Annual Air Temperatures Anomalies between 1973 and 2020.
source: Mumbai Climate Action Plan (MCAP), 2022 by BMC

Urban Heat

(**Figure 02**) Three of the five years have shown a divergence of more than 1 ° C from the baseline average air temperature (1973-2020), indicating an increase in the frequency of warmer years. Twenty-fur years between 1973 and 2020 had air temperature above the baseline average (27.3 °C). Every year since 1998 has been warm, with the exception of 1999, 2001, and 2005. The warmest years on record were 2015,2018, and 2020 with departure of more than 1 °C (Mumbai Climate Action Plan [MCAP],2022).

The study of Land Surface Temperature for MCAP (2022) to understand where heat islands form in the city (**Figure 03** and **Figure 04**) re-

Urban Heat

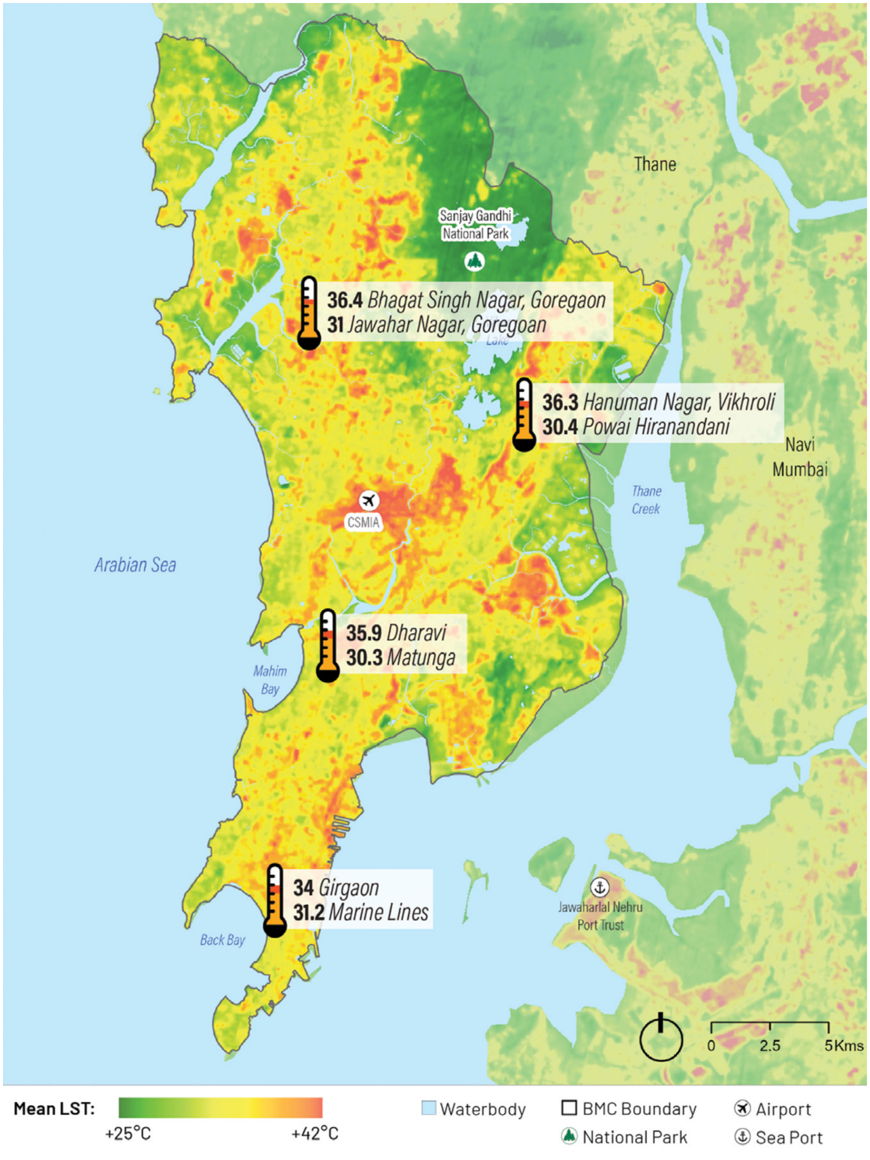


Figure 03: LST map for Mumbai (Source: WRI India using LandSat 8 (USGS), October (2017-2019))

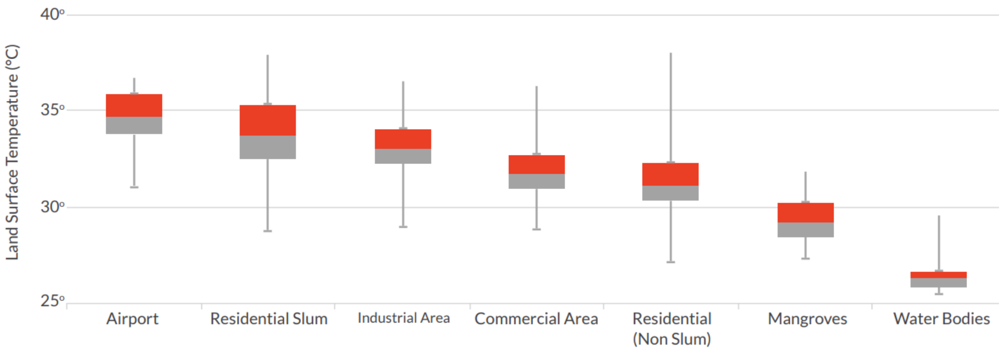


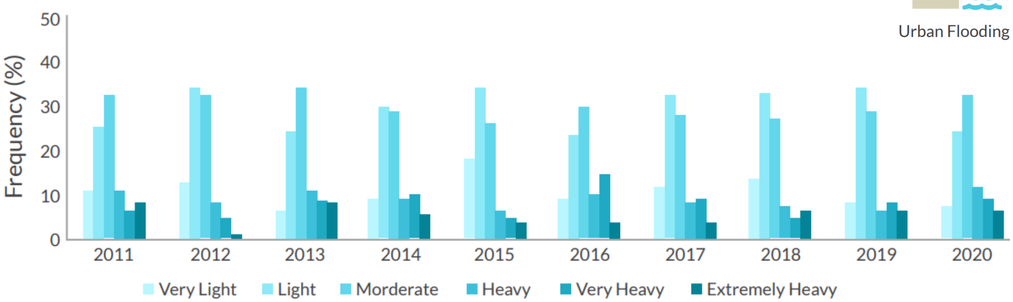
Figure 04:
Difference in surface temperature by land use and land cover in Mumbai (Source: WRI India using LandSat 8 (USGS), October (2017-2019))

Urban Heat

vealed that these hotspots are strongly influenced by certain land uses - like industrial and commercial zones - along with limited vegetation and the presence of heat-absorbing or heat-reflecting materials such as metal roofing, glass, and steel structure. For an instance, Mumbai's Airport showed temperatures above 35 °C, mainly because of its vast built-up area, heavy use of concrete and asphalt, almost no green cover (MCAP,2022; WRI India, 2022), and built on the reclaimed land from the river Mithi.

In contract, with temperatures being 25 °C and 30 °C, areas near the mangroves and the Sanjay Gandhi National Park remained much cooler because of their dense and extensive vegetation (MCAP,2022; WRI India, 2022). Overall, LST shows a clear inverse relationship with green cover (NDVI): places with less vegetation have higher temperatures, contributing to stronger heat islands, leaviing some parts of the city more exposed to heat than others.

Urban Flooding



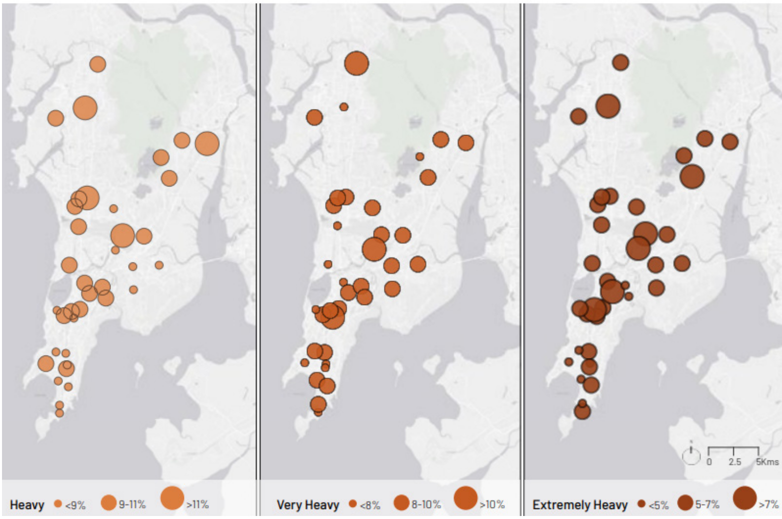


Figure 05:

(a) Frequency of Extreme Rainfall Events (ERE) in Mumbai during 2011-2020 (Source:Mumbai Climate Action Plan (MCAP), 2022 by BMC) (b) Inter-annual Spatial Variation in frequency of different Rainfall Events betweem 2011 and 2020 (Source: rain guage data from BMC AWS Assessment, as cited in Rangwala L.,2022)

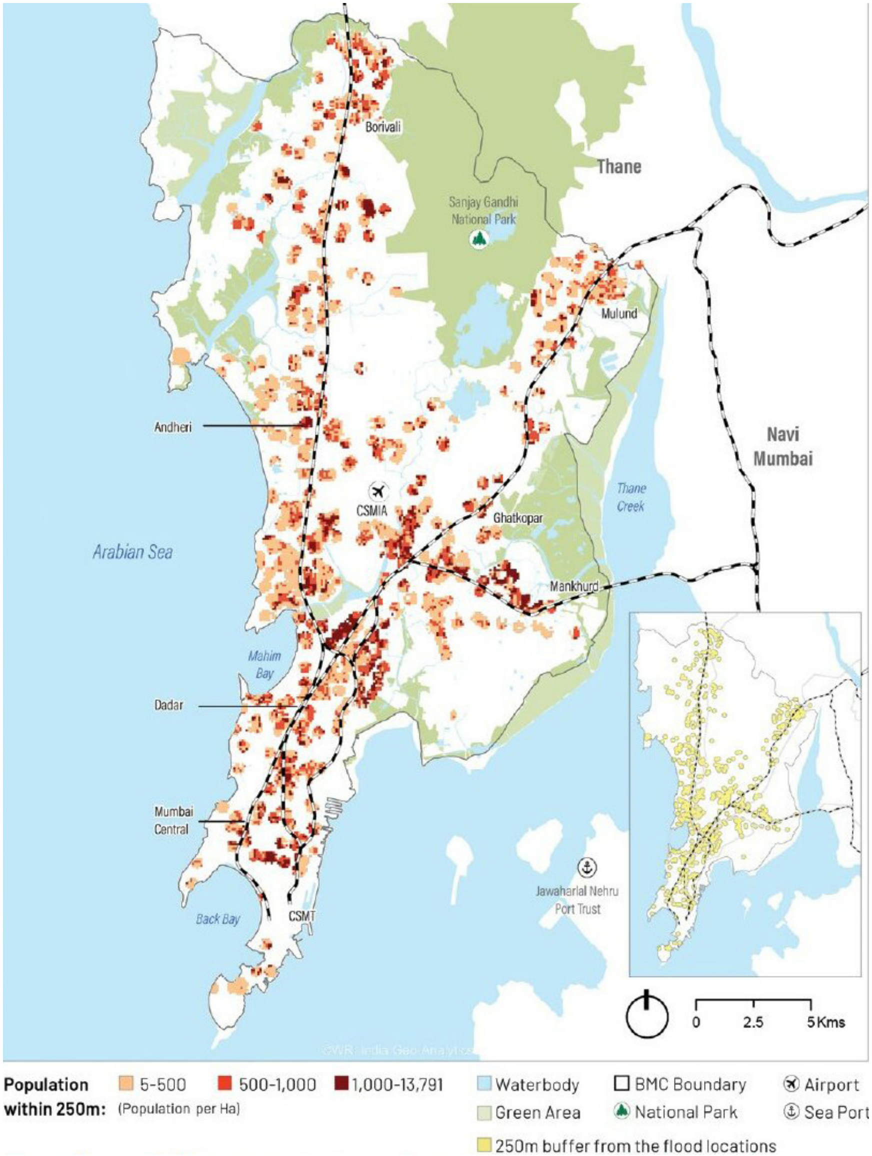


Figure 06: Map showing BMC waterlogging hotspots and population density exposed within 250m risk area around each spot (Source: BMC and WRI India)

According to rainfall timeseries data from 37 locations over the previous ten years, Mumbai typically sees (**Figure 05**)six heavy (64.5-115.5 mm), five very heavy (115.6-204.4 mm), and four extremely heavy (>204.5 mm) rain occurences per year. Approximately 9.5%, 8.7%, and 5.8% of all monsoon rainfall are categorised as heavy, very heavy and extremely heavy each year (MCAP, 2022). BMC, with support from WRI India and C40 Cities (WRI India, 2022), mapped 699 flood hotspots (**Figure 06**) accross the city. Wards - F-North, H-East, H-West, L and M-West (roughly covering 35% of Mumbai's residents) - each contain more than 40 hotspots, are exposed to flood risk, with wards like H-East, H-West and F-North being the most affected, wher more than 60% of the population faces potential flooding. There are a large share of residents residing in informal settlements and a notable concentration of flood spots in wards P/N ans S, leaving them higly vulnerable (MCAP,2022; WRI India, 2022).

NOAA and Climate Lab Projections (MCAP, 2022) indiacte that by 2040, about 60% of Mumbai's day may endure temperatures above 32 °C. This will escalate heat exhaustion combined with high humidity, sharply reducing productivity as working hours are lost (McKinsey Global Institute, 2020, as cited in MCAP, 2022), and also singnificantly increase heat related illnesses and deaths (MCAP, 2022).

In conclusion, this indicates the need for mitigation and adaptation measures. Hence, this research focuses on restoring Mumbai's lost river floodplains, particularly the Mithi River, which will considerably mitigate flooding events in and around the low-lying areas. While upgrading Mumbai's storm-water drainage system could reduce losses by up to 70% (Ranger et al., 2010), restoring river floodplains - natural drainage areas - offers an even more effective alternative, bringing additional co-benefits such as increased green cover and carbon sequestration.

1.1.2. SIGNIFICANCE OF THE MITHI RIVER IN FLOOD CONTROL

> ***"The Mithi River used to serve as an important stormwater drain but has been reduced to a sewer over the years"***
>
> ***– Mithi River Development Authority (MRDA)***

Figure 07:
Image showing the exploited state of the Mithi River with slums encroached on both the sides, part of the river reclaimed by Mumbai Airport at the back of the bridge, waste disposal in the river (source: Modified by the author, adapted from"As India struggles to clean up its polluted urban rivers, ecological and economic costs are mounting" by Chandrashekar V., 2018)

On July 2005, Mumbai suffered a disaster when more than 900 people lost their lives, around 250,000 homes were damaged, and neraly $2 billion were lost during an extreme rainfall event which brought the city to a stanstill (Chandrashekar V., 2018). The flooding forced mumbai residents to realise the presence the Mithi River in their midst (Chandrashekar V., 2018). The Mithi begins in the suburban hills and winds 11 miles down to the Arabian Sea. The river is a glorifired sewer for most of its run serving the airport, slums, housing, small workshops, and a business center - Bandra Kurla Complex (BKC) - which was built by reclaimimg flood prone wetland and mangrove swamps of the Mithi River Floodplain (Jamwal N., n.d.). All these areas were flooded during the extreme event when heavy rain in conjunction with the high tide caused the river to overflow its banks and flood the city (Chandrashekar V., 2018).

