Water Sensitive Urban Design for Indian Cities

Synergising Key Principles and Grey Infrastructure Elements in New Delhi, India

by **Abhishek Sharma**

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Date of submission
27th November 2023

Declaration of authorship

Hereby I declare that I have written this thesis with the title '**Water Sensitive Urban Design for Indian Cities – Synergising Key Principles and Grey Infrastructure Elements in New Delhi, India**' without any help from others and without the use of documents and aid other than those cited according to established academic citation rules. The thesis is submitted in fulfilment of the requirement for the **Master of Science degree in Resource Efficiency in Architecture and Planning** to the **HafenCity University, Hamburg.**

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ACKNOWLEDGEMENT

The present master's thesis is dedicated to the city of Delhi, India, as well as to my friends and colleagues who share a similar passion for making our cities more liveable and equitable. Having spent five years in Delhi as a young architect from 2016 to 2021, I gained first-hand experience with the annual flooding of its streets. This experience fuelled my urgency to delve deeper into this issue and explore potential solutions to mitigate urban flooding.

First and foremost, I would like to extend my sincere gratitude to my supervisor, Professor Wolfgang Dickhaut, for his invaluable professional expertise, guidance, and unwavering support throughout the entire research process. I am equally thankful to Mr Depinder Singh Kapur, Director of the Water program at the Centre for Science and Environment (CSE) in New Delhi, India. Mr Kapur and the dedicated team at CSE developed a Water Sensitive Urban Design and Planning framework for cities in the Global South. This position paper significantly influenced the selection of my thesis topic.

I would also like to express my heartfelt thanks to the experts who generously provided essential feedback. I extend my appreciation to Mr Ajith Edathoot, Mr Dhruv Pasricha, Ms Pratima Joshi and Ms. Shambhavi Gupta for their valuable contributions to this research. Additionally, this master's thesis is inspired by the work of Anastasiya Andrukovich from 8th generation REAP at Hafencity University. Her work on "Adaptation Guidance For Flooding Risk Mitigation In Minsk, Belarus" is commendable.

Special thanks are due to my friends, Aaron Wieland, Akash Maan, Avi Shiplu, Florian Isufi and Gabriela Lugones, for their time, effort, and meticulous proofreading, as well as for adding their invaluable feedback to this research. I would also like to extend my gratitude to Ananya Bhanot for designing the cover page.

GLOSSARY

Catchment area
the territory where all accumulated surface runoff flows to the same outlet destination, such as a rainwater collector or surface water body.

Constructed wetland
a shallow basin with substrate, often sand or gravel, and planted with vegetation adapted to saturated conditions. Greywater flows through the basin, removing large waste matter in the inflow and sedimentation zone before entering the wetland/ root zone.

Dense urban settlement
the residential areas of the city with high population density, and lack of services. These are often unplanned settlements, unauthorised colonies and unrecognised by the government.

Ephemeral zone
zone in a constructed wetland which is periodically inundated area that experiences temporary changes in water levels due to factors like rainfall.

Extreme rainfall event
relatively rare cloudburst, generally considered to be an event with a return period of 10 years and more.

Grey infrastructure
infrastructure in cities related to water supply, stormwater management and wastewater management.

Hydraulic load
volume of wastewater or greywater that is applied to the wetland system over a specific time period. It is a critical design parameter influencing the efficiency of wastewater treatment by determining the contact time between the water and the wetland substrate, vegetation, and microorganisms.

Isohyetal
a line on a map or chart connecting areas of equal rainfall.

Pervious area
an area of ground that allows water to be infiltrated.

Runoff
water flows over the ground surface to the drainage system.

LIST OF ABBREVIATIONS

%	Per cent
°C	Degree Celsius
$	Dollar
AC	Assembly Constituency
ADB	Asian Development Bank
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
amsl	Above mean sea level
bgl	Below ground level
BGS	Blue Green Streets
BOD	Bio chemical oxygen demand
COD	Chemical oxygen demand
CSE	Centre for Science and Environment
C&D	Construction and Demolition
CGWB	Central Ground Water Board
CPHEEO	Central Public Health and Environmental Engineering Organisation
CW	Constructed Wetland
cu m	Cubic metre
DDA	Delhi Development Authority
DJB	Delhi Jal Board
DO	Dissolved oxygen
DMP	Drainage Master Plan
DPR	Detailed Project Report
DUEIIP	Delhi Urban Environment and Infrastructure Improvement Project
DWA	German association for Water, Wastewater and Waste
FSM	Faecal Sludge Management
GPA	General Power of Attorney
GNCTD	Government of National Capital Territory of Delhi
wha	Hectare
HDPE	High Density Polyethylene

I&FC	Irrigation and Flood Control Department
IITD	Indian Institute of Technology, Delhi
IMD	India Meteorological Department
INTACH	Indian National Trust for Art and Cultural Heritage
IUWM	Integrated Urban Water Management
GIS	Geographic Information System
GNCTD	Government of National Capital Territory of Delhi
JBCA	Japan Bank for International Cooperation
JJ	Jhuggi Jhopri/ Slums
km	Kilometre
LID	Low Impact Development
LULC	Land Use/ Land Cover
MDPI	Multidisciplinary Digital Publishing Institute
MGD	Million gallons per day
mm	Milli metre
m	Metre
MLD	Million litres per day
MPD	Master Plan of Delhi
NCT	National Capital Territory of Delhi
NDC	Nationally Determined Contributions
NIUA	National Institute of Urban Affairs
PWD	Public Works Department
RCC	Reinforced Cement Concrete
REAP	Resource Efficiency in Architecture and Planning
ROW	Right of Way
RWH	Rainwater harvesting
SDG	Sustainable Development Goals
STP	Sewage Treatment Plant
sq m	Square Metre
sq km	Square Kilometre
SuDS	Sustainable Urban Drainage Systems
UAC	Unauthorised Colonies

UNFCCC	United Nations Framework Convention on Climate Change
WASH	Water Sanitation and Hygiene
WSC	Water Sensitive Cities
WSP	Water Sensitive Planning
WSUD	Water Sensitive Urban Design
WSUDP	Water Sensitive Urban Design and Planning
WTP	Water Treatment Plant

ABSTRACT

Water Sensitive Urban Design (WSUD) recognises the urgent need for water as the critical component towards efforts to mitigate urban flooding and manage high runoff volumes generated from urban catchments. WSUD is essentially the efficient management of the urban water cycle. The current thinking around the urban water cycle and its management has emerged from research and discourse developed in Australia and Europe. These are appropriate in the context of Western cities, however, similar principles are dominating the conversations around Water Sensitive Cities in the Global South as well.

Indian cities much like the cities of the Global South are witnessing rapid urbanisation, predominant with informality in the built environment. There is an urgent need to develop a new Water Sensitive Cities framework in the Indian urban context. This new framework must introduce the term "Planning" as an integral part of its solution to tackle the issue of urban flooding. Indian cities must shift to Water Sensitive Urban Design and Planning (WSUDP) guidelines and principles instead of merely applying normative WSUD principles. Urban water systems in Indian cities are confronted with significantly changing conditions and are fundamentally different from developed Western Cities. The escalating challenges of unplanned growth, intensified water cycle and outdated grey infrastructure are aggravating current water issues, including flooding, water scarcity, and escalating rehabilitation costs, reaching a scale that could overwhelm the capacities of Indian cities.

By analysing the dense unplanned settlement in Sangam Vihar, New Delhi, this research acknowledges the inequity in Indian cities. It envisions a Water Sensitive Planning (WSP) framework for Indian cities rooted in inclusive planning, that aims to mitigate urban flooding by integrating adequate grey infrastructure with decentralised solutions for sustainable urban drainage. The key principles of the WSP framework in the Indian context are initially suggested, followed by the identification of essential principles tailored to Sangam Vihar. Subsequently, an in-depth analysis of the existing grey infrastructure (stormwater and sewage management) is conducted in the study area. The implementation of WSP principles is then translated into a concept design, yielding fitting recommendations to mitigate flooding risk in the settlement.

Key principles involve prioritising the enhancement of suitable grey infrastructure in dense unplanned settlements as per the site hydrogeography. Implementing decentralised solutions for urban flood mitigation involves harnessing existing green spaces as potential retention ponds and incorporating nature-based approaches for effective greywater treatment. This not only significantly contributes to groundwater recharge but also aids in the revitalization of arid water bodies.

Keywords: urban water cycle, urban flooding, water sensitive urban design and planning , framework, grey infrastructure, decentralised solution, stormwater management.

CONTENTS

01 INTRODUCTION

Urban water systems in India face substantial shifts in their operating conditions. Climate change, rapid urban growth, and the degradation of ageing drainage infrastructure exacerbate the existing water-related issues, such as flooding, water scarcity, and the high costs associated with infrastructure rehabilitation. These challenges are reaching a critical point, overwhelming the capabilities of urban centres. Specifically, stormwater management and the water supply in cities bear the brunt of this impact, and this is particularly evident in the case of India's capital, Delhi. In a significant portion of Delhi, the groundwater table lies as deep as 40 meters below the surface, affecting up to 30 % of the city (Rohilla et al., 2020). The city experiences annual urban flooding during the monsoon season, leading to social and economic constraints. The city witnessed the infamous flooding of July 2023 during which roads in several parts of the capital were submerged in knee-deep water as it was inundated with 153mm of rain, the highest precipitation in a single day in July in 40 years (Aljazeera, 2023).

In Delhi, the conventional method of handling stormwater involves the direct discharge of runoff into the sewer system. This approach presents two major challenges due to its inflexibility. Firstly, the current drainage system is dilapidated and has a limited capacity, and when the inflow surpasses its designed volume, it leads to flooding. Additionally, the accumulation of solid waste and sediment in the drainage and sewer collectors diminishes system performance and leads to blockages. Additionally, water is a precious resource, and its scarcity is becoming increasingly apparent due to the impacts of climate change. It is crucial for urban development to adopt a more conscientious and resource-centric approach, making responsible resource management a guiding principle.

The densely populated informal settlements in Delhi currently house nearly 30 % of its population, totalling around 10 million people (Rohilla et al., 2020). These settlements are predominantly unauthorised or are in the process of being regularised. They exhibit notable characteristics such as a lack of adequate physical infrastructure, high population density, and uncontrolled growth.

The latest drainage master plan of Delhi dates back to 1976 and the same was envisioned for a population of 6 million to cater to a maximum rainfall of 50 mm per day as reported by the Public Works Department (PWD) of Delhi. This is grossly undersized. The current population predictions as per the UN estimate that the population of Delhi is expected to reach around 35 million by 2030. The urban expansion clubbed with the intensified rainfall pattern overwhelms the fragile drainage network. Indian Institute of Technology, Delhi (IITD) prepared an extensive Drainage Master Plan (DMP) for Delhi in 2018, however, it was rejected by the Delhi government's technical expert committee citing it as "not worth considerable for recommendation" (N. M. Babu, 2021).Since then, no concrete measures have been taken up for developing a new DMP for the city of Delhi.

There is an urgent need for Indian cities to develop a new Water Sensitive Cities framework for sustainable management of its stormwater by integrating water planning and city planning. In contrast to cities in the Global North, which already possess well established grey infrastructure, the Water Sensitive Cities framework in the Global South faces the primary challenge of initially establishing sufficient grey infrastructure and services, specifically related to sewerage and stormwater drainage, particularly within densely populated urban areas. Kumar et al. (2023) argue that the fundamental differences between cities in the Global North and Global South should be recognised. Indian cities much like the Cities in the Global South share certain fundamental characteristics. These include predominantly informal development patterns, inadequate investments in grey infrastructure, diverse methods of water access (such as reliance on water tankers), fragmented and weak urban local governance structures lacking a robust tax base, and instances of local rent-seeking.

As highlighted by Kapur (2023), a Global South Water Sensitive Cities framework must start by improving what exists. The functionality and efficiency of existing systems of water supply, wastewater and stormwater management are important. The framework must emphasise the primacy of urban planning and the need to enforce planning norms that will allow for improved water sensitive outcomes. It must also recognise that water is a contested domain that needs to be addressed from the inclusive planning. Furthermore, he suggests that interventions for improvement, including climate change resilience, must not worsen existing inequity.

1.1 Defining Water Sensitive Urban Design (WSUD)

Water sensitive urban design (WSUD) is an inter-disciplinary approach to urban planning and development which provides opportunities for integration of land use and freshwater management and aims to protect and enhance natural freshwater systems, by sustainably managing water resources and mimicking natural processes (Lewis et al., 2015). As seen in Figure 1-01, the water cycle illustrates the various phases of water as it circulates through the environment. This journey involves precipitation as rain, infiltration into groundwater, movement toward streams, evaporation into the atmosphere, and more.

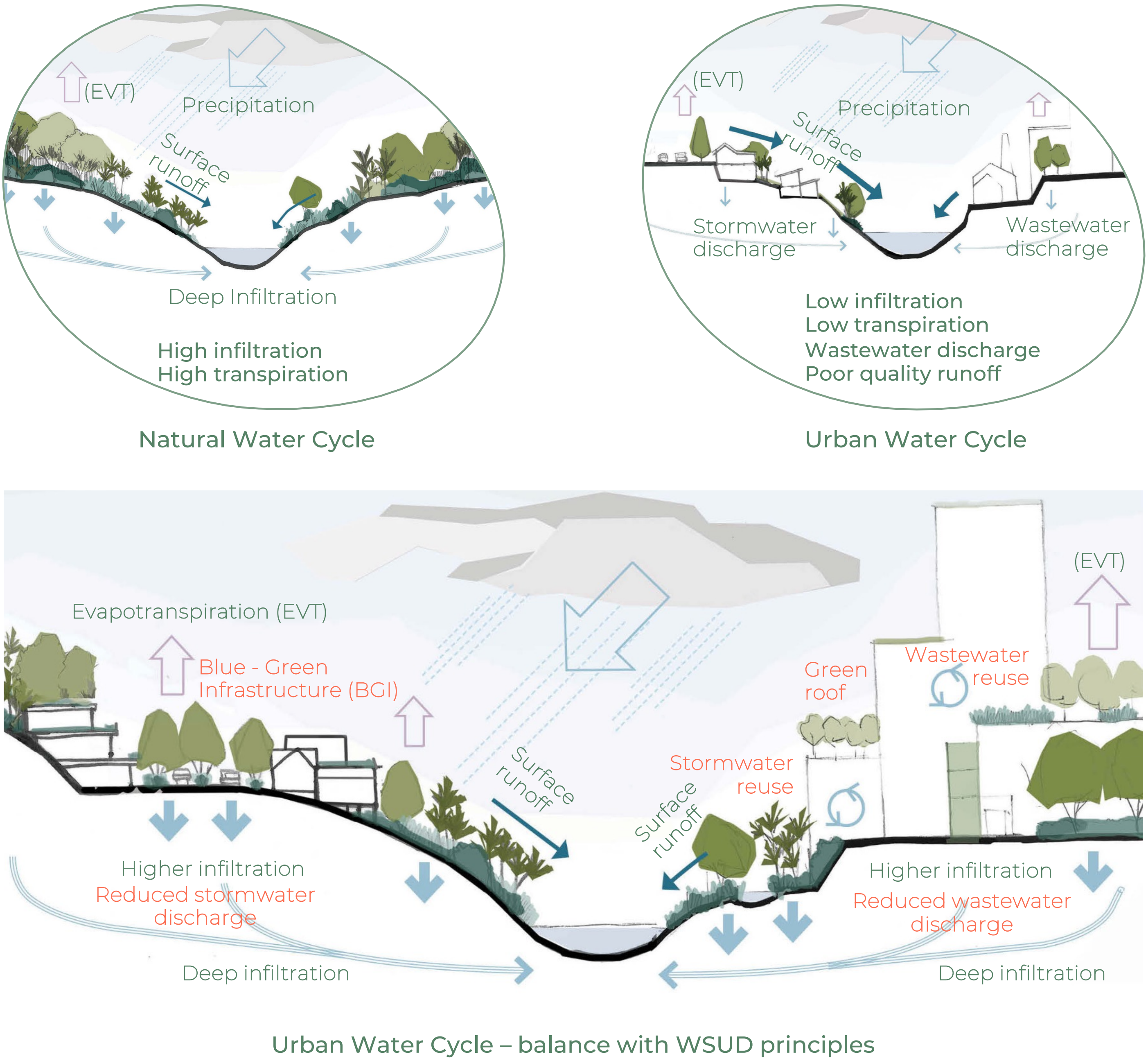


Figure 1-01: Urban water cycle. Source: Adapted from Lewis et. al (2015)

Water interacts with natural systems along the way: trees intercept rainfall, soil and humus layers slow down stormwater runoff and allow it to seep into the ground, and both terrestrial and aquatic vegetation capture and release water back into the atmosphere.

However, urban development disrupts these natural processes by altering the natural water cycle. Developed areas, characterised by impermeable surfaces and drainage systems like often bypass natural systems and divert substantial volumes of stormwater to lower catchment areas. This can lead to flooding and potentially harm the natural stream and wetland environments.

A WSUD approach to urban development on the other hand seeks to make minimum alterations to the natural water cycle. It directs stormwater runoff towards vegetated landscapes and utilises WSUD measures to essentially decrease the stormwater runoff volume by increasing the time interval between runoff and discharge. These components mimic the natural processes by enhancing infiltration, transpiration, and flood attenuation in floodplains.

This relationship is seen in Figure 1-02 and Figure 1-03, it is inferred that runoff volume is lower with WSUD measures.

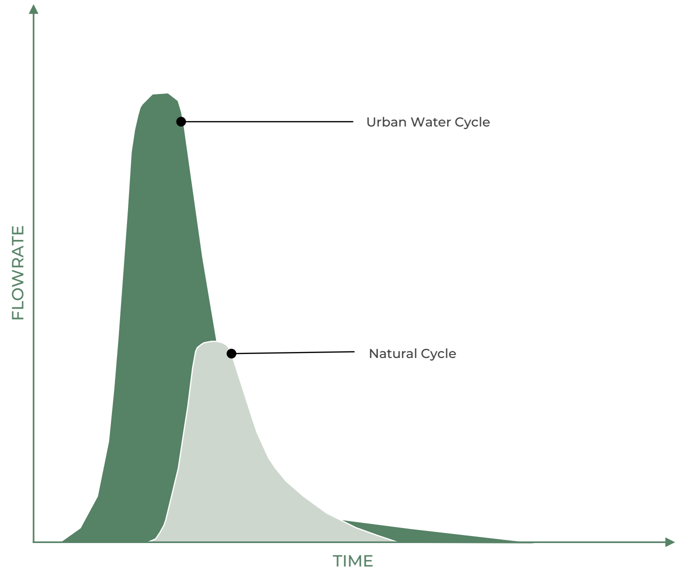


Figure 1-02: Water Cycle balance - relationship between runoff flowrate and time interval without WSUD measures

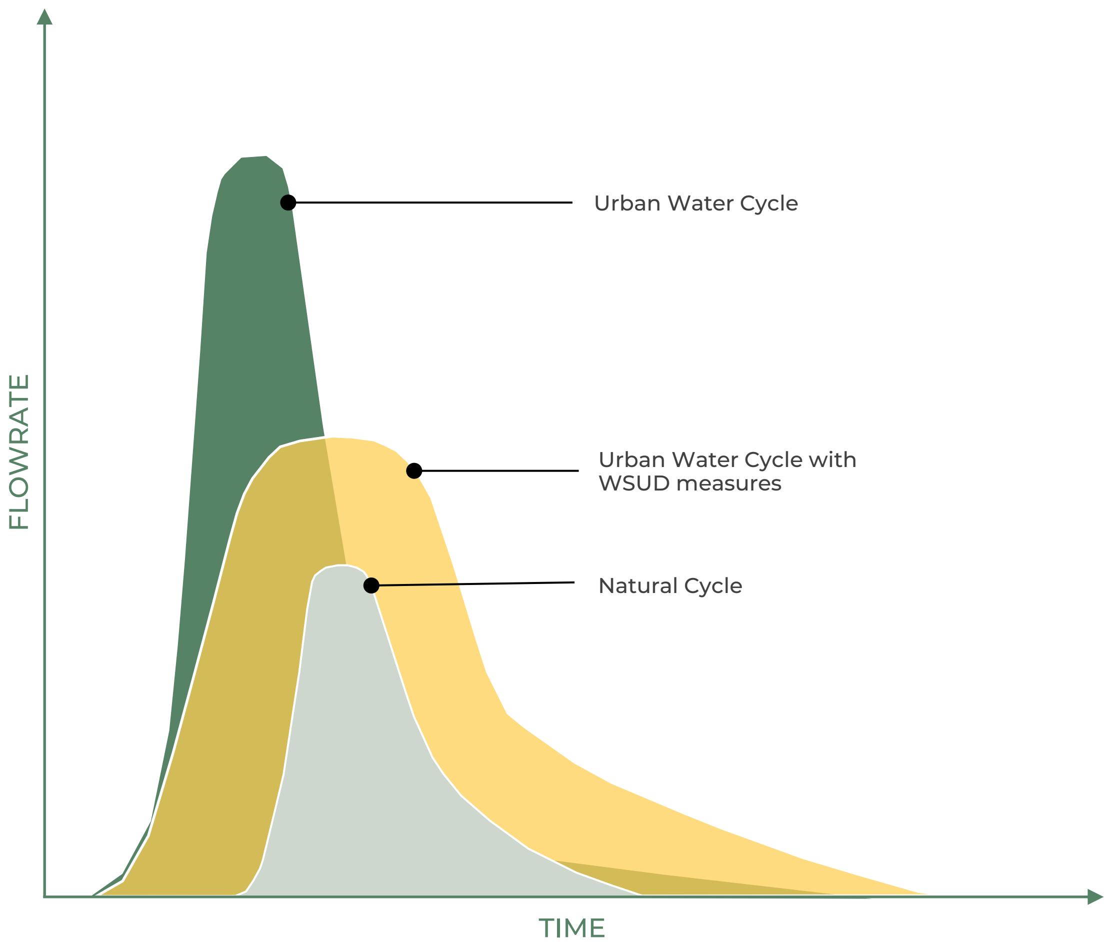


Figure 1-03: Water cycle balance - relationship between runoff flowrate and time interval with WSUD measures

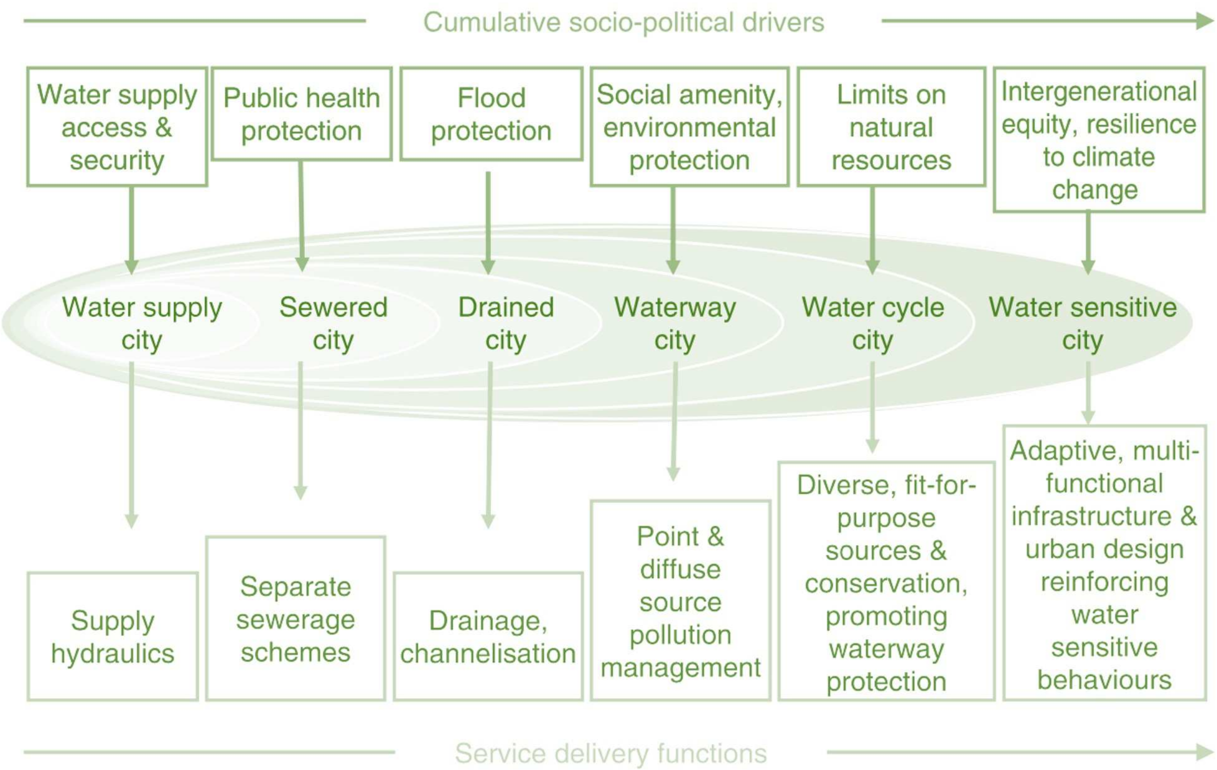


Figure 1-04: Urban water management transitions framework. Source: Adapted from Brown et. al (2009)

Theoretical Framework

The larger objective of any WSUD approach is to look at stormwater as a resource and to realign the urban water infrastructure in a city towards a circular economy. However, its implementation may vary from city to city. This difference is specifically visible when we compare cities of the Global North and Indian Cities. Indian Cities are predominantly unplanned when it comes to the nature of settlements indicating a high level of informality.

Confronted with the imperative of devising sustainable solutions that encompass a comprehensive approach addressing social, technical, economic, and environmental dimensions, and recognising that conventional urban water management systems are inadequate for the demands of urban settings, the concept of Water Sensitive Cities (WSC) emerged. To achieve this sustainable vision, as described by Brown & Wong (2009) after a study of several Australian cities, a water transition is required, understood as a progressive historical evolution of water-social contracts. They are perceived as the values or agreements between various actors in society (government, private sector, communities) on water use. The study inferred six cumulative transition stages to pursue a shift towards a more sustainable future, a water-sensitive city.

Essentially, the three stages depicted in Figure 1-04 signify the initial modern advancements in ensuring water supply, sanitation, and drainage levels that many cities in developing countries are currently striving to achieve. Wong et al. (2020) also argue that implementing a WSC framework is based on three interdependent pillars that must be integrated into the urban environment –

- Cities as water supply catchments
- Cities providing ecosystem services, and
- Cities comprising water sensitive communities

The first pillar emphasizes that cities should have access to a range of water sources, going beyond surface water, runoff, or groundwater sources. This entails a combination of centralised and decentralised infrastructure, enabling the collection, treatment, storage, and distribution of water.

In contrast, the second pillar underscores the importance of cities offering ecosystem services by melding the built and natural environment. This involves integrating urban landscape design into urban water management to mitigate the impacts of climate change and enhance natural capital to reap its manifold benefits. The third pillar implies that socio-political capital needs to be dedicated and attuned to water within the context of sustainability.

Presently, a few urban settings, primarily in developed regions, are in the process of transforming into water-sensitive cities, often driven by climate-related factors like drought and flooding. Leading this transition are notable examples such as The Netherlands and Singapore, which serve as hubs for urban innovation in this regard. As of now, no Water Sensitive City has fully reached the ultimate stage of evolution, which would ensure its productivity, competitiveness, and long-term sustainability through comprehensive intersectoral integration. This ongoing challenge is primarily attributed to obstacles that must be surmounted, including institutional and technical factors.

In contrast, Armitage et. al (2014) proposes a departure from the linear evolution model put forth by Brown et. al (2009), emphasising the importance of accounting for the influence of factors inherent to developing cities on the urban water cycle. In this context, elements such as formal and informal areas and undeveloped green spaces continually facing pressure from urban expansion play a pivotal role in shaping this transition. Consequently, when using these elements as a reference, any evolution should take into account two distinct processes: formal areas equivalent to developed cities and informal areas characterised by limited physical infrastructure.

The formal area is usually found as Drained Cities, requiring a transition that initially seeks to adopt integrated management of the urban water cycle, counteract polluting aspects to improve the quality of sources, and reduce water demand. On the contrary, informal areas are Water Supply Cities with multiple water and sanitation systems limitations. They require, in addition, to cover the urgent gap to grant secondary benefits to the population and contemplate maintenance aspects, this being a determining factor for success (Leon, 2021).

The transitions diagram, as seen in Figure 1-05, therefore, emphasizes the fact that enhancing water sensitivity in informal areas has the potential to not only address issues of resource availability and environmental damage but also to address related problems of social exclusion, equity and equality (Armitage et al., 2014). As described by the author and as shown in Figure 1-05, this scheme would allow that at a given point in the process, both zones (formal and informal) transit under a system of equity towards a Waterways City (Armitage et al., 2014).

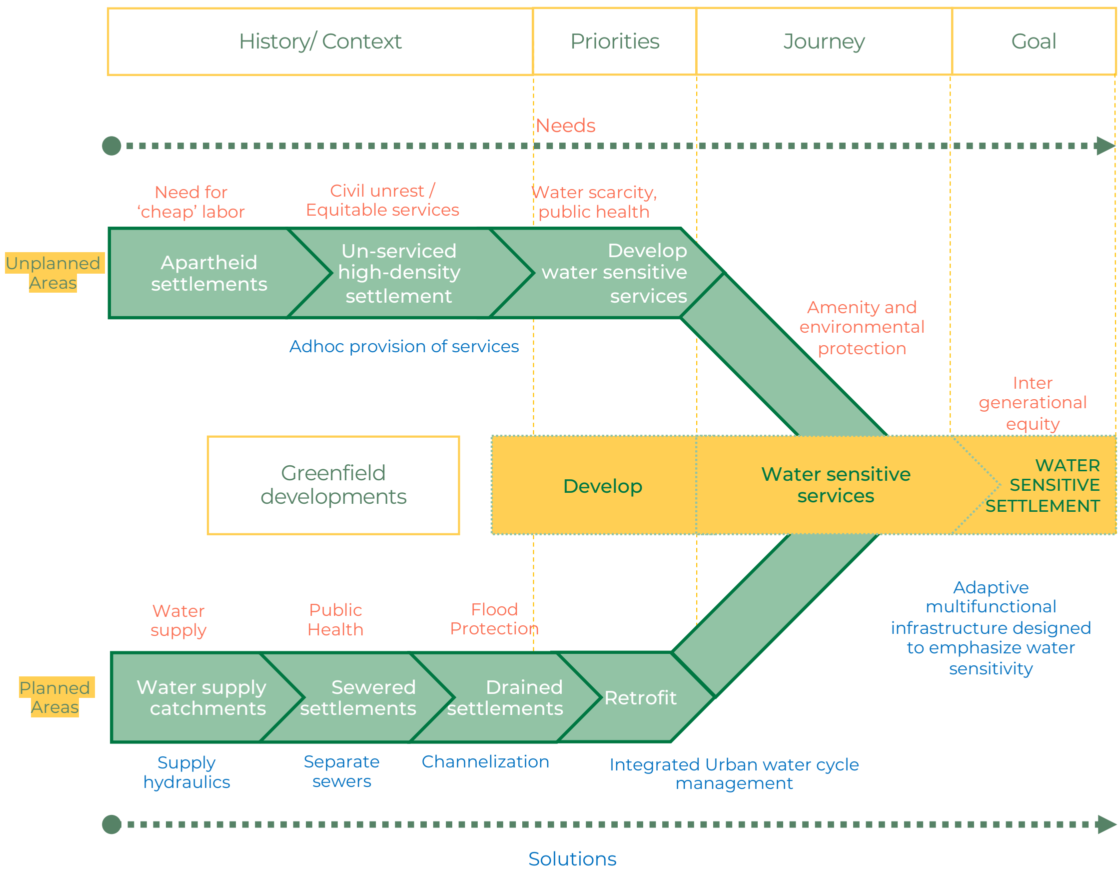


Figure 1-05: Urban water management transitions framework for developing cities. Source: Adapted from Armitage et. al (2014)

1.2 Paradigm Shift to Water Sensitive Urban Design and Planning (WSUDP)

As highlighted by Kumar et al. (2023), traditional urban planning and development policies are often viewed as unsustainable growth models, promoting environmental threats, and economic and social distress. Furthermore, growing evidence on global environmental challenges and the emergence of the paradigm of sustainable development as a potential solution to urban climate vulnerabilities further supports an urgent focus on Water Sensitive Planning in the cities of the Global South.

1.2.1 Integrating 'Planning' into Water Sensitive Urban Design Discourse

The existing literature on Water Sensitive Planning (WSP) offers a limited perspective of the comprehensive approach, primarily due to its origins and concentration on specific countries. Figure 1-06 indicates the global timeline for the development of discourse on Water Sensitive Cities.

A significant portion of the literature on water-sensitive planning and urban design has originated from Western contexts, particularly countries such as Australia, the United Kingdom, the Netherlands and Germany. However, this literature may not fully align with the planning needs of rapidly urbanising cities in the Global South.

In the case of literature originating from Australia, design rather than planning appears to be the major focus of large and valuable scholarship. Country-specific scholarship is helpful in identifying elements for a comprehensive WSP approach. The Dutch approach to water management, while comprehensive, is context-specific to the Netherlands. The principle of living with water, as opposed to attempting strict control, is particularly relevant in areas characterised by abundant water resources and low topography. This underscores the importance of tailoring water management strategies to the unique conditions of each location.

Kumar et al. (2023) highlight that large-sized unplanned cities of the Global South with inadequate infrastructure such as drains and roads, low municipal budgets, low institutional capacities, and misrecognition of citizenship are major aspects that remain unaddressed by the currently existing Water Sensitive Planning approach. Carmon et al. (2010) argue that a separate theory of water sensitive planning is needed because there appears to be a lack of communication between scholars of the Global North and South.

Consequently, much of the current discourse in WSP and WSUD literature places a substantial emphasis on stormwater related issues, while the actual urban planning processes often receive less attention or are not thoroughly discussed.

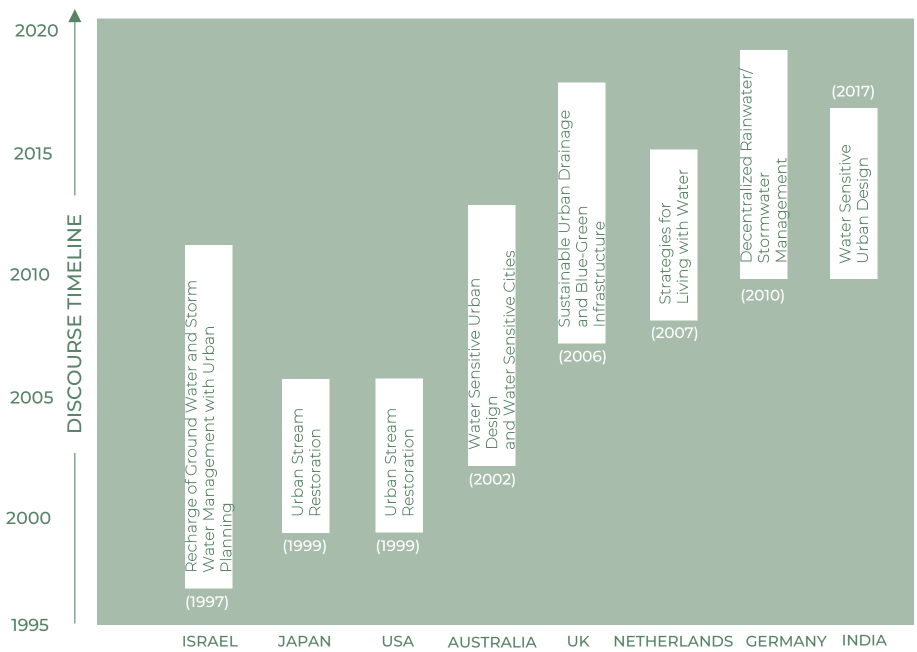


Figure 1-06: Water Sensitive City Discourse – Global timeline.
Source: Adapted from Kumar et. al (2023)

Indian scholars must prioritise the development of literature on Water Sensitive Urban Design (WSUD) within the Indian context, with a strong emphasis on integrating urban planning principles. By addressing the unique challenges of Indian urban environments, this research holds the potential to inform policymakers and practitioners, enriching both academic knowledge and practical applications in the realm of sustainable urbanisation.

1.2.2 WSUDP for Indian Cities

In contrast to cities in the Global North, which already possess well established grey infrastructure, the water sensitive cities framework for Indian cities faces the primary challenge of initially establishing sufficient grey infrastructure and services, specifically related to sewerage and stormwater drainage, particularly within densely populated urban areas. The research contends that it is imperative to acknowledge the fundamental disparities between cities in the Global North and the Indian cities. These include predominantly unplanned development patterns, inadequate investments in grey infrastructure, diverse methods of water access (such as reliance on water tankers), fragmented and weak urban local governance structures lacking a robust tax base, and instances of local rent-seeking (Kumar et al., 2023).

The divergent contexts of Global North and Global South cities present unique challenges. While Global North Cities are typically well planned with functional grey infrastructure and minimal gaps between supply and demand, the priorities in these cities are country specific. The contrast in these contextual factors requires tailored approaches to address the distinct challenges faced by each.

A water sensitive city in the developed country context aims at achieving outcomes that include higher standards and more effective standards of water conservation and wastewater management (nutrient removal, carbon sequestration, energy extraction and methane reduction), and adaptation to water stress and/or urban flooding accruing from climate change impact—creating a safer, sustainable and attractive urban liveable environment, a city that becomes an attractive destination for housing, tourism and businesses (Kapur, 2023). The same is also highlighted in Figure 1-07.

Due to the considerable disparities in context and challenges between cities in the Global North and Indian cities, their priorities for goal attainment exhibit noteworthy distinctions. In the case of Indian cities, the paramount imperative lies in the establishment of a functional and inclusive grey infrastructure as the primary focus. Concurrently, there is a critical need to bolster statutory urban planning guidelines. This strategic approach must be further augmented with the deployment of decentralised solutions for stormwater management designed to effectively mitigate the risks posed by urban flooding and climate change.

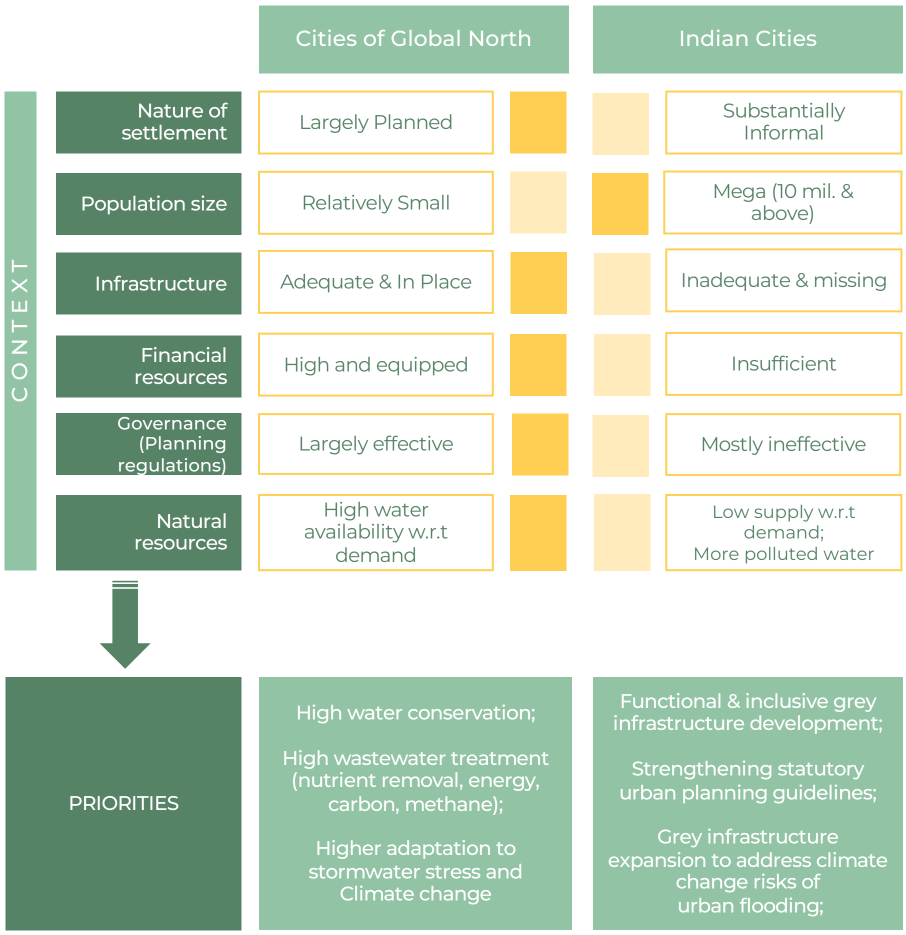
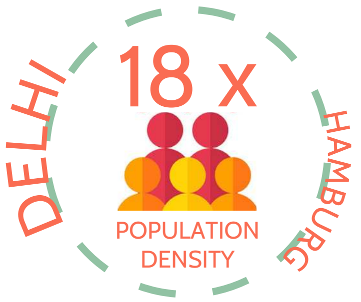


Figure 1-07: Comparison between the Global North and the Global South Cities
Source: Adapted from Kumar et. al (2023) and Kapur (2023), edited by Author

To gain a better perspective of distinctions between cities of a developed country and Indian cities, Hamburg in Germany and Delhi are compared. This provides an opportunity to analyse the contexts of priorities each city towards sustainable stormwater management. Apart from fundamental difference in climate and rainfall pattern (monsoon), other differences at planning level are observed too. As depicted in Figure 1-08, the significant disparities between these two cities become evident. Delhi, while roughly twice the size of Hamburg, is home to a staggering 18 times more people. Its current population stands at 33 million, resulting in a remarkable population density of 36,115 persons per sq km.



STATUS QUO	Hamburg, Germany	New Delhi, India
Land area	755 km²	1,483 km²
Population size	1.8 mil. inhabitants	32.9 mil. inhabitants
Nature of settlement	Planned	30 % population lives in dense unplanned areas
Grey infrastructure	In place; Needs restructuring	Inadequate; Highly iniquitous
Governance	Strong legislation & effective	Fragmented & weak
Gap btw. water supply-demand (daily/citywide)	No gap. Avg. daily demand of 106.8 litre/ per capita	Gap of 300 MGD or 1,135 MLD

Figure 1-08: Comparison between the Hamburg and Delhi
Source: Compiled from Planning Department GNCTD (2023) , Liehr & Lüdtke (2021), Kapur (2023) and Roychowdhury & Das (2021).

The nature of settlements in Hamburg is planned while in Delhi, approximately one-third of its population resides in dense unplanned settlements (Roychowdhury & Das (2021). Additionally, Delhi grapples with inadequate or a deficient existing grey infrastructure, fragmented and weak governance and faces a daily deficiency of 300 million gallons per day (MGD) of water supply.

Consequently, components of the WSUD approach for Indian Cities would inherently differ from the one outlined by scholars in the Global North, often rooted in best practices that may not fully consider the fundamental differences of population density, socio-economic diversity, climate variations, and existing infrastructure limitations. As highlighted by Hoyer et al. (2011), Figure 1-09 illustrates the key principles of WSUD, outlining goals and desired outcomes based on international best practices. However, the applicability of these principles to the context of developing countries, such as India, prompts a critical examination of whether they sufficiently incorporate the principles of inclusive planning and upgradation of existing grey infrastructure.

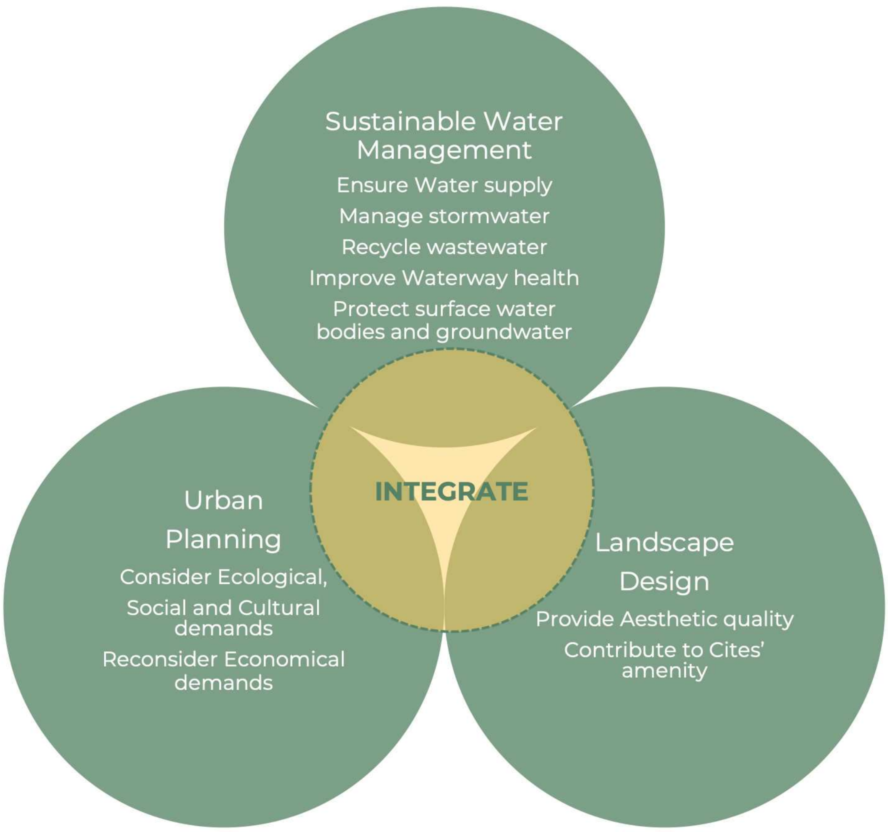


Figure 1-09: Key components of water sensitive urban design - best practice.
Source: Hoyer et. al (2011)

1.3 The Leapfrogging Fallacy

Kapur (2023) argues that the Global North "water sensitive cities" (WSC) framework assumes that cities need more and more green-blue infrastructure and not grey infrastructure, coupled with smart urban design elements that will leapfrog Indian Cities to a higher stage of water and wastewater management, making our cities more liveable. He goes on to emphasise that when we attempt to apply the framework from developed countries to cities in the Global South, we often overlook a critical distinction. Developed country cities are, for the most part, meticulously planned cities with urban planning frameworks that have carefully ensured rational housing density, road layouts, and the establishment of water and sewerage infrastructure as fundamental building blocks of these cities.

Stretching a linear evolution model for the water sensitive cities concept fails to consider the unique context of Global South cities. This model implies the possibility of leapfrogging, suggesting that cities in the Global South can somehow make a direct transition from a lack of infrastructure to achieving the status of a water sensitive city. It presupposes that cities can independently manage all aspects, from infrastructure to governance, and reap the benefits of technology and design solutions to become water-sensitive cities. It sees a lack of infrastructure as an advantage and ignores the absence of urban planning completely (Kapur, 2023).

The transitional journey for Indian Cities towards a WSC is fundamentally different from the cities of the Global North. As seen in Figure 1-10, the foundation of a water sensitive city lies in the presence of well-functioning infrastructure - water supply city and sewered city.

> *"One may ask if it was possible for cities to somehow transcend directly to water sensitive cities, what is stopping them from achieving this?" - (Kapur, 2023)*

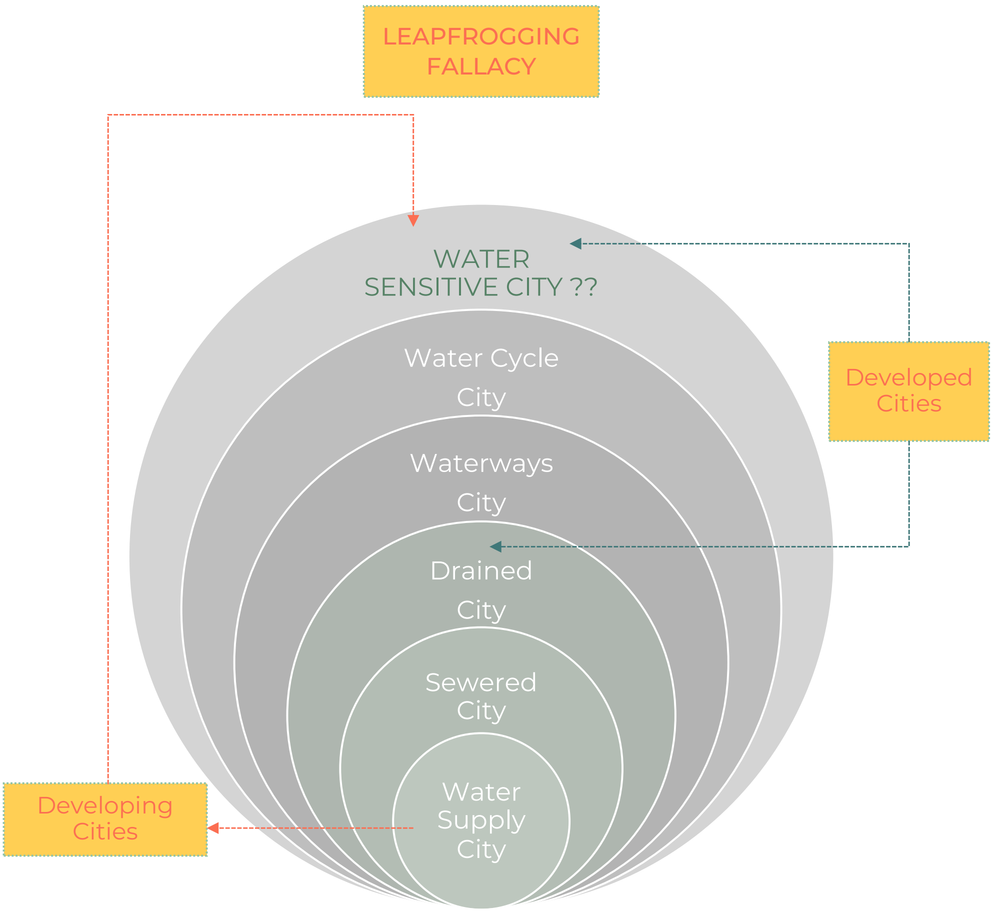


Figure 1-10: Transition framework for a water sensitive city – Leapfrogging Fallacy

1.4 Research Question And Objectives

The rapid pace of urbanisation in Indian cities presents a formidable challenge. This challenge is compounded by the substantial presence of densely populated, unplanned settlements in Delhi, characterised by a lack of basic infrastructural services. These areas frequently experience urban flooding.

The necessity for a Water Sensitive Planning (WSP) framework that guarantees not only efficient stormwater management but also recognizes inequity in dense urban settlements as the basis of urban planning and designing interventions is crucial for Delhi and other Indian cities. This led to the formulation of the following research question:

Which design principles of the WSP framework can be applied to dense urban settlement in Sangam Vihar, New Delhi to mitigate urban flooding risk?

Supplementary, the following sub-questions arose:

- How can these principles enhance grey infrastructure elements in dense urban settlements to mitigate flooding risk?
- How can the existing legislative framework for its implementation be improved?
- How can this framework be applied to other Indian cities with a similar context?

Consequently, the following objectives of this research are outlined:

- To develop a new WSP framework for Indian cities.
- To implement the principle(s) of the framework to mitigate flooding risk in dense unplanned settlements.
- To implement decentralised strategies for stormwater management.

02 RESEARCH FLOW & METHODOLOGY

2.1 Structure and Research Overview

The development of this research is divided into 7 chapters. The interconnection between chapters and the flow of the master thesis research – Water Sensitive Urban Design for Indian Cities, is illustrated in Figure 2-01. The starting point for the topic selection was the recognised issue regarding urban flooding risk in New Delhi.

Chapter 1, titled "Introduction" provides a rationale for why the chosen master's thesis topic is relevant to the Indian context. It discusses the basic principles, benefits, and philosophy of the WSUD approach globally. A theoretical framework for WSUD and a city's transition into a Water Sensitive City (WSC) is discussed through the perspective of multiple scholars. The importance of integrating the term 'Planning' in the water sensitive discourse of Indian Cities is highlighted by comparing the context, priorities and objectives of the Global North Cities and Indian Cities. Furthermore, the idea of the possible opportunity for developing cities to leapfrog the transitional path towards a WSC is deliberated. Consequently, the research question and objectives are derived.

The structure and the research flow of the master's thesis, as well as methodology and details concerning data, are explained in Chapter 2, titled "Research Flow And Methodology". The challenges connected with lack of information in public domain regarding data on existing drainage networks is also discussed as well.

Chapter 3, titled "Status Quo In New Delhi" furnishes essential input information for Delhi such as geographical, climatic, and precipitation aspects, the urban water cycle, the legislative framework, and the involved stakeholders.

Chapter 4, titled "Case Studies" analyses two examples. The first, China's "Sponge Cities" initiative, which applies WSUD at a city-state level to address urban flooding, offering a valuable basis to understand the relevance of blue-green infrastructure. The second, the Neela Hauz Lake rejuvenation project in Delhi, demonstrates decentralised stormwater and wastewater treatment at the neighbourhood scale while revitalising a dried lake. These cases collectively showcase the practical application of WSUD principles in the context that is similar to Indian cities.

Chapter 5, titled "Framework Guidance For Indian Cities" summarises the purpose and idea behind developing a new framework for the Indian context. The key principles and desired outcomes are discussed based on multi-authored literature research. In summary, the primary outcomes are a clear vision and recommendations. These recommendations provide guidance for enhancing the legislative framework towards a Water Sensitive Planning (WSP) for Indian Cities.

Chapter 6, titled " Concept Design: Framework Implementation" is dedicated to the focus area of this research which is one of the largest dense unplanned settlements in New Delhi. Firstly, the criteria of the area selection and definition of its boundaries, historical overview as well and development outlook are discussed. Subsequently, the problem tree is formulated to consolidate the overarching causes and effects related to recurrent flooding in the region. The main outcome is the data about the urban density, ratio of sealed and unsealed surfaces, street typology and identification of strengths, weaknesses, opportunities, and threats. The final part presents the programme for the study area and offers a decentralised solution based on the principles of the new WSP framework for Indian Cities with a similar context.

Chapter 7, titled "Conclusion" serve as the evaluation of the master thesis's outcomes. They provide answers to the main research question and sub-questions. Additionally, these sections offer recommendations for the future advancement of the topic and potential prospects.

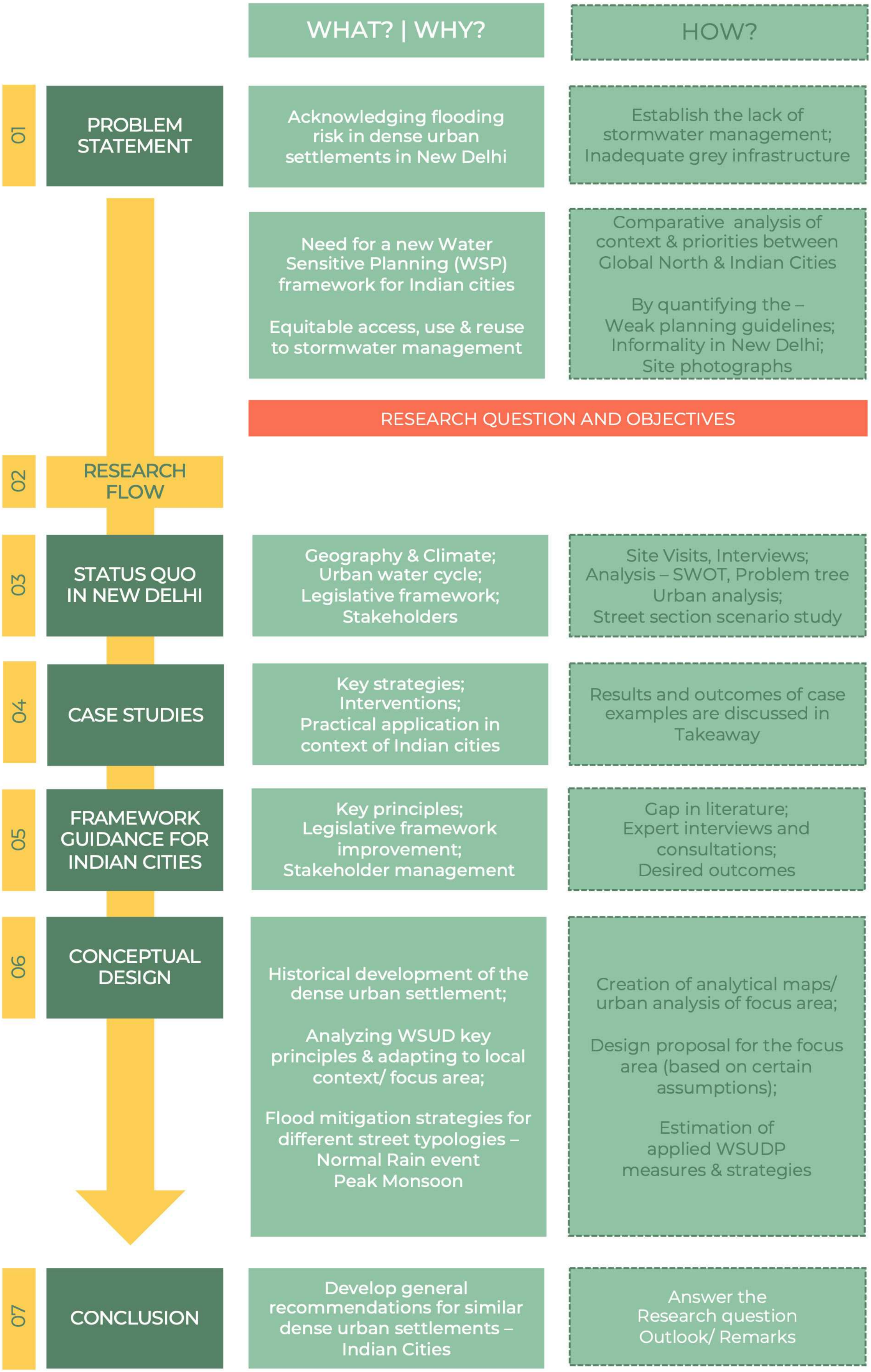


Figure 2-01: Overview of the research flow and methodology

2.2 Research Methods and Data Collection

For this master's thesis, the primary research is conducted through site visits, site surveys, questionnaires and expert interviews. A collaboration with the Urban Water – Waste Management department at the Centre for Science and Environment (CSE), New Delhi has significantly guided this research. CSE's position paper on the Water Sensitive Cities Framework for the Global South Cities has been influential in the selection of the topic.

As a secondary research method, published research papers, journals, reports, handbooks and case studies of cities in the Global South are analysed to review the existing literature as well as to find the gaps in the literature. Although there are numerous publications regarding the best practices and key principles of WSUD for global standards, however, only a handful of publications are addressed to the cities of the Global South.

Subsequently, desk research and Geographic Information System(GIS) analysis with the help of QGIS software is carried out to gather data at the city level to evaluate Delhi's profile concerning natural factors, including climate, topography, drainage, groundwater, and land cover.

Limitation

The details for existing grey infrastructure in Sangam Vihar are not available in the public domain. However, data from IIT Delhi's drainage master plan (prepared in 2018) for Delhi has provided significant information regarding the existing drainage network and flooding hotspots around the study area in Sangam Vihar. In addition to this, the data regarding the ongoing underground sewage network at the site is also limited and not available to the public. Therefore, this research heavily depended upon primary data collection at the site. The maps generated may not be accurate. However, as the author of this paper, diligent efforts were made to close this gap through multiple site visits and triangulating the information with published reports.

2.2.1 Rainfall

The data for rainfall for the region of New Delhi is compiled from the India Meteorological Department (IMD), it is the principal department responsible for meteorological observations and weather forecasting under the Ministry of Earth Sciences, Government of India. Additionally, groundwater and regional data such as topography and geology for New Delhi are analysed from the Ground Water Year Book for Delhi for the year 2021-2022 (CGWB, 2022). The Ground Water Year Book is an annual report published by the Central Ground Water Board (CGWB) which is the Department of Water Resources, River Development & Ganga Rejuvenation under the Ministry of Jal Shakti, Government of India.

2.2.2 Legislative Framework

The review of the policy instruments at international, national, and local levels related to sustainable development, Drainage Master Plan of Delhi-2018 and the Master Plan of Delhi-2041 is the input data for the policy analysis. The objective is to identify the deficiencies in the legislative framework and the controversies surrounding the current WSUD approach, which are either absent at the planning level or are implemented in Indian cities on a piecemeal basis. Consequently, India's journey towards sustainable water management is discussed through a chronological understanding of various policies related to Water.

2.2.3 Stakeholder Interviews and Dialogue with Experts

To obtain a thorough grasp of the challenges related to flooding risks in densely populated urban areas within New Delhi, a series of on-site visits were carried out in Sangam Vihar which is the area of focus for the research. Interviews were conducted with the stakeholder group of workers and residents living in Sangam Vihar, to gain insights into the historical development of the settlement, its present challenges, and potential opportunities. Face-to-face structured interviews (predetermined questions) were employed to elicit opinions and feedback from the local community. The questionnaire used for this purpose can be found in Annexure-1. The interviews were conducted on one of the site visits on 2nd March 2023 in Sangam Vihar, the questions (refer to Annexure-1) were narrated to the interviewees in the local language for their better comprehension. Their oral narration was recorded and later transcribed. In the interest of inclusivity, they were chosen from different demographic backgrounds, encompassing differences in gender, age, and occupation.

Furthermore, this research builds on structured interviews conducted with other stakeholder groups (see Table 2-01). Most of these interviews took place around October 2023 over video conferencing, a questionnaire was shared with the interviewees before the meeting. The recorded answers were then shared with them over email to avoid any discrepancy in opinions shared by them, the questionnaire used for this purpose can be found in Annexure-2. In the interest of inclusivity, interviewees were selected from different groups ranging from academicians, urban planners, scholars, private consultants, non-profit organisations as well as government organisations.

Stakeholders	Stakeholder group	No of Interviewees	Method applied
Academia	Significant	1	Video conference
Local Government/ Organization	Critical	1	On site - Oral
Residents of Sangam Vihar	Minor	4	On site - Oral
Planners (private and Non profit)	Significant	2	Video conference

Table 2-01: List of interviewees

2.2.4 Conceptual Design Process

The initial step involves an analysis that combines desk research and on-site exploration. This phase has culminated in the SWAT analysis and urban assessment of the Sangam Vihar study area. To create the maps, various data sources were used, including satellite imagery from Google Maps and Open Street Map, topographical maps from published reports, information on the current drainage network, and data gathered during site visits regarding physical infrastructure. Multiple layers of data were superimposed and subsequently examined using GIS software, specifically QGIS. The result is a set of quantitative data that reveals the distribution of different surface types, as well as qualitative information about urban density, building patterns, street networks, the arrangement of green spaces, impermeable surfaces, and the location of existing grey infrastructure, particularly the drainage network within the study area.

The data regarding the average rainfall density in Delhi is based on the Drainage Master Plan (DMP-2018) of Delhi (Gosain et al., 2018). The rainfall IDF curve for Safdarjung station has been referred.

Runoff estimation

To calculate the stormwater runoff in the catchment, 'rational method' as mentioned in the Central Public Health and Environmental Engineering Organisation (CPHEEO) manual is applied (CPHEEO, 2019). The formula applied for estimating the runoff is given as below:

$$Q_p = 10 * C * I * A$$

where;

Q_p → Peak flow at the point of design, m^3/ hr

C → Runoff coefficient, dimensionless

I → Average rainfall intensity, duration of rainfall equal to the time of concentration, mm/ hr

A → Catchment area, hectares (ha)

Surface area of Constructed Wetland

To estimate the surface area of the constructed wetland (CW), two methodologies are applied, namely:

- Person equivalent load
- Hydraulic load

In the first method, the required specific surface area of CW is estimated using "area requirement per person" or "person equivalent" as a design parameter. This is in accordance with Hoffmann et al. (2011).

The guideline suggests that the required specific surface area for a CW (horizontal flow bed) is about 3-10 sq m per person depending on temperature and other local factors at site (Hoffmann et al., 2011). In warm climates like Delhi, less area is required due to the higher biological activity.

In general, area requirement per person is lower when treating greywater from an average person(Hoffmann et al., 2011). Therefore, keeping in view all the conditions, a factor of 3 sq m/ per person is applied for determining the surface area of the constructed wetland (horizontal flow type).

The data regarding the exact population of Sangam Vihar is unavailable in public domain. For the purpose of approximate estimation, the total number of buildings in the catchment is multiplied with total number inhabitants living in each building. Since each building comprises of multiple households, firstly, the number of buildings are counted by overlaying the Open Street Map on QGIS software, collaborated with the observations during field trips. Additionally, during the site interviews with the residents (refer Section 6.3.2), the research observed that the average size of households ranged from 5 to 7 persons per household. The number of inhabitants in each household is considered as an average of 4.5 inhabitants per household. Subsequently, since each building accommodates multiple households, a factor of 3 households per building is applied.

As a secondary methodology, the surface area of CW is also estimated using hydraulic load as the design parameter. Hydraulic load in the context of CWs refers to the volume of wastewater or greywater that is applied to the wetland system over a specific time period. It is a critical design parameter influencing the efficiency of wastewater treatment by determining the contact time between the water and the wetland substrate, vegetation, and microorganisms. The hydraulic load for the catchment is derived through runoff estimation.

The applied equation to calculate the size of wetland is based on the equation proposed by Kickuth (UN HABITAT, 2008). The formula is given as:

$$A_h = (Q_d (\ln C_i - \ln C_e)) / K_{BOD}$$

where;

A_h → Surface area of bed, m²

Q_d →Average daily flow rate of sewage, (m^3/d)

C_i → Influent BOD_5 concentration, mg/l

C_e → Effluent BOD_5 concentration, mg/l

K_{BOD} → Rate constant, m/d

While it is ideal to incorporate Biochemical Oxygen Demand (BOD) loading of wastewater/ greywater as a design parameter, the absence of this data in the selected study area has led to the necessity of making a suitable assumption.

K_{BOD} is temperature dependent and the BOD degradation rate generally increases about 10 % per °C. Thus, the reaction rate constant for BOD degradation is expected to be higher during summer than winter. It has also been reported that the K_{BOD} increases with the age of the system (UN HABITAT, 2008).

It is crucial to note that the catchment discharges a combined runoff, comprising both stormwater and greywater from households. Consequently, the volume generated during the non-monsoon period is considerably lower than during the monsoon period, given the increased volume of stormwater in the runoff.

Additionally, considering both person equivalent and hydraulic load methodologies enhances the accuracy of estimating the specific area of the Constructed Wetland, accounting for variations in runoff composition. This pragmatic approach ensures the relevance and feasibility of the proposed mitigation strategy for urban water management in the selected study area.

It is crucial to emphasise that detailed technical design aspects, including the design of each wetland cell employing methods like Darcy's law, as outlined in UN HABITAT (2008), are not incorporated into subsequent calculations. These technical intricacies are explicitly excluded from the scope of this master's thesis. The focus here is on providing a comprehensive conceptual framework and practical methodologies for estimating the specific area of the Constructed Wetland, ensuring the feasibility and relevance of the proposed stormwater management strategy.

2.2.5 Case Studies

To bridge the gap between theory and practical implementation, and to delve deeper into the application of Water Sensitive Urban Design (WSUD) principles in the context of Indian cities, two notable examples are examined.

The first case explores the concept of “Sponge Cities” in China, where WSUD measures were applied at the city-state or macro level, involving approximately 30 pilot cities since 2013. Given the shared challenge of heavy monsoons leading to urban flooding in both Chinese and Indian cities, this example serves as a valuable foundation for comparative analysis and learning.

The second case centers on the Neela Hauz Lake rejuvenation project in Delhi, offering insights into the application of decentralised solutions for stormwater and wastewater treatment at the neighborhood scale. Simultaneously, it addresses the revitalization of a dried lake in the city. While smaller in scale compared to the “Sponge Cities” initiative, this example showcases the practical application of WSUD principles in rejuvenating a crucial water body within the urban landscape of Delhi.

Examining these examples highlights the adaptability of WSUD principles across diverse urban landscapes. The “Sponge Cities” initiative in China showcases large-scale macro-level interventions, offering valuable lessons for addressing common challenges faced by Indian cities during monsoons. On the other hand, the Neela Hauz Lake rejuvenation project in Delhi exemplifies the localised implementation of WSUD, emphasising decentralised solutions for stormwater and wastewater management. Together, these case studies provide a comprehensive perspective on how WSUD principles can be tailored to suit varying urban contexts, guiding the way for sustainable and resilient water management practices in Indian cities.