Mithi plays a significant role in managing Mumbai's floods, however, its ecosystem - particularly its shrinking flooplain - needs urgent attention and restoration anyway (Dave, 2023).

1.2. RESEARCH AIMS AND OBJECTIVES

This research aims to investigate how shifting from hard-engineered solutions to Nature-based Solutions (NbS) can enhance Mumbai's flood resilience, focusing on the restoration and management of the Mithi River floodplains. The primary objective is to restore the natural environment - a prerequisite for water to flow easily without the hindrance of urbanised areas. To achieve this aim, the thesis is structured around the following key objectives:

Understanding the significance of floodplains in mitigating floods

This objetcive aims to explore natural way of water storage, peak reduction, and groundwater recharge to mitigate fluvial flooding, along with co-benefits such as erosion control and improvement in water quality.

Consolidating knowledge available on NbS

This objetcive includes conducting a literature review to examine various types of NbS for floodplain restoration focused on the mitigation of fluvial floods. Various global examples have been studies to gather valuable insights into best practices and planning approaches accross the globe.

Examining legal frameworks and guidelines for floodplain zoning in India

The dedication of zones should align with the existing policies and development plans of India, so, studying the technical guidelines and frameworks for floodplain zoning and river-centric urban planning to assist in navigating through the zones for the execution of NbS becomes necessary. It will also help in identifying gaps in governance.

Conducting a vulnerability Analysis for the affected areas and communities

The next objective is to identify the areas and communities that are most vulnerable to the impacts of the Mithi river flooding. This will help us sift through the various layers of urbanization encroached by illegal settlements and other infrastructure on the naturally occuring floodplain along the river.

Developing an urban flood resilience strategy

The ultimate objective is to develop a set of NBS that can be implemented to restore lost and degraded floodplains by studying the most constricting part of the Mithi River. Furthermore, dedicating specific areas and zones to the floodplains is recommended to ensure healthy ecosystems along the river and maximum protection for the city against the overflow of the Mithi.

By setting out these main objectives, this research seeks to demonstrate the potential of naturally occuring processes in solving not only environmental but also societal challenges without depending on traditional hard-engineered interventions, and hence, is a new paradigm shift to boost the resilience of cities. The selected area of the Mithi - the lower reach - holds great potential for demonstrating how restoring and managing floodplains can mitigate fluvial floods in a dense urban setting.

1.3. RESEARCH QUESTIONS

"How can Nature-Based Solutions, implemented for restoration and management of floodplains, contribute to mitigating fluvial floods in Mumbai, with a specific focus on the overflow of the River Mithi?"

What are the main causes of fluvial flooding in Mumbai, and how does it impact the city?

what role do floodplains play in controlling floods, and why are they an important part of the river ecosystem?

what are the limitations of hard-engineered solutions, and why do we need a paradigm shift to non-structural - nature-inspired - solutions to tackle fluvial floods?

which types of Nature-based Solutions can be used to restore floodplains to enhance the city's flood resilience?

what are the various technical, social and political challenges in implementing these strategies in Mumbai?

How do the proposed strategies align with the goals of the 2030 Agenda for Sustainable Cities and Climate Adaptation?

1.4. RESEARCH DESIGN

Stage 1: Assimilate and Scrutinize

The first stage of the research focuses on the assimilation of necessary concepts and theories important for the foundation of the main topic addressed in this thesis, laying the groundwork for the subsequent chapters. This involves conducting a literature review related to the subjects under study using various academic databases, such as Scopus, Google Scholar, and other documents available online.

Documents related to the technical guidelines, legal frameworks, and planning policies established by the Government of India or the state government also need to be scrutinised to gain sufficient information to align with the rules and regulations and to identify gaps in the current planning practices.

Stage 2: Identify and analyze

The second stage of this research involves studying successful examples of floodplain restoration and flood mitigation actions around the globe, consolidating the best practices, and analyzing them for incorporation in the study area.

Furthermore, it aims to identify the study area along the River Mithi that has the most potential for demonstrating the outcomes of the theory and successful practices and is most vulnerable to the impacts of flooding.

Stage 3: Design and Assess

This is the ultimate stage of this research, dedicated to employing theories into practice, designing, and proposing interventions on a local scale for mitigating fluvial floods from the Mithi, followed by assessing the effectiveness of interventions and the co-benefits obtained.

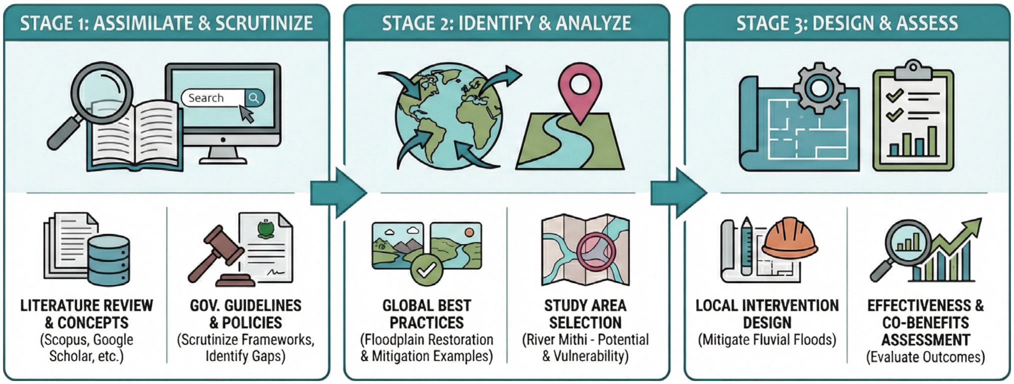


Figure 08: Process of the research design (Source: modified by the author, generated with AI- Nano Banana Pro)

02
Literature Review

2.1. THE IMPERATIVE OF PROTECTING AND RESTORING FLOODPLAINS

2.1.1. More than Risk Zones

2.1.2. floodplain restoration and Ecosystem Services

2.2. NATURE-BASED SOLUTIONS (NBS)

2.2.1. The crisis of grey infrastructure and the paradigm shift

2.2.2. The Meaning of Nature-Based Solutions: A Comparative Poli cy Analysis

2.2.3. Types of NBS Interventions

2.2.4. Fluvial Mitigation Strategies: Reconnection of the River

2.2.5. Pluvial Mitigation and Sponge Cities

2.2.6. Coastal and Estuarine Strategies

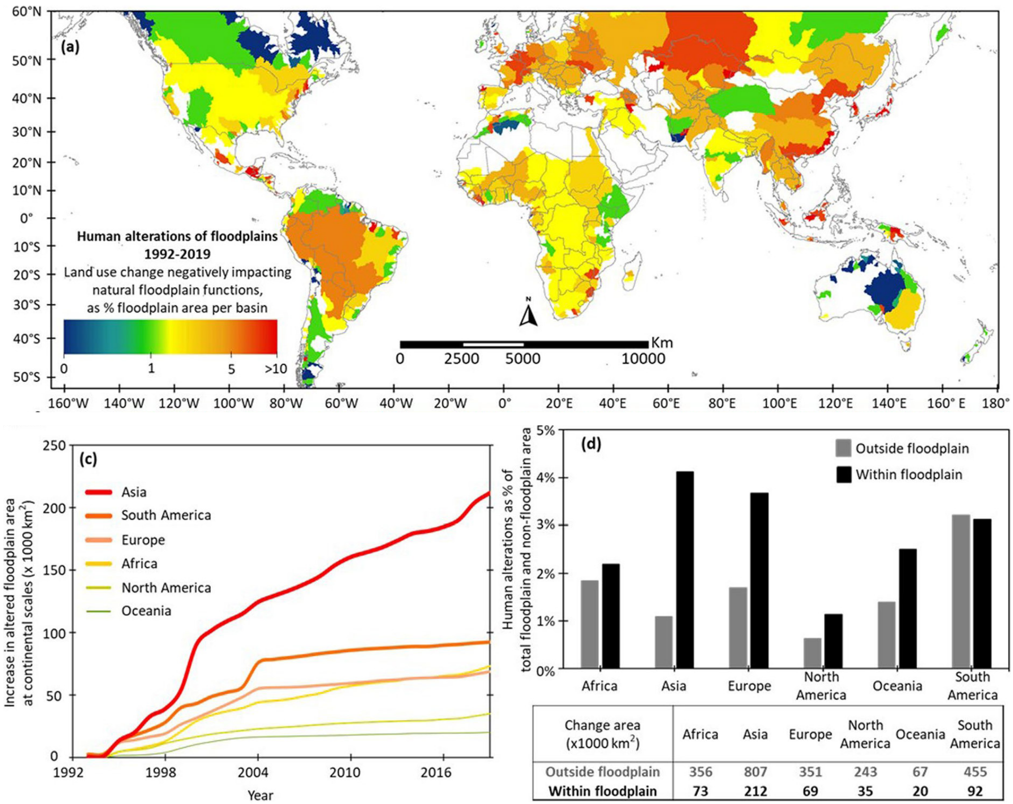
2. LITERATURE REVIEW

2.1. THE IMPERATIVE OF PROTECTING AND RESTORING RIVER FLOOD-PLAINS

This section of the research explores the duality that humanity has created between nature and humans. We have forgotten that, as argued by McHarg (1969), humans are a part of nature, not separate from it. Hence, moving beyond the binary of flood control versus the conservation of rivers and their floodplain becomes imperative (Liao, 2012). A unified framework that incorporates climate resilience, ecological integrity, and other aspects of an urban setting in a mutually inclusive manner is the only way forward (Meerow et al., 2015).

In a recent study about human alterations of the global floodplains, Rajib A. et al. (2023) found that due to land conversion, approximately 600,000 square kilometres of natural floodplains were lost worldwide, from 1992 to 2019 (Rajib A. et al., 2023). Asia has lost the highest rate of floodplains. According to Adnan Rajib, a civil engineer at the University of Texas at Arlington and the Lead author of that study, floodplains were 1.75

times more affected than areas outside floodplains because of the rapid urban agglomeration and severe encroachment on floodplains.



Change area (x1000 km²)	Africa	Asia	Europe	North America	Oceania	South America
Outside floodplain	356	807	351	243	67	455
Within floodplain	**73**	**212**	**69**	**35**	**20**	**92**

Figure 09: Human Alteration of Total Floodplains and Non-floodplain Areas
(a) Map showing the total area of "negatively impacting" land use change within floodplain area, as a percentage of the floodplain area basin (c) Time series graph showing the continuous increase in the area of altered floodplains at continental scales ove 27 years of analysis (1992-2019) (d) Graph showing the comparision of of the degree of alterations within and outside the floodplain, respectively, for every continent (Source: "Human alterations of the Global floodplains 1992-2019" by Rajib A. et al., 2023)

2.1.1. MORE THAN RISK ZONES

Floodplains are periodically flooded areas adjacent to rivers, ponds, lakes, and oceans at different points in time. They are ecologically productive areas because they benefit wildlife by generating a variety of habitats for fish and other animals. Moreover, they are not only environmentally sensitive as their nutrient-rich sediments contribute to a fertile environment for vegetation but also valuable to society as they store and convey floodwater, protect water quality, and recharge groundwater. River floodplains are subject to periodic flooding due to excessive rainfall (Natural & Beneficial Functions of Floodplain | Walton County, FL - Home Page, n.d.). Natural floodplains provide a range of benefits that are often overlooked while making land-use decisions as they contain wetlands and other significant ecological areas wich help in risk reduction by slowing down runoff and storing floodwater (FEMA, 2025).

According to the Federal Emergency Management Agency (FEMA, NFIP), flood risk areas in the United States, and corresponding bodies worldwide, bifurcate the Floodplains into two main zones to regulate development and communicate risk: the Floodway and the Flood Fringe, corresponding to how floodplains function – or fail to function (Texas Department of Transportation, 2019). ***The Floodway*** is the major component of a riverine system and is heavily regulated in terms of development (Walton County, Florida, n.d.). The Texas Department of Transportation (2019), defines floodway as the adjacent land areas and the channel of a river that is necessary to discharge the base flood without overflowing a designated height of the water-surface elevation ***The Floodway Fringe,*** as defined by the Department of Environmental Protection,New Jersey (2025), is the area less restricted than and outside of the floodway, normally characterized by shallow/ little or no visible flow of water.

2.1.2. FLOODPLAIN RESTORATION AND ECOSYSTEM SERVICES

Restoring floodplains is more than simply conserving them as they provide signficant economic and ecological benefits when they are healthy and functional. These benefits, called ecosystem services, fall into four main categories according to Opperman et al., 2009: managing wter quantity (flood control), carbon sequestration, providing important habitat, and improving water quality (nutrient cycling).

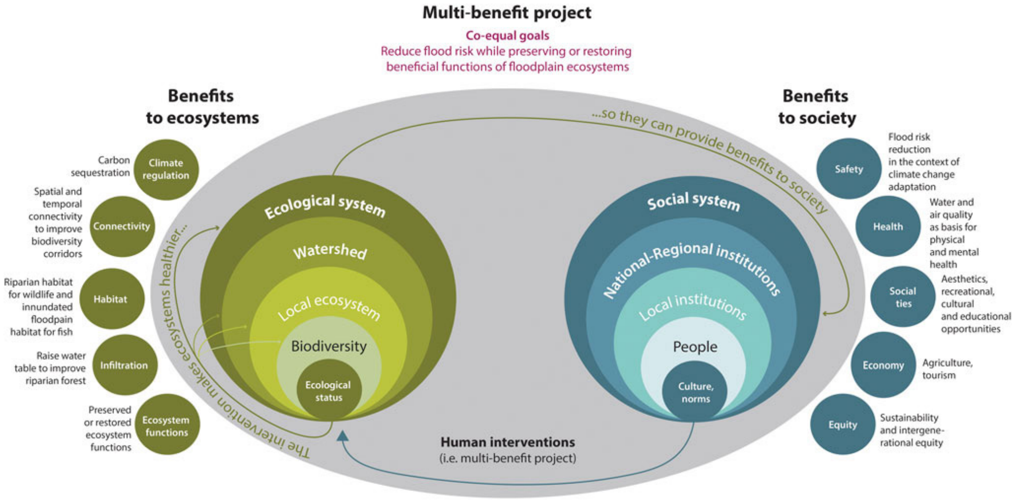


Figure 10: Conceptual diagram of the role of multi- benefit projects in context of social-ecological systems (Source: "Restoring Rivers and Floodplains for Habitat and Flood Risk Reduction: Experiences in Multi-Benefit Floodplain Management From California and Germany", modiefied by Serra-Llobet et al. (2022), from EEA (European Environment Agency), 2010)

"The Sponge Effect"

Floodplains, basically, act as a safety valve for rivers as whenever the river overflows its banks, a healthy floodplain allows it to spread out horizontally - a process very crucial in protecting communities located in low-lying areas and downstream from severe inundation (Junk et al., 1989).