03

STATUS QUO IN NEW DELHI

3.1 Climate and Geography

Climate

Delhi, the National Capital Territory of India is bordered by Haryana on three sides and by Uttar Pradesh in the east (Figure 3-01. It's climate is an overlap between monsoon-influenced humid subtropical (Köppen climate classification Cwa) and semi-arid (Köppen climate classification BSh), with high variation between summer and winter temperatures and rainfall. The peak summer temperature can reach up to 45 °C (May – June) while the peak winter temperature can be as low as 4 °C (December – January). The average rainfall in Delhi is 779 mm, about 80 % of which occurs in the monsoon season, from July to September (see Figure 3-02: Rainfall pattern in Delhi from 2021 to 2022). Maximum rainfall is recorded in the central, southern and eastern parts of Delhi (see Figure 3-03: Isohyetal map of Delhi) (CGWB, 2022).

Figure 3-01: Delhi location map and boundary

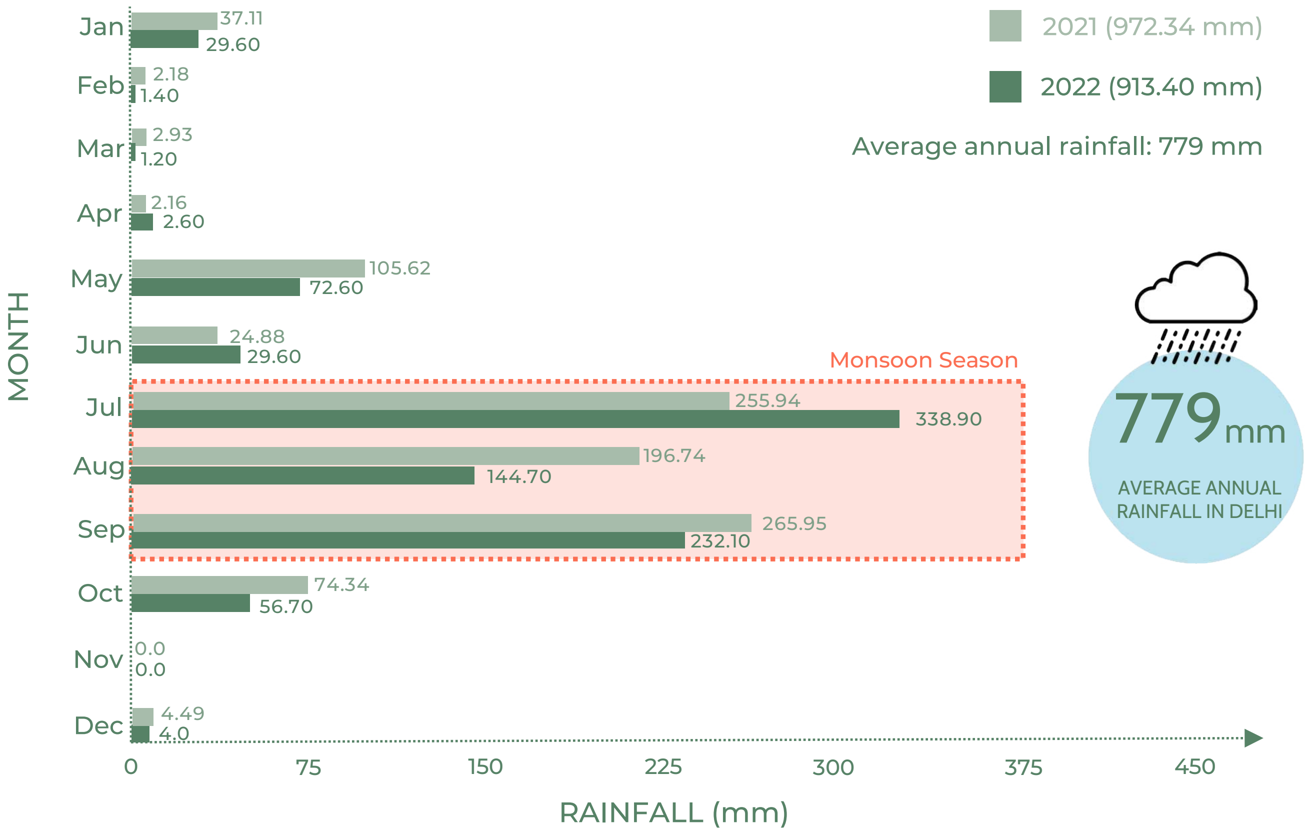


Figure 3-02: Rainfall pattern in Delhi from 2021 to 2022. Source: Compiled from IMD (2023)

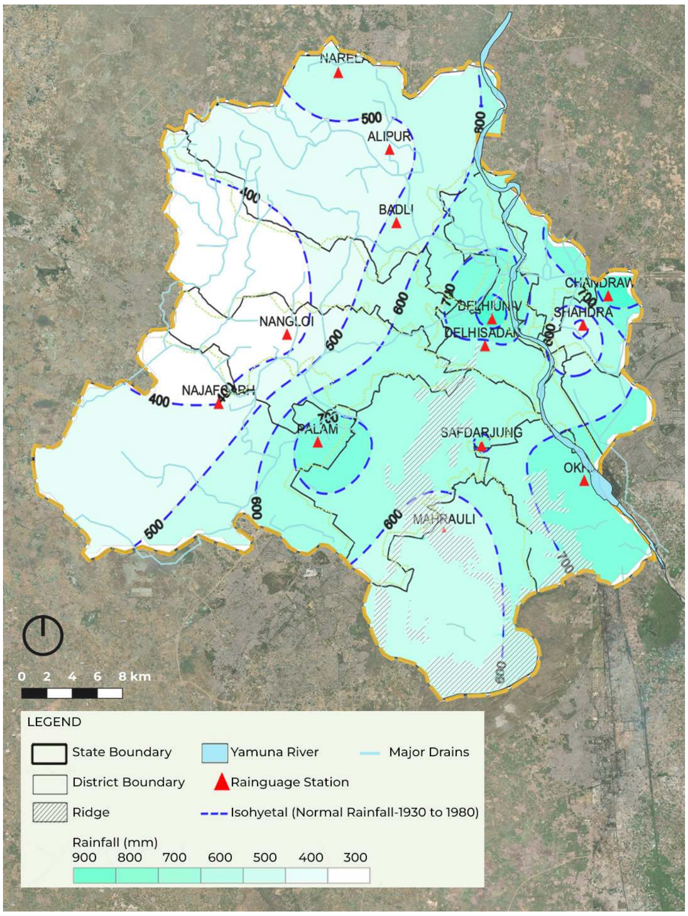


Figure 3-03: Isohyetal map of Delhi
Source: Adapted from CGWB (2022)

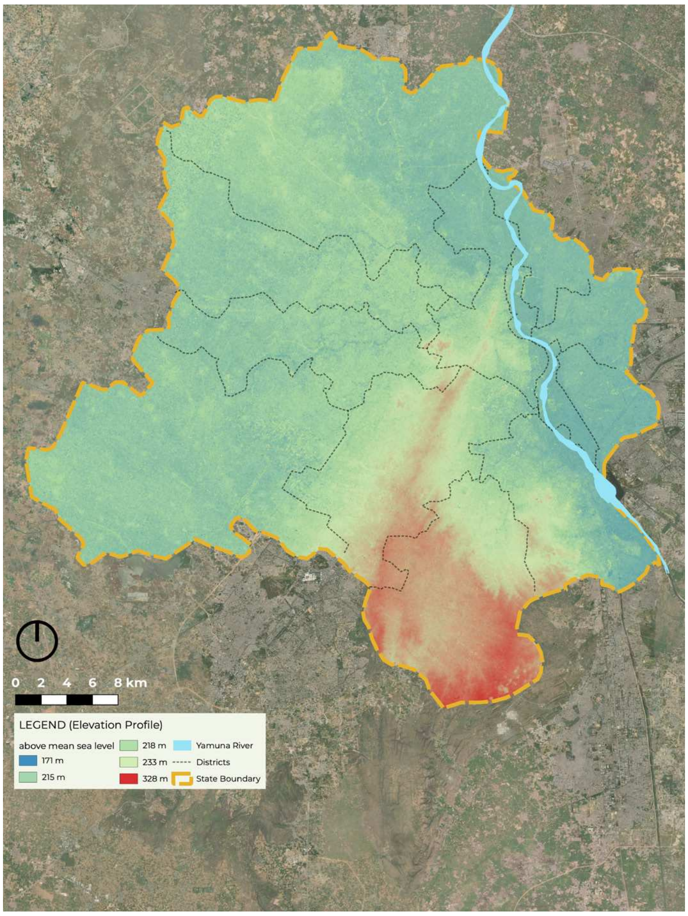


Figure 3-04: Digital elevation map of Delhi
Source: Adapted from NASA earthdata (2023)

Topography

The maximum elevation in the city is 328 m above mean sea level, observed in the Delhi Ridge, whereas the minimum elevation has been observed near the flood plains of River Yamuna at 171 m above mean sea level. The floodplains of Yamuna are at an average elevation of 198 m above mean sea level (CGWB, 2022). The city slopes outwards from the Ridge, towards the River Yamuna on the eastern side, and the agricultural areas on the western outskirts (see Figure 3-04: Digital elevation map of Delhi).

Geology

Chatterjee et al. (2009) provide insights into six significant geomorphic units (as depicted in Figure 3-05). The older floodplain located in the northern and eastern parts of the city displays various geomorphic characteristics, including paleochannels, marshes, and meander cut-offs. On the other hand, the southern upland areas feature strike ridges, dissected hills, badlands with rills, and ravines (Sarkar et al., 2016).

The Aravalli Ranges, which stretch in a south-southwest to north-northeast direction, are known as the Delhi Ridge. They cover the south-central region of Delhi, extending from

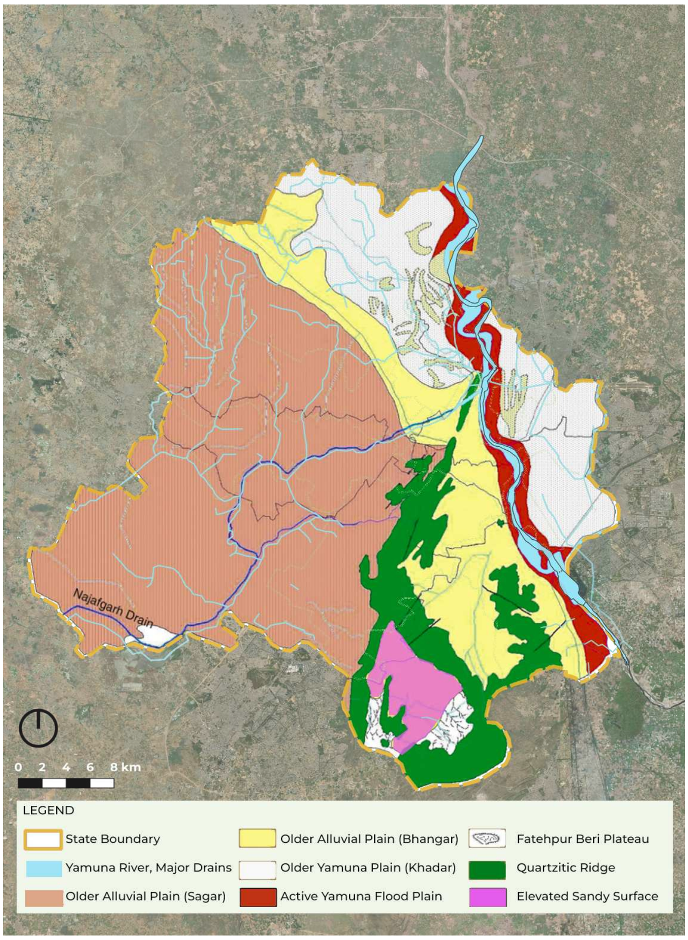


Figure 3-05: Geological profile of Delhi
Source: Adapted from Chatterjee et al. (2009)

the southern point near Okhla on the western bank of the Yamuna River to the northeastern edge at Wazirabad. Ecologically, the Aravalli Ridge serves as a natural barrier between the Thar Desert and the surrounding plains, effectively reducing the movement of dust and winds from the desert region (CGWB, 2022).

Groundwater Depth and Fluctuations due to Monsoons

The groundwater in Delhi is highly dependent on the monsoon. For the year 2021, data from the Ground Water Year Book of Delhi (CGWB, 2022) depict that during the pre-monsoon period, around 11% of the National Capital Territory (NCT) of Delhi have shallow water level up to 5 m below ground level (bgl) which falls in parts of North, North West, West, South West & Central districts. Deep water levels of 20 m bgl to 65 m bgl are observed in around 24 % of NCT Delhi, which falls mainly in South & New Delhi districts & small pockets of South West, South East, and North districts. In the rest of NCT Delhi i.e. 65 % of areas have water levels ranging between 5 m bgl to 20 m bgl. This is observed in Figure 3-06.

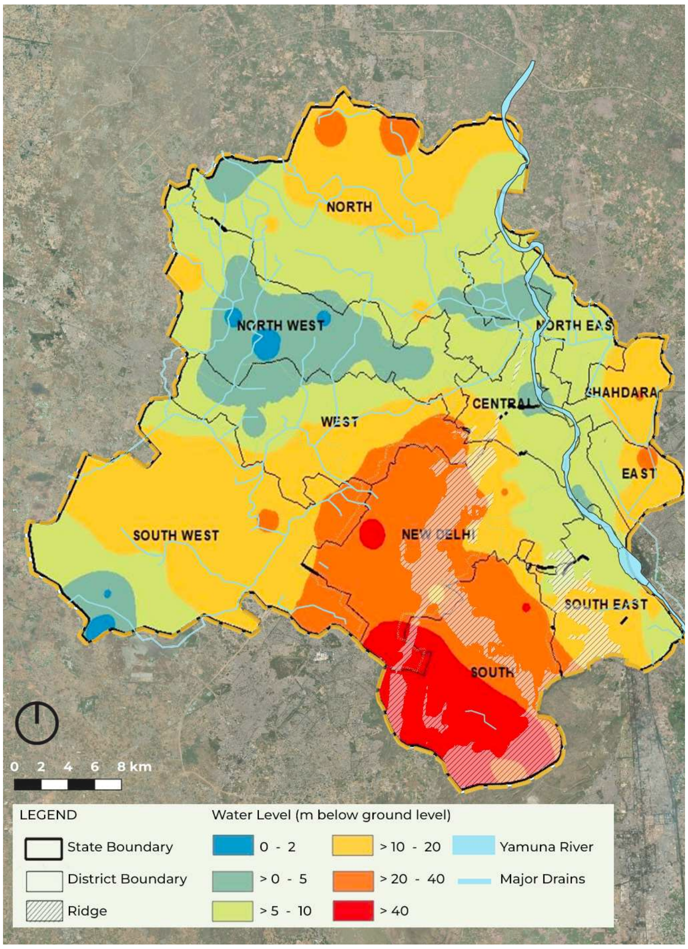


Figure 3-06: Groundwater level in Delhi - Pre monsoon 2021
Source: Adapted from CGWB (2022)

However, post-monsoon (around November 2021) variations in the groundwater levels is observed. This is depicted in Figure 3-07. Around 26% of NCT Delhi, which falls in parts of North, North West, Northeast, South East, Central, West and Southwest districts have shallow water levels up to 5 m bgl. Deep water levels of 20 to 66 m bgl are observed in around 18 % of NCT Delhi, which falls in the South, South East, New Delhi & South West districts. In the rest of NCT Delhi, 56 % of areas have water levels in the range of 5 to 20 m bgl. There is a significant fluctuation in the groundwater levels post-monsoon in Delhi, an evident rise in water level is observed (Figure 3-08: Fluctuation in groundwater level in Delhi - 2021).

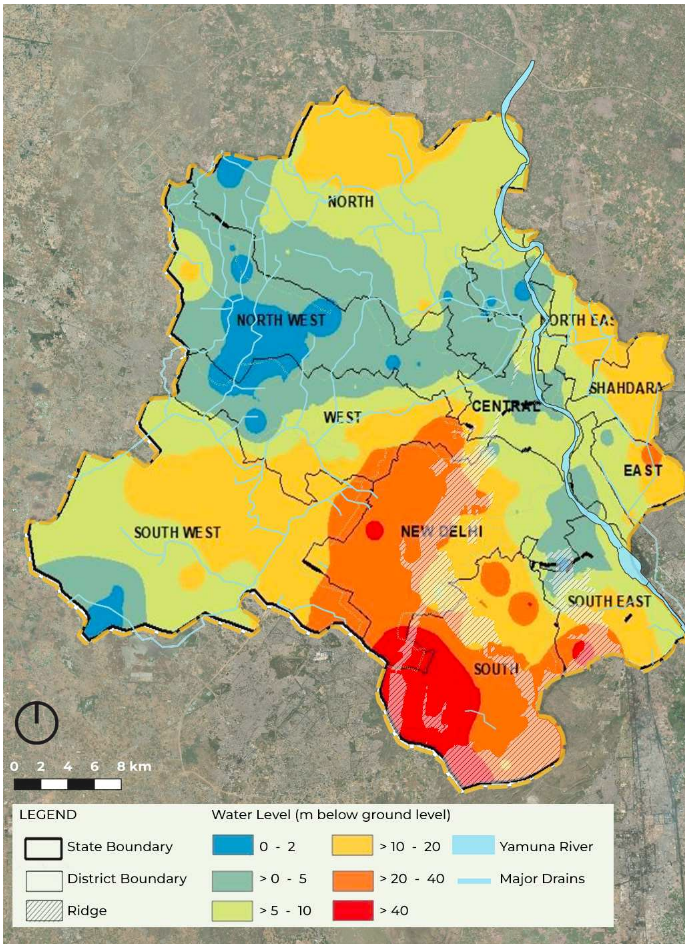


Figure 3-07: Groundwater level in Delhi - Post monsoon 2021
Source: Adapted from CGWB (2022)

Groundwater Pollution

As per the report of the Central Ground Water Board (CGWB) for aquifer mapping of Delhi, the DRASTIC index methodology is applied to find out the groundwater pollution vulnerability (CGWB, 2016). The map (Figure 3-09) indicates that the overall potential for groundwater becoming polluted is low for the Delhi Ridge area, in the southern region and parts of central Delhi. Low-sensitivity areas lay outside the agricultural areas in the basin. It is observed that the occurrence of these pollutants is high in Zones III and IV, that is towards northern, western and eastern parts of Delhi.

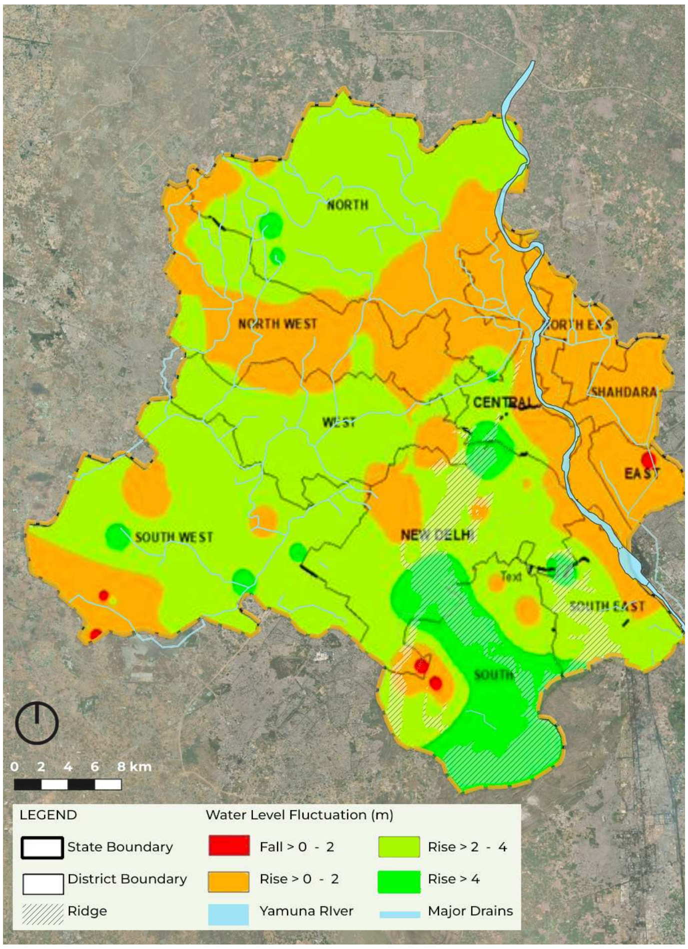


Figure 3-08: Fluctuation in groundwater level in Delhi - 2021
Source: Adapted from CGWB (2022)

Land Use and Land Cover

The recent land utilization data for the year 2020-21 reveals that out of 1474.8 sq km of areas accounted for Land Records in the NCT of Delhi, more than 57 % area is not available for cultivation whereas only 192.25 sq m is available for cultivation. Nearly 435 sq km is gross cropped/ agriculture areas (CGWB, 2022). Nearly 6 % of the total area is under forest, covering mostly notified ridge areas and other forest pockets under Delhi Development Authority (DDA) & government forest land. The breakdown of land utilization is presented graphically in Figure 3-10.

Historically, the detailed classified images of Delhi depicting nine different Land Use and Land Cover (LULC) classes for the years 1977, 1993, 2006 and 2014 are shown in Figure 3-11 (Jain et al., 2016). Over around four decades, a significant transformation in the Land Use and Land Cover (LULC) pattern has become evident. The urban landscape has experienced radial outward growth from the initial urban settlements such as Old Delhi, Mehrauli, and Shahdara. Urban expansion has reached a state

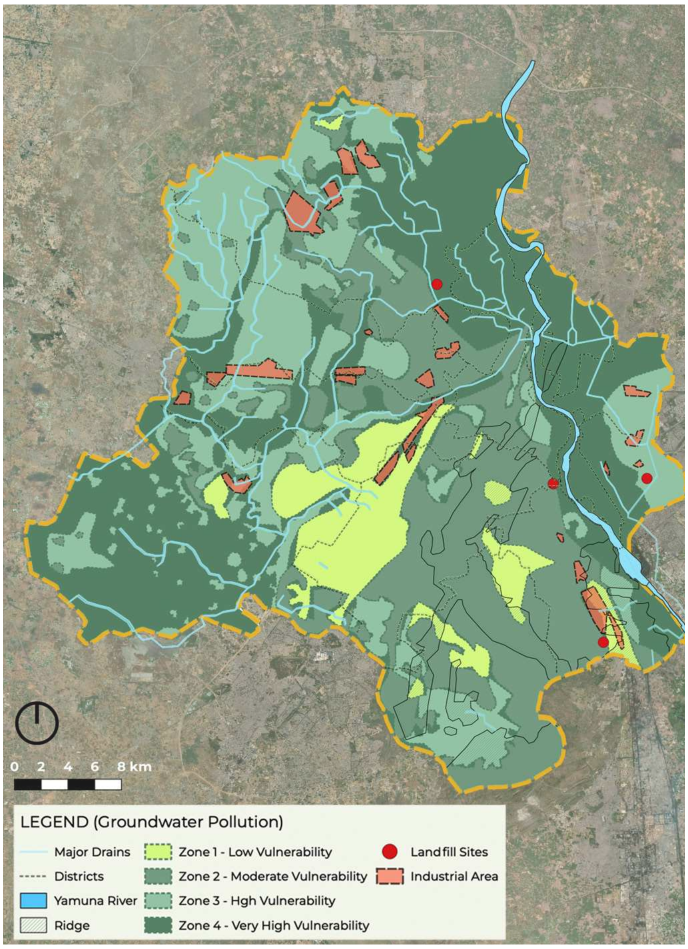


Figure 3-09: Groundwater level in Delhi - Post monsoon 2021
Source: Adapted from CGWB (2022)

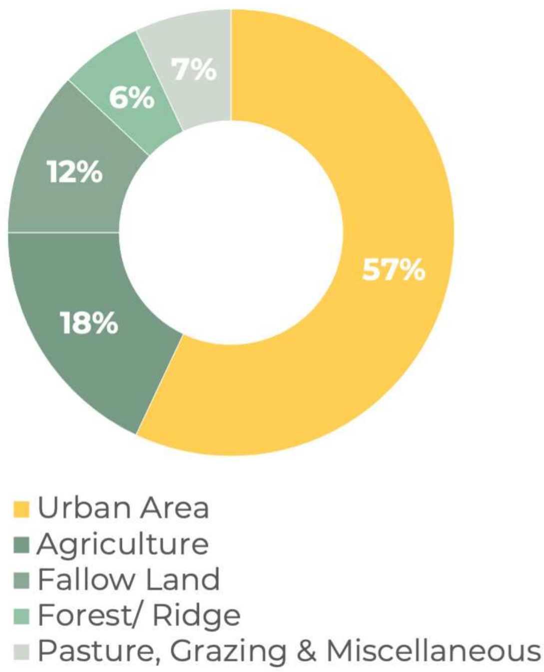


Figure 3-10: Land utilization data for Delhi for 2020-21
Source: Adapted from CGWB (2022)

of near spatial saturation in the trans-Yamuna region, while comparatively newer colonies like Dwarka and Rohini continue to exhibit signs of ongoing development. At present, approximately 40% of Delhi's land is covered by urban structures. The major surge in the built-up area is attributed to the 1990s and 2000s. Over time, Delhi has witnessed significant urban expansion, particularly in the trans-Yamuna region, while older areas like Old Delhi, Mehrauli, and Shahdara have experienced outward growth. The city's floodplains have also been encroached upon and narrowed, reducing their width from an average of 800 meters in 1986 to around 300 meters in 2016 (Rohilla et al., 2020). Similarly, water bodies in Delhi have significantly shrunk, with a 52.9% reduction in their total area from 1997 to 2008, resulting from ongoing urbanization and habitat loss.

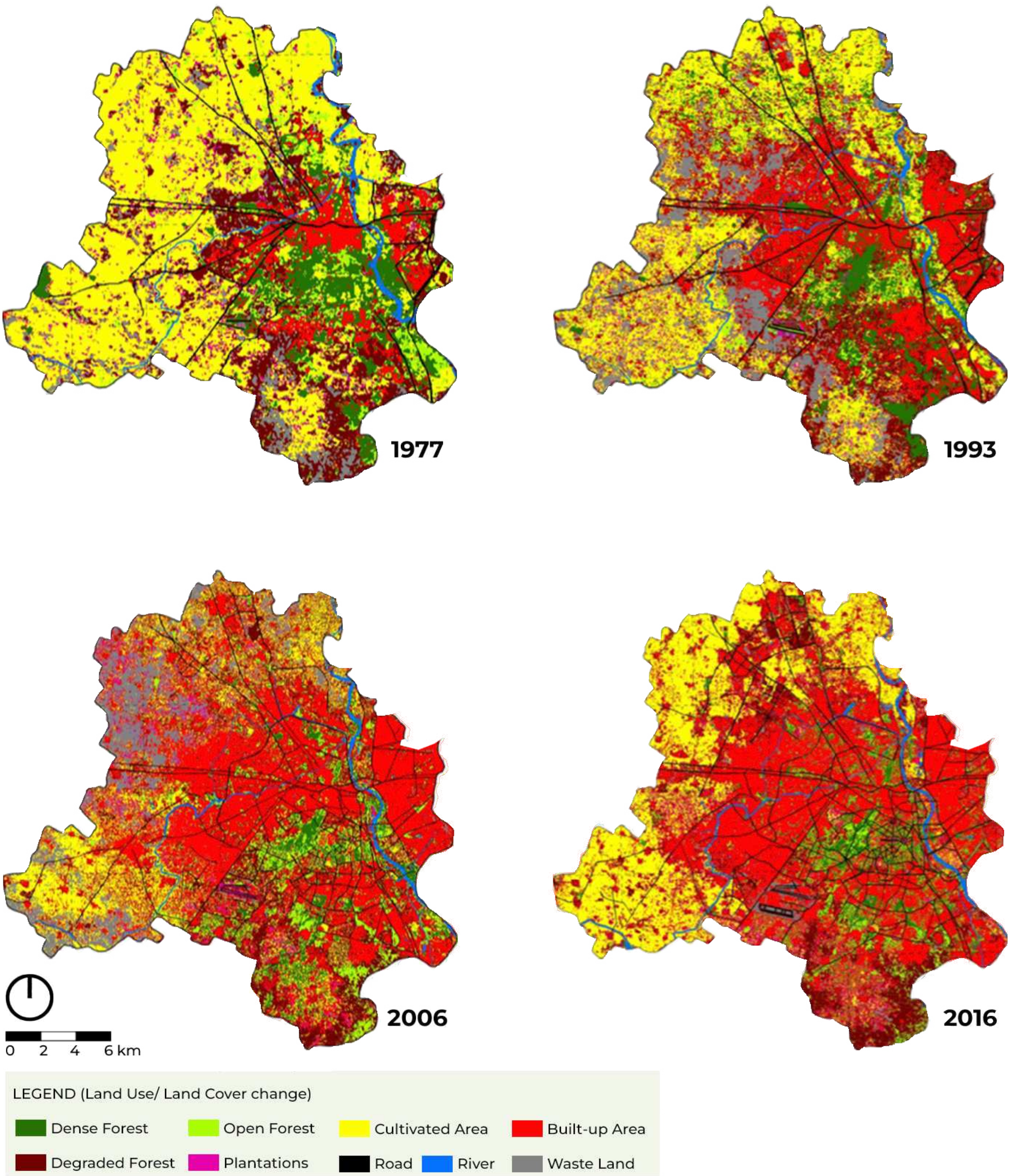


Figure 3-11: Land Use and Land Cover (LULC) classes for the years 1977, 1993, 2006 and 2014 for Delhi
Source: Jain et al., (2016)

3.2 Legislative Framework

The upcoming section offers a review and analysis of existing policy tools related to sustainable development, climate change adaptation, and water, with a special focus on Delhi. The main objective is to identify gaps in the legal framework and discrepancies between theoretical principles and practical applications in the context of stormwater management.

Emphasis is also placed on the examination of international agreements, national strategies and programs, city guidelines, building codes and regulations, and the latest master plan of Delhi. The framework is outlined in Figure 3-12 and organised into the following categories:

- International agreements
- National strategies and policies
- National Missions
- City guidelines and Building codes

On the international stage, India is a signatory to the Paris Agreement, which is an international treaty adopted in 2015 as part of the United Nations Framework Convention on Climate Change (UNFCCC). The Paris Agreement superseded the Kyoto Protocol of 1997. According to the Paris Agreement, all participating countries commit to taking measures to limit global warming to well below 2°C, thereby reducing the risks associated with climate change (UNFCCC, 2015). As part of this commitment, each involved country submits a comprehensive plan known as Nationally Determined Contributions (NDCs) and ensures its implementation.

India has also committed to working toward the achievement of the Sustainable Development Goals (SDGs) by 2030. The goals are centred around the 17 SDGs and 169 associated targets that cover various aspects of sustainable development, including poverty eradication, gender equality, clean energy, climate action and reduced inequality (UNSDG, 2015).

Moreover, India is part of the G20 group. G20 is an international forum consisting of 19 individual countries and the European Union (EU) that represents the world's major economies. Currently, in 2023, India holds the G20 Presidency. India has included water management as a theme for the Environment and Climate Sustainability Working Group (Khanduja et al., 2023) for its current G20 presidency. It indicates the country's commitment to addressing water-related challenges, which are particularly crucial in the context of climate change and sustainable development. Effective water management is critical for both mitigating and adapting to the impacts of climate change, such as droughts, floods, and changing precipitation patterns.

3.2.1 National Missions and Strategies

In addition to India's commitment to international agreements, the nation advances its pursuit of sustainable development and water security through the implementation of various policies and missions at the national level. These domestic initiatives serve as essential drivers in India's ongoing journey to achieve these critical objectives. Some of these are outlined in Figure 3-12.

It is important to highlight at this stage, the scale at which Indian cities need to manage their urban water cycle. Khanduja et al. (2023) highlight in their report that India's journey towards sustainable water management is unique as India with an average annual withdrawal of about 239 billion cubic metres, is the largest consumer of groundwater in the world. Almost 2 million habitations (about 85 % of total habitations) have groundwater-based public water supply services. Groundwater is also used for irrigating about 65 million ha (about 63 %) of gross cropped area. Further, India generates about 72 billion litres of domestic wastewater per day which needs to be managed properly to ensure that the surface water bodies (such as lakes and rivers) are not polluted (Khanduja et al., 2023).

Furthermore, a notable example of a national mission is the SMART Cities Mission, inaugurated in 2015. This initiative is designed to foster innovative practices for sustainable urban development. Another significant mission, the Atal Mission for Rejuvenation and Urban Transformation (AMRUT), is dedicated to enhancing grey infrastructure provision, with a focus on ensuring universal water supply and substantial improvements in sewerage coverage throughout Delhi. In addition, the Swachh Bharat Mission (Urban), launched in 2014, prioritises efficient used water management and treatment, including faecal sludge management (FSM), before its discharge into water bodies, with an emphasis on maximising the reuse of used wastewater. These national missions collectively are further briefly discussed in Table 3-01.

International agreements	National strategies and policies	National missions	City guidelines and Building regulation/ codes
Kyoto Protocol (1992)	National Action Plan on Climate Change (2008)	National Water Mission (2011)	Environment Impact Assessment
Paris Agreement (2015)	National Urban Sanitation Policy (2008)	National Aquifer Mapping and Management (NAQUIM) Programme (2012)	Urban and Regional Development Plans Formulation & Implementation – URDPFI Guidelines (2014)
2030 Agenda for Sustainable Development (2015)	Revised National Water Policy (2012)	Namami Gange Programme (2014)	Stormwater Index - National Mission on Sustainable Habitat (2015)
G20 Action Plan for Agenda for Sustainable Development (2016)	National Land Utilization Policy (2013)	Swachh Bharat Mission - Urban (2014)	Model Building Byelaws (2016)
	National Housing Policy for India (2015)	Atal Mission for Rejuvenation and Urban Transformation - AMRUT (2015)	Drainage Masterplan of Delhi – DMP 2018 (2018)
	National Hydrology Project (2016)	Smart Cities Mission - Delhi (2015)	Manual on Stormwater Drainage Systems by CPHEEO (2019)
	Ministry of Jal Shakti formed (2019)	Delhi Draft Water Policy (2017)	Masterplan of Delhi – MPD 2041 (2023)
	National Framework on Safe Reuse of treated water (2022)	Jal Shakti Abhiyan (2019)	
		Jal Jeeven Mission (2019)	
		National Framework for Safe Reuse of Treated Water (2022)	

Figure 3-12: Legislative framework for water-related policies in India
Source: Adapted from Khanduja et al., (2023) and Rohilla et al., (2020)

3.2.2 Planning Policies for Delhi

This section delves into the discussion of two pivotal planning documents: the Drainage Master Plan (DMP) – 2018 and the Master Plan of Delhi (MPD) – 2041. The DMP, conducted by the Indian Institute of Technology (IIT) Delhi, represents a comprehensive study focused on drainage and stormwater management within the city. In contrast, the MPD 2041 was developed by the National Institute of Urban Affairs (NIUA) on behalf of the Delhi Development Authority (DDA). These documents serve as cornerstone planning frameworks that significantly influence the future urban development and stormwater management strategies for Delhi.

Drainage Master Plan of Delhi - 2018

The existing drainage network, initially established based on a drainage master plan prepared in 1976 by the Irrigation and Flood Control (I&FC) department, was designed to accommodate a maximum daily rainfall of 50 mm. DMP – 2018 aimed at alleviating urban flooding and water logging issues within the city through a methodology that comprised a systematic approach with the following steps:

- Simulating the existing system, validating the modelling of the present infrastructure, and assessing its functionality.
- Introducing necessary interventions to mitigate flooding issues, addressing problems in the drainage infrastructure, and incorporating cost-effective measures like water body restoration and rainwater harvesting using parks.
- Implementing Low Impact Development (LID) options to enhance the overall drainage system.

Recommendations by DMP-2018

Through a comprehensive analysis, the DMP – 2018 quantifies for every drain the volume of surplus runoff that needs to be managed using various mechanisms or scenarios to reduce the occurrence of flooding events to zero (Gosain et al., 2018). To mitigate the city's flooding issues, it recognises enhancing the efficiency of existing stormwater infrastructure as the priority.

This involves addressing existing drainage system flaws and implementing cost-effective flood prevention measures, such as restoring water bodies, promoting rainwater harvesting through parks, and adopting LID solutions. Key recommendations include preventing encroachments on storm drains, ensuring no sewage or solid waste enters these drains, and maintaining effective desilting practices. DMP-2018 also suggests on implementing flood monitoring through sensors that can bolster flood management.

Takeaway

The DMP-2018 deliberately did not offer a comprehensive flood prevention strategy for the entire NCT of Delhi (Gosain et al., 2018. Instead, it focused on quantifying the surplus runoff for each drain and proposed various measures, through in-depth analysis of various scenarios to address this issue and ensure no urban flooding occurs. Apart from general recommendations, the primary priority as identified in the master plan is to rectify the existing dilapidated drainage infrastructure.

The effectiveness of the scenarios generated in the report can only be verified on-ground conditions after implementing this strategy (Gosain et al., 2018). A particularly noteworthy recommendation pertains to the management of the entire stormwater drainage system within the NCT of Delhi. The proposal suggests that a single institution should undertake comprehensive responsibility for overseeing and managing this critical aspect of urban infrastructure.

A major critique of the DMP is the proposal's disclaimer regarding the absence of dependable infrastructure data, particularly cross-sections and invert levels of drains. Persistent discrepancies were found within the drainage network that remains a significant issue. Moreover, the process of integrating data on pump and sump locations, capacities, and operational policies into the networks has been characterised by multiple iterations with the relevant departments, highlighting the need for more streamlined and accurate data management practices.

Master Plan of Delhi - Vision 2041

For this master's thesis, in this section, MPD-2041 is discussed after a thorough review, keeping stormwater management in Delhi as the central point of discussion. The new master plan provides in its framework, discourse about integrated management of 'Green-Blue Infrastructure' in the city envisaging an increase in both, the net area under natural green-blue assets and planned green spaces delivered as part of new projects in the city.

	Framework	Year	Objective
POLICY	Water Policy for Delhi	2017	Ensuring water security for Delhi in the face of an uncertain resource scenario
	National framework for Safe Reuse of Treated water	2022	Widespread and safe reuse of treated used water; reduce the pressure on scarce freshwater resources, pollution and risks to public health; sustainable circular economy
NATIONAL MISSIONS	National Aquifer Mapping and Management Programme	2012	To delineate and characterise aquifers in three dimensions, identify and quantify issues, and develop management plans to ensure the sustainability of groundwater
	Swachh Bharat Mission (Urban)	2014	1st Phase focussed on making urban India open defecation free through the adoption of improved sanitary facilities by 2019 2nd Phase aims to achieve 'garbage free' status in all Indian cities by 2026
	Atal Mission for Rejuvenation and Urban Transformation (AMRUT)	2015	To provide universal water supply and substantial improvement in sewerage coverage
	Delhi SMART Cities Mission	2015	Aims to promote innovative practices for sustainable urban development
	Jal Jeevan Mission	2019	Provide safe drinking water to every rural household through a functional household tap connection by 2024
	Jal Shakti Abhiyaan	2019	Promote water conservation and water resource management
PLANNING	Master Plan of Delhi - 2021	2007	To make Delhi a global metropolis and a world-class city, where all the people would be engaged in productive work with a better quality of life, sustainable environment.
	Drainage Master Plan for NCT of Delhi	2018	Aimed at mitigation and elimination of issues related to urban flooding and waterlogging
	City of Lakes - Delhi	2018	To rejuvenate dried water bodies and lake redevelopment in Delhi. The broader goal is to close the gap of 300 million gallons per day (MGD) between water supply and demand. Delhi's daily water demand of 1,260 MGD
GUIDELINES and REGULATIONS	**National Level**		
	Environment Impact Assessment	2006	Obtaining clearance for scheduled development projects that are likely to result in significant environmental effects
	Urban and Regional Development Plans Formulation & Implementation (URDPFI) Guidelines, 2014	2014	Prepares the proposed land use bifurcation for different urban centres
	Storm water Index— National Mission on Sustainable Habitat	2015	Assess and monitor the implementation of sustainable storm-water management
	Manual on Stormwater Drainage Systems by CPHEEO	2019	To aid government functionaries in the better planning, design, operation and maintenance, and management of stormwater infrastructure in urban areas.
	State Level - Delhi		
	Model Building Bye-Laws	2016	Provisions for rainwater harvesting, green buildings, segregated toilets, wastewater reuse and recycle etc.

Table 3-01: Overview of significant national policies, missions, city guidelines and planning policies for water in India. Source: Adapted from Khanduja et al., (2023) and Rohilla et al., (2020)

Strategies towards potential WSUDP	Remarks		
	Key words	Use of WSUDP techniques	Grey infrastructure provision
Provision of rain water harvesting (RWH) at rooftop or building level defined, with incentives and penalties w	RWH	**YES**	NO
Achievement of SDG 6.3 on improving water quality through increased recycling and safe reuse.	SDG 6.3; increased recycling and safe reuse	**YES**	NO
Through geophysical investigations, exploratory drilling, water-level monitoring, water quality analysis, and preparation of management plans.	Groundwater sustainability	NO	NO
Sustainable solid waste management and Used water management including faecal sludge management (FSM), before discharge into water bodies, and maximum reuse 'Jan Andolan', that is, citizen outreach through Information, Education; behaviour change campaigns	Solid waste management; Reuse of treated used water; FSM Public awareness and behavior change	**YES**	**YES**
Developing a City Water Balance Plan for each city focusing on recycling/reuse of treated sewage, rejuvenation of water bodies, and water conservation.	Circular economy of Water	**YES**	**YES**
RWH projects in parks and open spaces are not implemented under the Smart Cities Mission	RWH		
In addition to creating water supply infrastructure, JJM aims to ensure regular water supply of prescribed quality (as per Bureau of Indian Standards:10500) and in adequate quantity (minimum 55 litres per person per day).	Water supply infrastructure	NO	**YES**
Water conservation and RWH, renovation of traditional and other water bodies, reuse and recharge of bore wells, watershed development, and afforestation	Recharge of borewells; watershed development; rainwater harvesting	**YES**	NO
The provisions state that apart from buildings and various land uses, public parks and gardens need to reserve area for RWH and stormwater harvesting	Stormwater harvesting in public parks	**YES**	**YES**
Upgradation of existing infrastructure; Adoption of low-impact development (LID) options to manage stormwater run-off, wherever feasible and Rejuvenation of water bodies	Upgradation of existing grey infrastructure; LID; Rejuvenation of rivers	**YES**	**YES**
Recharge groundwater and improve water quality; Recycling treated water from STPs to develop lakes and to recover of groundwater to meet water supply needs	Recycling treated water; Recharge groundwater	**YES**	**YES**
Crucial environment factors are not conspired e.g. consumption of water, increase runoff	-	NO	NO
Provides enough open area to design the SuDs structures	SuDs	**YES**	NO
Defines Rainfall Intensity Index and Stormwater Discharge Quality Index to enhaning monitoring	-	NO	NO
Mentions WSUDP as 'Innovative Stormwater Management Practices'	Innovative Stormwater Management Practices	**YES**	NO
Emphasis is given to generate approximately 40 % of total waste with provisions for water conservation and management by RWH, low water consumption fixtures, etc.	Reduction of impermeable surfaces; RWH	**YES**	NO

Table 3-01: Overview of significant national policies, missions, city guidelines and planning policies for water in India. Source: Adapted from Khanduja et al., (2023) and Rohilla et al., (2020)

Recommendations by MPD-2041

There is a critical emphasis on the improvement of pervious surfaces throughout the city by adopting water-sensitive urban design (WSUD) principles for all new layout plans. Some of the WSUD principles such as bio-swales, vegetated filters, pervious stormwater drains, rain gardens, semi-pervious pavements, public parking areas, etc. are proposed to be adopted in public areas as per ground conditions. The plan recommends promoting the reduction of stormwater runoff and maximising rainwater utilization, whether through direct storage or indirect groundwater recharge (DDA, 2021). Some of the suggested strategies include:

- Locating parks and open spaces in low-lying areas to facilitate recharge and prevent construction in flood-prone locations.
- Allowing rainwater harvesting as a shared recharge infrastructure in green fields.
- Designing stormwater networks in new areas to ensure that a portion of the stormwater is directed into existing or suitable groundwater recharge sites.
- Employing bio drainage at specific locations to create natural sponges in the city, particularly along rivers, natural drains, and lakes, to manage excess water during monsoon seasons.
- Natural and engineered drains are to be kept free of obstructions and encroachments with regular desilting.

Urban local bodies (ULBs) may earmark certain parks and gardens in flood-prone areas to serve as flood detention sinks as identified in the Drainage Master Plan of the I&FC department.

Takeaway

MPD-2041 advocates for the establishment of a single, overarching institution tasked with the comprehensive responsibility for managing the entire stormwater drainage system within the National Capital Territory (NCT) of Delhi. This strategic approach is pivotal in effecting positive change, primarily because the existing stormwater management in Delhi is currently fragmented among ten different governmental organisations, resulting in a notable lack of accountability.

However, in many critical areas, the master plan falls short, such as limited public participation in decision making processes, the draft master plan was issued only in English, a language that is inaccessible to Delhi's broader public. For a larger section of Delhi's population, it was practically impossible to disseminate the contents of the draft MPD-2041. The baseline data used reflected inaccurate population projections.

MPD - 2041 represents a significant milestone in addressing urban water management through the introduction of a much anticipated discourse on water sensitive urban design (WSUD) principles. However, the strategy and target specifics within MPD-2041 are somewhat lacking, presenting a broader discussion without financial information, comprehensive and actionable measures.

3.2.3 Challenges Regarding the Existing Framework

Delhi continues to rely on a drainage system that is more than 50 years old, necessitating immediate planning-level enhancements to address contemporary urban and climatic challenges. The stormwater network is incapacitated and overwhelmed considering the urban expansion Delhi witnessed as well as the intensified rainfall patterns. Even though National policies and National Missions, namely AMRUT, and Swachh Bharat Mission aim to reduce inequity by extending access to grey infrastructure to all citizens, however, a clear path is missing.

The government of Delhi had rejected the DMP – 2018, however, even after 6 years, the city still awaits a new drainage master plan. There is an urgent need to upgrade the framework for effective management of stormwater. Kapur (2021) points out that the water, wastewater and solid waste management chapters of the MPD-2041 do not even summarise the numerical targets and plans, disaggregated actions and solutions proposed by the MCD, the DJB, the Cantonment Board and I&FC. Instead, these crucial components of Delhi's urban water cycle are merely presented as annexures. These issues, if addressed comprehensively, can significantly improve the efficacy and impact of the existing framework and enhance its ability to meet the evolving needs and challenges of urban development.

The overview of India's journey in sustainable water management, as depicted in Figure 3-13, highlights the thematic objectives of each mission and the corresponding Sustainable Development Goals (SDGs) it seeks to achieve through its execution.

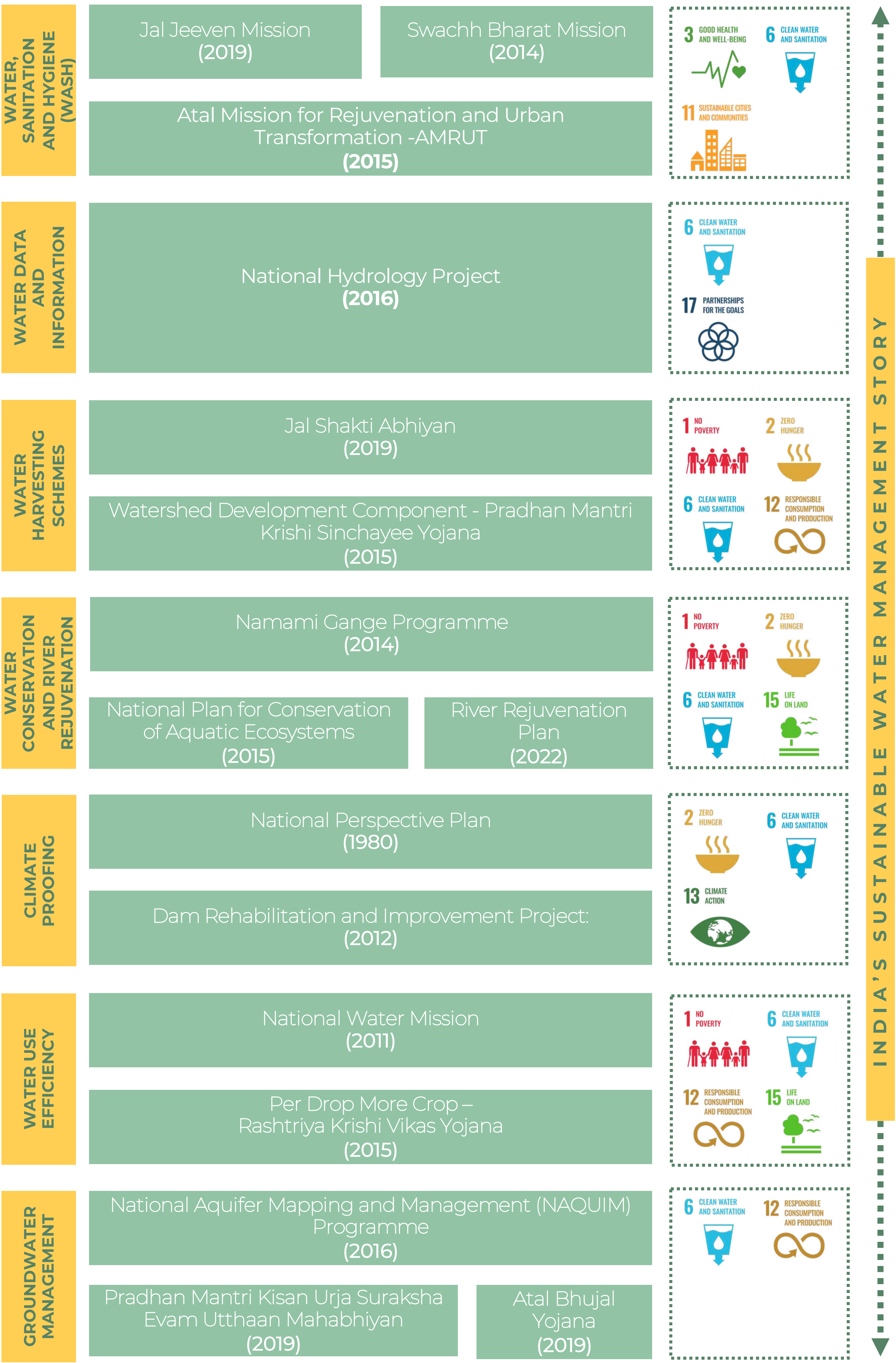


Figure 3-13: India's journey towards sustainable water management (as of 2023)
Source: Adapted from Khanduja et al., (2023)

3.3 Urban Water Cycle

The urban water cycle of Delhi refers to the complete process of water supply, distribution, usage, wastewater generation, treatment, and disposal within the city. Delhi, as a rapidly growing and densely populated metropolis, faces complex challenges related to water management. Understanding the urban water cycle in Delhi is crucial for addressing the social and environmental concerns associated with water management in a densely populated urban setting. The urban water cycle of the city is further discussed in the upcoming sections.

3.3.1 Flowing Waters

The surface or flowing waters of Delhi refer to natural and artificial bodies of water that can be found within the city. These waters include rivers, streams, canals, lakes, ponds, reservoirs and wetlands. These play a vital role in the city's ecology, environment, and overall quality of life.

The most significant of them is the Yamuna River which flows through the eastern regions of the city. The amount of water in the river fluctuates throughout the year. During the monsoon season, spanning two to three months from July to September, the water level is high. However, during the summer months, from April to June, water levels drop significantly due to increased demand from various northern Indian states, including Delhi, all of which rely on Yamuna River water.

Delhi is crisscrossed by a network of canals, including the Western Yamuna Canal, the Agra Canal, and the Delhi Parallel Eastern Canal (see Figure 3-15). These canals play a crucial role in irrigation, groundwater recharge, and water supply to various parts of the city. Wetlands and marshy areas exist within and around Delhi, such as the Najafgarh Jheel, which plays a crucial role in flood control, groundwater recharge, and as a habitat for various bird species. Water reservoirs like the Wazirabad Barrage and the Okhla Barrage regulate water flow along the Yamuna River and help manage water supply to Delhi.

These surface waters are essential for various purposes, including water supply, irrigation, recreation, and maintaining ecological balance. However, they face various challenges and threats, including pollution, encroachment, and unsustainable development.

3.3.2 Water Supply and Wastewater

Currently, the Delhi Jal Board (DJB) serves as the primary institution responsible for water supply and sanitation in Delhi at the local level. DJB manages the treatment of raw water obtained from different sources and the distribution of water to regions falling under the jurisdiction of the Municipal Corporation of Delhi (MCD), which covers approximately 95% of Delhi's geographical area. The MCD plays a key role in enforcing water-related bylaws, which include regulations regarding rainwater harvesting structures and wastewater recycling facilities at both household and community levels, and overseeing various water consumption and disposal activities within its respective areas.

Delhi's available raw water supply amounts to approximately 983 million gallons per day (MGD), and this supply is drawn from different river basins. As depicted in Figure 3-14, out of this total, 612 MGD, accounting for 62%, is sourced from the neighbouring state of Haryana through a carrier line, canals and the course of the Yamuna River, while the remaining 117 MGD is distributed between the Ganga River and groundwater. The estimated requirement for Delhi on the norm of 274 litres per capita per day or 60 gallons per capita per day (GPCD), however, is around 1260 MGD for the projected population of 21 million (Planning Department GNCTD, 2023). Therefore, there is a gap of roughly 300 MGD between daily water supply and demand in Delhi.

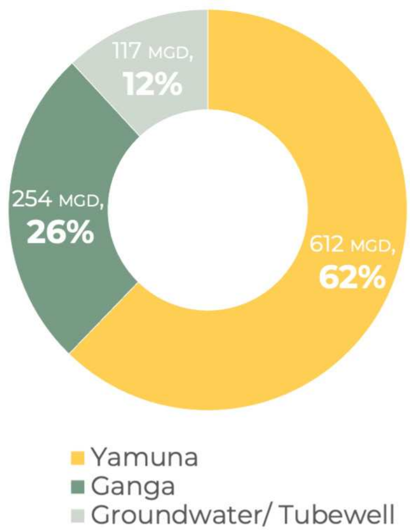
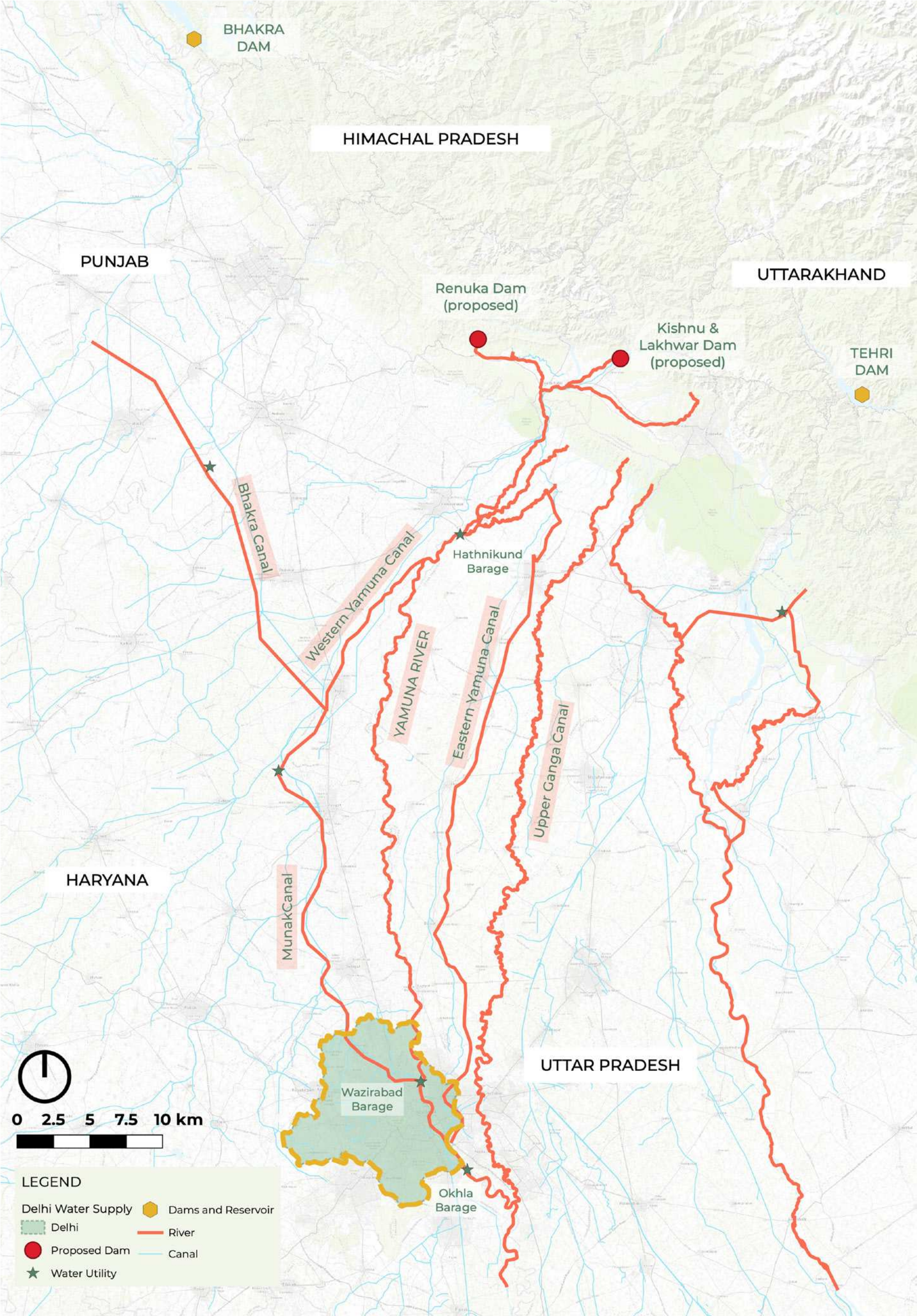


Figure 3-14: Sources of water supply for Delhi. Source: Economic Survey of Delhi (2022)



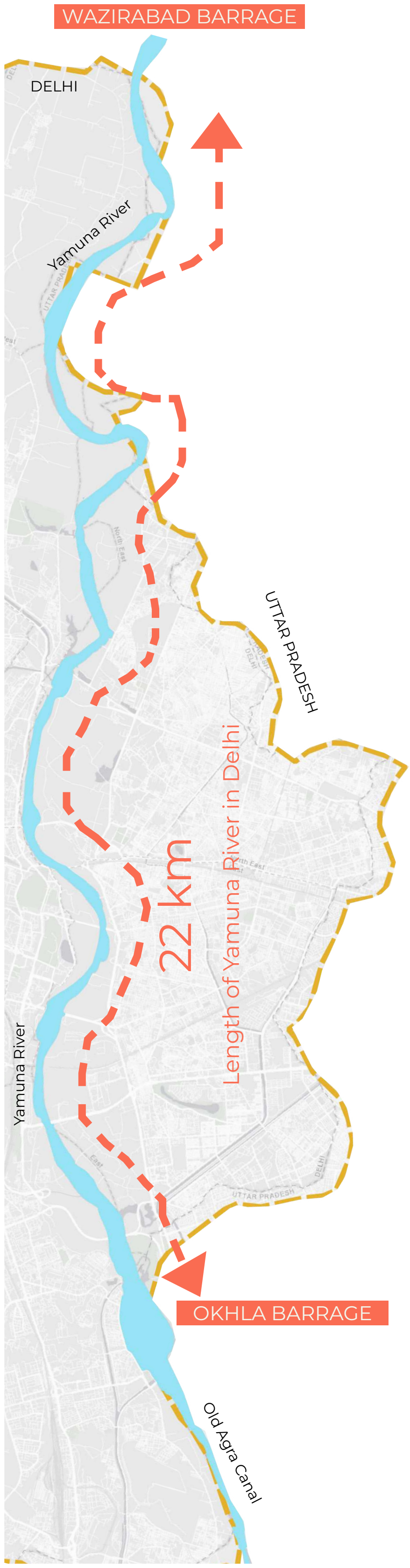


Figure 3-15: Sources of water supply and its network for Delhi Jal Board; Schematic path of Yamuna River(right). Source: Data adapted from Kumari & Biswas (2022)

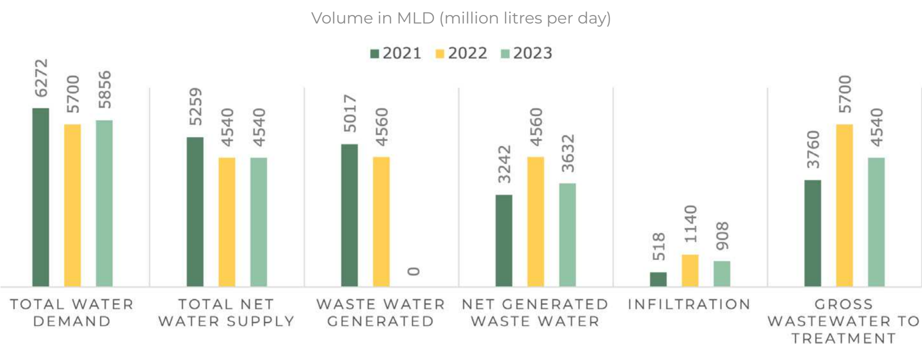


Figure 3-16: Estimate of water supply requirement and waster water generated in Delhi from 2021 to 2023. Source: Economic Survey of Delhi (2022)

Delhi's water supply is reliant on raw water received from neighbouring states through a canal, under the Yamuna water sharing agreement established in May 1994. This agreement involves the states of Haryana, Uttar Pradesh, Uttarakhand, Himachal Pradesh, and Delhi, as outlined in the Planning Department of the Government of National Capital Territory of Delhi (GNCTD) in 2019.

The agreement pertains to the sharing of water in the upper Yamuna region, spanning from the Yamunotri Glacier (the river Yamuna's origin point) to the Okhla barrage, and it necessitates the cooperation of various state governments, including Haryana and Uttar Pradesh (see Figure 3-15).

The water governance system of Delhi is diverse and interdependent in nature, convergence, and coordination at both horizontal and vertical level is of utmost importance (Kumari & Biswas, 2022).

With regards to wastewater, DJB's sewage treatment capacity as of 31st March 2022 is 632 MGD which is managed with a network of trunk sewers of 200 km length and peripheral sewers of about 9300 km (Planning Department GNCTD, 2023).

The same report also mentions that at present, sewage generation is around 784 MGD while the treatment is 560 MGD. Approximately, 224 MGD of sewage is disposed untreated. Furthermore, DJB supplies about 89 MGD of treated wastewater to I&FC and power plants for irrigation, horticulture and industrial purposes.

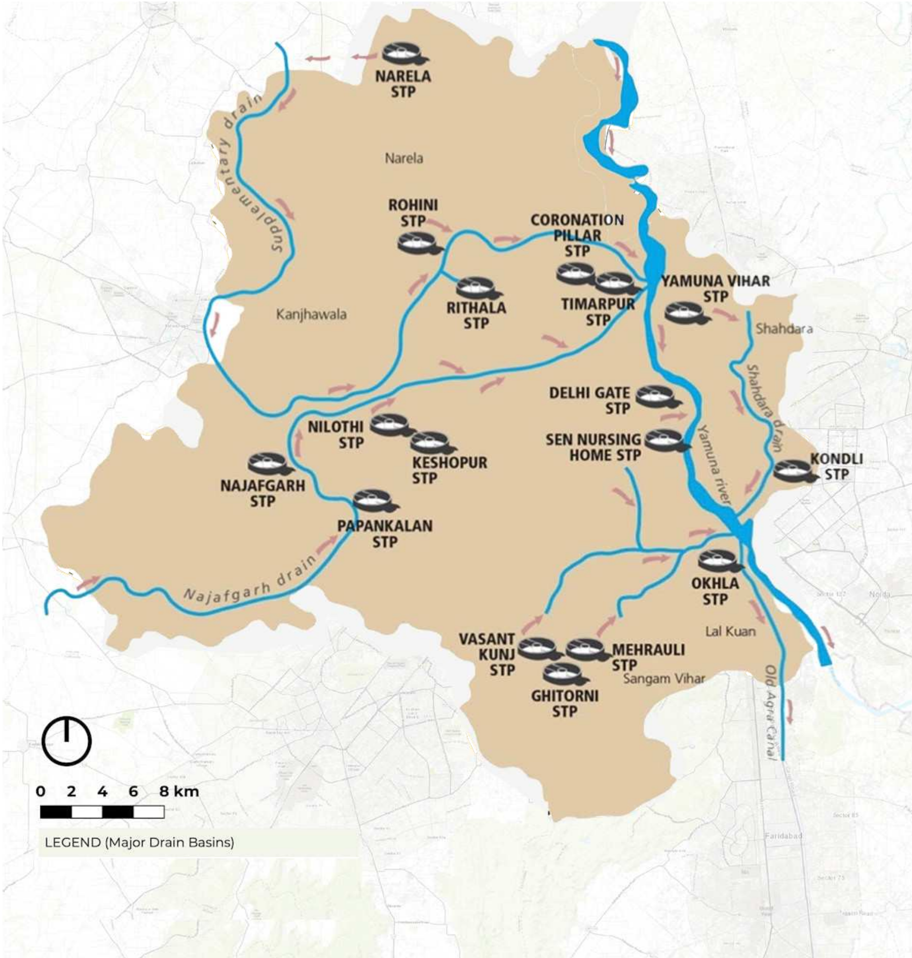


Figure 3-17: Major drain basins and STP locations in Delhi
Source: CSE (2012)

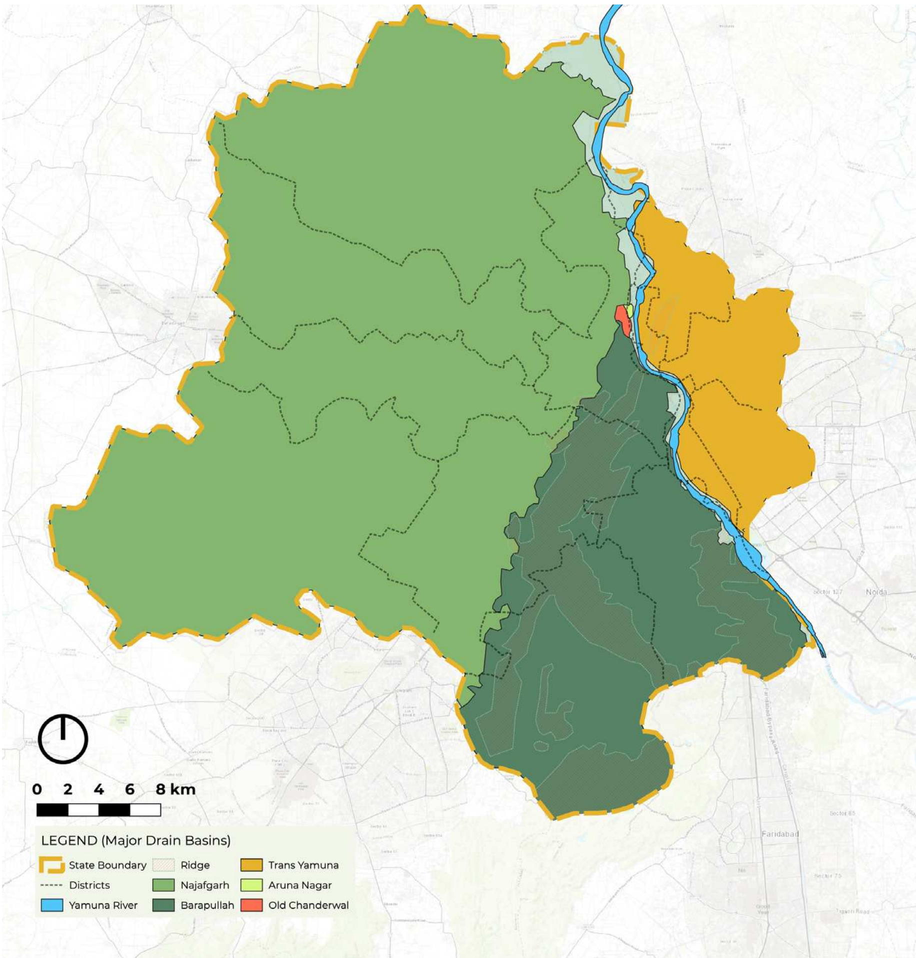


Figure 3-18: Major drain basins in Delhi
Source: Data adapted from Gosain et al. (2018)

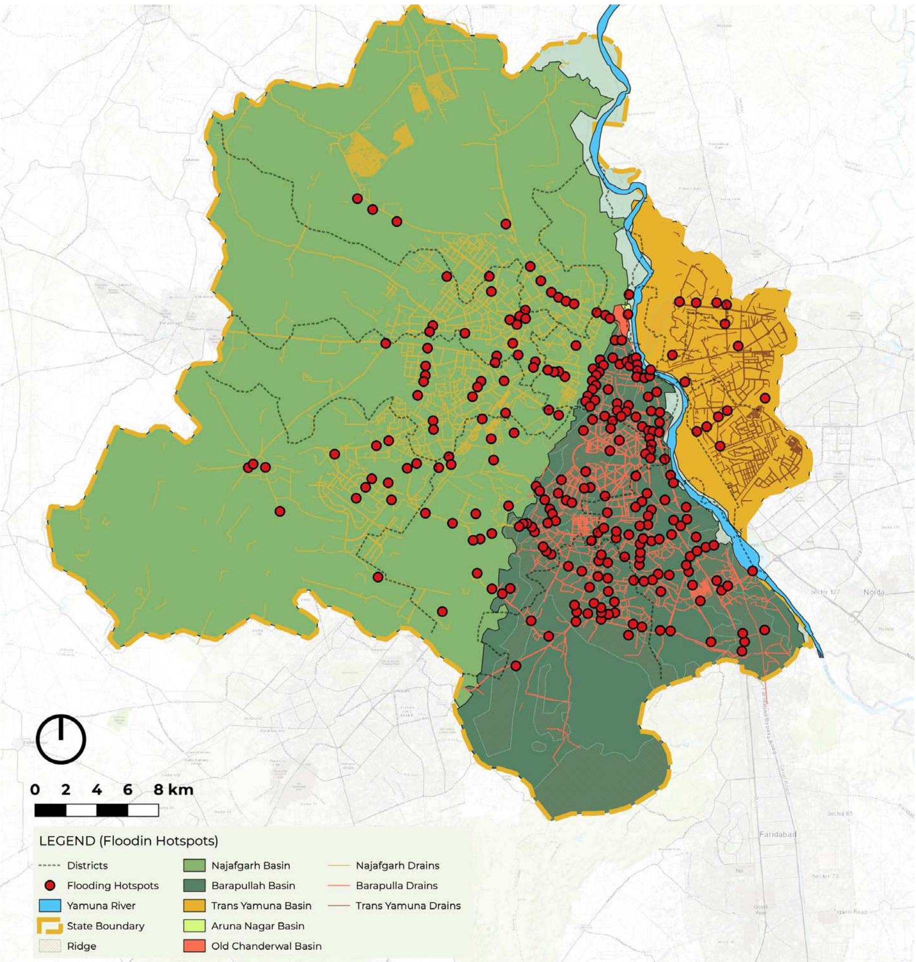


Figure 3-19: Major waterlogging and flooding hotspots in Delhi
Source: Data adapted from Gosain et al. (2018)

Drainage Basin	No of Drains	Catchment Area (km²)
Trans Yamuna	34	196.92
Barapullah	44	376.27
Najafgarh	123	977.26
Total	**201**	**1550.45**

Table 3-02: Basin-wise natural drains in Delhi as per the 1976 Drainage Masterplan.
Source: Gosain et al., (2018)

3.3.3 Stormwater

Delhi has been geographically divided into three prominent natural drainage basins, i.e, Trans Yamuna, Barapullah and Najafgarh basin, as illustrated in Figure 3-18. In addition to these, there are also a couple of notably smaller drainage basins, Aruna Nagar and Old Chanderwal, which discharge directly into the Yamuna River. Among these basins, the Najafgarh basin is the largest, covering nearly two-thirds of the total land area within the National Capital Territory (NCT) of Delhi. These three major basins collectively comprise a total of 201 natural drainage channels, as detailed in Table 3-02. The final destination for the majority of stormwater runoff originating in Delhi is the Yamuna River, achieved through a network of discharge points along its course as it traverses the city.