The water **storage Capacity** of a floodplain is staggering. A foot of water flooded in one acre of land can hold approximately 330,000 gallons by holding and releasing it slowly as river recedes, reducing the peak run-off (Natural Resources Conservation Sevice, 2007).

Apart from this, the texture of the land also matters as vegetation like tall grasses, wetland reeds, and riparian buffers create resistance by slowing down the speed of the water across the land (Arcement & Schneider, 1989). Replanting the riparian buffer adds to the physical complexity of the landscape, acting like a brake system (Broadmeadow &Nisbet, 2004) and, hence, yields considerable flood mitigation results. Forest soils are sponges because trees create “macropores” that allow water to seep deep underground and recharge aquifers instead of running off immediately (Marshall et al., 2014).

In conclusion, the approach to constructing rigid controls are static and stationary. It is widely accepted that “stationarity is dead” (Milly et al., 2008). The world is facing a reality of more intense storms, longer droughts, and rising sea levels as the atmosphere warms (IPCC,2023). Rigid concrete sytems are becoming a liability in this new normal for they degrade over time and can fail when their limits are exceeded. In contrast, floodplains are resilient, self-maintaining and flexible infrastructures that grow stronger and complex as time passes. Apart from providing flood protection, Floodplains serve as critical carbon sinks, and act as refuges for biodiversity (Costanza et al., 1997).

2.2. Nature-based solutions (NBS) and blue-green infrstrastructure

To face this, such a 21st-century city is at an unstable crossroads between rapid urbanisation and climate change with ecologies in systemic decline. For over a century the paradigm that has prevailed with respect to urban development is one of conquest and control – it's essentially been about domination, as exemplified by "hard" or "gray" engineering. Rivers were straightened and lined, wetlands were dewatered and paved, shorelines were cemented to create the most transferable land possible as well as quick water conveyance (Gleick 2003).

This worked well enough for driving industrial growth in the 20th century but was also based on a myth of stationarity — the notion that natural systems harbor an intrinsic level of variation, and as long as we don't mess with it too much, everything will be fine. Yet, that "stationarity is dead" (Milly et al., 2008) is one of the teachings of modern climatological research. Compounded by the rise in magnitude and frequency of extreme weather events — a phenomenon we are already experiencing as fluvial (riverine) and pluvial (rainfall-induced) flooding — the vulnerability of inflexible systems has been laid bare.

Engineered systems are generally engineered to be "fail-safe," able to meet pre-determined standards (e.g., withstand a 100-year storm), But when these limits are exceeded, the system frequently collapses in a sudden, rapid and complete failure and local communities have little scope to adjust or recover (Ahern, 2011). In addition, ubiquitous imperviousness of the soil creates "heat islands" and deprives cities of the regulating services that ecosystems used to provide in their natural state (Oke et al., 2017).

Somewhere within this complex reality, Nature-based Solutions (NbS) have been positioned not just as a nice-to-have greenscreen or conservation approach but rather an infrastructure investment in the preservation of urban life. This move from "fail-safe" to "safe-to-fail" is characterized by adaptability, multifunctionality, and resilience. NbS harnesses the restorative capabilities of natural processes to control water, cool temperature and maintain biodiversity while creating active social and economic co-benefits (Cohen-Shacham et al., 2016).

2.2.1. THE CRISIS OF GREY INFRASTRUCTURE AND THE PARADIGM SHIFT

The movement towards adopting Nature-based Solutions (NbS) is underpinned by an understanding that conventional urban infrastructure is becoming more of a misfit with ‘an increasingly unstable climate’. The gray infrastructure exhibits properties of stiffness and single function. A concrete storm drain is a simple structure: the only thing that moves through it is water from location A to location B; there’s no amenity, no carbon storage, or biodiversity value. And it provides a false sense of security; many times when a levee or pipe is overwhelmed by design capacity, the consequent disaster is worse due to the infrastructure that was suppose to prevent such things from happening in first place- something referred as “levee effect” (Ahern, 2011).

The transition to NbS is a move towards ‘bio-engineering’ and ‘ecological engineering,' where the materials of the solution (e.g., fences made from bamboo wood for sediment capture or embankments fronted by saltmarsh) are part of the defensive mechanism itself (Mitsch, 2012). This is along the lines of "safe-to-fail," where systems are built to handle failure and recover; it introduces resilience, such as that we find in nature. Unlike concrete, which remains as is, NbS are living infrastructure: They expand; they evolve; and many of them become stronger over time (e.g., when mangrove roots mature or wetland vegetation densifies) (Ahern 2011).

This transition is also a response to the "twin crises" of extinction and climate change. Global institutions such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the International Panel on Climate Change (IPCC) acknowledge NbS specifically as one of the imperative means to address these overlapping crisis in parallel, emphasizing engineered solutions can no longer be detached from ecologic reality (Pörtner et al., 2021).

2.2.2. THE MEANING OF NATURE-BASED SOLUTIONS: A COMPARATIVE POLICY ANALYSIS

'Nature-based Solutions' is frequently used informally, but much clearer policy definitions apply in international development and planning. These definitions highlight that NbS is a „boundary concept, situated at the interface of natural and social sciences, and questioning compartmentalised urban governance "(Nesshöver et al., 2017).

The European Commission (EC):

NbS are seen as "solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience" (European Commission, 2015). This definition highlights the systemic nature of interventions, stating that they need to bring diverse nature into cities. 2017b) Crucially, the EC requires that NbS deliver benefits to biodiversity; a green intervention reducing biodiversity (e.g. monoculture plantation) does not qualify.

International Union for Conservation of Nature (IUCN):

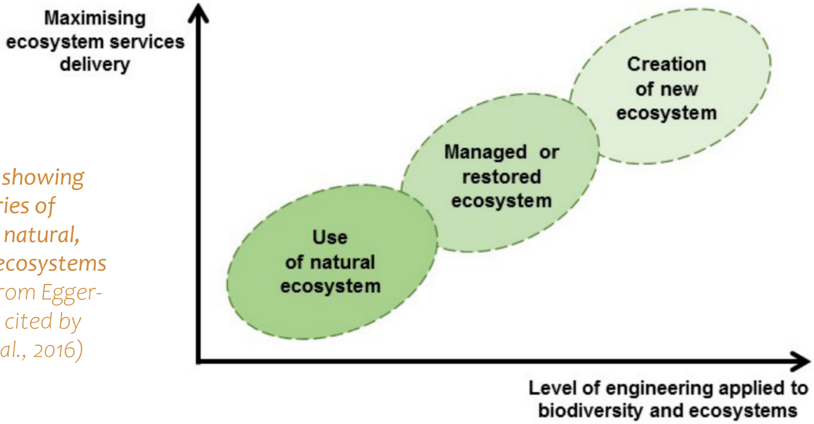
IUCN definition is based in conservation science, and it involves "actions to protect, sustainably use, manage and restore, natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al., 2016). This definition prioritizes societal challenges. NbS are not conservation for the sake of conservation; they're a utilitarian intervention using natural systems to solve specific human problems — like flooding or food security.

The World Bank:

The World Bank defines NbS as the application within disaster risk management and development financing. They consider NbS as a cost-effective option to fight climate change and land degradation concurrently (World Bank, 2017). But they offer an essential caveat when it comes to implementation: "it's not automatic that everything you plant becomes a nature-based solution." For instance, non-native trees that are poisonous to local wildlife or not well adapted to the climate would be unlikely to satisfy this test since they don't provide any biodiversity benefits and may even hinder ecosystem quality.

2.2.3. TYPES OF NBS INTERVENTIONS

In order to facilitate the integration of NbS in urban planning, characterizing NbS by degree of engineering intervention and ecosystem condition is key. The typology of Eggermont et al. (2015) has been validated in European research settings and offers a continuum of intervention intensity.



A typology of NbS showing three main categories of solutions based on natural, restored and new ecosystems (Source: adapted from Eggermont et al., 2015 as cited by Cohen-Shacham et al., 2016)

The hydrological reaction of the landscape to urbanization changes its structure. Infiltration and evapotranspiration are dramatically diminished when pervious soils are replaced with impervious surfaces (asphalt, concrete, rooftops). This leads to greater runoff volumes and more rapid peak flows, resulting in the “urban stream syndrome”—a phenomenon whereby drainage systems created for past rainfall patterns are subjected to constant overuse (Walsh et al., 2005).

The objective of Nature-based Solutions (NbS) in this context is to “naturalize” the urban watershed, restoring the capacity of the land to act as a sponge (Yu et al., 2015).

2.2.4. FLUVIAL MITIGATION STRATEGIES: RECONNECTION OF THE RIVER

Fluvial flooding is a result of rivers bursting their banks. Classical engineering controls this through the channelization of streams and rivers and by constructing taller levees. NbS turns this around by “making room for the river,” emulating the water storing, water slowing function of a natural floodplain.

Floodplain Restoration and Depoldering:

This entails either lowering the land alongside rivers or building dykes farther into dry lands to allow for washlands or retention areas. In times of high flows, these areas fill with water thus clipping the peak of a flood hydrograph and thereby also protecting urban centres that may be located downstream (Klijn et al., 2013). This is an imitation of the actual pulse of a river system."

Riverbank Re-naturalisation:

Hard embankments speed up water. In so doing, natural vegetated banks are replaced with artificial hard structures such that the hydraulic roughness (Manning's n) is elevated. Then, the vegetation will slow down the flow and its roots prevent erosion. This forms an ecotone which is a zone of aquatic terrestrial biodiversity (Prominski et al., 2012).

Stream Daylighting:

Several urban streams were "daylighted" — brought back to the open air from culverts they'd been buried in during the 19th and earlier 20th centuries. The practice is known as "daylighting," which means digging up these streams and opening them to the air. A meandering, naturalized stream channel also holds much more water than a straight pipe and allows the release of runoff over an extended time period to the main river stem (Pinkham 2000).

`by providing a physical barrier to sediment and pollutants, as well as having "roughness" that slows the overland flow into the channel (Hawes & Smith, 2005).

2.2.5. PLUVIAL MITIGATION AND SPONGE CITIES

Pluvial flooding results from heavy rainfall exceeding drainage capacity, often not involving concurrent river-overbank flooding. NbS tackles this through Source Control – controlling rain at the source.

Bioretention Cells and Rain Gardens:

These are engineered depressions that contain porous, water-absorbing soil and flood-tolerant plants. They emulate the filtering abilities of the forest floor. Runoff is moved into these cells, where it can pool and percolate to the groundwater. In such a process the vegetation extracts nutrients and pollutants by phytoremediation (Davis et al., 2009).

Vegetated Swales (Bioswales):

Unlike a concrete gutter, swales are wide and shallow vegetated channels. They move stormwater but it moves slowly permitting infiltration along the conveyance length. They trap sediment and intercept the “time of concentration” (time required for a drop of water to reach the outlet from the farthest point on a catchment) (Fletcher et al., 2015).

Constructed Wetlands:

Where space is available in peri-urban areas, or in larger parks, constructed wetlands replicate a natural marsh. They’re huge stormwater sinks, temporarily holding massive amounts of the stuff. Physical, chemical and biological processes occurring in the wetland (sediment microbial activity, plant uptake) detoxify the water by reducing heavy metals and nutrients loading before discharging to the larger catchment area (Vymazal, 2010).

Green Roofs:

Cities can use roof tops with soil and plants to intercept rain. The rain will percolate (abstraction) through the soil air pockets, and some of it is transpired back into the atmosphere by plants. This slows the peak of the runoff, so that the drainage system is not overloaded at once (Mentens et al. 2006).

2.2.6. COASTAL AND ESTUARINE STRATEGIES

Mangrove Restoration:

Mangroves are living seawalls. Their extensive root systems dissipate wave energy and capture sediment, enabling the coast to adjust to rising sea levels by increasing in elevation. They are believed to prevent billions of dollars in flood damage around the world (Menéndez et al., 2020).

Oyster Reefs and Salt Marshes:

These biogenic features serve to dissipate waves before they hit the coastline, weakening erosion and surge heights. Unlike concrete breakwaters, they are living structures that grow and self-repair (Sutton-Grier et al., 2015).

The integration of Nature-based Solutions (NbS) into urban planning is a key growing up milestone in the discipline. The shift from the static, reactive stance of grey infrastructure to the adjustable and resilient one of NbS is crucial for urban areas dealing with Anthropocene's non-linear threats (Elmqvist et al., 2013).

03

Best Practices

3.1. NINGBO, CHINA: NINGBO EAST NEW TOWN ECO-CORRIDOR

3.2. ASSAM, INDIA: CHANG GHAR – HOUSE ON STILTS

3.3. ROTTERDAM, NETHERLANDS: BENTHEMPLEIN WATER SQUARE

3.4. SEOUL, SOUTH KOREA: CHEONGGYE STREAM

3. BEST PRACTICES

3.1. Ningbo, China: Ningbo East New Town Eco-Corridor

Location: Ningbo, Zhejiang, China

Type of Project: Restoration of Wetland ecosystem

Duration: 2011 – ongoing

Scale: District/ neighbourhood level

Project area: 900000 m2 / 3.3 km living filter

Figure 11: *Brownfield replaced with "Living Filter" System at the Ningbo Eco-corridor.* (Source: SWA Group)

The Ningbo East New Town Eco-Corridor represents a significant intervention in urban ecological restoration and green infrastructure within the “Eastern New Town” district of Ningbo, Zhejiang Province, China (SWA Group, n.d.). Spanning approximately 101 hectares (250 acres) and extending 3.3 kilometers, this linear ecological “spine” is situated within a rapidly expanding urban zone (SWA Group, n.d.). Historically, the site was characterized as a degraded post-industrial brownfield, comprised of fragmented farmland, village settlements, factories, and a network of polluted canals located on the rural-urban fringe (Urban Nature Atlas, n.d.). The project was conceptualized within the district’s master plan to synthesize ecological restoration with sustainable urban development, thereby establishing a multifunctional green-blue infrastructure (GBI) that offers ecosystem services and establishes a civic identity for the burgeoning city (SWA Group, n.d.).

Issues addressed:

Environmental degradation, Water Quality Detoriation, Loss of Biological Diversity, No Public Space.

Planning and Design Concepts

The approach was based on a living filter concept of ecological engineering within landscape architecture:

Topographical and Hydrological Transformation

Major earth moving was carried out to transform the channelized canals into the meandering channels, ponds and marshes. This morphological transformation slows flow velocities and increases the recharge of aquifers, restoring much-needed hydrological patterns in a natural state (ASLA, 2013).

Wetland Restoration

Reintroduction of wetland vegetation native to the watershed in riparian buffers enhances nutrient uptake, and filters pollution (World Landscape Architecture, 2013).

Green-Blue Infrastructure (GBI)

The corridor serves as a holistic stormwater management treatment train using bio-swales, rain gardens, permeable pavements and ecological floating islands for in situ runoff treatment (Urban Nature Atlas, n.d.).