3.3.4 Summary

Challenges persist in the water supply, stormwater and wastewater management sector that would require concentrated efforts from all stakeholders. Some of these include the declining groundwater levels, elevated fluoride concentrations in groundwater, distribution losses in water supply, insufficient wastewater treatment capacity, fragile drainage infrastructure, combined wastewater and stormwater networks, and the recurring issue of urban flooding.

This issue is primarily attributed to the significant population residing in unplanned and unauthorised settlements, making it challenging to establish a formal water supply system under the current institutional setup as well as the density of these unplanned areas. The uneven, unreliable, and intermittent availability of water in both planned and unplanned settlements has resulted in social injustices and an unequal distribution of water resources in Delhi. The inequity is further reflected during every monsoon season in Delhi when urban flooding impacts the lower-income group inhabiting these dense settlements in the worst manner. Figure 3-19 depicts the flooding and waterlogging hotspots in Delhi. There are approximately 260 critical locations as highlighted in the Drainage Master Plan of 2018.

3.4 Stakeholders

3.4.1 Stakeholder Matrix

The stakeholders are structured into six groups namely Central and State institutions, Public institutions and Associations, NGOs, Private enterprises, Mass media, Individuals and International organisations. The summary of the stakeholder analysis is presented in the register (see Annexure-3). The register consists of a description of the stakeholder`s focus area and responsibilities, an evaluation of their interest and power regarding urban flooding risk mitigation, and recommendations to manage this stakeholder. The stakeholder register is peer reviewed by two colleagues in Delhi who are in the field of urban planning and architecture. They were requested to evaluate the stakeholder register and provide their estimation of interest and power. Based on the obtained results, the mean values are depicted in the final stakeholder register in Annexure-3.

In this section, the Stakeholders matrix is discussed. A Stakeholders matrix is a diagram illustrating the distribution of interest and power of various stakeholders. The players with low power and interest, 0–5 points, are "Minor". In general, they are tertiary stakeholders and impacted the least but have to be monitored in case of disposition changes and informed to increase the interest. "Significant" has high interest, 5–10 points, but low power, 0–5 points. Thus, they have to be informed and kept involved. The next group with high interest and power, 5–10 points, are "Critical". They are key players in the project's success and must be engaged in the decision-making bodies. The last group is "Major" with low interest, 0–5 points, but high power, 5–10 points. They present both threats and opportunities. The main focus is to increase the level of interest and prevent any obstacles from their side.

It is found that the highest power belongs to State institutions and enterprises. The Irrigation and Flood Control Department (I&FC) and Delhi Jal Board (DJB) are major governmental organisations responsible for the management of stormwater and water supply and sewage disposal in Delhi respectively. The Municipal Corporation of Delhi (MCD) is responsible for managing local services, including drainage, waste management, and sanitation, which are essential components of flood control. The Public Works Department (PWD) is also tasked with the construction and maintenance of drainage infrastructure along roads and bridges. All these stakeholders can be categorised in the "Critical" group as they hold high power but significantly lower interest.

NGOs, government think tanks and public institutes like the Centre for Science and Environment (CSE), National Institute of Urban Affairs (NIUA), and Indian Institute of Technology (IIT) are "Significant" stakeholders as they showcase high interest and advocate for a more efficient policy implementation but do not hold high power.

The Individual's group includes residents living in dense urban settlements, the citizens of Delhi, urban activists, as well as elected officials and local representatives of the flood-prone areas of the city. The group Media is represented by State and Independent radio, newspapers, magazines, and internet sources. The United Nations (UN) and international development cooperation like GIZ are grouped under the International Organisations group.

To sum up, the dominance of state institutions presents the most significant barrier to urban development as a whole and, more specifically, to stormwater management in Delhi. To begin with, the prevailing political system, which employs a top-down decision-making process, does not foster active civic participation. Furthermore, a lack of transparency, open data, and public engagement conceal corruption and substandard construction practices and project implementation. Finally, the outdated norms in design and construction fail to incentivise specialists to enhance their professional expertise.

The stakeholder register's visual summary is depicted as a stakeholder matrix in Figure 3-20. It is evident that state authorities and public institutions wield substantial influence, but their level of interest is relatively modest.

On the other hand, residents, non-profit organisations, and activists exhibit significant levels of interest, but they do not possess substantial power. The ruling political party, Aam Aadmi Party (AAP), demonstrates both a strong influence and a keen interest. International organisations and cooperation also fit into a similar category, striking a well-balanced equilibrium between power and interest to drive change.

Figure 3-20: Stakeholder matrix for flooding risk mitigation in Delhi

Legend

MoHUA: Ministry of Housing & Urban Affairs
MoJAL: Ministry of Jal Shakti
PWD: Public Works Department
I&FC: Irrigation & Flood Control Department
MCD: Municipal Corporation of Delhi; NDMC: New Delhi Municipal Corporation
CGWB: Central Ground Water Board
DJB: Delhi Jal Board
DDA: Delhi Development Authority
DDMA: District Disaster Management Authority
AAP: Aam Aadmi Party (Current government)
OPP: Opposition Political Party
MLA: Member of Legislative Assembly (Politician)
CSE: Centre for Science & Environment
NIUA: National Institute for Urban Affairs
EXP: Experts (Council of Architecture; The Institute of Engineers India)
GIZ: German Corporation for International Cooperation
UN: United Nations

3.4.2 Stakeholder Interviews

Interviews were conducted to gain insights into the current state of affairs regarding stormwater management in Indian cities, its present challenges, and potential opportunities.

The interviewees were selected from different groups ranging from academicians, urban planners, scholars, private consultants, non-profit organisation as well as government organisation. Most of the interviews took place over video conferencing and the questionnaire used for this purpose can be found in Annexure-2. The summary of the interviews is discussed in the upcoming section.

Ms Pratima Joshi
Architect
Founder of Shelter Associates, Non Profit
Pune, India

Mr Dhruv Pasricha
Urban-environmental Planner
WASH Consultant
Delhi, India

Ms Pratima Joshi, the founder of Shelter Associates, a non-profit organisation established in 1994, is passionate about ensuring equitable access to essential services for under served communities. Ms Joshi holds a Master's in Architecture from the Bartlett School of Architecture and Planning in London and is the only Indian recipient of the 'Google Earth Hero Award.' She's recognised as a leading 'Slum architect of India' by the BBC.

Regarding urban flooding challenges in Indian cities, Ms Joshi mentioned that the primary concern is the protection of natural waterways from encroachment and haphazard development. The emphasis is on aligning planning with the natural flow of rivers rather than altering canals and stormwater channels, which have exacerbated urban flooding issues. Unplanned settlements, often located near water bodies due to their critical need for water access, play significant roles in city functionality, yet they are frequently overlooked in planning and remain unacknowledged.

"Effective planning involves public participation, stakeholder engagement, and management, with a shift away from top-down approaches".

She further highlighted that data is of utmost importance for efficient planning, and reliable data collection and analysis are essential components for rapidly growing cities. While Nature-Based Solutions (NBS) provide alternatives for stormwater management, they cannot entirely replace critical infrastructure for water supply, sanitation, and stormwater management. There's a call for a data-driven approach to planning in rapidly growing Indian cities, emphasising the need for revisiting planning guidelines at least once every five years. She urged urban planners to prioritise sensitive planning, respecting existing green infrastructure, and avoiding excessive concretisation.

Mr Dhruv Pasricha, is an urban-environmental planner with more than five years of experience in the WASH (water, sanitation and hygiene) sector. His area of expertise include integrated urban water management, waster sensitive city planning, green infrastructure, city sanitation plans and water bodies management. He was engaged as a Deputy Programme Manager at the Centre for Science and Environment's (CSE) Water Program. At CSE, he has contributed to more than 30 publications on WASH.

He considers the challenges faced by Indian cities regarding urban flooding to be multifaceted. Current guidelines focus primarily on disposing of stormwater rapidly, leading to issues like combined sewers with high pollutant loads. Drainage infrastructure is often lacking, and even in planned areas, stormwater infrastructure capacity is inadequate for current rainfall patterns. A proactive approach is needed, considering both planned and unplanned settlements. He further adds that unplanned settlements play crucial role in the city's economy, providing services, income, and goods. Good data is essential for planning, including information about natural features, infrastructure, and people. Involving stakeholders is critical for success. He suggests that for effective stormwater management, Indian cities must consider a circular economy approach, proactive design, and interventions at various scales. Regarding Water Sensitive Urban Design (WSUD), it's essential to focus on decentralised solutions and manage drainage locally. In summary, he suggests that addressing urban flooding and stormwater management requires a holistic and forward-thinking approach, better governance, and more accountability in the systems in place.

"Incorporating nature-based solutions alongside grey infrastructure is essential, not as a replacement but as a complementary approach".

Ms Shambhavi Gupta
Urban Planner
Co-author of 'Water Sensitive Planning for the Cities of the Global South'. Delhi, India

Mr Jayant Kumar
Junior Engineer
Delhi Jal Board (DJB)
Government official
Delhi, India

Ms Shambhavi Gupta, an urban planner currently pursuing a Master of Public Administration at Columbia University, is recognised as one of the co-authors of 'Water Sensitive Planning for the Cities in the Global South,' an article published by MDPI in January 2023.

When discussing about the urban flooding challenges faced by Indian cities, she highlights the alarming recurrence of abnormal rainfall patterns within a 50-year cycle. A major hurdle in the case of Delhi is its dependence on inter-state governance for about 90 % of its water supply. The city's history, from pre-colonial to the present, has been marked by a fragmented approach to development, resulting in housing typologies lacking basic drainage and sewage systems.

"A new approach to urban planning, centered around water, is advocated, along with policies and frameworks that prioritize water considerations".

Regarding the state of existing grey infrastructure in Indian cities, she notes significant gaps in the information and maps available, particularly in the water supply, stormwater, and sewerage networks. Nature-based solutions (NBS) for stormwater management are viewed as a complementary system rather than an alternative, ensuring the current infrastructure is not undermined.

In response to the question of whether informality provides an opportunity for urban planners, Ms Gupta asserts that it the inability to recognize these unplanned settlements often results in their criminalization. Ms Gupta mentions the draft Water Policy prepared by the Indian National Trust for Art and Cultural Heritage (INTACH), describing it as a promising start. However, the policy is still at the draft stage due to political reasons, and a major challenge remains the lack of accurate data.

Mr Jayant Kumar, a junior engineer at the Delhi Jal Board (DJB) was interviewed regarding the ongoing infrastructure development works in Sangam Vihar. DJB is the responsible governing body for water supply and sewage management in Delhi. The in-person conversation took place at his office in Jal Vihar near Lajpat Nagar on 2nd March 2023. The questionnaire designed for this purpose can be found in Annexure-3.

He further highlighted that the neighbourhood has expanded in terms of its size in the last 20 years. On being asked about the current state of grey infrastructure in Sangam Vihar, he added that DJB is carrying out works for providing services for wastewater collection and disposal.

The details of the same could not be shared with the public for technical reasons. It was also informed that currently, all the wastewater discharge from Sangam Vihar connects to the main sewer trunk drain on the Mehrauli-Badarpur road which further transports it to the nearest pumping station, finally transporting it to the Okhla sewage treatment plant.

He believes that the expansion of Delhi Metro's network to Sangam Vihar is an opportunity that would help the community with better public transport and possible job opportunities. Lastly, he adds that the residents of Sangam Vihar could contribute by cooperating with DJB for the greater benefit of the community.

"The biggest challenge at Sangam Vihar in terms of infrastructure development is the dense nature of the settlement and overall space constraints".

3.5 Informality in Delhi

In this chapter, the focus is on the existence of dense urban settlements, commonly referred to as informal settlements, within Delhi. A brief exploration of these settlements is crucial for a more comprehensive understanding of this research. These unplanned settlements are characterised by their unplanned nature, often lacking secure and adequate housing, as well as essential services such as water supply, stormwater drains, and sewage networks. This situation exacerbates existing inequities within the city, as residents of these settlements face challenges in accessing necessities and living in suboptimal conditions.

It's noteworthy that while the contribution of informal settlement residents to greenhouse gas emissions and climate impact is minimal, they are highly susceptible to the consequences of climate change, particularly in the form of urban flooding events. Based on data from geoportal of the National Capital Region Planning Board (NCRPB), the spatial distribution of dense unplanned settlements currently existing in Delhi is observed in Figure 3-21.

Roychowdhury & Das (2021) in their report mention that according to the Economic Survey of Delhi 2019–20, about 7.7 million people, i.e., one-third of Delhi's population, live in unplanned settlements (this is over and above those living in urban villages and resettlement colonies). Constant immigration is increasing the number of people living in unplanned settlements. As per Census 2011, in Delhi, about 40 % of the people are inter-state migrants, and 1.78 million people live in slums that are scattered across the city.

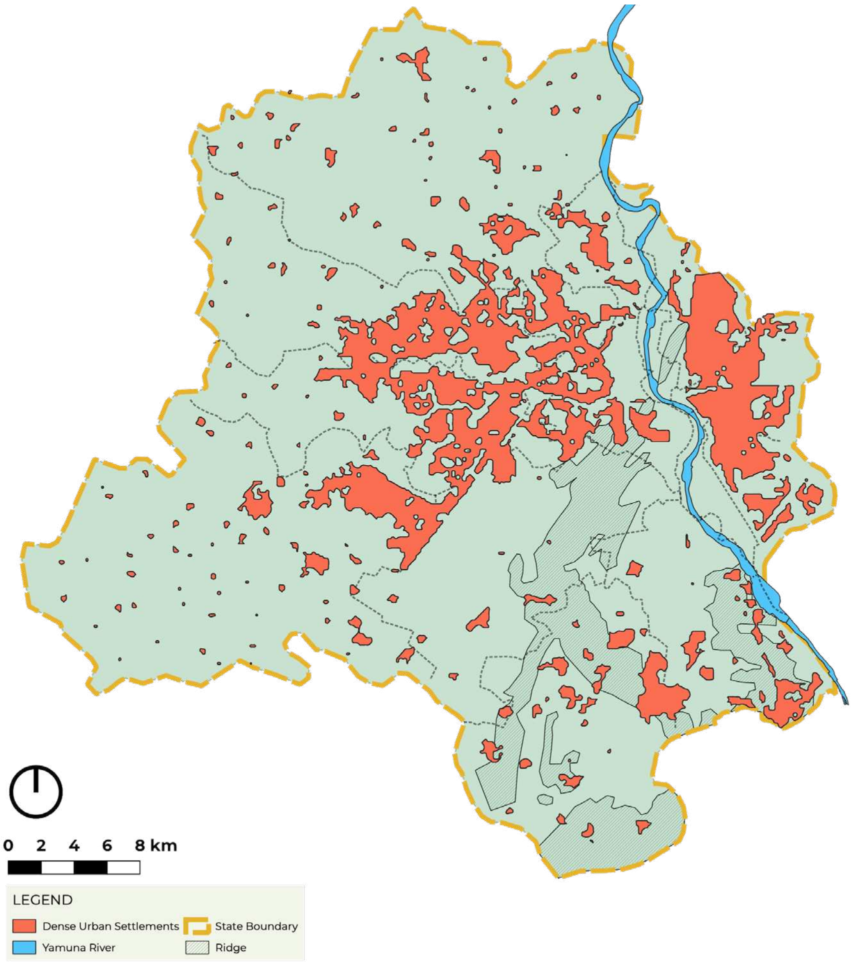


Figure 3-21: Spatial distribution of dense unplanned settlements in Delhi
Source: Adapted from NCRPB Geoportal (2023)

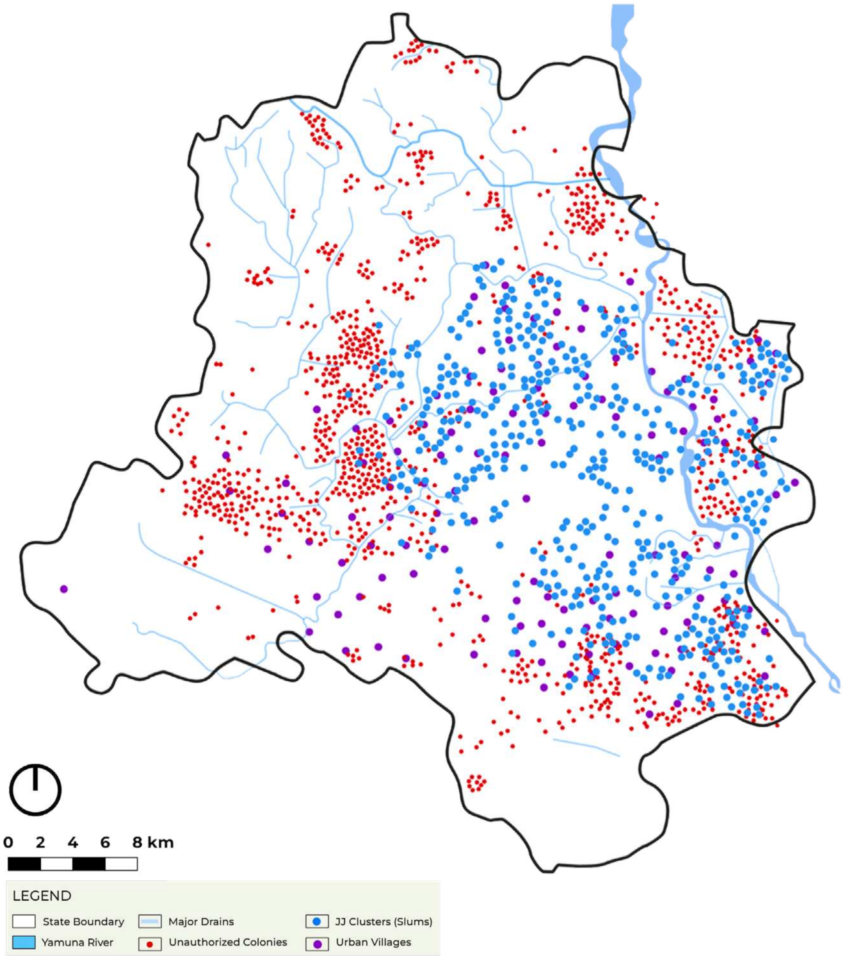


Figure 3-22: Location of dense unplanned settlements in Delhi
Source: Yadav (2020)

Informal settlements are frequently developed as stand-alone efforts, without integration into the city's overall development plan. Consequently, low-income settlements are often left disconnected from mainstream development, leading to a lack of accountability and community engagement.

The master plan of Delhi, MPD-2021 categorises settlements into formal and informal settlements where formal settlements are the ones complying with MPD norms, and informal settlements include unauthorised colonies, resettlement colonies, slums, etc. A more comprehensive classification of informal settlements has been undertaken in the Economic Survey of Delhi, it distinguishes six categories of informal settlements: unauthorised colonies, regularised unauthorised colonies, designated slum areas, Jhuggi Jhopri (JJ) Clusters, resettlement colonies, and urban villages. It's worth noting that unauthorised colonies, both those that have been regularised and those that have not, constitute the largest clusters (Roychowdhury & Das, 2021). Figure 3-23 provides an overview of the classification of settlements in Delhi, while the spatial distribution of various informal settlement typologies in Delhi can be seen in Figure 3-22.

Characteristics (Infrastructure And Services)

(Roychowdhury & Das (2021) assess the quality of housing and access to basic infrastructure in slums and other dense unplanned settlements in Delhi based on Census 2011 data. The report highlights that only 51 % of households in slums have access to drinking water, while the Delhi average is 80 %. Access to electricity, on the other hand, is relatively good in slums However, only 49 % of slum households have access to covered or closed drainage, which is significantly lower than the city's overall average. Regarding other essential services, only 55 % of households in slums have access to banking services, while the Delhi average stands at 79 %. Additionally, most unplanned settlements in Delhi are not served by the Metro network.

About 20% of Delhi's population receives 92% of the city's water, while the remaining 80% receives only 8% of the available supply of water (Ahmed & Araral, 2019). To make matters worse, distribution losses in the water supply are estimated at 58 % in Delhi (Planning Department GNCTD, 2023). It is evident that there is significant inequality in the city, and due to unplanned urban expansion, this gap is further widening.

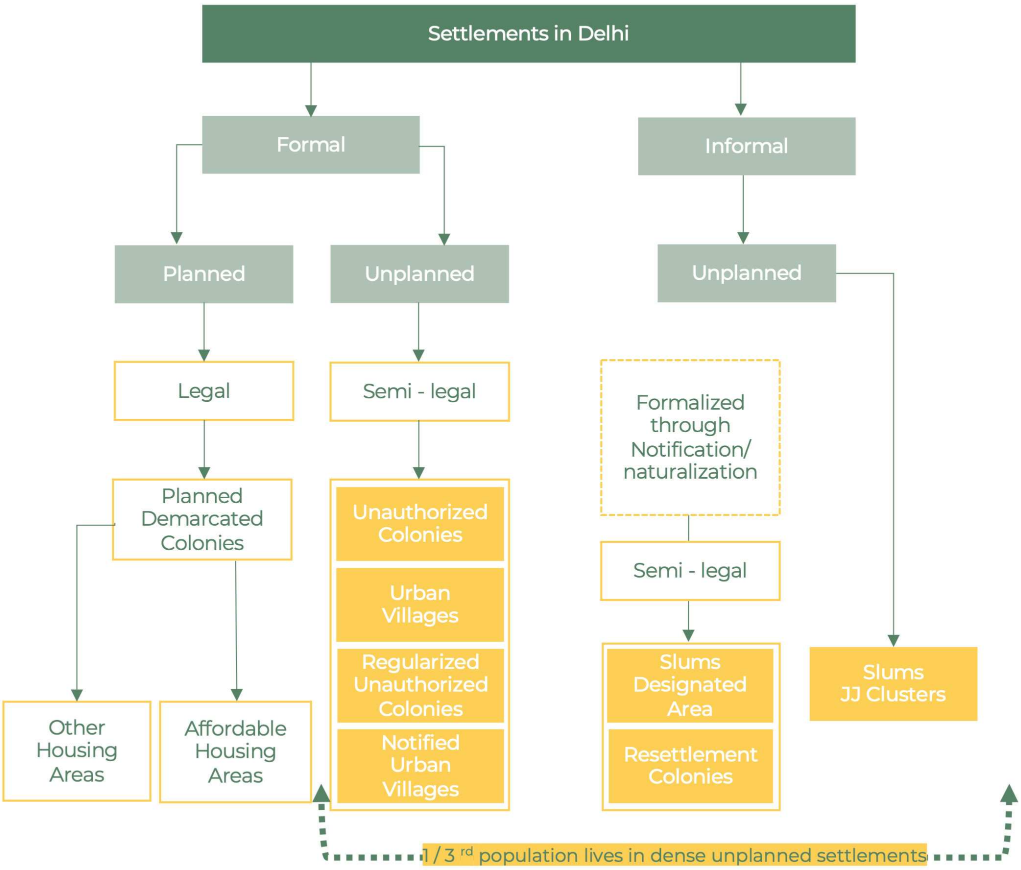


Figure 3-23: Classification of settlement typologies in Delhi
Source: Adapted from Roychowdhury & Das (2021)

3.6 Challenges and Potential for Stormwater Management

The challenges posed by urban flooding in Indian cities are multifaceted, with guidelines often focusing on rapid stormwater disposal, leading to combined sewers with pollution concerns. Drainage infrastructure is frequently inadequate, and even planned areas lack adequate stormwater infrastructure capacity, necessitating a proactive approach that accounts for both planned and unplanned settlements.

Another major challenge is the intensified precipitation pattern. In the current year 2023, Delhi witnessed torrential rainfall in the beginning of monsoon during July and the city came to a standstill. Delhi recorded over 153 mm of rain on 9 July 2023, marking the highest precipitation in a single day in July in over 40 years (Subramaniam & Suri, 2023). The combined economic loss of the floods in Delhi and northern states of India is estimated to be in the upper range of $ US 1.2 billion, as per a report, by Ecowrap (Madhukalya, 2023). This amount of rainfall resulted in both fluvial as well as pluvial flooding as the City was not well equipped.

Moreover, a fragmented approach to the development and management of stormwater is observed in Delhi. There is no single institution with comprehensive responsibility for the entire stormwater management in Delhi posing jurisdictional concerns. The administrative authority is distributed among numerous civic bodies and various departments of the Government of the NCT of Delhi and the Government of India (see Table 3-03). These entities include:

- Public Works Department, Delhi (PWD)
- Municipal Corporation of Delhi (MCD)
- Irrigation & Flood Control Department (I&FC)
- New Delhi Municipal Council (NDMC)
- Delhi Development Authority (DDA)
- Delhi State Industrial & Infrastructure Development Corporation (DSIIDC)
- Delhi Cantonment Board (DC)
- National Thermal Power Corporation Limited (NTPCL)
- Uttar Pradesh Irrigation (Old Agra Canal)

The PWD covers the largest share with 55 % of drainage length along the roadside. MCD and NDMC are responsible for 14 % and 9 % respectively and cover drainage within the districts. This fragmented approach gives rise to a highly complex and decentralised management for stormwater drainage in Delhi. Consequently, the absence of a singular accountable entity exacerbates the failures in the drainage network and perpetuates the recurring problem of urban flooding in the region (see Figure 3-24: Institutional jurisdiction for stormwater management in Delhi). The same was also pointed out in the drainage master plan prepared by IIT Delhi (Gosain et al., 2018).

Institutional Jurisdiction	Length (km)
Public Works Department (PWD)	2,064
Municipal Corporation of Delhi (MCD)	520
Irrigation and Flood Control (I&FC)	426
New Delhi Municipal Corporation (NDMC)	335
Delhi Development Authority (DDA)	251
Delhi State Industrial and Infrastructure Development Corporation (DSIIDC)	98
Delhi Cantonment (DC)	40
National Thermal Power Corporation Limited (NTPCL)	3
Uttar Pradesh Irrigation (Old Agra Canal-OAC)	0.3

Table 3-03: Institution-wise length of runoff network in Delhi. Source: Gosain et al., (2018)

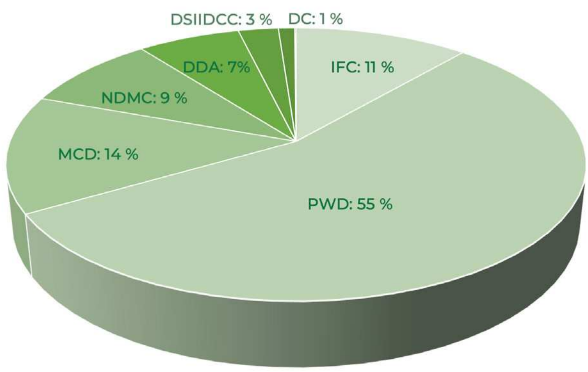


Figure 3-24: Institutional jurisdiction for stormwater management in Delhi. Source: Gosain et al., (2018)

The potential solution to challenges regarding urban flooding in Delhi lies in a shift towards a holistic approach in planning that promotes Water Sensitive Planning (WSP). Departing from the traditional focus of planning, a water sensitive planning decentres city planners' sole focus on land and reorients it towards water, creating a situation whereby equal emphasis is placed on land and water, viewing them as conjoined elements (Kumar et al., 2023).

Planning for the rapid growth of Indian cities, including Delhi, should adopt a data-driven approach. It's essential to regularly revisit planning guidelines, updating population predictions at least once every five years to keep them current. Additionally, planning should prioritise aligning with the natural flow of rivers rather than altering canals and stormwater channels, which have contributed to urban flooding issues.

Nature Based Solutions (NBS) for stormwater management should be seen as a complementary system rather than an alternative, ensuring that existing infrastructure remains effective with adequate upgradation. Advocating a new approach to urban planning that centres around water, along with policies and frameworks that prioritise water considerations, is essential. Effective stormwater management necessitates a circular economy approach, proactive design, and interventions at various scales – city, neighbourhood and building scale. Decentralised solutions and local drainage management (wherever applicable) should be a focal point. Effective planning should include public participation, stakeholder engagement, and management, moving away from top-down approaches.

According to a report by Rohilla et al. (2020), it is estimated that on an annual basis, 3,424 million litres of stormwater runoff go unutilised, ultimately creating additional stress on the city's fragile drainage network. If managed efficiently, this runoff can be harnessed, stored, recharged in parks, and moderated during periods of peak rainfall. The calculations for the estimate are based on certain baseline assumptions, including an annual rainfall in Delhi of 800 mm, peak rainfall ranging from 100 to 150 mm, infiltration structures with a depth of 2 m, and infiltration structures covering an area of 1.5 % to 3 % of the total area of parks.

Table 3-04 provides an overview of indicators related to the potential of Water Sensitive Urban Design and Planning (WSUDP) in Delhi.

Indicator	Potential of WSUDP in Delhi
Post-monsoon groundwater level	WSUDP designs for areas having shallow groundwater table are based on principles of retention and moderation of excess run-off
	Areas with steeper groundwater levels are better suited for WSUDP interventions based on the principles of infiltration
Geology and soil type	WSUDP designs for areas having a rocky terrain are limited to small-scale retention areas
	For areas having higher content of clayey soil, retention strategies are more suitable, whereas areas with sandy—loamy soil are better suited for infiltration-based WSUDP interventions
Flooding hotspots	WSUDP interventions based on retention and moderation of run-off in parks and open spaces in the vicinity of flooding and water logging hotspots can mitigate flooding risk
Low-lying areas	WSUDP interventions in parks and open spaces in low-lying areas vulnerable to flooding are essential for flood mitigation

Table 3-04: Indicators for determining potential for WSUDP. Source: Adapted from (Rohilla et al., 2020)

04 CASE STUDIES

4.1 Sponge Cities in China

Chinese cities much like the Indian cities have encroached upon areas that were once natural drainage systems such as lakes, wetlands and forests, forcing China to build new infrastructure to handle rainwater runoff. This is now being pushed to extreme limits with global warming driving more frequent and intense precipitation worldwide. In 2013, the Chinese national government initiated the "Sponge City" programme as a response to the urban water management challenges the country was facing. This program aimed to incentivise cities to embrace green and blue infrastructure, which relies on natural elements and water features, as opposed to the development of traditional grey infrastructure.

Oates et al. (2020) highlight that the program established ambitious targets: by 2020, 20 % of the total land area in each pilot city should conform to sponge city standards, and this percentage is expected to increase to 80 % by 2030. To facilitate these goals, the national government provides co-funding as initial capital. The funding ranges from US $ 59 million for regular cities US $ 88 million for municipalities directly under state government jurisdiction. An additional 10 % subsidy is granted if the pilot city successfully engages in a public-private partnership, and financial institutions are required to prioritize providing credit for sponge city projects.

For this master's thesis, a deeper analysis of one of the pilot projects - Sponge City of Qiputang Ecological Park in Taicang is summarised. The Qiputang Ecological Park project in Taicang is situated at the convergence of the Qiputang and Yangtze rivers. Acknowledging the wild nature of the location, the project aimed to preserve the existing site's natural characteristics. The objectives of the Sponge City construction were defined as focusing on stormwater regulation and storage, while concurrently emphasising ecological conservation.