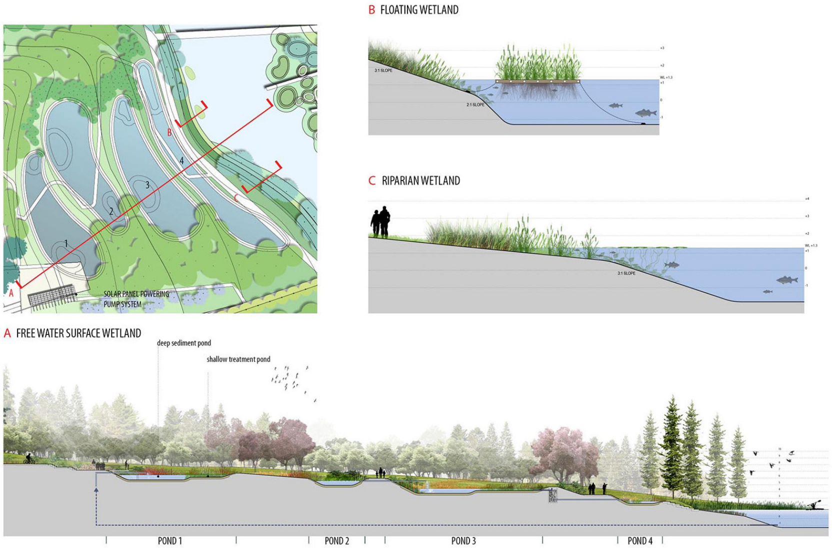


Figure 12: Wetland Restoration (Source: SWA group)

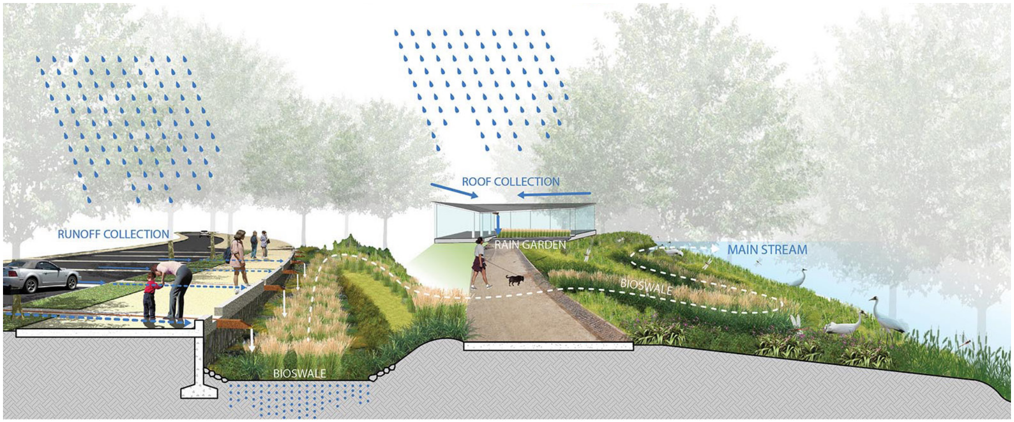


Figure 13: Stormwater Management (Source:SWA)

Adaptive Reuse

Left-over industrial structures and the hydrological pattern were saved or respected to save resources and keep the memory of place (World Landscape Architecture, 2013).

Socio-ecological integration

The design integrates boardwalks, biking paths and observation towers into the ecological matrix, layering recreational value onto environmental function (SWA Group, n.d.).

This case study shows that reconciliation ecology (the ability of human-dominated landscapes to support biodiversity) can work. It demonstrates that in allowing nature to take its course, it would be folly for ecologically sensitive restoration to be sacrificed at the expense of high-density build-out; it should be the other way round, where “landscape as infrastructure” could serve as an underlying urban pattern. And as a model for brownfield regeneration project, it also holds great significance to other developing countries, especially the cities in Asia with both industrial heritage clearance and rapid urban growth (SWA Group, n.d.).

Figure 14: boardwalk and pavilions (Source:Ningbo Eastern New Town Ecological Corridor | Turenscape)

SYNERGY BETWEEN HUMANS AND WILDLIFE

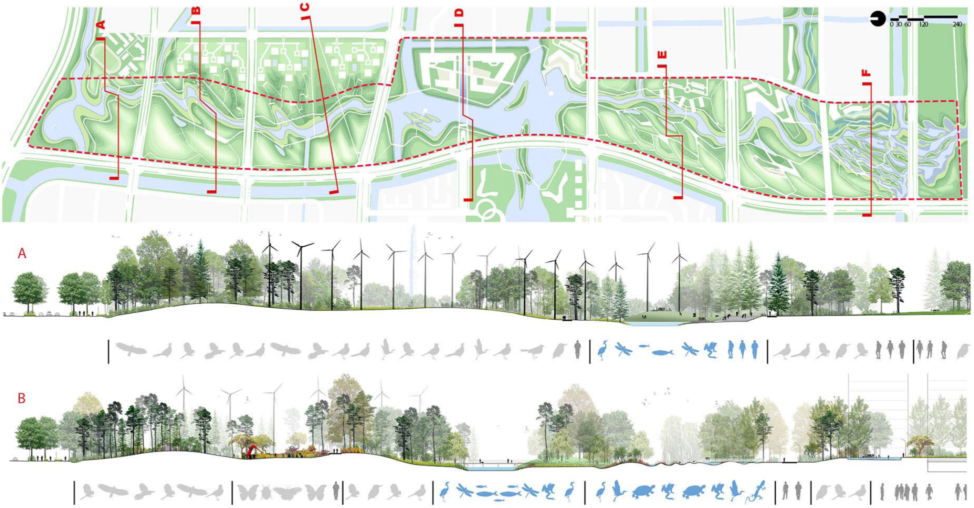


Figure 15: Master plan showing all the design interventions at Ningbo eco corridor (Source:SWA group)

3.2. Assam, India: Chang Ghar – House on stilts

Type – Vernacular Architecture of India

Purpose – Flood Resilience

Figure 16: People row a boat past partially submerged huts in Morigaon district, Assam, during the 2017 floods (Source:Alamy as cited by Krishna G, 2021)

Chang Ghar (first house) is a vernacular typology of house found in the Mising community and other ethnic riverine populations within the Brahmaputra Valley of Assam. 1 Known for its light superstructure elevated on bamboo or wooden stilts, the structural type has traditionally been designed in response to the hot-humid climate and regular inundation of the Brahmaputra river system (Choudhury & Chettry, 2023). 2 Made from locally available materials bamboo, cane, thatch and mud the Chang Ghar is an example of Traditional Ecological Knowledge (TEK), presenting an affordable bio-climatic solution for settlement within a dynamic floodplain ecosystem (Krishna, 2021).

Relevance: This case provides important lessons for planning in flood-prone urbanizing deltas:

Appreciate Local System

I think, this is an example how resilience relies on transformation of existing typologies rather than the introduction to alien forms. The permeable nature and elevation of the Chang Ghar are better than concrete at ground level in flood areas (Choudhury & Chettry, 2023).

Participatory Resilience The "Chang Ghar 2.0" is an attempt to make the technology transfer as a "bottom-up" approach, where local craftsman are included in the co-production of solution which would ensure cultural acceptance and easier maintenance (Krishna, 2025).

Policy & Regulatory Challenges

It also brings to the fore the incongruity in planned legislation – or the lack of it - with structures like bamboo/vernacular housing often perceived and classified as kutcha (temporary/sub-standard) throwing them outside mortgage, insurance etc. Planners need to negotiate between the formal building codes and functional requirement of vernacular materials (Krishna, 2021).

Effectiveness of Solutions:

Flood resilience

Retrofitted buildings have thus far been able to survive repeated cycles of flooding (and some heavy floods within the past seven years) as demonstrated by the lower incidence of structural damage relative to traditional bamboo homes left untreated (Krishna, 2021; SEEDS India n.d.).

Economic feasibility

The adapted huts at USD 800 per unit have 20% higher initial investment than the conventional hut but lowers the annual RRE to maintenance cost (Krishna, 2025).

the importance of policy innovation: planning systems will need to adapt to value and fund hybrid vernacular forms. Adaptation planning should focus on accrediting local resources and training local labor force to build solutions that are structurally sound, socially embedded, and financially accessible (Krishna, 2025; Barbhuiya et al., 2025).

Figure 17: Homeowners can decorate and expand the core house area as required (Source: Siddhart behl, SEEDS)

3.3. Rotterdam, Netherlands: Benthemplein Water Square

Figure 18: The Benthemplein water square as a temporary water storage facility during a downpour (Source: Urban Green Blue Grids)

Location: Rotterdam, The Netherlands

Type of Project: Flood resilience, Urban Public Space and Stormwater Storage

Duration: Design 2011 – 2012, completed 2013

Status: Completed

The Benthemplein Water Square (Waterplein Benthemplein) is an urban plaza in Rotterdam, which doubles as water storage to reduce flood risk and create play opportunities within the city. This design is part of the “living with water” approach in Rotterdam and it’s a test case for the “water square” typology. Design was led by the Dutch landscape architecture De Urbanisten in partnership with the City of Rotterdam and Schieland & Krimpenerwaard water board to address climate adaptation through public space (De Urbanisten, n.d.; Howe, 2014).

Problems addressed:

This Agniesebuurt area around Benthemplein was often prone to extensive localized flooding during heavy rainfall. The city had a combined sewer system that was prone to overflow during rapid storm events from its heavily paved urban surfaces, resulting in flooded streets and basements (Dutch Architects, n.d.; Howe, 2014).

Causes:

Impenetrable Surfaces

A significant amount of asphalt roads, roofs and squares accelerated the speed of runoff, not allowing it to seep in due to natural means (Howe 2014).

Climate Change

The increased rate of rainfall increased the peak storm water load above what aging sewerage infrastructure could handle (German Institute of Development and Sustainability [IDOS], 2017).

Space and cost considerations

In a compact urban tissue, storage of large volumes of water underground was rated as too expensive) and being less valuable for the society compared to multi-benefit surface solutions ((De Urbanisten, n.d.).

Design Interventions:

Adjustment Basins

The square includes three concrete basins with different depths. Their surfaces can be adapted to serve as sports courts and seating areas in dry weather, or temporary detention reservoirs during heavy rain (Land8, 2015).

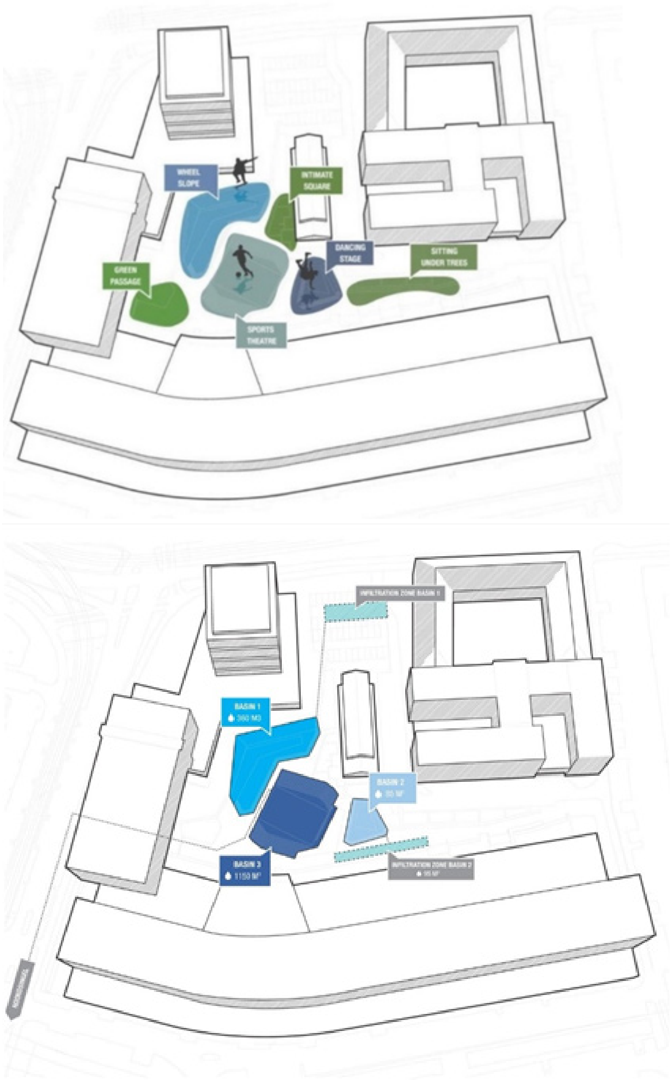


Figure 19: Multifunctionality of the water square when it is dry (upper).The three basins that collect water when it rains/ floods (lower) (Source: Landscape Architecture Platform LANDEZINE)

Surface drainage system

To drain the water from rooftop and square to the basins, visible channels are built. Water is temporarily stored until it can be released into the sewer at a pre-set maximum rate (De Urbanisten, n.d.; Land8, 2015).

Landscape Integration

The design uses colour to create local distinction, with blue and green painting schemes combined with stainless steel elements and podium details to make the 'ability' of the hydraulic control for the space more legible; it also integrates planting and play facilities so that it remains engaging all year round (Landezine, 2013;World Landscape Architecture, 2013).

Stakeholder Participation

The resulting design process was highly participatory and included students, church groups, residents. 7 These co-designing stakeholders contributed to the design of, for example, the square's dry weather functions (skating, sports), which was important to addressing public concerns about open water storage (Netzel et al., 2021).

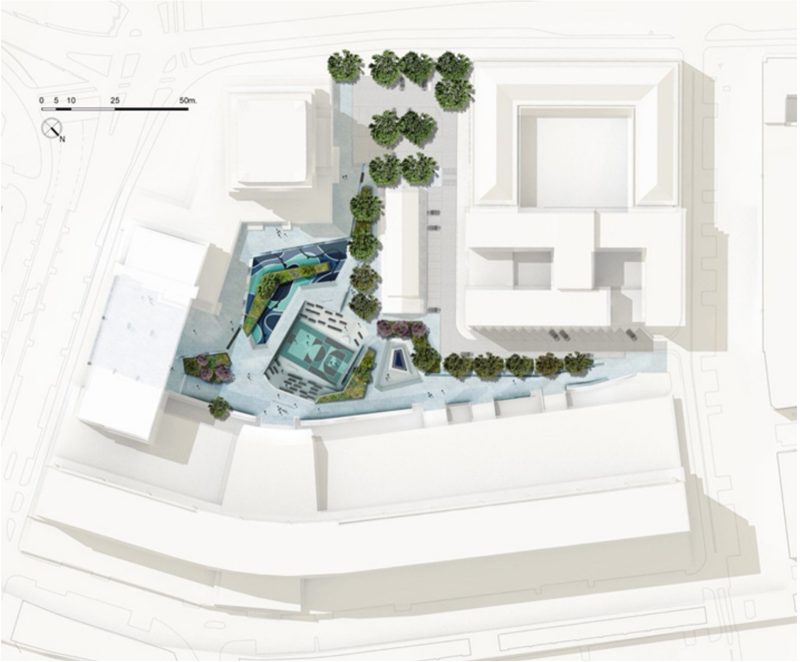


Figure 20: Masterplan showing Benthemplein water square and its unique features (Source: Landscape Architecture Platform LANDEZINE)

The square holds about 1.7 million Liters of stormwater and has relieved stress on the sewer system, while becoming a colourful community focal point. Although satisfactory for local pluvial flooding, the square cannot mitigate large riverine discharges or sea level rise. Secondly, given the dual-use character of the facilities the maintenance is more demanding, and it must be stringent to allow for maintaining fishponds sanitary for humans after rain events (IDOS, 2017; Netzel et al., 2021).