Strategies and Interventions

The project incorporated economical natural revetments, gravel pavements, rain gardens, and wild vegetation communities that naturally evolve, reducing the need for costly permeable and stone pavements. This approach fostered diverse biological habitats, forming the ecological foundation for future development goals that can be decided at a later date. The water systems were interconnected through local topographical adjustments. The project implemented careful earthwork filling and excavation techniques to maintain a balance on-site and create vertical spaces for rain-collection areas. The design approach prioritised minimal intervention and employed cost-effective, low-technology, and low-maintenance sponge construction methods. These measures aim to increase the water retention time in the wetlands and enhance their ecological treatment capabilities.

Outcomes

This design places a strong emphasis on enhancing habitat and water purification within the wetland park, taking into account factors like scale, water capacity, flow rate, and water purification efficiency. It's worth noting that due to the hydraulic load associated with subsurface flow wetlands, bed filling and ongoing maintenance can be challenging and costly. Given the substantial size of the project, this design proposal opts to forego the expensive and high-maintenance subsurface flow wetland design. Instead, it focuses on more natural, ecological, and horizontally flowing wetlands, which are considered to be a more cost-effective and sustainable approach.

Figure 4-01: (a) Master plan and (b–d) actual photographs of Qiputang Ecological Park in Taicang. Source: (Ji & Rao, 2023)

An article by Stanway (2023) highlights opinions from multiple Chinese scholars and researchers regarding the Sponge City programme. Researchers add that even if the Sponge City measures had been fully executed, they would have been insufficient to avert the disasters of the 2023 floods. Experts posit that sponge city infrastructure can effectively manage rainfall amounts of no more than 200 mm per day. Severe rainfall impacted cities in typically arid northern regions, where sponge city development is less advanced. As per China's emergency ministry, the recent floods of July 2023 alone caused unprecedented damage. Floods and related geological disasters caused 142 deaths and disappearances, destroyed 2,300 homes and caused direct economic losses of US $ 2.19 billion (Stanway, 2023).

Figure 4-02: Flooded streets,Xiaogu, Sichuan province, China August 19, 2020. Source: Stanway (2023)

Figure 4-03: Flooded village after August 2023 rainfall in Zhuozhou, Hebei province. Source: The Straits Times (2023).

Takeaway

In the case of Wuhan's Sponge City programme, cost of implementing green infrastructure for a 38.5 sq km area amounted to approximately 2.13 billion US $. Comparatively, the cost of upgrading the entire city's drainage infrastructure was estimated at around 2.7 billion US $, including the installation of new pipes and 30 years of operation and maintenance (Oates et al., 2020). This cost differential challenges the common perception that green infrastructure is significantly more cost-effective than traditional drainage systems. In certain cases, the expenses associated with green infrastructure prove competitive, considering the long-term benefits and sustainability aspects of NBS solutions. While the Sponge City initiative in China has potentially lessened the consequences of recent floods, it has not fully addressed the urban flooding risk. This prompts the question of whether cities in the Global South should also prioritise the establishment of traditional grey infrastructure. NBS alone may not suffice, particularly given the extreme rainfall during monsoon seasons. An alternative approach to consider combines the advantages of NBS with infrastructure development, allowing them to complement each other.

4.2 Neela Hauz Lake Rejuvenation, Delhi

Neela Hauz is a stagnant water body in the shallow depression surrounded by low-lying Aravalli hills of Southern Ridge, and entire precipitation of the hills used to drain into Neela Hauz and the fresh water was used to supply drinking water to South Delhi at one time. Over some time due to urbanization, the source of fresh water to the lake was disrupted and the only source of water today is raw sewage and STP-treated water of 1 million litres per day (mld) (C. R. Babu, 2020).

Situated next to the Sanjay Van, opposite Jawahar Lal Nehru University in South Delhi, it is a component of the Barapullah drainage basin, which ultimately flows into the Yamuna River. This area is part of the Southern Ridge in the city. In the past, Neela Hauz covered an expanse of 7 hectares, but due to urbanization, its size dwindled to under 3 hectares.

In 2011, following various efforts and Public Interest litigation by local community groups, a high court ruling compelled the Delhi Development Authority (DDA) to undertake conservation and protection measures for the lake. The adopted approach involved establishing a biodiversity park around the lake and implementing a naturally constructed wetland technique to treat sewage. The implementation took place in 2012 with the collaborative efforts from DDA, the local community and Prof. C. R. Babu and his team from the Delhi University.

Figure 4-04: Polluted and dried up Neela Hauz lake around 2010. Source: Babu et al. (n.d.)

Strategies and Interventions

Dredging was done to revive the water depth and remove the construction debris. Water supply was restored with the treated water from the Wastewater Treatment Plant. A constructed wetland similar to a natural wetland is engineered for efficient treatment of sewage. It has two oxidation ponds, a gradient channel with a sieve/mesh and boulders acting as filters, three physical treatment tanks with stone filters, larger riverbed pebbles and with smaller riverbed pebbles, ridges of the gavel (20 mm) and furrows having 25 aquatic plants, and microbial communities. The treated water at the outlet has almost the same quality as that of river water. A floating wetland was introduced, which consists of plants grown on a mat built from wire mesh, drainage pipes and used water bottles. The plants purify the water by removing algae and absorbing nitrates, phosphates and other heavy metals.

Outcomes

It took two years to make it functional with zero energy input. Today the constructed wetland converts one million litres of sewage water per day into clean water comparable to tap water having less than BOD 4mg/litre per day. The lake's water quality and volume have been rejuvenated by implementing a natural ecosystem-based approach, ensuring sustainability and minimal maintenance, as it operates without any energy consumption. The constructed wetland system is effectively processing 0.5 mld of wastewater. The return of birds to Neela Hauz serves as a crucial indicator of the lake's improved health and biodiversity. Following its complete restoration through entirely natural methods, the lake has become a symbol of environmental regeneration.

Figure 4-05: Restoration process of Neela Hauz lake. De-silting works (top left); In situ constructed wetland (top right); citizens bird watching at the restored laked (middle); Neela Hauz after restoration in 2015 (bottom). Source: Babu et al. (n.d.)

Takeaway

The Neela Hauz Lake rejuvenation initiative stands as a remarkable success story on multiple fronts. It effectively addresses urban challenges related to water supply, stormwater and wastewater management, and offers a promising solution by transforming an old catchment area into a thriving biodiversity park. The current state of the lake serves various purposes and serves as a stellar illustration of utilising nature-based approaches to mitigate the risk of urban flooding. Perhaps, driven by the need to combat climate change risks and implement similar successful strategies, the Delhi government launched the "City of Lakes" initiative in 2018, encompassing the entire capital region of New Delhi to address water supply issues and implement sustainable stormwater management. While the potential for such concepts is undoubtedly high, the challenge lies in extending their benefits to densely populated urban areas. In the context of Delhi, decentralised solutions like the Neela Hauz Lake rejuvenation, in conjunction with the provision of suitable grey infrastructure for densely populated settlements, present a practical and effective solution for mitigating the risk of urban flooding.

05 FRAMEWORK GUIDANCE FOR INDIAN CITIES

In this chapter, the discussion centres on the rationale for the development of a new framework for Water Sensitive Urban Design and Planning (WSUDP) in Indian cities. The analysis draws from extensive research as well as literature reviews, and it proceeds to outline the key principles that serve as the foundation of this WSUDP framework. Consequently, the chapter presents the anticipated outcomes and impacts that this emerging WSUDP framework is expected to generate. These projected outcomes and impacts are expected to be closely aligned with the framework's core principles and will be instrumental in illustrating its potential significance in the context of equitable urban development.

5.1 The Purpose and Need of a new Framework for Indian Cities

The purpose and the need for a new framework are explored by examining the key challenges that are specific to Indian cities, as well as those shared to some extent by cities in the Global South with comparable size and population density. This underscores the necessity for a tailored WSUDP approach to address these challenges effectively. This is also visually summarised in Figure 5-01.

Impact of Climate Change

Indian cities frequently contend with the rigours of tropical monsoons, characterised by brief, intense bouts of rainfall interspersed with dry intervals. The existing combined sewerage and drainage infrastructure in these urban areas is often in a state of disrepair, proving ill-equipped to cope with even minor rain events.

During episodes of heavy precipitation, it is not uncommon to witness streets serving as makeshift drainage channels, particularly in unplanned settlements, slums, and other unplanned urban areas. This phenomenon underscores the urgent need for improved stormwater management strategies and infrastructure development.

Urban built environment

Indian Cities are witnessing not only rapid urbanization but also congested and dense urban habitations. Delhi has outgrown its state limit, into four neighbouring cities of Ghaziabad and Noida in Uttar Pradesh, and Faridabad and Gurgaon in Haryana. The built footprint of Indian cities is creating an urban watershed/catchment that in normal rainfall periods generates large volumes of runoff that is difficult to retain for groundwater recharge or other WSUDP measures (Kapur, 2023).

Growing urban inequity and lack of urban planning

The fundamental tenets and application of urban planning are encountering substantial hurdles as numerous Indian cities extend into unplanned settlements and exclusive, gated communities. Urban planning norms are being disregarded in the development of built-up areas within cities. The increased population density adds extra pressure on the existing grey infrastructure (water supply, stormwater and sewage). As highlighted by Kapur (2023), this scenario in the context of the Indian Cities, translates into two things.

First, the need for more grey infrastructure to meet the water supply, sanitation, wastewater and stormwater drainage requirements of unplanned settlements that now constitute as much as 50 % or more of the population in several cities. Second, there is a need to ensure that the benefits of green infrastructure (of lakes and water bodies rejuvenation and groundwater recharge) are shared with unplanned settlements through cross-subsidy of water and sanitation services.

Sub-optimally functioning existing infrastructure

Small and medium-sized cities lack sanitation and drainage infrastructure. Combined sewers that also drain stormwater overflow in the monsoons. No Indian city is 100 % sewered or treats all its sewage and septage.

The functionality of existing sanitation infrastructure (sewered and non-sewered systems) remains a challenge for Indian cities. In Chapter 1 of this research, it is observed in Figure 1-04: Water Sensitive City Transition Framework that a full water supply city (pillar 1) and sewered city (pillar 2) are the cornerstones of any city's transition to a water sensitive city.

Water conflicts

India Cities have a range of water conflicts including inter cities and intra-city, rural–urban, agriculture–industry–domestic water priorities. In the case of Delhi, its high dependency on neighbouring states for water supply leads to water-sharing disputes, flow regulation, flood control and pollution control challenges. Therefore, reducing the city water and wastewater footprint will potentially reduce the water conflicts, with a spillover benefit to rural areas.

Weak and inter-dependent jurisdiction

Delhi currently has approximately nine organisations tasked with managing stormwater in the city along involvement of various inter state agencies due to its dependence of raw water. This fragmented approach, consequently, leads to the absence of a single responsible entity and exacerbates the issues within the drainage network, perpetuating the persistent problem of urban flooding in the region (please refer to Figure 3-28 in chapter 3 for a breakdown of governmental jurisdiction for stormwater management in Delhi).

Figure 5-01 is an adapted representation derived from Hoyer et al. (2011), highlighting the fundamental principles of Water Sensitive Urban Design (WSUD). It delineates goals and desired outcomes informed by international best practices. The figure incorporates an overlay of country-specific challenges encountered by Indian cities, including factors such as a densely urbanised built environment, sub-optimal existing grey infrastructure, governance challenges, water conflicts, poor citizen awareness and engagement, growing inequity, and more. These intricacies, often overlooked in the WSUD discourse and literature originating from the Global North, underscore the imperative for a framework specifically tailored to the unique context of Indian cities. By addressing these challenges, a nuanced Water Sensitive Urban Design and Planning (WSUDP) framework can pave the way for sustainable and resilient stormwater management in the Indian context.

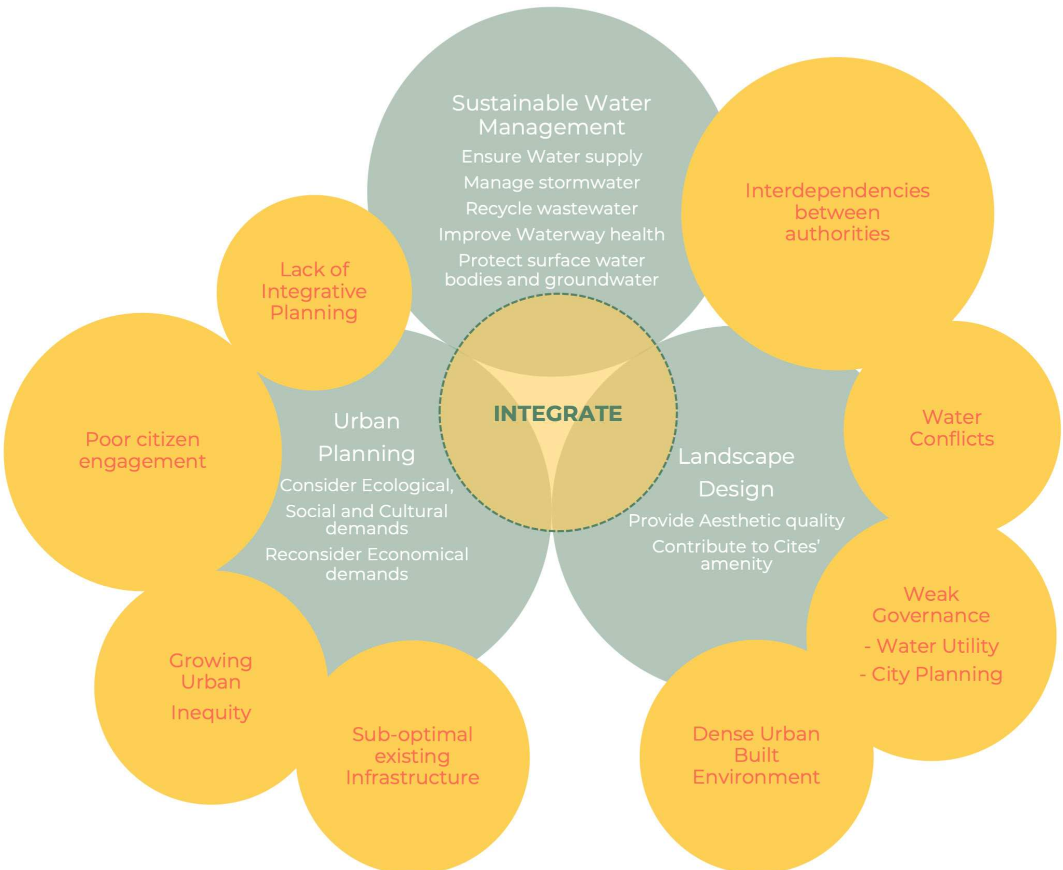


Figure 5-01: Country specific challenges faced by Indian cities that are missing in Global North WSUD literature

5.2 Key Principles

The Rationale of the Framework

The rationale of the proposed Water Sensitive Planning (WSP) framework is rooted in equity. In unplanned areas of the city characterised by high population density and lack of planning, where the conservation of water resources is challenging, it may not be feasible to expect groundwater recharge efforts. These areas typically receive piped water supply and have access to affordable and inclusive sewerage infrastructure and services.

In economically more affluent settlements, often planned, residents have the means and resources to implement groundwater recharge measures, thereby reducing their reliance on piped water supply. They also manage their sewage in a decentralised manner, minimising the burden on the centralised sewerage system to the greatest extent possible. This is also visually summarised in Figure 5-02.

The framework outlines several key principles of WSP that can be instrumental in making water a central focus in the planning process for Indian cities. These principles as depicted in Figure 5-03 include:

- **Safeguarding Water Commons**: Resolving conflicts around existing water bodies, giving them legal protection and restoration under water or city planning guidelines.
- **Strengthen statutory norms**: Enhancing urban planning and stormwater management regulations, improving enforcement, and ensuring compliance with building standards
- **Land use zoning**: Prioritising water availability in land use zoning, emphasising water-conserving land use, and considering the relationship between water availability, demand, and pollution.
- **Improved efficiency of existing grey infrastructure**: Focusing on the operational efficiency and maintenance of infrastructure for drainage and wastewater treatment.

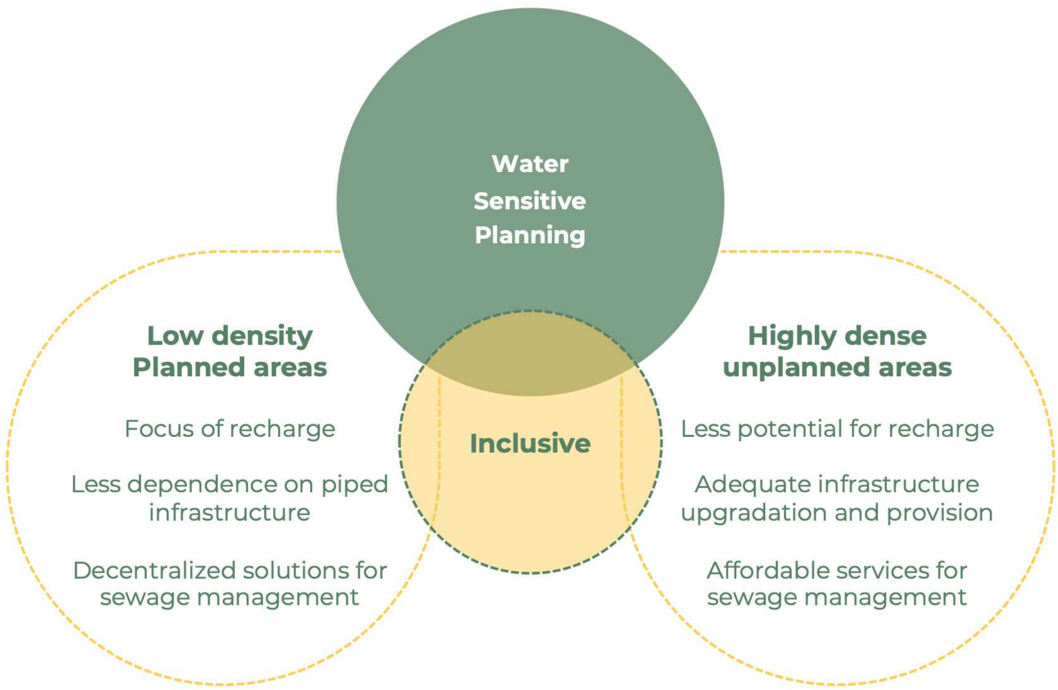


Figure 5-02: Rationale of the WSP framework for Indian Cities
Source: Adapted from Kapur (2023)

- **Sustainable urban drainage and permeable spaces**: Incorporating green open spaces for stormwater recharge, aligning road layout with hydro geographical features, and connecting them with city-level drainage systems

- **Separate stormwater and wastewater network**: Establishing separate drainage and sewerage systems, as well as decentralised sewage treatment systems

- **Wastewater reuse and treatment**: Reuse after treatment is another guiding value of the WSP. Promoting the reuse of adequately treated wastewater for various purposes, with an emphasis on reuse rather than just treatment.

- **Decentralisation**: Encouraging decentralised solutions such as rainwater harvesting and wastewater treatment at the local level for water management that consider hydro geographical orientations and population density.

- **Planning roads**: Redesigning roads and pavements to reduce flooding from stormwater. Decentralised drainage systems should be built along both sides of a road transporting stormwater to the nearest pervious places such as parks and water bodies.

- **Data-driven decision making**: Utilising data and technology to make informed decisions and monitor the effectiveness of water sensitive planning initiatives. Emphasis need to be paid to maintain and update data regularly. Availability of this data in public domain for research and knowledge sharing is of paramount importance.

- **Public participation and transparency**: Involving the public and various stakeholders in decision-making process before implementation of strategies, ensuring transparency and inclusivity through awareness campaigns in local language and pictograms.

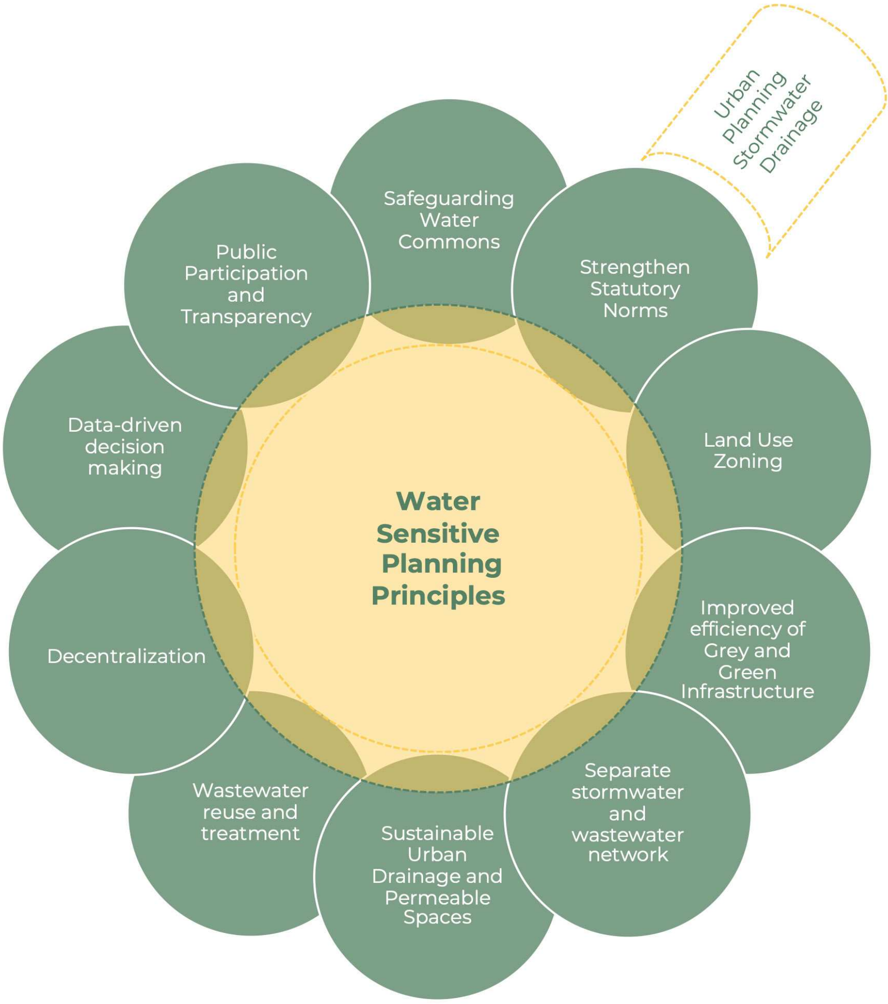


Figure 5-03: Key principles of water sensitive planning framework for Indian cities

5.3 Desired Outcomes and Impact

The following are the desired outcomes of the Water Sensitive Planning framework, and these outcomes along with their indicators are also briefly summarised in Table 5-01.

- Hybrid approach to sanitation and wastewater infrastructure: A combination of centralised and decentralised sanitation and wastewater systems is recommended to be put into practice in the city.
- Urban flooding mitigation: Implementation of strategies and infrastructure to effectively mitigate urban flooding, with an emphasis on less privileged areas, by addressing stormwater management, drainage systems, and flood-prone zones within the city.
- Stormwater reuse: Harnessing the potential of stormwater reuse to supplement the city's water resources, promoting sustainable practices such as rainwater harvesting and stormwater capture for non-potable uses like landscaping and irrigation, reducing the strain on conventional water supplies.
- Addressing infrastructure gaps in less privileged areas: A comprehensive assessment of water, wastewater, and drainage infrastructure in under-served communities is crucial. Priorities must be established, and incremental, substantial planning should be carried out to bridge these gaps.
- Efficiency of existing wastewater facilities: Prioritising the improvement of operational efficiency and maintenance of existing wastewater treatment plants over creating new capital infrastructure.
- Incorporating stormwater drainage standards: Review and integration of stormwater drainage norms and design parameters into new Detailed Project Reports (DPRs) and infrastructure upgrade plans for the city.
- Enhanced water planning for security: Improved city-wide water planning for enhanced water security, including aquifer mapping and the development and execution of water recharge policies and strategies.
- Mitigating water pollution: Efforts to reduce pollution levels in both surface and groundwater sources.
- Energy efficiency: Achieving energy savings by promoting rainwater recharge and reducing electricity and energy consumption in the long-distance pumping of water from rivers and reservoirs.
- Substitution with groundwater: A shift towards groundwater as a replacement or substitute for the city's water supply to reduce electricity and energy consumption associated with long-distance water pumping.
- Wastewater reuse: Utilising treated wastewater and biosolids within the city and in rural areas, both inside and outside the city limits.
- Knowledge and awareness: Increasing knowledge and awareness of water-sensitive city initiatives through open-source platforms, information systems, and feedback mechanisms. These tools enable better planning for future interventions.

Impacts

The framework aims to enhance the quality of urban living in Indian cities by delivering measurable reductions in urban flooding, with a particular focus on improving conditions for the less privileged living in densely populated urban areas. It also seeks to establish greater accountability among service providers, ensuring the effective implementation of strategies and their ongoing maintenance. Additionally, the framework contributes to the integrity of the water and nutrient cycles, promoting sustainable resource management.

Goal of the framework

Indian cities commit to the inclusive use and reuse of water resources, including water supply, sewage systems, and stormwater management. The framework acknowledges the existing inequity and the need to address disparities in dense urban settlements, forming the basis for long-term interventions towards water sensitive cities.

S No	Outcome	Indicator	Unit
1	Hybrid approach to sanitation and wastewater infrastructure	Percentage of households or areas implementing hybrid systems.	%
2	Urban flooding mitigation	Reduction in the frequency and volume of urban flooding events	Number
3	Stormwater reuse	The volume of stormwater captured and reused for non-potable purposes, such as landscaping and irrigation, compared to the total stormwater generated.	litres
4	Addressing infrastructure gaps in less privileged areas	The number of under-served communities with improved water, wastewater, and drainage infrastructure, as well as the extent of coverage of incremental planning in these areas.	Number; %
5	Efficiency of existing wastewater facilities	Percentage increase in the operational efficiency of existing wastewater treatment plants.	%
6	Incorporating stormwater drainage standards	The number of infrastructure upgrades that have incorporated stormwater drainage.	Number
7	Enhanced water planning for security	Progress in aquifer mapping, water recharge policies, and strategies developed and executed to enhance water security.	%
8	Mitigating water pollution	Reduction in pollution levels in both surface and groundwater sources.	Number; %
9	Energy efficiency	Energy savings achieved through reduced electricity consumption.	%
10	Substitution with groundwater	Increase in the use of groundwater as a substitute for long-distance water supply.	%
11	Wastewater reuse	Volume of treated wastewater and biosolids reused within and outside the city.	litres
12	Knowledge and awareness	The number of citizens and stakeholders engaged through open-source platforms	Number

Table 5-01: Outcomes along with their indicators of WSP framework

06 CONCEPT DESIGN: FRAMEWORK IMPLEMENTATION

In this chapter, Concept design: framework implementation in New Delhi, an in-depth understanding of the study area, Sangam Vihar (dense unplanned settlement) is developed by delving into its historical development and rapid growth over the years. The chapter further explores the condition of the existing grey infrastructure and related services within the settlement. This assessment is accomplished through a combination of site interviews with residents, the utilization of SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis, problem tree analysis, and urban analysis of the unplanned settlement of Sangam Vihar. Additionally, data from an on ongoing research by CSE (2023) has been utilised. The framework proposed in chapter 5 serves as a foundational guide, offering a potential solution for the application of Water Sensitive Planning (WSP) principles aimed at mitigating flooding within the settlement.

6.1 Study Area and Selection Criteria

Sangam Vihar is geographically delineated by the Mehrauli-Badarpur road to its northern boundary, while the southern and eastern limits adjoin the Asola Bhatti Wildlife Sanctuary. To the west, it shares its border with the rural villages of Tigri, Deoli, and Khanpur.

As per the most recent ward and zone map of Municipal Corporation Delhi (MCD) (State Election Commission, 2022), Sangam Vihar falls within Delhi State Assembly constituency number 49, further divided into three municipal wards. As indicated in Figure 6-01, these municipal wards numbers 163, 169 and 168 constitute Sangam Vihar A, Sangam Vihar B and Sangam Vihar C respectively. Ward A falls under the South zone while wards B and C fall under the central zone (see Figure 6-01).

The total land area is 8.46 sq km, out of this, roughly 3.34 sq km is inhabited while the remaining 5 sq km is protected land under Asola Bhatti Wildlife Sanctuary (refer Figure 6-02). The reported population for the entire settlement of Sangam Vihar stands at 220,330 individuals (voters), as per data from the State Election Commission (2022). This figure significantly under represents the actual population as it only includes individuals eligible for voting, excluding residents under the age of 18 years. The true population of Sangam Vihar is notably higher when considering all age groups.

Presently, two primary roads namely, Ratiya Marg and Mangal Bazaar Road run north-south through Sangam Vihar from the Mehrauli-Badarpur Road. These roads boast mixed and commercial land use lined with shops selling goods and services at the ground level, while floors above indicate residential use. These roads are the only two entry-exit points for the settlement, connecting it with the city via the Mehrauli-Badarpur Road. All interior roads in the various blocks of Sangam Vihar start from one of these two main roads. During peak hours traffic is very heavy, and it can take an hour to get from anywhere in Sangam Vihar to the main Mehrauli- Badarpur road (Banda et al., 2015). Sangam Vihar lacks public bus services within its boundaries, with the nearest bus stops situated near the entrances along the two main roads. As a result, residents rely on various modes of transportation such as bicycles, cycle rickshaws, scooters, motorbikes, autorickshaws, and private cars to travel in and out of the settlement. However, shortly, Sangam Vihar will be connected to the Delhi Metro as the construction work for the metro network extension is ongoing.

During multiple site visits in March 2023, the settlement revealed a diverse landscape of housing, reflecting incremental construction over time. The houses vary significantly in both size and quality, majority of them are multi-storeyed, with some households even having basements. According to the Delhi Jal Board (DJB), Sangam Vihar relies on various water sources, including the Sonia Vihar pipeline, DJB water tankers, private water tankers, community bore wells, and public stand posts (CSE, 2023). The same report also highlights that despite having approximately 60 km of regular water supply network infrastructure

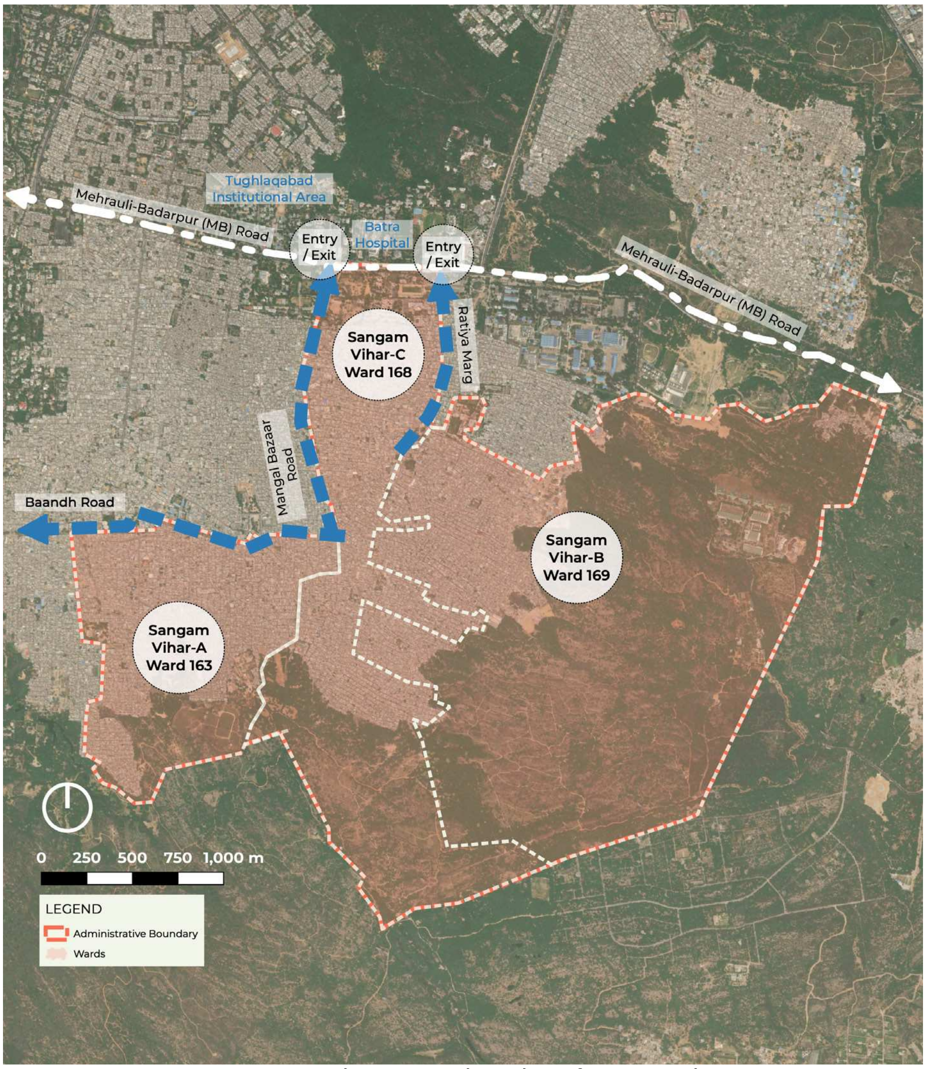


Figure 6-01: Administrative boundary of Sangam Vihar
Source: Data adapted from State Election Commission (2022)

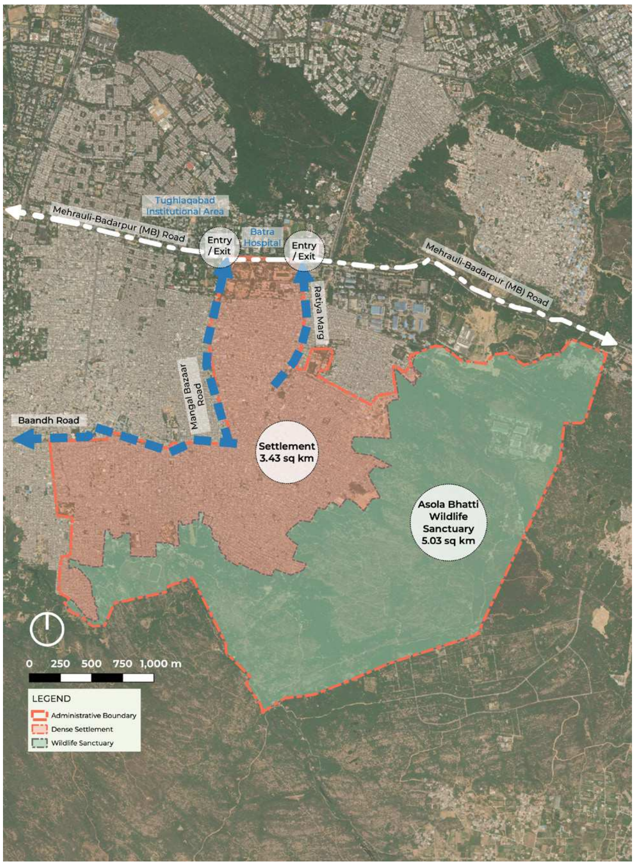


Figure 6-02: Boundary of study area in Sangam Vihar

8.46km²
Total land Area

220,330
Voters
(as of 2022)

65,967
Voters/ km²
Population Density

in place throughout Sangam Vihar, only a meagre 2 MGD (million gallons per day) of water is being supplied which is significantly short of the specified water demand, estimated at 6.6 MGD, based on a per capita water consumption rate of 150 litres per capita per day, as recommended by the Central Public Health and Environmental Engineering Organization (CPHEEO).