3.4. Seoul, South Korea: Cheonggye Stream

Location: Seoul, South Korea
Type of Project: Stream Restoration
Duration: 2003- 2005
Scale: District/ neighbourhood level
Project area: 252000m2
Status: Completed

The former land use of the Cheonggyecheon project was transportation (Robinson A. et al., 2011). It is a 10.84 km-long stream that flows west to east through downtown Seoul, then connects to the Han River after meeting Jungnancheon empties into the Yellow Sea. 5.8km of the Cheonggyecheon stream was restored, with a total landscape area of 276,650 m2 that includes 22 bridges, pedestrian paths, cultural zones, and green spaces (Cheonggyecheon Stream Restoration: A Detailed Urban Planning Analysis, 2024).

The Cheonggye Stream is historical and balanced flowing water of Seoul Korea. It used to be an important part of the city's hydrographic network, but with the accelerated urbanization and industrial modernization during the mid-20th century, it became culverted. The stream was then re-

Figure 21:Re-naturalised urban waterway of Cheonggyecheon stream and public spaces in downtown Seoul, South Korea (Source: Archdaily, 2024)

stricted and covered up with road systems such as the Cheonggye Elevated Highway so effectively, no remnants of the water artery remained within the urban landscape (Seoul Metropolitan Government [SMG], 2014).

Just a few years after, in 2002 the Seoul Metropolitan Government (SMG) started a new urban regeneration scheme to remove overpasses, open up the stream and develop it into a pedestrian-oriented greenbelt

(Seoul Museum of History, n.d.). The restoration project was finished in October 2005 following 2 years and 3 months of construction, with the length restored being around 5.8 km (ECRR, n.d.; Seoul Museum of History, n.d.). The project has been widely known as a leading paradigm of soft-city conversion and urban regeneration even in the global context (Lee Kuan Yew World City Prize, 2018; The Korea Times, 2009).

Urban Challenges:

Ecological collapse

After it was converted into a street, the place soon started to suffer ecological disaster. The concrete pavement disrupted the natural environment, habitat for wildlife decreased, biodiversity was lost and water resources were polluted which made it an uncomfortable community for living (ECRR, n.d.; Seoul Guide, n.d.).

Congestion and Pollution

The raised highway -a conception of mobility- were generating congestion. The building led to increased noise and air pollutants that degraded the urban fabric (SMG, 2014).

Socio-economic Deterioration

The crumbling infrastructure was a physical barrier creating an urban gap. As a result, the Central Business District (CBD) and surrounding area declined in economic terms as buildings deteriorated and commercial activity diminished (Bocconi University, n.d.; SMG 2014).

Physical Restoration and Circular Economy

The project teardown the elevated highway to unbury the stream; recovering 95% of the concrete and all scrap iron in order to reduce waste. The channel was re-created with naturalized riverbanks, and wetlands, though water is artificially maintained by pumping from the Han River because of lost natural tributaries (ECRR, n.d.; The Korea Times, 2009; Landscape Architecture Foundation [LAF], 2011).

Infrastructure, mobility & governance

As part of the process to eliminate road capacity, the city invested in public transit (BRT, subways) and built 22 bridges to try restoring some degree of urban function. The program was informed by a rigorous multi-stakeholder governance structure that included the Seoul Development Institute, citizen committees and diverse experts (Bocconi University, n.d.; LAF, 2011; SMG, 2014).

Effectiveness and Outcomes

Environmental & Social Upsides: The day lighted channel greatly increased resilience; spontaneous biodiversity took off (plants numbered 308 vs. only 62 before the works), and urban heat islanding was mitigated with temperatures within the corridor now 3.3°C to 5.9 °C cooler than in the suburbs, even though it is located at some of their core (LAF, 2011). It is also a channel of 200-year flood protection and has spurred the economic transformation of the district (Lee Kuan Yew World City Prize, 2018).

Challenges

Despite achieving recognition, the project is seen as highly artificial in terms of hydrology (energy-heavy pumping), displacement of local small traders due to gentrification and initial overlooking of full access for the disabled (LAF, 2011; SMG, 2014; Seoul Museum of History n.d.).

Conclusion

The restoration of the Cheonggyecheon provides living proof that a dense city can "daylight" gray infrastructure to form resilient, multifunctional new public spaces. Though it is not without its legitimate criticisms on issues such as gentrification and engineered water management, the canal remains a powerful case study for how political will coupled with comprehensive planning can reverse urban decline. For future development, planners should prioritize inclusivity at the outset and try to minimize displacement of existing vulnerable local economies.

Figure 22: Cheoggyecheon Stream before restoration (left) and after restoration (right). (Source: Cheonggyecheon Stream Restoration Project." Landscape Performance Series. Landscape Architecture Foundation, 2011)

04

Study Area: The Mithi River, Mumbai

4.1. The Urban Context of Mumbai and Governance

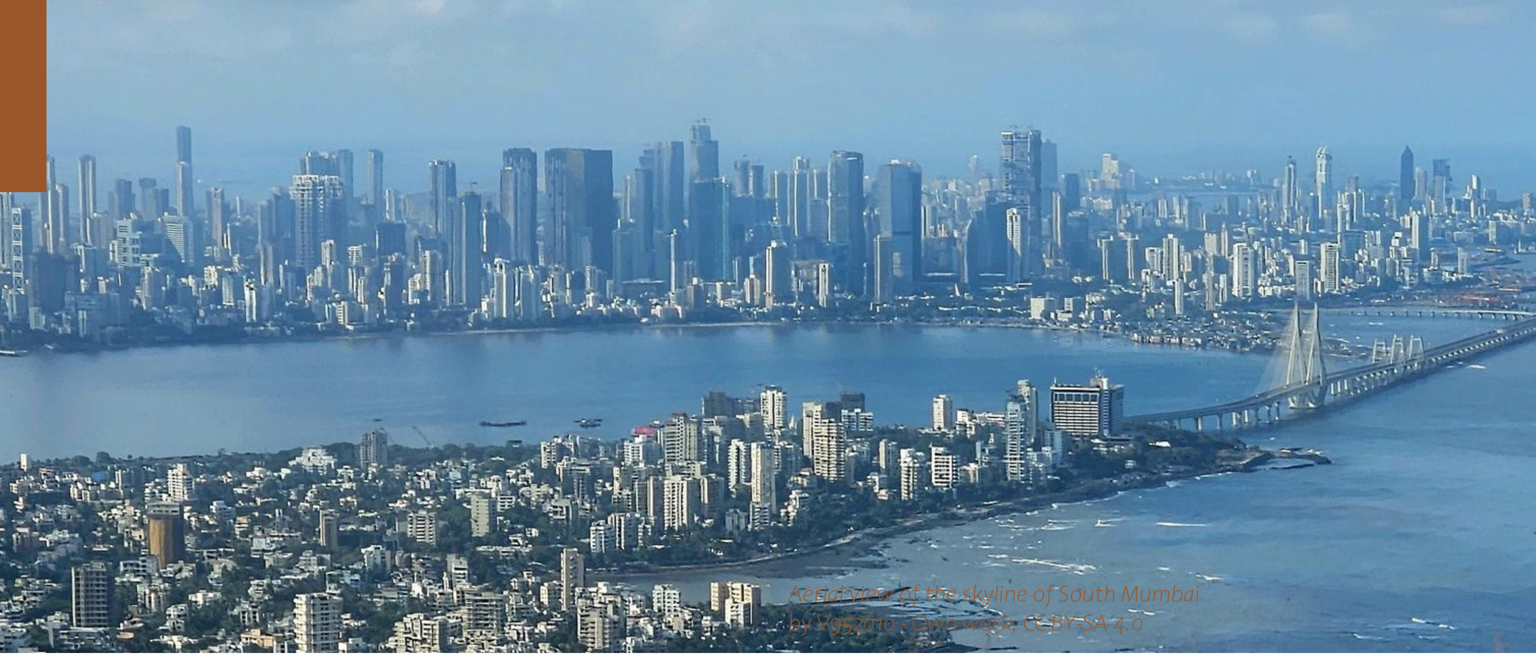
4.1.1. Factors Influencing Fluvial Floods in Mumbai

4.1.2. The Mithi River

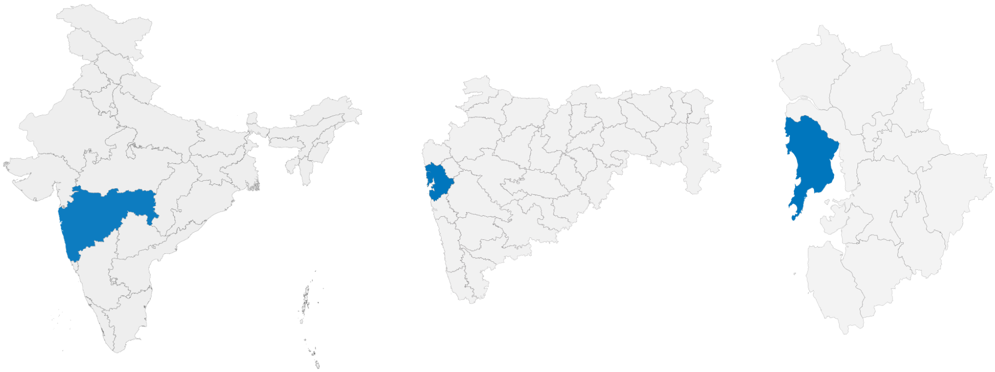
4.2. Mumbai's Alignment with Agenda 2030 and Sustainable Development Goals (SDGs)

4.2.1. Alignment to Agenda 2030

4.2.2. Key Sustainable Development Goals and Core Challenges



Aerial view of the skyline of South Mumbai
by V952010 - Own work, CC BY-SA 4.0



Maharashtra
Area: 307,713 km^2
Density: 365 persons/km^2

Mumbai Metropolitan Region
Area: 6,328 km^2
Density: 3,700 persons/km^2

Brihanmumbai Municipal Corporation (BMC)
Area: 437.71 km^2

Figure 23: Location of Mumbai City in the State of Maharahstra in India
(Source: " Vulnerability Assessment report" by MCAP, 2022)

4. STUDY AREA: THE MITHI RIVER, MUMBAI

4.1. The Urban Context of Mumbai and Governance

Mumbai is the capital of Indian state of Maharashtra and India's financial powerhouse. Mumbai stands as the country's most populous city, ranks as the seventh most populous, and Projected to be the sixth largest by 2030 (UNDESA, 2018). Geographically and administratively, Greater Mumbai, is formed by the Mumbai city and Mumbai Suburban districts. is further divided into 24 Sub City Administrative Units (SCAU) and three suburbs: Western, Eastern and South Mumbai. Mumbai administrative wards are denoted by letters.

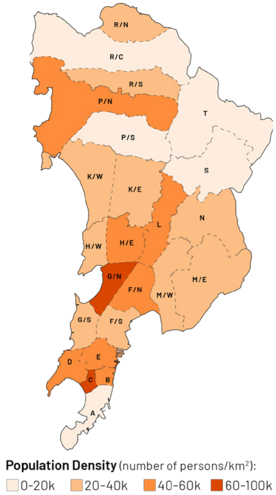


Figure 24: (left) Population density of Mumbai (source: census 2011)

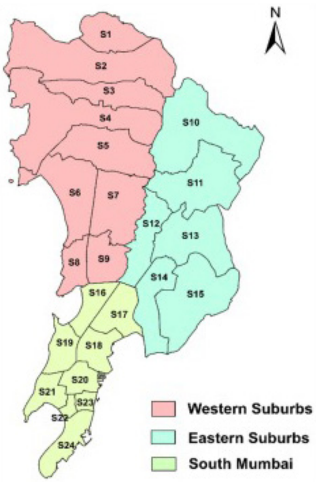


Figure 25:(right) divison of Mumbai into 24 SCAUs and three suburbs (source: "Analysis of urban flood vulnerability at the sub-city administrative unit level in Mumbai: A comparison over two time periods" by Prajapati et al., 2025)

4.1.1. FACTORS INFLUENCING FLUVIAL FLOODS IN MUMBAI

Figure 26: Land Reclamation in Mumbai over the decades (source: SOAK-Mathur/Da Cunha)

Figure 27: Maps showing the shrinkage of the Mithi over the decades (Source: SOAK- Mathur / Da Cunha)

land reclamation

Mumbai has undergone extensive land reclamation over the decades to accommodate its rapidly growing population. This process has adversely impacted the natural floodplains, which served as vital natural buffers in absorbing and retaining excess floodwaters. Because of the erosion of these floodplains, the Mithi River's carrying capacity has been constrained so much that it overwhelms the river's ability to hold peak discharge during intense rainfall events.

Rapid Urbanisation

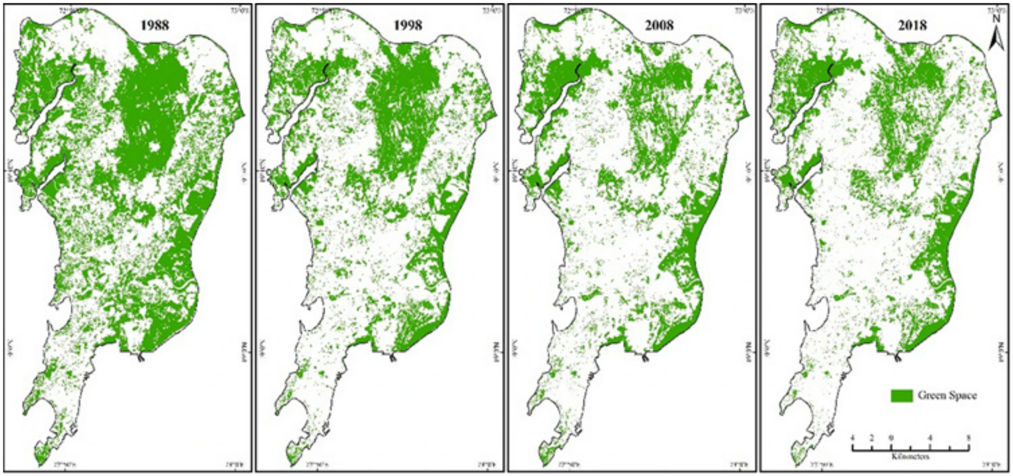


Figure 28: Maps showing the decline of the total green cover of Mumbai (1988, 1998, 2008, 2018) (source: Rahaman et al., 2021)

Hard-Engineered Infrastructure

Figure 29: Embankments built around the river to contain the floodwaters (source: EARTH5R)

Informal Settlements and Encroachments

The river ecosystem exhibits a dynamic relationship between humans, flora and fauna, hydrological and geomorphological aspects (Parihar, 2021). The course of Mithi River has been built upon and thus constricted over the decades. Around 600 acres of wetlands and mangroves were that acted as natural sponges were destroyed to construct Bandra-Kurla Complex (BKC) along the Mithi River. Due to this the narrowing of the Mithi River's mouth has created a "bottleneck" that forces the floodwaters to run off into Sion and Kurla during rains.

Figure 30: Slums line a branch of the Mithi River near the National Stock Exchange (Source: UNEQUAL SCENES)

Slums and other uncontrolled development along the riverbanks impede the river's natural flow. Debris and solid waste accumulate in the river channel because of these encroachments' frequent lack of adequate waste disposal systems. Flooding risks are increased when this waste clogs the watercourse, further decreasing its conveyance capacity. Nearly 53% of Mumbai's population are slum dwellers and most of them dwell along the river floodplains, making them the most vulnerable community to the impacts of flooding.

Inadequate Waste Disposal Systems

Figure 31: Waste disposal in the Mithi River (Source: QUESTION OF CITIES, 2023)

4.1.2. THE MITHI RIVER

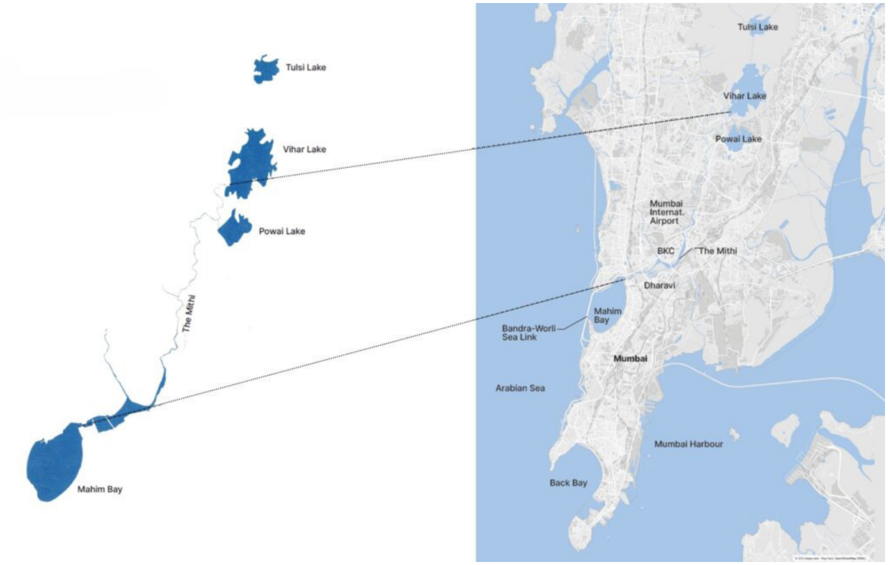


Figure 32: (left) Drawing of Mithi as found in SOAK: Mumbai in an Estuary, 35 (right) Map of Mumbai showing the location of the Mithi River as found in "What does the Mithi want?" by Mrinalni Ghadiok, 2014

Mithi River, 17.84 km long, is the overflow of Vihar Lake, subsequent overflow of Powai Lake joins Mithi and ultimately flows in the Arabian Sea through the Mahim Creek. It passes through important areas like BKC, Dharavi and sensitive areas like the International Airport (Dhagey J. et al., 2023). Mithi has shrunk over the years as seen in the following maps by (Dhagey J. et al., 2023).

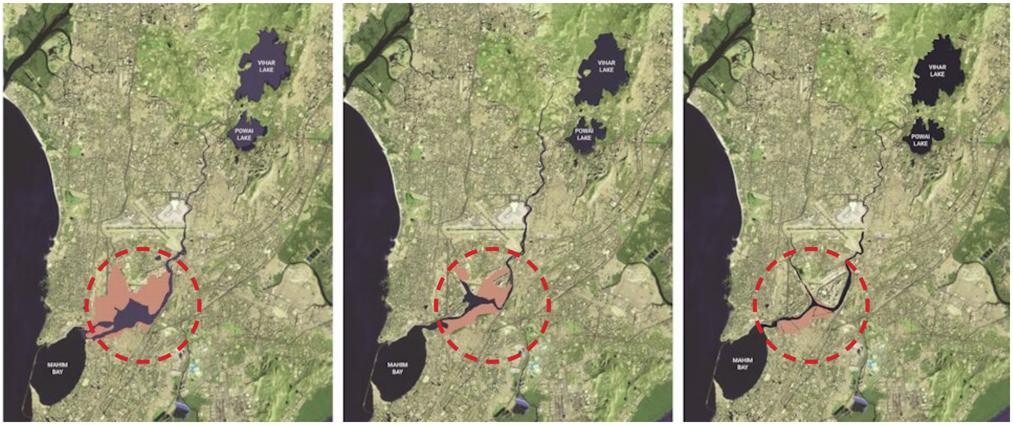


Figure 33: Mithi's shrinking ecosystem over the years (1946-2023) (Source: "Mithi: Desperately seeking course correction, ecological restoration" by Dhagey J., Dave S., 2023)

4.2. Mumbai's Alignment with Agenda 2030 and Sustainable Development Goals (SDGs)

Mumbai presents a difficult duality in the context of Agenda 2030. A good example to illustrate this is Mumbai, being India's financial Capital, contributes 6.16% of the Indian GDP; however, 60% of its population is still estimated to be living in slums (Forbes, 2023). Hence, a convergence of frameworks rather than a single linear policy is its approach to sustainable development.

4.2.1. ALIGNMENT TO AGENDA 2030

The state of Maharashtra is one of the frontrunners in the reports on SDG India Index, scoring 70 out of 100 in 2020-2021 and 73 out of 100 in 2023-2024 (NITI Aayog, 2025).

Mumbai Climate Plan (MCAP)

MCAP was launched in 2022, is a roadmap dedicated to a net-zero and climate-resilient Mumbai by 2050. Being the first climate action plan from a C40 City Network in the South and West Asia region, it aligns with the goals of the Paris Agreement and follows the C40 Climate Action Planning Framework. It covers six priority strategic areas- sustainable waste management; urban greening and biodiversity; urban flooding and water resource management; energy and buildings; air quality; and sustainable mobility (C40 Cities, 2022).

District Indicator Framework (DIF)

DIF is a system at the district level that works by tracking and identifying a set of key indicators to monitor the progress of development for each district, aligning with the Sustainable Development Goals (SDGs). The

Maharashtra government monitors Mumbai City and the Mumbai Suburban Districts at the district level.

4.2.2. KEY SUSTAINABLE DEVELOPMENT GOALS AND CORE CHALLENGES

SDG 11 (Sustainable Cities and Communities) is the core challenge and the most critical goal for Mumbai because of its density. Mumbai is home to one of the largest slums in the world in terms of its population density, known as Dharavi, which alone has a population of nearly one million people. Although Dharavi is a slum, it has cultural, economic and historical prominence. The Slum Rehabilitation Authority (SRA) was established in 1995 to rehabilitate slum dwellers. Upgrading slums will not only help in the development of SDG 11 but also many other SDGs such as SDG 1 (no poverty), SDG 3 (Good health and well-being), SDG 6 (clean water and sanitation).

Another challenge is fragmented governance, leading to uncoordinated planning. Multiple agencies like BMC, MMRDA, SRA, etc. have overlapping jurisdictions. Other infrastructural projects such as the Coastal Road and Metro Car Shed often pose incompatible development, as on one hand it enhances infrastructure (SDG 9) and on the other hand hinders the ecology underwater and on land (SDG 14 and 15).

The BMC is shifting towards nature-inspired measures over hard-engineered structures by proposing Sponge Parks and permeable pavements as a pilot project to the NDMA (National Disaster Management Authority). Under the initiative to build Miyawaki forests, BMC plans to plant 50,000 trees across the city (Times of India,2025).

Banner of 17 Sustainable Development Goals
(Source: United Nations)

05

Proposed Interventions

5.1. Pilot Site: BKC - Kurla Junction

5.2. Proposed Interventions

5.2.1. Rehabilitation of Slum Dwellers

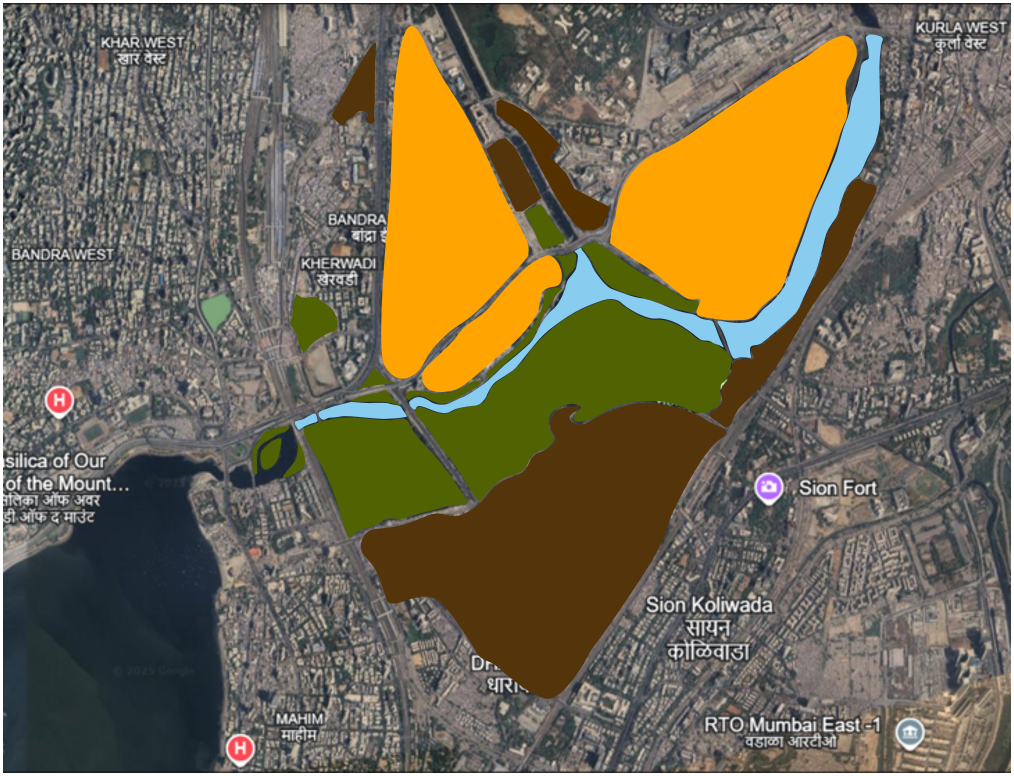
5.2.2. Making Space for the River

.2.3. Slowing the River

5.3. Conclusions

5. PROPOSED INTERVENTIONS

5.1. Pilot Site: BKC Junction



Commercial Area
Slum encroachments
Mithi River
Green area

Figure 34: Lower reach of Mithi, the junction of Bandra Kurla Complex, image showing the encroached floodplains and narrowed river (Source: google earth image furthur modied by the author)

5.2. Proposed Interventions

Restoring floodplains to the pre- human era is often an impossible goal in developed landscapes. Hence, reviving the natural functions and dynamics of the river systems can be acheived from making simple changes in land management to major climate interventions (Beechie et al.,2010).

5.2.1. REHABILITATION OF SLUM DWELLERS

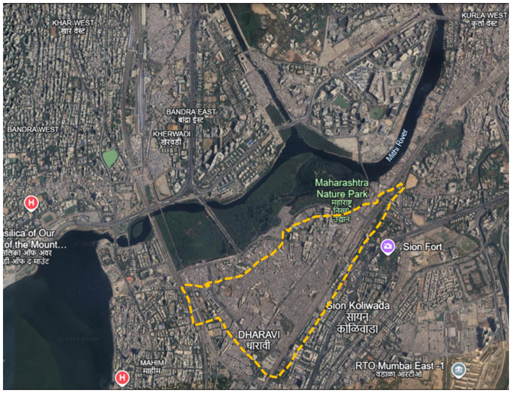


Figure 35: Image showing Asia's largest slum, Dharavi (Source: google earth image furthur modied by the author)

Figure 36: Image showing the current dwellings patterns in Dharavi (Source: Bambi Vincent)

Dharavi is a slum, the most densely populated area in the world, with a population of approximately 1 million people. Resettlement of Dharavi dwellers to some other destination than Dharavi is not an easy task. We need an integrated strategy that aligns ecological, environmental health with the local community of dwellers in Dharavi.

Houses built on stilts can serve the purpose of both. Since Dharavi is the most affected/ vulnerable community to floods, houses on stilts perched 2-2.5 m above the ground not only protects from floods but also allows the ground to be permeable and allow the water to flow without causing casualties and other damages.

The proposed intervention would be effective in the following ways:
`

1. ***The river can reconnect to its floodplains again.***
2. ***The slum dwellers will be protected from flood and will still have the space to move around during inundation via the network of elevat ed'green coloured'pathways as shown in (figure 37).***
3. ***During the dry days, the space below the stilt houses can be used a community gathering space, temporary urban area, markets, and other activities.***
4. ***This intervention allows for rehabilitation of slum dwellers in the same place as before without displacing them to a typical "vertical slum".***

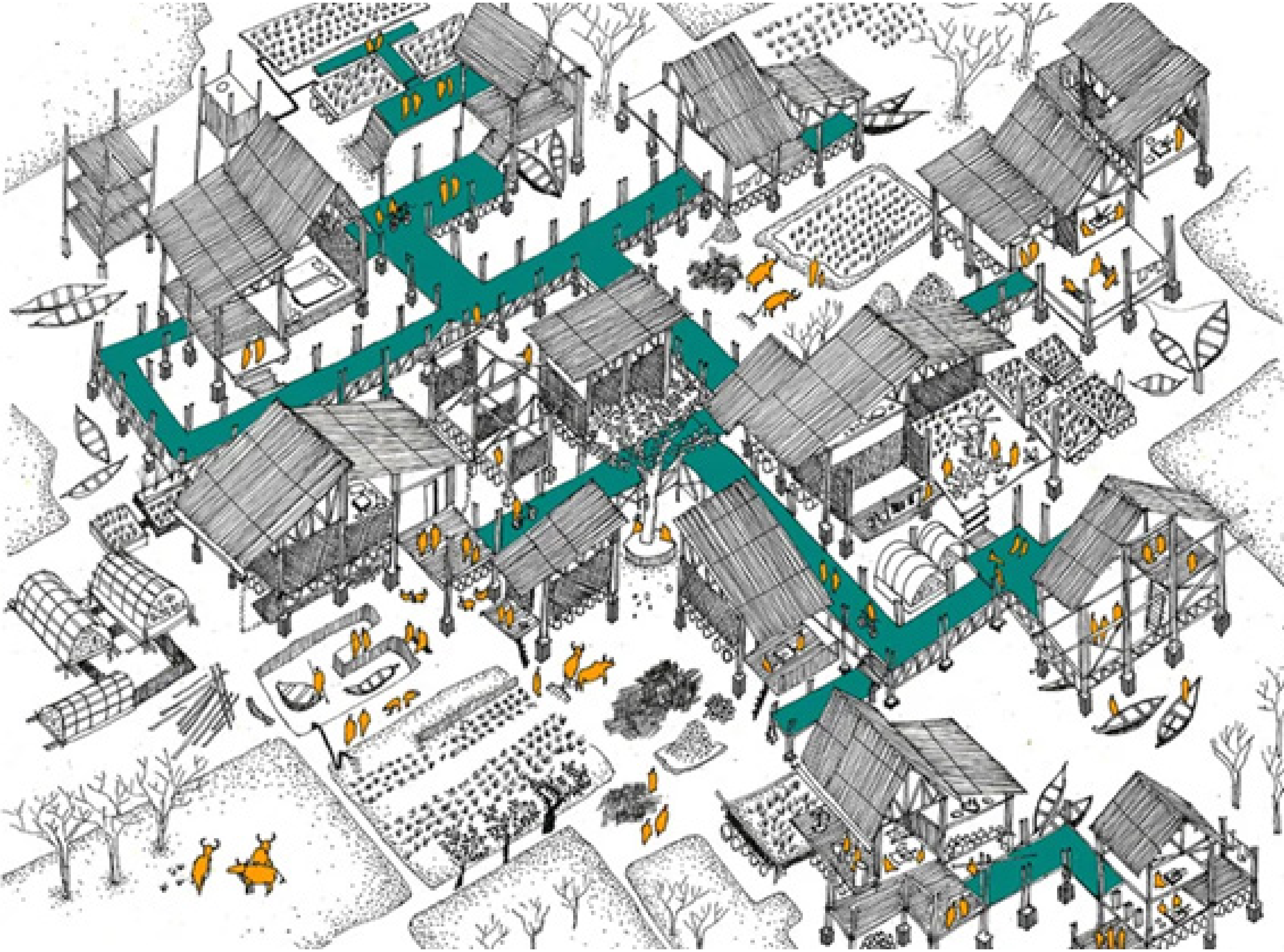


Figure 37: Proposed housing on stilts to accommodate floodplains while protecting the vulnerable communities of the slum from flooding (Source: Archidiaries / Parth Champaneri, 2018)

5.2.2. MAKING SPACE FOR THE RIVER

Step 1: Desilting

Cleaning and Desilting the Mithi River will remove pollutants from the water, improving water quality, and restoring the aquatic ecosystems. It will also increase the flow capacity of water, reducing the risk of overflowing.