Based on ongoing research by CSE (2023), the DJB has undertaken the construction of peripheral sewer lines along the main Devli Road and Ratiya Marg. These sewer lines are connected to the trunk sewer line on MB Road, which ultimately terminates at the Okhla Sewage Pumping Station (SPS) through Sarita Vihar SPS. Approximately 58 km of sewerage network infrastructure is being laid in this effort, with roughly 70% of the work already completed. This initiative aims to enhance wastewater management and sanitation services in Sangam Vihar.

Selection

The dense urban unplanned area underscores the fundamental distinctions between cities in the Global North and India. The haphazard nature of this settlement, population size and insufficient grey infrastructure, provides a compelling illustration of the imperative for implementing a framework that prioritises equity and inclusive development. The settlement indicate high vulnerability to urban flooding risks during monsoons annually. Frequent cases of waterlogging are also reported in non-monsoon seasons, primarily due to clogged stormwater drains.

6.2 Historical Overview

The emergence of Sangam Vihar in the 1980s identifies early settlers as labourers who had come to Delhi from Uttar Pradesh, Haryana, Bihar, and Rajasthan. These labourers migrated to Delhi to work on construction for the 1982 Asian Games and in the Okhla Industrial Area and needed affordable housing (Banda et al., 2015). This settlement predominantly occupies agricultural land that originally belonged to the villages of Tigri, Deoli, Tughlaqabad, and Khanpur. During the 1980s, some private property dealers acquired the land from farmers, subdivided it into multiple plots, and sold them to people." By the end of the 1980s, it is estimated that approximately 100,000 people had settled in the area (Banda et al., 2015).

From the inception of the settlement, plots have been transferred through the use of a General Power of Attorney (GPA). However, in 2012, the Supreme Court clarified that the use of GPA in property transactions is severely restricted, emphasising that a "power of attorney is not an instrument of transfer concerning any right, title, or interest in an immovable property." Despite GPAs being used as documentary evidence of land and structure transfer, they do not establish legal ownership, which remains with the original landowner.

Property dealers continue their operations in the settlement and possess expertise in the necessary documentation for buying and selling plots and constructed houses. Although most residents are aware that GPAs do not grant them clear land titles, buyers frequently refer to themselves as the "owners" of the plots. Furthermore, it is common practice for the second and third storeys of constructed houses to be rented out to tenants.

The population residing in Sangam Vihar today comprises migrants from various regions of India, with a predominant presence from Uttarakhand, Uttar Pradesh, and Bihar. As reported by Banda et al. (2015), an elected representative from Sangam Vihar aptly pointed out that the settlement's name, "Sangam," mirrors this diversity. Just as Sangam refers to the confluence of three holy rivers—Ganga, Yamuna, and Saraswati, Sangam Vihar serves as a confluence point for people from all corners of the country who flock to bigger cities from rural India in search of better job security.

6.3 Study Area Research

The methods applied to evaluate the status quo in Sangam Vihar involve a combination of research methodologies. The problem tree analysis sets the base and guides better comprehension of the study area, coupled with site interviews with residents during the site visits, the utilization of SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis and urban analysis of Sangam Vihar.

The problem tree analysis reveals a distressing confluence of factors contributing to recurring flooding incidents in dense urban settlements in Delhi, and this predicament applies to Sangam Vihar as well. The primary causes are intensified precipitation patterns driven by climate change and inadequate urban planning guidelines. The unplanned nature of the settlement and deficient stormwater infrastructure stand out as prominent contributors to this issue.

Furthermore, within Sangam Vihar, the absence of adequate solid waste infrastructure, coupled with a lack of public awareness, often results in the obstruction of open drains designed for stormwater runoff. The presence of a substantial amount of sealed surfaces leads to a substantial volume of runoff that overwhelms the existing drainage network, effectively transforming Sangam Vihar into a watershed. The settlement experiences recurring flooding and waterlogging incidents.

Consequently, these conditions manifest in social and economic losses. Streets become inundated, causing increased traffic congestion and a surge in road accidents during the monsoon season. Unsegregated solid waste floating on the streets is a common sight in Sangam Vihar even during the non monsoon months. The combination of stormwater and grey water from the settlement is a serious health hazard. This effluent potentially leads to waterborne diseases that pose a significant health threat to the community. Notably, the most severe damage occurs on an ecological front as the excessive runoff overflows and mixes with trunk sewer drain on MB road. The untreated discharge eventually flows into the Yamuna River, natural drains along its way, and the ground, resulting in severe environmental degradation and long-term hazards. Figure 6-03 provides an overview of the current situation in Sangam Vihar.

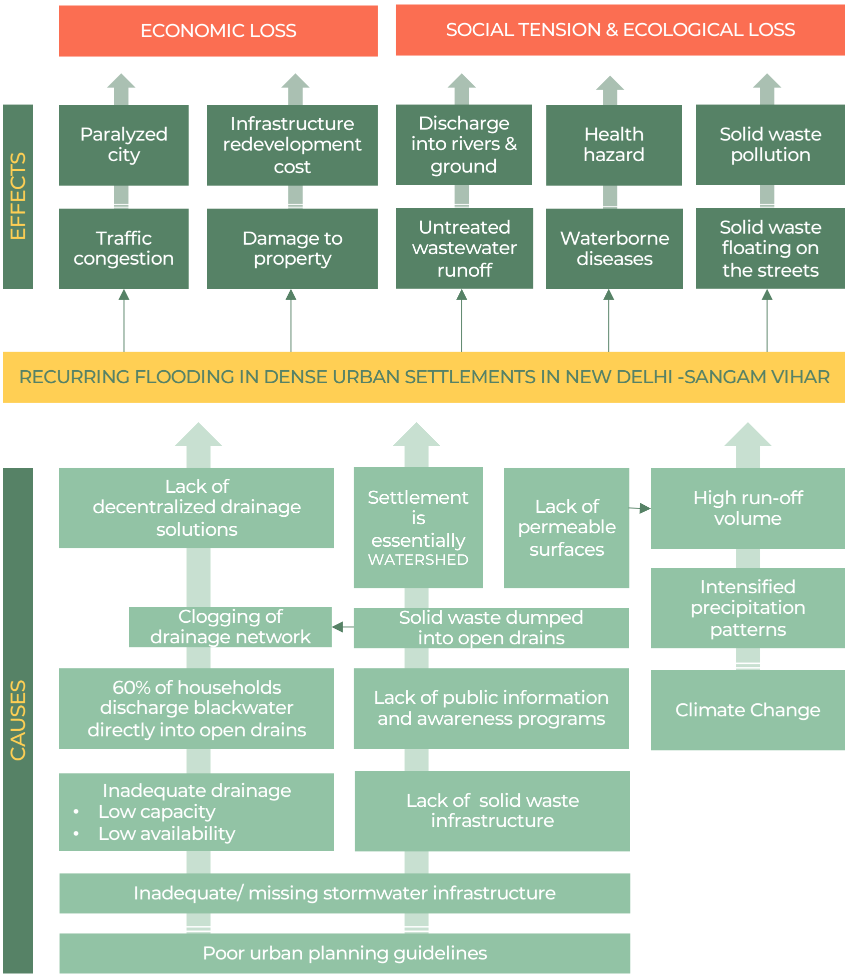


Figure 6-03: Sangam Vihar – Problem tree

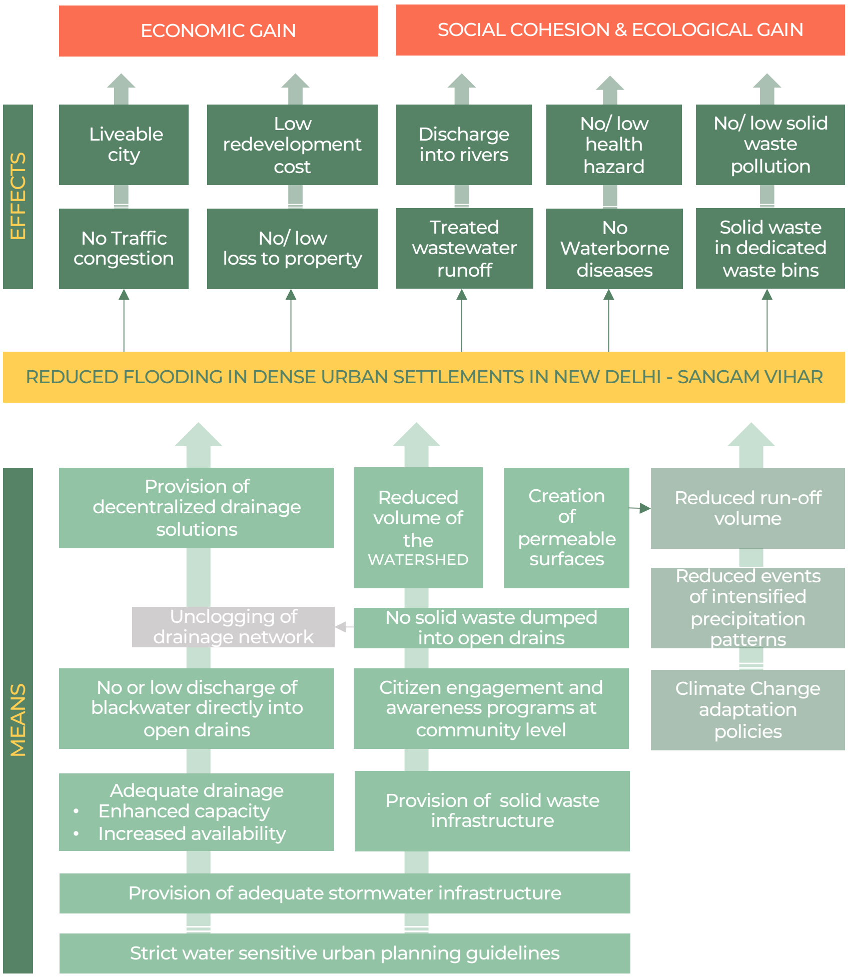


Figure 6-04: Sangam Vihar – Objective tree

It is important to recognize that while urban flooding incidents are prevalent, they can be mitigated through the adoption of specific measures (refer Figure 6-04: Objective tree).

There is a pressing need for enhanced urban planning guidelines grounded in the principles of Water Sensitive Planning. This necessitates the modernisation and enhancement of existing grey infrastructure which is further complemented by the incorporation of decentralised drainage solutions designed to manage excess runoff effectively. Moreover, the establishment and efficient management of a robust solid waste infrastructure represents pivotal steps in ensuring effective stormwater management.

Achieving this objective requires concerted efforts from all stakeholders, including awareness campaigns aimed at educating and empowering residents to manage their solid waste responsibly, thus averting the obstruction of drainage systems. These multifaceted actions are instrumental in reducing the incidence of urban flooding and enhancing the overall resilience of urban settlements like Sangam Vihar.

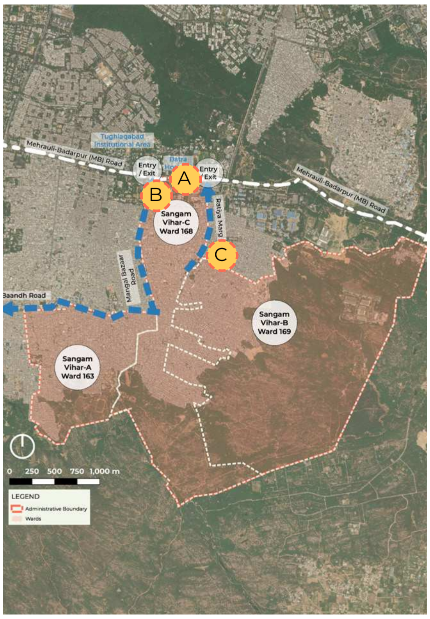
These means can also achieve long-term benefits of social cohesion and ecological gain. The WSUDP framework will not only improve the overall liveability in such dense settlements in Delhi but also reduce property damage, waterborne diseases and groundwater pollution. An overview of the same is also reflected in Figure 6-04: Sangam Vihar – Objective tree analysis.

6.3.1 Identification Of Strengths, Weaknesses, Opportunities, and Threats of the Study Area

Strengths

The Sangam Vihar DDA park, situated to the north along the Mehrauli-Badarpur (MB) road, stands as a prominent asset within the settlement. Additionally, the presence of the Asola Wildlife Sanctuary to the south serves as a valuable green space amid the densely populated urban environment of Sangam Vihar. These two green areas represent significant positive aspects in the vicinity of the settlement. It is noteworthy that the Asola Bhatti Wildlife Sanctuary is a designated protected area, separated from the settlement by a 3 m high boundary wall to prevent any further organic expansion of Sangam Vihar into the Aravalli range. Meanwhile, the DDA park holds the potential to serve as a crucial community space and a potential area where WSP strategies could be implemented.

The ongoing construction for the extension of Delhi's Metro network near Sangam Vihar is a major boost towards an accessible public transport. Furthermore, other spaces within the settlement which feature unsealed and partially permeable areas, such as government schools, temples, mosques, and smaller land parcels. These spaces contribute to the overall diversity and potential for improving the environmental quality and community life in Sangam Vihar. Figure 6-05 provides an outlook for the existing situation, highlighting strengths of Sangam Vihar



Key Plan of Sangam Vihar

Figure 6-05: Sangam Vihar strengths - metro network (right top, location A); DDA park (right middle, location B); playground in school (right bottom, location C)

Weaknesses

During the site visits, a prevailing and critical issue that emerged was the recurrent occurrence of obstructed open stormwater drains. These drains, left uncovered and designed with inadequate dimensions, are ill-suited to accommodate the substantial volume of runoff generated within Sangam Vihar. In most cases, the open drains from secondary streets are clogged at the junction where it connects the drainage network under the primary streets, leading to waterlogging issues. The absence of a robust solid waste infrastructure is glaringly evident throughout the neighbourhood.

Compounding the problem, these stormwater drains convey mixed water, combining rainwater with greywater originating from toilets and kitchens within households, effluents from garages and other small scale industries in Sangam Vihar. The accumulation of debris and waste within these drains frequently leads to overflows, resulting in a heightened risk of waterborne diseases and a significant health hazard for the community. This issue underscores the urgent need for improved stormwater and solid waste management solutions in Sangam Vihar. Figure 6-06 indicate the weaknesses in the settlement.

Figure 6-06: Sangam Vihar weaknesses - solid waste on streets (bottom left); clogged open drains (top right and middle right); haphazard grey infrastructure - water supply pipes (bottom right)

Opportunities

The provision of services of water supply, stormwater management, and wastewater infrastructure presents a pivotal opportunity for improving the living conditions in Sangam Vihar. As of March 2023, the Delhi Jal Board (DJB) is actively engaged in the phased development of essential infrastructure within the area. During the site visit, it was observed that a double walled corrugated high-density polyethylene pipe (HDPE) for sewage conveyance is being installed in both secondary and tertiary streets throughout Sangam Vihar. The construction works are ongoing at multiple locations, the proposed grey infrastructure network layout is not available in public domain making it difficult to quantify the total network coverage. Additionally, green field area in Asola Bhatti Wildlife Sanctuary provides a potential for utilising low lying open/ green spaces for a decentralised solution for stormwater management. Figure 6-07 provides an overview of possible opportunities in Sangam Vihar.

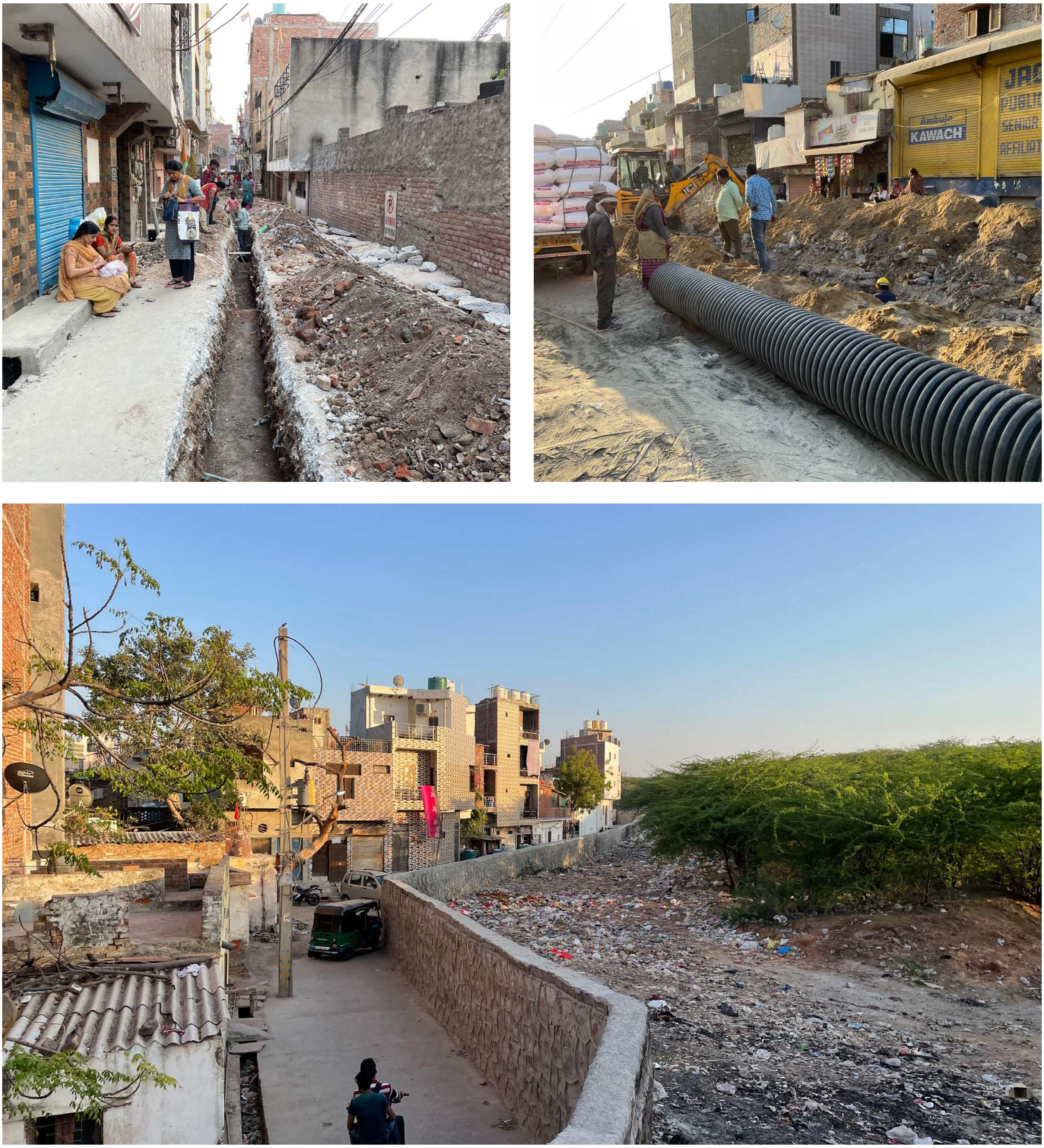


Figure 6-07: Sangam Vihar opportunities - sewage network ongoing works (top left and top right); Boundary wall between settlement and green field of Asola Bhatti Wildlife sanctuary (bottom)

Threats

One of the primary threats in Sangam Vihar is the direct intermixing of greywater and stormwater. Additionally, buildings that have ground floor below the road level are most vulnerable during flooding of streets. This situation is exacerbated by the mixed land use within the settlement. The streets serve as host to a variety of polluting activities, including small-scale factories and garages. These activities operate without adhering to any regulatory guidelines and directly discharge their waste into the open drains, which were originally intended for stormwater runoff. This compounding of issues not only strains the existing infrastructure but also poses a considerable environmental and health risk to the community. Figure 6-08 depicts possible threats that the residents of the Sangam Vihar face on daily basis.

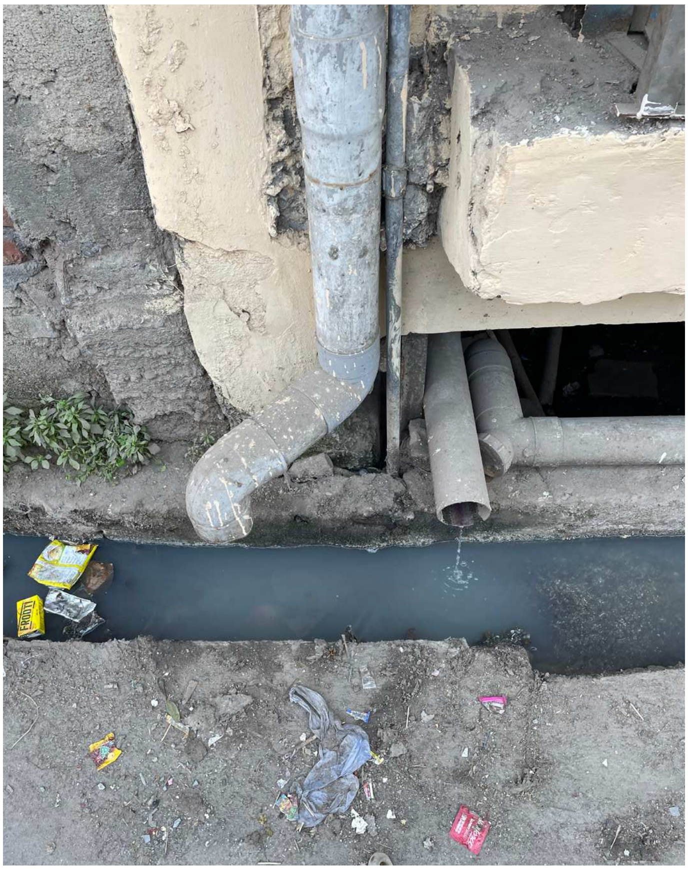


Figure 6-08: Sangam Vihar threats - residences with basements (top left); greywater being discharged into open stormwater drains(bottom left); garage directly discharging effluents onto the street (bottom right)

6.3.2 Site Interviews

To gather insights into the historical development of Sangam Vihar, as well as its current challenges and opportunities, interviews were conducted with residents, visitors, and workers in the area. Face-to-face interviews were conducted to collect the opinions and feedback of the local community. The questionnaire designed for this purpose can be found in Annexure-1. To ensure inclusivity, interviewees were selected from diverse backgrounds in terms of gender, age, and occupation. The oral narratives shared by the interviewees serve as an authentic portrayal of the existing fragile grey infrastructure within the settlement. Their opinions have been paraphrased in this section.

Ms Mamta
School drop out
17 years
Unemployed
Sangam Vihar, Delhi

Ms Mamta, a young woman who unfortunately had to discontinue her education and is currently unemployed, shares a similar story of challenges in Sangam Vihar. Her primary struggle revolves around the lack of accessible water supply, particularly during the monsoon months when the streets become inundated with water from overflowing open drains. Living in a family of seven persons, she often has to purchase packaged drinking water. In addition, the domestic water supply in her household comes from a privately operated borewell.

"The government should provide us with basic infrastructure at optimal cost".

Her house has a toilet that is connected to a septic tank, which fills up rapidly. The tank requires frequent cleaning, sometimes as often as once a month, incurring a cost of approximately 600 (7.21 US $) to 800 rupees (9.61 US $). As she primarily relies on walking for transportation, she feels significantly hindered during the monsoon season. Her young siblings are particularly vulnerable to health risks in such conditions.

Mr Vinay Kumar
Autorickshaw driver
34 years
Self employed
Sangam Vihar, Delhi

Mr Vinay Kumar, a self-employed auto-rickshaw driver residing in Sangam Vihar with his family (5 persons) for the past decade, expressed several significant challenges faced by the neighbourhood. The foremost concern he highlighted is the inadequate water supply for both domestic use and drinking purposes. Additionally, even a minor rainfall leads to extensive street flooding, exacerbating the situation. However, one positive development in the neighbourhood over the past two decades is the construction of the new Metro line on the Mehrauli-Badarpur road, which is expected to benefit the residents.

Mr Kumar currently purchases packaged bottled water from outside sources, paying 20 rupees (0.24 US $) for a 20 litres container. However, during the summer months of May, June, and July, the price can escalate to as high as 50 rupees (0.6 US $). Although he has a toilet at his residence, the flushed water directly flows into the open stormwater drain network, contributing to the health hazards. He is uncertain if the government provides any water supply initiatives. He further states that presently, the progress of infrastructure development in Sangam Vihar seems to be progressing at a sluggish rate, estimated to be around 10% of what it should be.

"The issues can only be solved when all of us work together as a community".

Regarding solid waste management, Mr Kumar suggested that involving beggars or unemployed individuals in temporary employment for solid waste collection could help mitigate the problem. He firmly believes that resolving these issues requires collective efforts from all members of the community.

Mr Mohammed Anas
Mechanic
24 years
Self employed
Sangam Vihar, Delhi

Mr Anas, a 24-year-old air conditioner mechanic, has been living with his family of five in Sangam Vihar for the past 23 years. The major challenges he faces in the area are related to traffic congestion and the threat of theft. Despite recently purchasing a motorbike, he lives in constant fear of it being stolen.

Regarding water supply, he recognizes it as the most significant change in Sangam Vihar over the past 20 years. He recalls that a decade ago, the situation was dire, with water being available only twice a week or even less frequently. Now, the water supply is available every day. He has a toilet connected to a septic tank that needs to be emptied monthly. Mr Anas is not familiar with waste segregation and solid waste management practices. He suggests that the government should install public dustbins outside each street to improve solid waste management, as currently, there are no visible dustbins in the area.

"Some of my neighbours eventually connected their toilet's grey water directly to the open stormwater drains as they either lack a septic tank or they just want to avoid its maintenance cost".

He added that when the government constructed shallow open stormwater drains in the streets, the situation regarding stormwater improved temporarily. Unfortunately, some of the neighbours decided to connect their toilets directly to these drains, either because they didn't have septic tanks or to avoid their tanks filling up quickly. Additionally, during the monsoon season, when the drains overflow, people create makeshift barriers in front of their homes to block the water. However, those whose houses are located below road level suffer the most, as their homes get flooded with black/grey water, posing a significant health hazard.

Mr Ram Lakhan
Service
43 years
Employed
Sangam Vihar, Delhi

Mr Ram Lakhan, who relocated to Sangam Vihar two decades ago in search of improved employment opportunities, shared his perspective on the lack of substantial changes in the area during this time. According to him, the persistent issues of blocked stormwater drains and inadequate water supply remain largely unresolved. Although the Delhi Jal Board (DJB) has undertaken some work near the main road and periphery, the majority of Sangam Vihar still grapples with these problems While a piped water supply network has been laid out by the DJB, many of the pipes are not functional.

"The scale and density of Sangam Vihar is huge and perhaps it may need another 20 years to make things better here".

Mr Lakhan expressed criticism regarding the government's pace of work, suggesting that it might take another two decades to address the challenges in Sangam Vihar due to its expansive and highly populated nature. He shared that his home has a toilet, but the flushed water directly flows into the stormwater drain on the main road since he lacks a septic tank. During the monsoon season, the stormwater drains always overflow into the roads and become impassable, posing difficulties for him and his children to commute to work and school. Although the Municipal Corporation of Delhi (MCD) provides dedicated auto rickshaws for waste collection multiple times a week, the drains often become clogged with garbage.

The domestic water supply in Sangam Vihar is sourced from a privately operated borewell rather than being provided by the government. Mr Lakhan concluded by stating that given the scale and density of Sangam Vihar, significant improvements may require another 20 years to materialise.

6.3.3 Urban Analysis - Creation of Analytical Maps for the Study Area

The analysis process utilised satellite images from sources like Google Maps, and Open Street Map as base maps. Subsequently, desk research and Geographic Information System(GIS) analysis with the help of QGIS software is carried out. The information is triangulated during multiple on-site field research.

The information regarding administrative boundary and land use in Sangam Vihar was considered from Muncipal Corporation of Delhi (MCD) and State Election Commision (2022). The resultant maps were instrumental in examining various aspects, such as the extent of built-up areas, street hierarchy, open spaces, sealed areas, the existing drainage network, and the local topography within the settlement.

Open Space Diagram

A summary of surface types is provided in Table 6-01, broadly categorised into sealed and unsealed surfaces. Sealed areas, include built-up areas like buildings with flat roofs and the street network, occupy approximately 2,645,396 sq m, constituting roughly 95 % of the entire catchment area. The remaining 5 % consists of unsealed areas which is roughly 139,599 sq m, including public parks, sports fields in schools, and small pocket gardens, typically community-owned, often situated around religious sites such as temples and mosques, among others. Figure 6-09 depicts the density of buildings in the study area.

The proportion of sealed and unsealed areas is highlighted in Figure 6-10 while Figure 6-11 indicates the different types of surfaces available in Sangam Vihar.

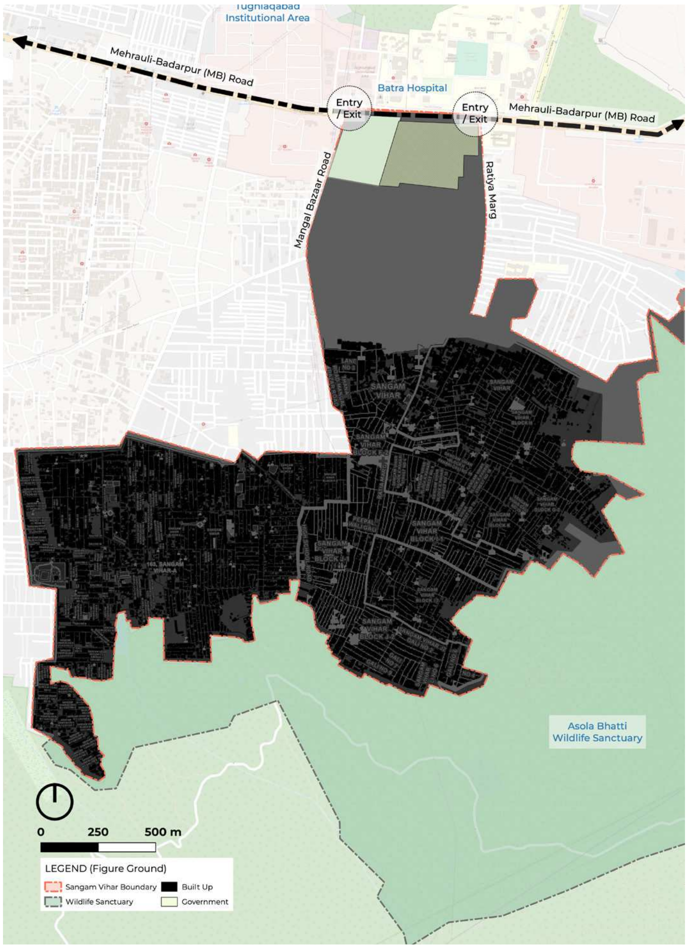


Figure 6-09: Sangam Vihar - Figure ground

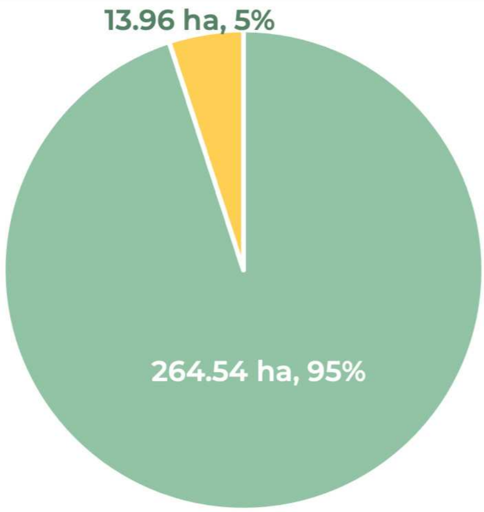


Figure 6-10: Sealed and unsealed surfaces in Sangam Vihar

Type of surface	Description	Area (m²)	Area (ha)
Built up (including streets)	Reinforced cement concrete flat roofs	2,645,396.00	264.54
Parks	Soil, grass, unpaved land	60,779.00	6.08
Green/ Open areas	Pocket lawns (soil); unpaved land	78,820.00	7.88
Total unsealed area		139,599.00	13.96
Grand Total		**2784995.00**	**278.50**

Table 6-01: Types of surface present in Sangam Vihar

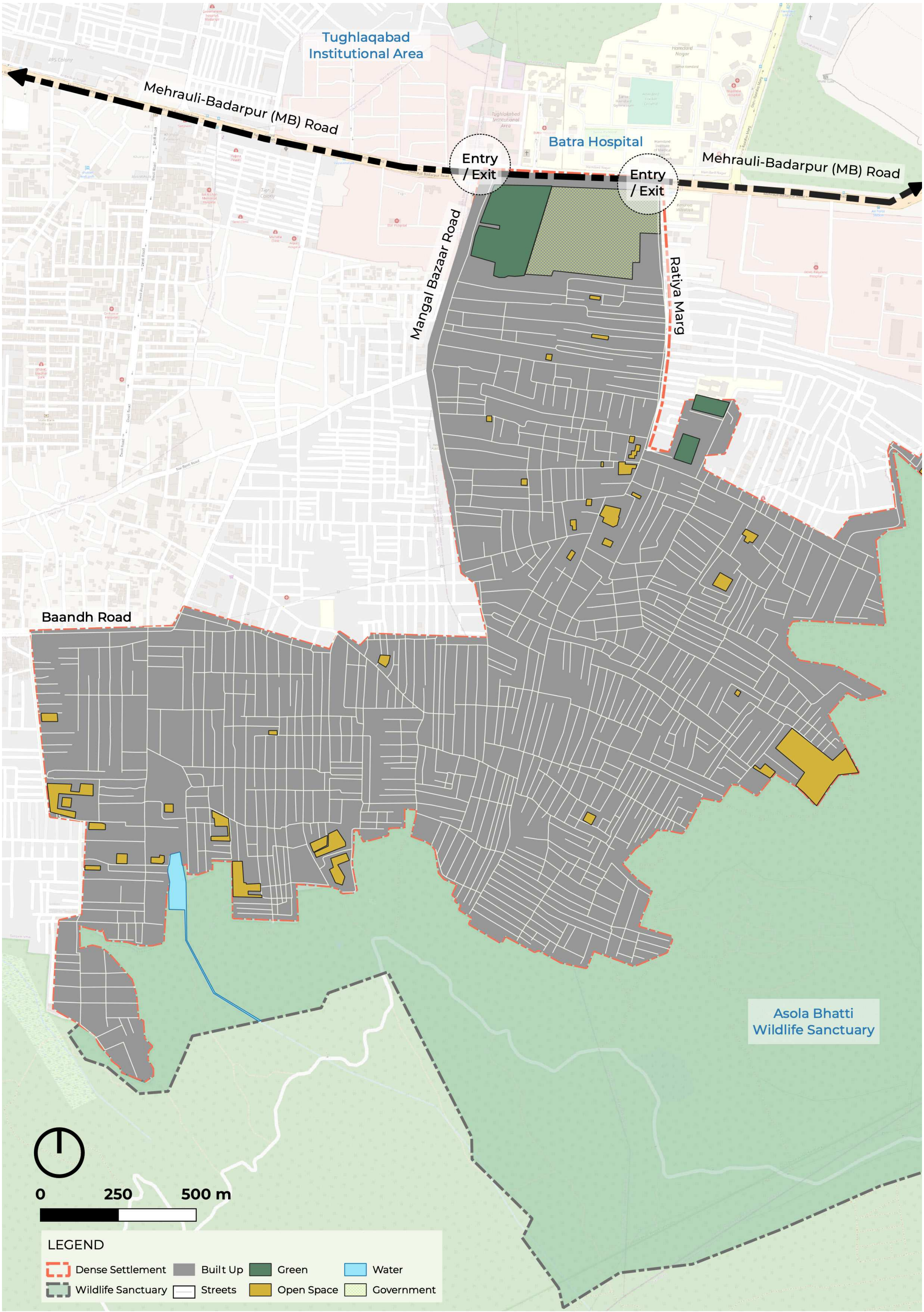


Figure 6-11: Sangam Vihar - types of surfaces present in the catchment

Street Hierarchy

The street hierarchy within the settlement is depicted in the corresponding map (Figure 6-14). The length of existing street network is estimated around 110.10 km. These can be categorsied as primary, secondary and tertiary based on their width and functions.