Figure 38: Desilting of Mithi River from flooding (Source: The Times of India)

Step 2: Levee setbacks: Removal of levees and embankments

This involves removing an existing levee and constructing a new line of defense farther away. Setting back levees is a powerful intervention as it widens the corridor available for the river and allows for a wider floodplain for restoration, allows the floodwater to slow down and spread, lowering

Figure 39: Concrete embankments along Mithi, constricting the flow of water, forcing the river to overflow. (Source: Hindustan Times further modified by the author)

the velocity and height of the flood. The additional floodplain received can be used to rebuild natural buffers with diverse ecosystems, lowering the risk of communities in the low-lying area to the flood hazard. This reconnects the river to its floodplain, while communities behind the new wall remain protected from floods (Opperman et al., 2009).

5.2.3. SLOWING THE RIVER

Increasing the physical texture/ roughness of the landby in planting Riparian Buffers, Native Vegetation, Urban Forest and Constructed Wetlands. This will ensure peak reduction and safeguard the nearby urban areas.The overbank zone as shown in (figure 40) buffers will be planted with dense low height grasses beneath the stilted houses to slow down the water, acting as a retention area.

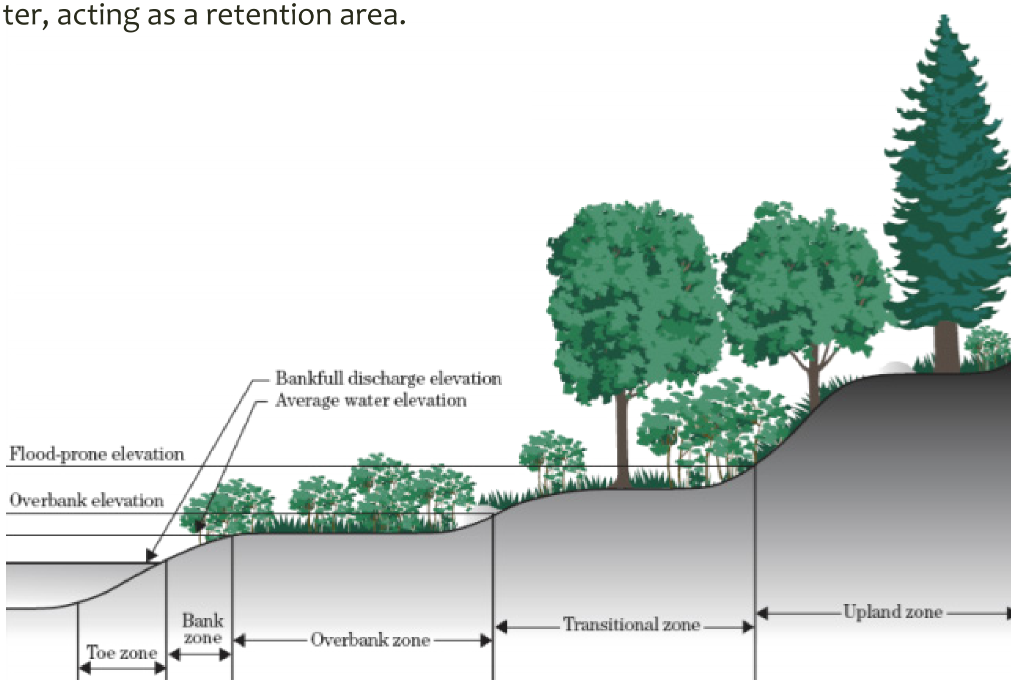


Figure 40: Riparian Planting Zones (Source: "Riparian Buffers | Indiana Soil & Watershed Conservation" by Swearingen S., 2020)

5.3. Conclusions

This research investigated the root causes of recurrent fluvial flooding in Mumbai due to the overflow of the Mithi River. The findings clearly identify these as a consequence of a stressed ecological environment as a result of constant urbanisation and historical land reclamation in Mumbai, along with the impacts of climate change. The carrying capacity of the Mithi river, being a crucial stormwater drainage network, has immensely reduced due to the anthropogenic pressures like encroachments, waste disposal, concretisation and other urban infrastructures along its banks. Above all, the main finding is that these conventional measures of constructing "grey infrastructure" for flood protection actually hinder the natural dynamics of water and diminish the natural storage capabilities of floodplains.

This research particularly focuses on the BKC – Kurla junction, most narrowing part of the Mithi River as a pilot project to restore the degraded floodplains and their ecosystems to gradually revive the river to its natural abode. It advocates for a paradigm shift to Nature-based Solutions from conventional hard-engineered methods for restoring the lost floodplains

Figure 41: Proposed Strategies (Source: the author)

of the river Mithi. Reviving and re-naturalising floodplains is a path to enhancing the city's flood resilience and hence, to do so, this study examined global best practices – such as the "Room for the River" concept in the Netherlands, restoration projects in Ningbo, China and Cheoggyecheon stream, Seoul, and Indian vernacular architecture of elevated houses to build a flood-resilient community dwelling for the slum area. These case studies demonstrate that urban planning does not have to exclude rivers and their floodplains but integrate them to mitigate floods and achieve crucial co-benefits like reduction in Urban Heat Island effect and experience fresh and more interactive public places.

In conclusion, the strategies and actions suggested for Mumbai in this research align with the following UN Sustainable Development Goals (SDGs):

SUSTAINABLE DEVELOPMENT GOALS

11 SUSTAINABLE CITIES AND COMMUNITIES

13 CLIMATE ACTION

15 LIFE ON LAND

6 CLEAN WATER AND SANITATION

06

References

Ahern, J. (2011). From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. Landscape and Urban Planning, 100(4), 341–343. https://doi.org/10.1016/j.landurbplan.2011.02.021

ASLA 2013 Professional Awards | Ningbo Eco-Corridor - 3.3 Km Living Filter. https://www.asla.org/2013awards/253.html. Accessed 8 Dec. 2025.

Barbhuiya, Salim, et al. "Sustainable Solutions for Low-Cost Building: Material Innovations for Assam-Type House in North-East India." Case Studies in Construction Materials, vol. 22, July 2025, p. e04461. DOI.org (Crossref), https://doi.org/10.1016/j.cscm.2025.e04461.

Beechie, T. J., Sear, D. A., Olden, J. D., Pess, G. R., Buffington, J. M., Moir, H., Roni, P., & Pollock, M. M. (2010). Process-based principles for restoring river ecosystems. BioScience, 60(3), 209–222. https://doi.org/10.1525/bio.2010.60.3.7

BMC: Desilting contractors fined 3cr+ for irregularities. (2025, June 4). The Times of India. https://timesofindia.indiatimes.com/city/mumbai/bmc-desilting-contractors-fined-3cr-for-irregularities/articleshow/121630055.cms

Broadmeadow, S., & Nisbet, T. R. (2004). The effects of riparian forest management on the freshwater environment: A literature review of best management practice. Hydrology and Earth System Sciences, 8(3), 286–305. https://doi.org/10.5194/hess-8-286-2004

Carchidi, V. (2011). Soak: Mumbai in an estuary. Electronic Green Journal, 1(31). https://doi.org/10.5070/G313110849

Chandrashekar, V. (2018, March 29). As India struggles to clean up its polluted urban rivers, ecological and economic costs are mounting. Scroll.In. https://scroll.in/article/869330/as-india-struggles-to-clean-up-its-polluted-urban-rivers-ecological-and-economic-costs-are-mounting

Cheonggyecheon Stream | Sur Atlas. https://suratlas.unibocconi.

eu/projects/cheonggyecheon-stream?_gl=1*2b1dhm*_up-*MQ..*_ga*ODk2NDM5ODYzLjE3NjUxOTU5MDQ.*_ga_WSL4X-FZ8M3*czE3NjUxOTU5MDEkbzEkZzEkdDE3NjUxOTU5MzAka-jMxJGwwJGgw. Accessed 8 Dec. 2025.

Cheonggyecheon stream restoration: A detailed Urban Planning analysis. (2024, November 16). Issuu. https://issuu.com/ann1224/docs/cheonggyecheon_restoration-_ank

Cheonggyecheon Stream Restoration Project | Landscape Performance Series. 1 Dec. 2011, https://www.landscapeperformance.org/case-study-briefs/cheonggyecheon-stream-restoration-project.

"Cheonggyecheon Stream." The Seoul Guide, https://www.theseoulguide.com/cheonggyecheon-stream/. Accessed 8 Dec. 2025.

Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (Eds). (2016). Nature-based solutions to address global societal challenges. IUCN International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2016.13.en

Cosmetic measures will not revive Mithi river in Mumbai. (2017, June 4). Hindustan Times. https://www.hindustantimes.com/mumbai-news/cosmetic-measures-will-not-revive-mithi-river-in-mumbai/story-iqiWEhQaFlMyJYPqBEoRZL.html

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., & Van Den Belt, M. (1997). The value of the world's ecosystem services and natural capital. Nature, 387(6630), 253–260. https://doi.org/10.1038/387253a0

Davis, A. P., Hunt, W. F., Traver, R. G., & Clar, M. (2009). Bioretention technology: Overview of current practice and future needs. Journal of Environmental Engineering, 135(3), 109–117. https://doi.org/10.1061/(ASCE)0733-9372(2009)135:3(109)

Dhagey, J., & Dave, S. (2023, August 11). Mithi: Desperately seeking course correction, ecological restoration - Question of Cities. https://questionofcities.org/mithi-desperately-seeking-course-correction-ecological-restoration/

Disaster resilient houses | architecture thesis. (n.d.-a). ArchiDiaries. Retrieved 8 December 2025, from https://archidiaries.com/academic-projects/disaster-resilient-houses-architecture-thesis/

Disaster resilient houses | architecture thesis. (n.d.-b). ArchiDiaries. Retrieved 8 December 2025, from https://archidiaries.com/academic-projects/disaster-resilient-houses-architecture-thesis/

Eggermont, H., Balian, E., Azevedo, J. M. N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Lamarque, P., Reuter, K., Smith, M., Van Ham, C., Weisser, W. W., & Le Roux, X. (2015). Nature-based solutions: New influence for environmental management and research in europe. GAIA - Ecological Perspectives for Science and Society, 24(4), 243–248. https://doi.org/10.14512/gaia.24.4.9

European Commission. Directorate General for Research and Innovation. (2015). Towards an EU research and innovation policy agenda for nature-based solutions & re-naturing cities: Final report of the Horizon 2020 expert group on 'Nature based solutions and re naturing cities' : (Full version). Publications Office. https://data.europa.eu/doi/10.2777/765301

Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J.-L., Mikkelsen, P. S., Rivard, G., Uhl, M., Dagenais, D., & Viklander, M. (2015). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. Urban Water Journal, 12(7), 525–542. https://doi.org/10.1080/1573062X.2014.916314

Floodplain and floodway 101: Managing flood risks in wnc. (2025, January 22). Builders Association of the Blue Ridge Mountains. https://bablueridge.com/floodplain-workshop/

Gleick, P. H. (2003). Global freshwater resources: Soft-path solutions for the 21st century. Science, 302(5650), 1524–1528. https://doi.org/10.1126/science.1089967

Global climate risk index 2020 who suffers most from extreme weather events? Wether-related loss events in 2018 and 1999 to 2018 (with Eckstein, D., Winges, M., Künzel, V., Schäfer, L., & Germanwatch). (2019). Bonn Germanwatch Nord-Süd Initiative e.V. 2019.

Google search. (n.d.-a). Retrieved 8 December 2025, from https://www.google.com/search?q=https://landezine.com/water-square-benthemplein-by-de-urbanisten

Google search. (n.d.-b). Retrieved 8 December 2025, from https://www.google.com/search?q=https://doi.org/10.5281/zenodo.5101125&authuser=1

Google search. (n.d.-c). Retrieved 8 December 2025, from https://www.google.com/search?q=http://documents.worldbank.org/curated/en/739421509427698706/Implementing-nature-based-flood-protection-principles-and-implementation-steps&authuser=1

Google search. (n.d.-d). Retrieved 8 December 2025, from https://www.google.com/search?q=https://elischolar.library.yale.edu/uri_course_work/1&authuser=1

Google search. (n.d.-e). Retrieved 8 December 2025, from https://www.google.com/search?q=https://rmi.org/wp-content/uploads/2017/04/W00-32_DaylightingNewLife.pdf&authuser=1

Google search. (n.d.-f). Retrieved 8 December 2025, from https://www.google.com/search?q=https://doi.org/10.1515/9783034611593&authuser=1

Green Guide—Page 2 of 5. (n.d.). Flood Science Center. Retrieved 7 December 2025, from https://floodsciencecenter.org/products/crs-community-resilience/green-guide/

Guide for selecting Manning's roughness coefficients for natural channels and flood plains. (1989). https://doi.org/10.3133/wsp2339

Hallegatte, S., Green, C., Nicholls, R. J., & Corfee-Morlot, J. (2013). Future flood losses in major coastal cities. Nature Climate Change, 3(9), 802–806. https://doi.org/10.1038/nclimate1979

Https://Www.Seedsindia.Org/Seedss-Flood-Resilient-Houses-Continue-to-Save-Lives/. https://www.seedsindia.org/seedss-flood-resilient-houses-continue-to-save-lives/. Accessed 8 Dec. 2025.

India's Mising tribe lives in traditional flood-resilient homes to adapt to climate change. (2022, February 9). Global Voices. https://globalvoices.org/2022/02/09/indias-mising-tribe-lives-in-traditional-flood-resilient-homes-to-adapt-to-climate-change/

Intergovernmental Panel on Climate Change (Ed.). (2023). Climate change 2022: Impacts, adaptation and vulnerability: working group ii contribution to the sixth assessment report of the intergovernmental panel on climate change. Cambridge University Press.

"Investigation of Bioclimatic Design Features in Vernacular Architecture of Northeast India: Case Studies of Assam-Type Houses and Stilt Houses (Chang Ghar) in Assam, India." Indian Journal of Traditional Knowledge, vol. 22, no. 3, Sept. 2023. DOI.org (Crossref), https://doi.org/10.56042/ijtk.v22i3.5757.

Jha, A. K. (with Bloch, R., & Lamond, J.). (2012). Cities and flooding: A guide to integrated urban flood risk management for the 21st century. World Bank Publications.

J, J. W. (1989). The flood pulse concept in river-floodplain systems. Canadian Journal Special Publication of Fishery and Aquatic Science, 106, 110–127. https://cir.nii.ac.jp/crid/1570291224982299264

Kabisch, N., Korn, H., Stadler, J., & Bonn, A. (2017). Nature-based solutions to climate change adaptation in urban areas—Linkages between science, policy and practice. In N. Kabisch, H. Korn, J. Stadler, & A. Bonn (Eds), Nature-Based Solutions to Climate Change Adaptation in Urban Areas (pp. 1–11). Springer International Publishing. https://doi.org/10.1007/978-3-319-56091-5_1

Klijn, F., De Bruijn, K. M., Knoop, J., & Kwadijk, J. (2012). Assessment of the netherlands' flood risk management policy under global change. AMBIO, 41(2), 180–192. https://doi.org/10.1007/s13280-011-0193-x

Krishna, Geetanjali. “The Modern Makeover of Assam’s Centuries-Old Stilt Houses.” Reasons to Be Cheerful, 16 Sept. 2025, https://reasonstobecheerful.world/assam-india-stilt-houses-flood-resilient-makeover/.

Landscape Architecture Foundation, Robinson, A., & Hopton, M. (2011). Cheonggyecheon stream restoration project. Landscape Architecture Foundation. https://doi.org/10.31353/cs0140

Lee, H., & Romero, J. (Eds) (with Intergovernmental Panel on Climate Change). (2023). Climate Change 2023: Synthesis report. Intergovernmental Panel on Climate Change.

Lee Kuan Yew World City Prize. https://leekuanyewworldcityprize.gov.sg/. Accessed 8 Dec. 2025.

Lehrman, B. (2011). SOAK: Mumbai in an Estuary Anuradha Mathur and Dilip da Cunha. 2009. New Delhi: Rupa, 216 pages, including front / back piece, note from the Director of NGMA, foreword by Arjun Appadurai and Carol Breckenridge, preface, epilogue, glossary, image lexicon, and notes. Color and black and white illustrations and photographs. $195, hardcover. ISBN 978-8-129114-80-1. Landscape Journal, 30(2), 315–317. https://doi.org/10.3368/lj.30.2.315

Liao, K.-H. (2012). A theory on urban resilience to floods—A basis for alternative planning practices. Ecology and Society, 17(4), art48. https://doi.org/10.5751/ES-05231-170448

LID SWM Planning and Design Guide. https://wiki.sustainabletechnologies.ca/wiki/Main_Page. Accessed 8 Dec. 2025.

Marshall, M. R., Ballard, C. E., Frogbrook, Z. L., Solloway, I., McIntyre, N., Reynolds, B., & Wheater, H. S. (2014). The impact of rural land management changes on soil hydraulic properties and runoff processes: Results from experimental plots in upland UK. Hydrological Processes, 28(4), 2617–2629. https://doi.org/10.1002/

hyp.9826

Masson-Delmotte, V. & Intergovernmental Panel on Climate Change (Eds). (2023). Climate change 2021: The physical science basis: working group i contribution to the sixth assessment report of the intergovernmental panel on climate change. Cambridge University Press.

McHarg, I. L. (1992). Design with nature (25th anniversary ed). John Wiley & Sons, Inc.

Meerow, S., Newell, J. P., & Stults, M. (2016). Defining urban resilience: A review. Landscape and Urban Planning, 147, 38–49. https://doi.org/10.1016/j.landurbplan.2015.11.011

Menéndez, P., Losada, I. J., Torres-Ortega, S., Narayan, S., & Beck, M. W. (2020). The global flood protection benefits of mangroves. Scientific Reports, 10(1), 4404. https://doi.org/10.1038/s41598-020-61136-6

Mentens, J., Raes, D., & Hermy, M. (2006). Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? Landscape and Urban Planning, 77(3), 217–226. https://doi.org/10.1016/j.landurbplan.2005.02.010

Miller, J. D., & Hutchins, M. (2017). The impacts of urbanisation and climate change on urban flooding and urban water quality: A review of the evidence concerning the United Kingdom. Journal of Hydrology: Regional Studies, 12, 345–362. https://doi.org/10.1016/j.ejrh.2017.06.006

Milly, P. C. D., Betancourt, J., Falkenmark, M., Hirsch, R. M., Kundzewicz, Z. W., Lettenmaier, D. P., & Stouffer, R. J. (2008a). Stationarity is dead: Whither water management? Science, 319(5863), 573–574. https://doi.org/10.1126/science.1151915

Milly, P. C. D., Betancourt, J., Falkenmark, M., Hirsch, R. M., Kundzewicz, Z. W., Lettenmaier, D. P., & Stouffer, R. J. (2008b). Stationarity is dead: Whither water management? Science, 319(5863), 573–574. https://doi.org/10.1126/science.1151915

Mithi river development works | mumbai metropolitan region development authority. (n.d.). Retrieved 7 December 2025, from https://mmrda.maharashtra.gov.in/en/projects/environment/mithi-river-development-works/overview

Mitsch, W. J. (2012). What is ecological engineering? Ecological Engineering, 45, 5–12. https://doi.org/10.1016/j.ecoleng.2012.04.013

Natural & beneficial functions of floodplain | walton county, fl—Home page. (n.d.). Retrieved 7 December 2025, from https://www.mywaltonfl.gov/733/Natural-Beneficial-Functions-of-Floodpla

Nesshöver, C., Assmuth, T., Irvine, K. N., Rusch, G. M., Waylen, K. A., Delbaere, B., Haase, D., Jones-Walters, L., Keune, H., Kovacs, E., Krauze, K., Külvik, M., Rey, F., Van Dijk, J., Vistad, O. I., Wilkinson, M. E., & Wittmer, H. (2017). The science, policy and practice of nature-based solutions: An interdisciplinary perspective. Science of The Total Environment, 579, 1215–1227. https://doi.org/10.1016/j.scitotenv.2016.11.106

———. "Ningbo East New Town Eco-Corridor." SWA Group, https://www.swagroup.com/projects/ningbo-east-new-town-eco-corridor/. Accessed 8 Dec. 2025.

Oke, T. R., Mills, G., Christen, A., & Voogt, J. A. (2017). Urban climates (1st edn). Cambridge University Press. https://doi.org/10.1017/9781139016476

Opperman, J. J., Galloway, G. E., Fargione, J., Mount, J. F., Richter, B. D., & Secchi, S. (2009). Sustainable floodplains through large-scale reconnection to rivers. Science, 326(5959), 1487–1488. https://doi.org/10.1126/science.1178256

Paul, R. (2024, April 5). Sinking city: Climate risk, adaptation and urban governance in Mumbai - Question of Cities. https://questionofcities.org/sinking-city-climate-risk-adaptation-and-urban-governance-in-mumbai/

Prajapati, P., Singhal, A., & Jha, S. K. (2025). Analysis of urban flood vulnerability at the sub-city administrative unit level in Mumbai:

A comparison over two time periods. Urban Climate, 62, 102536. https://doi.org/10.1016/j.uclim.2025.102536

Prominski, M., Stokman, A., Stimberg, D., Voermanek, H., Bajc, K., & Zeller, S. (2017). River.space.design: Planning strategies, methods and projects for urban rivers (B. Cunningham, D. Skogley, & M. Hale, Trans.; Second and enlarged edition). Birkhäuser.

Rajib, A., Zheng, Q., Lane, C. R., Golden, H. E., Christensen, J. R., Isibor, I. I., & Johnson, K. (2023). Human alterations of the global floodplains 1992–2019. Scientific Data, 10(1), 499. https://doi.org/10.1038/s41597-023-02382-x

Ranger, N., Hallegatte, S., Bhattacharya, S., Bachu, M., Priya, S., Dhore, K., Rafique, F., Mathur, P., Naville, N., Henriet, F., Herweijer, C., Pohit, S., & Corfee-Morlot, J. (2011). An assessment of the potential impact of climate change on flood risk in Mumbai. Climatic Change, 104(1), 139–167. https://doi.org/10.1007/s10584-010-9979-2

Re-naturalization of urban waterways: The case study of cheonggye stream in seoul, south korea. (2024, September 12). ArchDaily. https://www.archdaily.com/1020945/re-naturalization-of-urban-waterways-the-case-study-of-cheonggye-stream-in-seoul-south-korea

Riparian buffer restoration project. (2023, December 14). https://www.peacevalleynaturecenter.org/riparian-buffer-restoration

Rosenzweig, B., Montalto, F. A., Orton, P., Kaatz, J., Maher, N., Kleyman, J., Chen, Z., Sanderson, E., Adhikari, N., McPhearson, T., & Herreros-Cantis, P. (2024). NPCC4: Climate change and New York City’s flood risk. Annals of the New York Academy of Sciences, 1539(1), 127–184. https://doi.org/10.1111/nyas.15175

R, V. (2023, March 17). What mumbai’s climate action plan says about risks for the city. OpenCity. https://opencity.in/what-mumbais-climate-action-plan-says-about-risks-for-the-city/

Sayers, P. & Asian Development Bank. (2013). Flood risks management:

A strategic approach. Asian Development Bank.

Seoul Museum. https://museum.seoul.go.kr/. Accessed 8 Dec. 2025.

Seoulsolution. “Seoul Urban Regeneration: Cheonggyecheon Restoration and Downtown Revitalization.” [illegible] Seoul Solution, 11 Aug. 2014, https://seoulsolution.kr/en/content/seoul-urban-regeneration-cheonggyecheon-restoration-and-downtown-revitalization.

Serra-Llobet, A., Jähnig, S. C., Geist, J., Kondolf, G. M., Damm, C., Scholz, M., Lund, J., Opperman, J. J., Yarnell, S. M., Pawley, A., Shader, E., Cain, J., Zingraff-Hamed, A., Grantham, T. E., Eisenstein, W., & Schmitt, R. (2022). Restoring rivers and floodplains for habitat and flood risk reduction: Experiences in multi-benefit floodplain management from california and germany. Frontiers in Environmental Science, 9, 778568. https://doi.org/10.3389/fenvs.2021.778568

Shukla, P. R., Skea, J., Reisinger, A. R., & IPCC (Eds). (2022). Climate change 2022: Mitigation of climate change. IPCC.

“Stilt Houses Help People Withstand Floods in Assam.” Dialogue Earth, 14 Sept. 2021, https://dialogue.earth/en/climate/stilt-houses-assam-help-people-withstand-floods/.

Sur Atlas. https://suratlas.unibocconi.eu/. Accessed 8 Dec. 2025.

Sustainability (IDOS), German Institute of Development and. German Institute of Development and Sustainability (IDOS) - Home. https://www.idos-research.de/en/. Accessed 8 Dec. 2025.

Sutton-Grier, A. E., Wowk, K., & Bamford, H. (2015). Future of our coasts: The potential for natural and hybrid infrastructure to enhance the resilience of our coastal communities, economies and ecosystems. Environmental Science & Policy, 51, 137–148. https://doi.org/10.1016/j.envsci.2015.04.006

Thiefhunters in Paradise—Dharavi—Inside the giant Mumbai slum. (2012, October 19). https://bobarno.com/dharavi-mumbai-slum/

Tumbl3w33d. (n.d.). Ningbo east new town eco-corridor. SWA Group. Retrieved 8 December 2025, from https://www.swagroup.com/projects/ningbo-east-new-town-eco-corridor/

Tumbl3w33d. “Ningbo East New Town Eco-Corridor.” SWA Group, https://www.swagroup.com/projects/ningbo-east-new-town-eco-corridor/. Accessed 8 Dec. 2025.

UNITED NATIONS DEPARTMENT FOR ECONOMIC AND SOCIAL AFFAIRS. (2021). Sustainable development goals report 2021. UNITED NATIONS.

United Nations Department of Economic and Social Affairs. (2019). World urbanization prospects: The 2018 revision. United Nations.

Vymazal, J. (2010). Constructed wetlands for wastewater treatment. Water, 2(3), 530–549. https://doi.org/10.3390/w2030530

Walsh, C. J., Roy, A. H., Feminella, J. W., Cottingham, P. D., Groffman, P. M., & Morgan, R. P. (2005). The urban stream syndrome: Current knowledge and the search for a cure. Journal of the North American Benthological Society, 24(3), 706–723. https://doi.org/10.1899/04-028.1

“Waterplein Benthemplein Reveals the Secret of Versatile Water Squares.” Land8, 13 June 2015, https://land8.com/waterplein-benthemplein-reveals-the-secret-of-versatile-water-squares/.

“Water Square Benthemplein.” Craftvue, https://www.dutcharchitects.org/projects/water-square-benthemplein/. Accessed 8 Dec. 2025.

Watersquare benthemplein, rotterdam. (n.d.). DE URBANISTEN. Retrieved 8 December 2025, from https://www.urbanisten.nl/work/benthemplein

Welcome to the ECRR Website. https://www.ecrr.org/. Accessed 8 Dec. 2025.

What are retention ponds? - Retention ponds - water and waste - city of winnipeg. (n.d.). Retrieved 8 December 2025, from https://legacy.winnipeg.ca/waterandwaste/retentionPonds/types.stm

World Bank. (2017). Implementing nature based flood protection. World Bank, Washington, DC. https://doi.org/10.1596/28837

Yorgey, G. G., Hall, S. A., Allen, E. R., Whitefield, E. M., Embertson, N. M., Jones, V. P., Saari, B. R., Rajagopalan, K., Roesch-McNally, G. E., Van Horne, B., Abatzoglou, J. T., Collins, H. P., Houston, L. L., Ewing, T. W., & Kruger, C. E. (2017). Northwest u. S. Agriculture in a changing climate: Collaboratively defined research and extension priorities. Frontiers in Environmental Science, 5, 52. https://doi.org/10.3389/fenvs.2017.00052

Zope, P. E., Eldho, T. I., & Jothiprakash, V. (2016). Impacts of land use–land cover change and urbanization on flooding: A case study of Oshiwara River Basin in Mumbai, India. CATENA, 145, 142–154. https://doi.org/10.1016/j.catena.2016.06.009

[illegible]. & [illegible], 1963-. (2016). [illegible]: [illegible] = Sponge city : theory and practice. [illegible].