The primary street with a length of 2.9 km has a total right of way (ROW) of 9 m. A 6 m wide carriageway is flanked by 1.5 m wide footpaths on either side. A reinforced cement concrete (RCC) box drain underneath the footpath carries the stormwater from the catchment to the main sewer trunk drain towards the north side onto the Mehrauli-Badarpur (MB) road. The wastewater pipe is laid underground in the centre of the road. Notably, the primary streets are surfaced with asphalt, while secondary and tertiary streets are typically constructed using plain cement concrete.

Secondary streets and Tertiary streets have similar layouts but they vary in the ROW. Both the streets are flanked by 0.5 m deep open stormwater drains on either side. The stormwater mixed with grey water from households is discharged to the main RCC box drain located under the primary street. The overall length of streets and their ratio is highlighted in Figure 6-12.

A schematic view of existing grey infrastructure services along with the cross sections of primary, secondary and tertiary streets in the settlement is illustrated in Figure 6-15, Figure 6-16 and Figure 6-17 respectively.

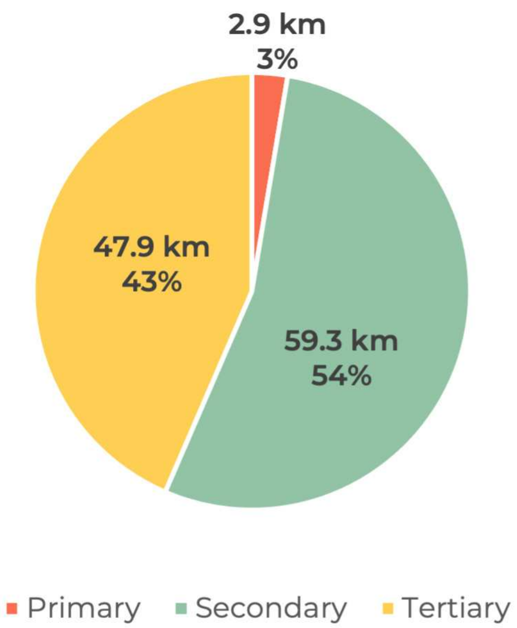


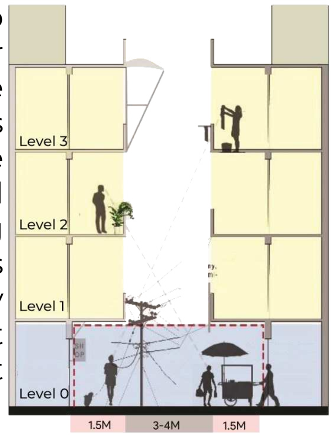
Figure 6-12: Sealed and unsealed surfaces in Sangam Vihar

Street Interface

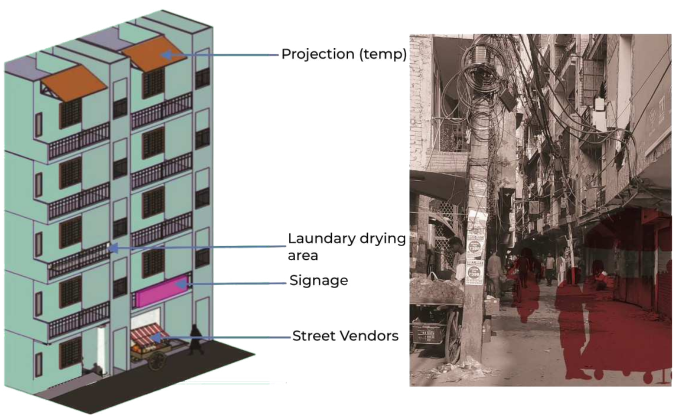
Streets form the major public realm in Sangam Vihar, the same is also true for various other dense unplanned settlements in Delhi. Streets are multi-functional and showcase an array of community activities and uses. This setting underscores the resilience of the community in adapting to constrained urban conditions, emphasising the need for comprehensive interventions to address infrastructural challenges in informal settlements.

Primary streets indicate commercial activities at the ground floor level and residential use for the above floors. The number of levels vary from 2 - 4 floors, creating a dynamic skyline. On the contrary, secondary and tertiary streets typically indicate residential land use with a few commercial activities in the form of shops, small scale industries. Most of the buildings are up to 3 to 4 storeys high, creating a sense of enclosure.

Buildings extend into the street from first floor level and above. The projected balcony acts as an important source of natural light and ventilation, for drying laundry, but also plays an informal community space for different households to interact with each other.



STREET CROSS SECTION



SCHEMATIC VIEW

SITE SITUATION

Figure 6-13: Sangam Vihar - Typical street interface

Source: Singh (2021)

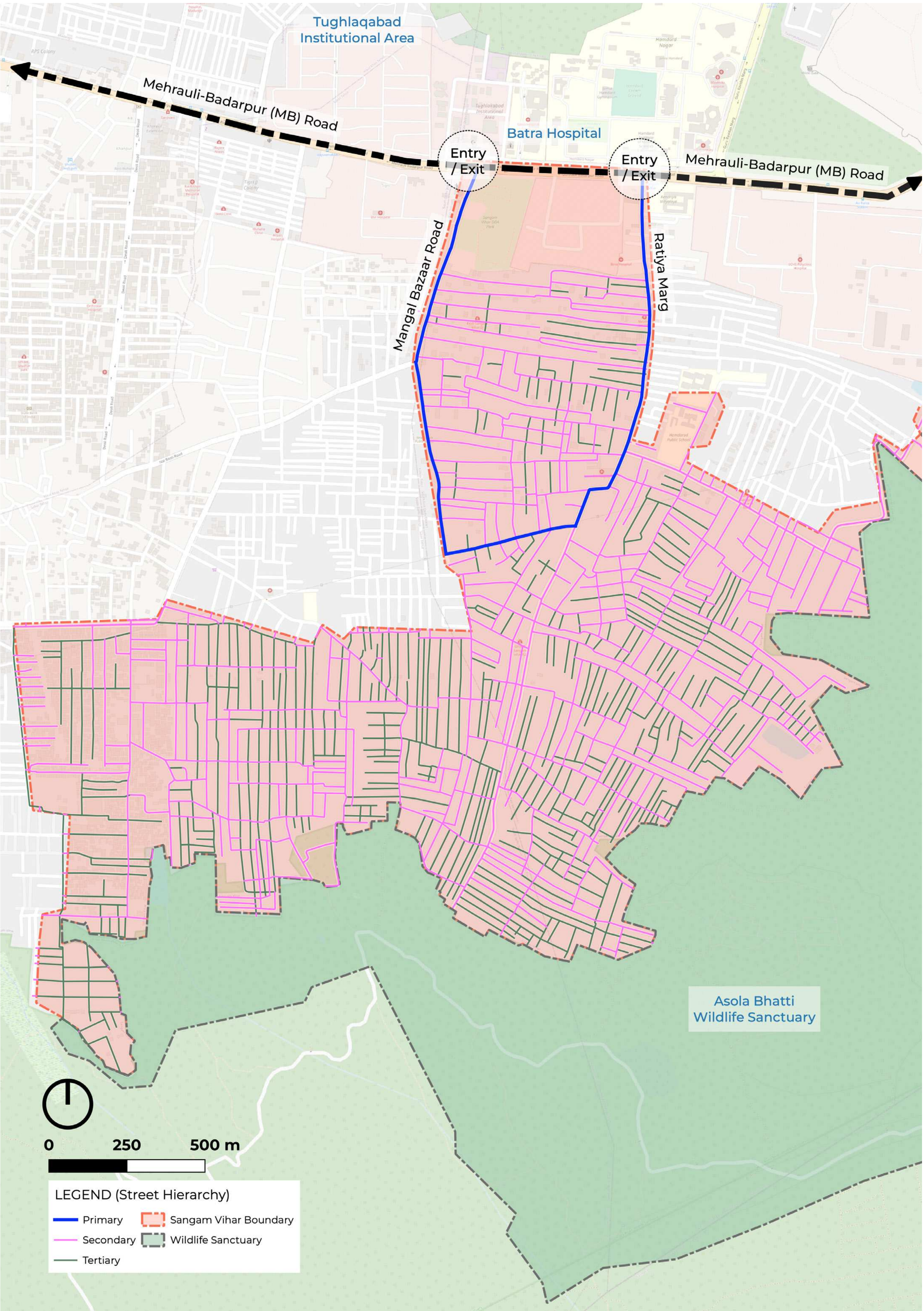


Figure 6-14: Sangam Vihar - Street hierarchy

Figure 6-15: Sangam Vihar - Cross sectional view of primary street

Figure 6-16 Sangam Vihar - Cross sectional view of secondary street

Stormwater Infrastructure and Flooding Vulnerability

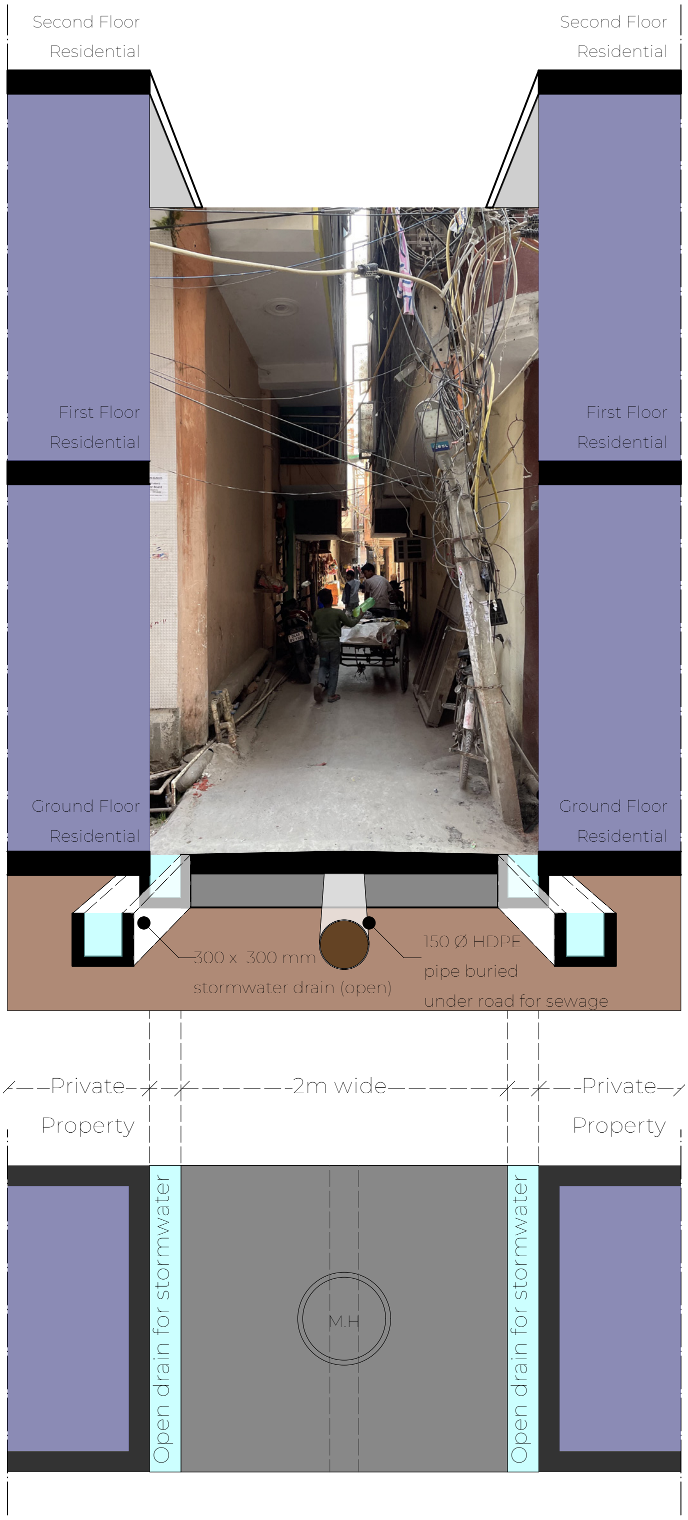


Figure 6-17: Sangam Vihar - Cross sectional view of tertiary street

The stormwater drainage system within Sangam Vihar relies on secondary and tertiary streets to channel stormwater towards the main drains situated along the primary streets. Ultimately, the runoff flows into the trunk sewer drain along the Mehrauli-Badarpur (MB) road. However, due to the substantial stormwater volume originating from a vast catchment area, instances of waterlogging are frequent, especially during the monsoon season. Figure 6-18 provides the vulnerability analysis of flooding and waterlogging hotspots within Sangam Vihar.

Towards the MB road, 3 locations are identified by the Delhi Traffic Police (Gosain et al., 2018). During the site visits, the research learned from the residents that the primary streets are completely flooded during monsoons, with the junctions being the most critical locations. The inadequate design of these drains fails to account for the cumulative stormwater flow from secondary and tertiary streets, especially as one moves south within the settlement. Consequently, waterlogging problems are more severe in these streets within the settlement. Similarly, secondary streets are impacted too, even with small amount of rainfall. Overflowing manholes, open drains with solid waste floating on the streets is a common sight, especially in monsoons. Figure 6-19 provides an insight into the situation in Sangam Vihar during rainfall annually. The images are from the most recent monsoon events in August 2023. In addition to these drainage challenges, natural drains and water bodies within the settlement have been encroached upon and are in a state of disrepair. These areas often serve as dumping grounds for municipal solid waste and construction and demolition (C&D) waste.

The stormwater infrastructure, where available, is often obstructed due to the improper disposal of solid waste materials, generated within Sangam Vihar. The mismanagement of urban waste is a significant issue exacerbated by poor coordination between various departments, including the Public Works Department (PWD), Irrigation and Flood Control (I&FC) and the Municipal Corporation of Delhi (MCD). MCD is tasked with solid waste management, and residents are expected to transport their C&D waste to designated collection points, however in most cases, the C&D waste is dumped along the periphery of the settlement.

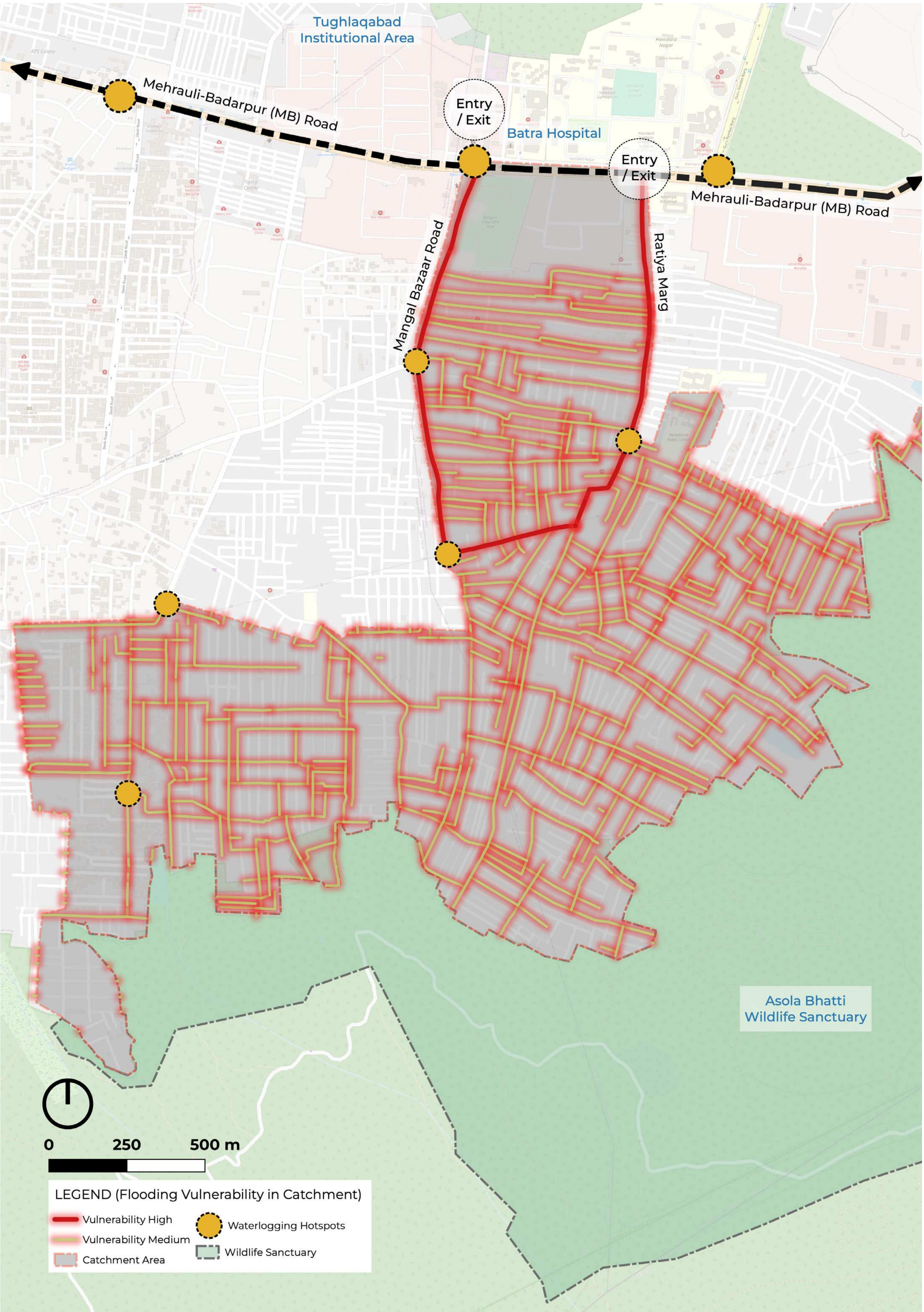


Figure 6-18: Sangam Vihar - Flooding vulnerability and location on waterlogging hotspots

Figure 6-19: Flooded street (Ratiya Marg) in Sangam Vihar in July 2023 monsoons (top left); one of the secondary streets flooded in July 2022 (bottom left); Flooded Ratiya Marg in 202 Source: Bhan (2023) and Manav (2022)

6.4 Concept Design Implementation

This research underscores the presence of inequity within Delhi, analysing the dense unplanned settlement of Sangam Vihar, and it identifies two core issues for recurrent flooding events: high built-up density (sealed area) and the lack of adequate grey infrastructure. The proposed conceptual design is rooted in the framework outlined in Chapter 5, which integrates the enhancement of existing grey infrastructure with Water Sensitive Planning (WSP) measures. This combined approach aims to address the runoff at its source, reducing both its volume and velocity, as well as its pollution levels.

In Sangam Vihar, utilising open spaces like the DDA park in the north and the southern greenfield of Asola Wildlife Sanctuary for stormwater storage can help in the reduction of flooding events. These areas can also serve as multi-purpose stormwater retention ponds, incorporating a constructed wetland for treatment and minimising runoff pollution, contributing to more effective flood mitigation. The overview of concept design in the form of a block diagram is depicted in Figure 6-20.

The preferred site for intervention is the green field towards the southern boundary, owing to its expansive open area. A comprehensive intervention plan envisions the integration of a community park with nature trails and the revitalisation of the existing water body using treated runoff. Beyond its role as a decentralised stormwater management solution for Sangam Vihar, this site offers a unique opportunity to introduce green spaces and open areas to the densely populated settlement. This multi-faceted approach not only addresses water management challenges but also enhances the overall quality of life in the community.

6.4.1 Defining Sub-Catchment Areas

Considering the large catchment area and the current flow of stormwater, the approach involves the subdivision of the large catchment area into smaller sub-catchment areas (see Figure 6-21). This division is determined by factors such as the direction of runoff, volume, existing drainage network, and proximity to low-lying areas. In the case of Sangam Vihar, the western segment of the area slopes towards existing water bodies, with a natural depression that follows the course of natural drains. The peripheral areas slope towards smaller water bodies, while the northern section of the catchment area slopes towards MB Road.

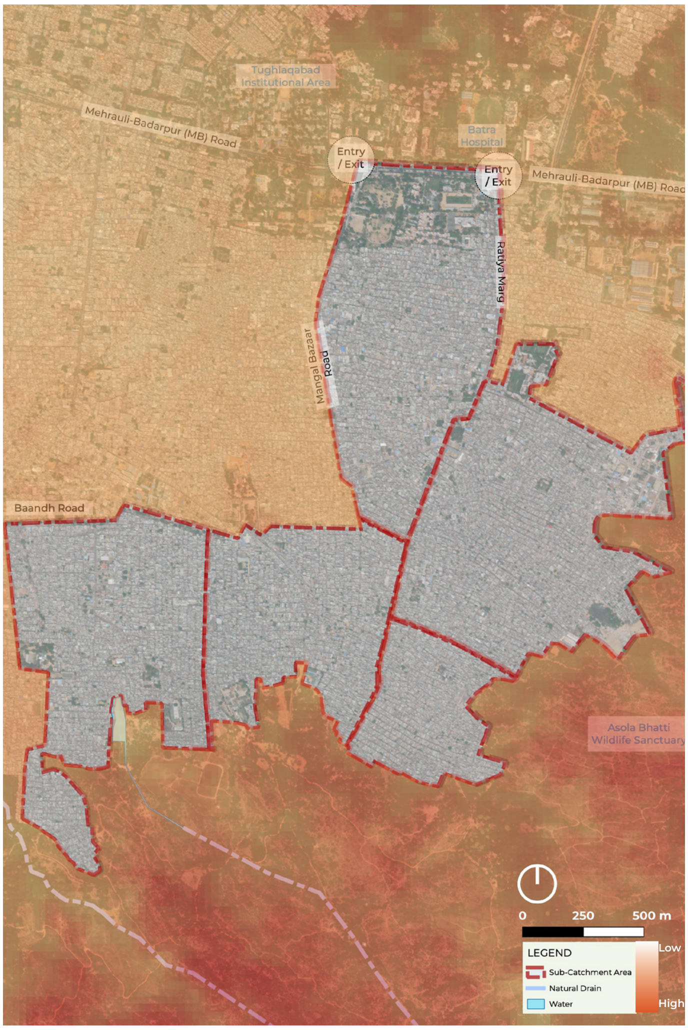


Figure 6-20: Catchment - slope analysis.
Source: Adapted from NASA earthdata (2023)

For the selection of sub-catchment area, slope analysis is carried out for understanding the existing topography (Figure 6-20). The settlement is surrounded with low lying green areas, towards southern side, near the green field area of wildlife sanctuary. Additionally, a natural water body (dried up) is also observed towards the southern boundary. The geographical layout naturally aligns with this approach as a low-lying area is identified on the periphery of sub-catchment that further supports the selection criteria. Keeping in view these factors and the flooding vulnerability (Figure 6-18), sub-catchment 2 is selected as a pilot. Its selection is underpinned by the proximity of the stormwater outflow direction to a low-lying green/ open area. This favourable geography creates an opportunity to direct excess stormwater runoff through an underground stormwater drain into nearest low lying area, leading into the CW. The specific size of this wetland is elaborated upon in the subsequent section.

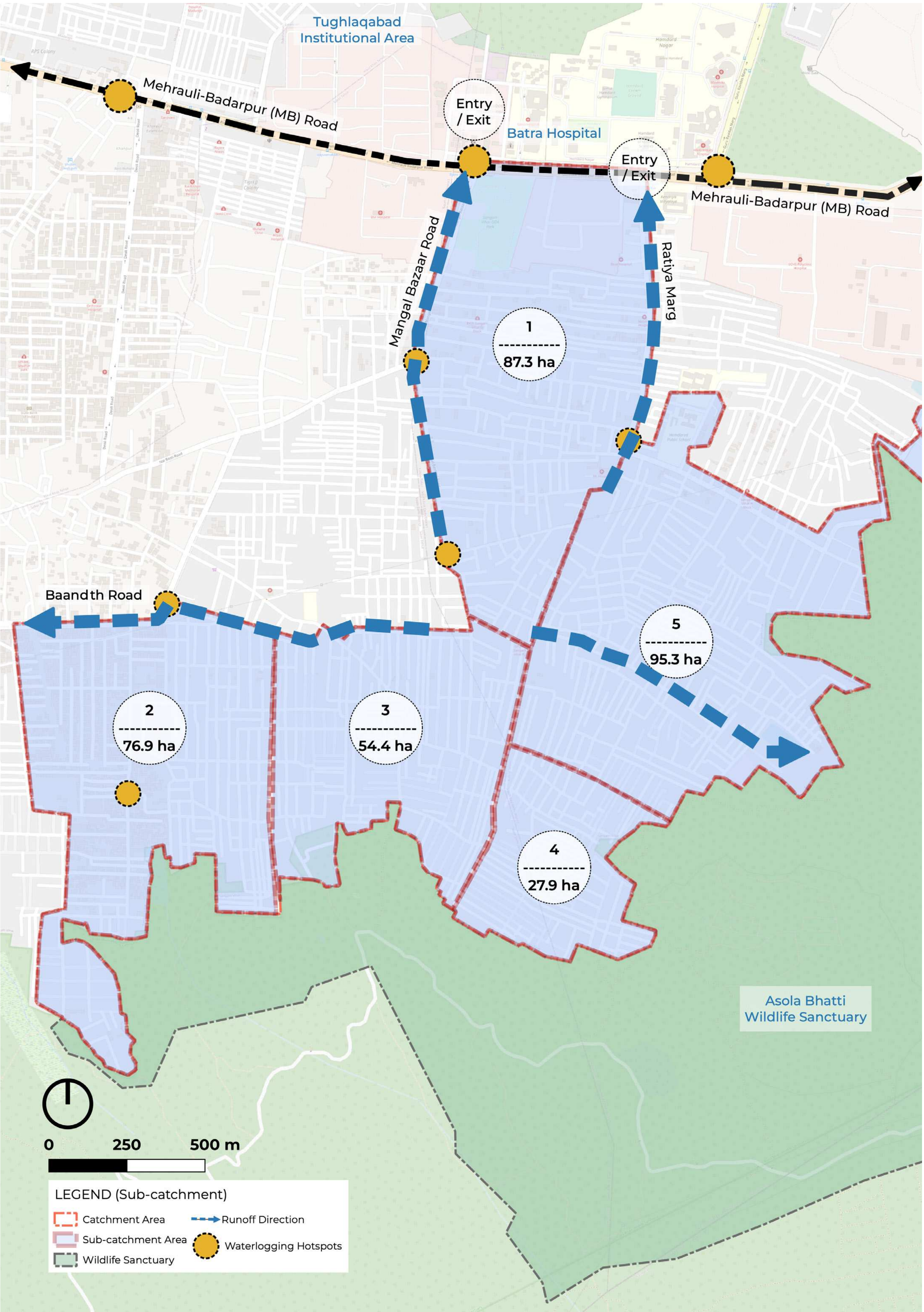


Figure 6-21: Sangam Vihar - Total sub-catchment area with the direction of stormwater runoff. Source: CSE (2023)

6.4.2 Design Proposal for the Sub-Catchment Area

Following an in-depth analysis, aligned with the principles outlined in Chapter 6.3, the most viable solution to mitigate flooding events entails the use of available open, low-lying areas within the Sangam Vihar settlement. The Sangam Vihar DDA park, located along the northern boundary, and the greenfield area to the south, can serve as provisional retention pond to contain stormwater. It is important to note that the stormwater drains in the area serve multiple functions, transporting runoff from streets and households, greywater from residential sources, and industrial effluents originating from small-scale industries and local garages. The inflow of greywater significantly contributes to the overall runoff volume within these drains. To effectively manage this situation, prior to the discharge of stormwater runoff, adequate treatment is necessary and suggested, potentially in the form of a constructed wetland (CW). The proposed CW can effectively reduce pollution levels in the runoff before it is allowed to recharge.

Critical areas that are susceptible to chronic waterlogging are identified through slope analysis and site conditions, and suitable pumping infrastructure can be installed to address peak monsoon seasons. These pumps can redirect stormwater to the updated drainage network which in turn directs the runoff to the nearest open spaces or low-lying areas. This can effectively decrease the pressure on the trunk drain along the MB road during peak rainfall events. This integrated, yet decentralised approach would greatly contribute to the reduction of the occurrence of flooding events.

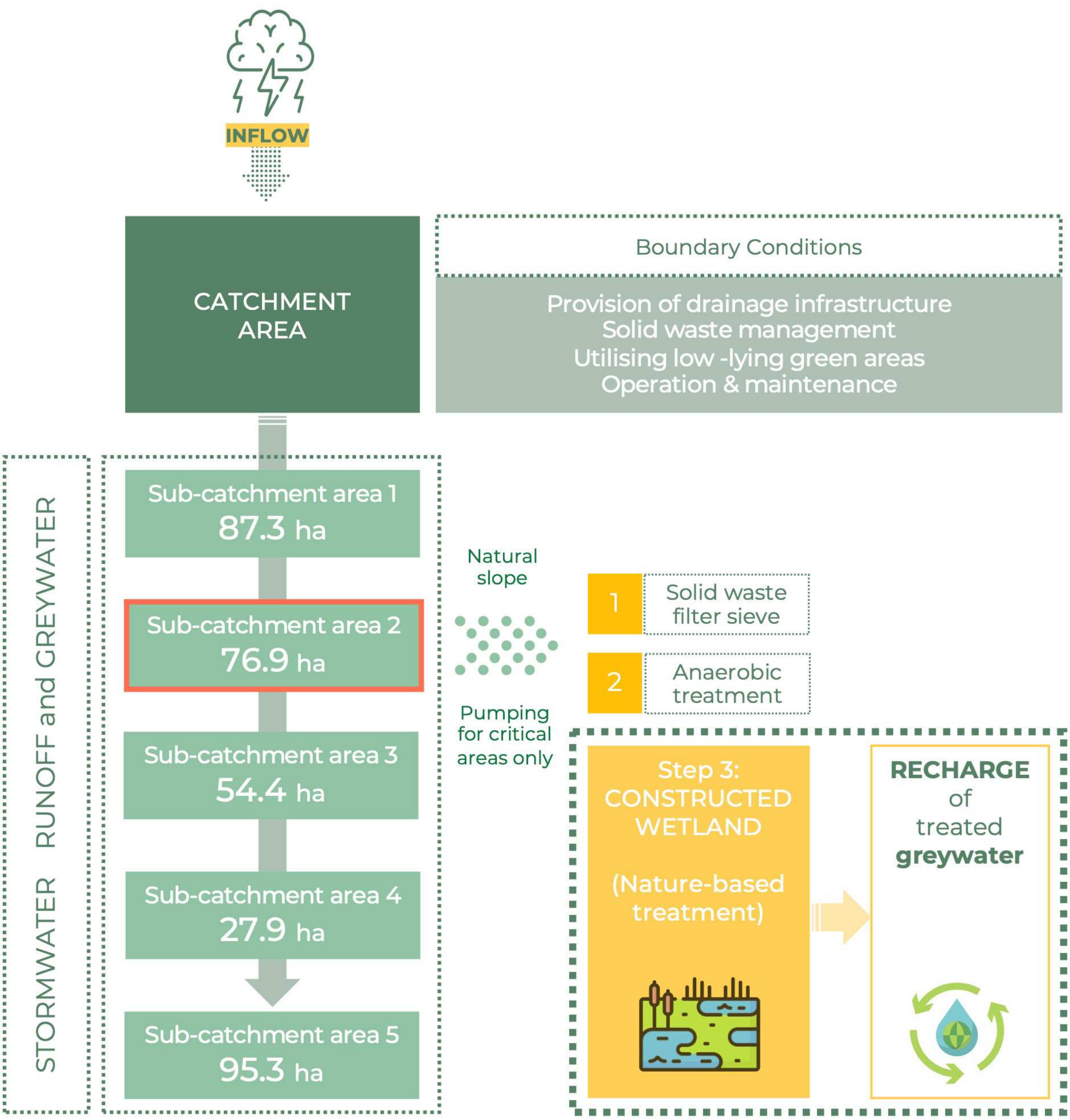


Figure 6-22: Block diagram of the concept design

Boundary Conditions

Certain boundary conditions are presumed for the effectiveness of the concept design and the proposed intervention. Firstly, substantial enhancements in the existing grey infrastructure, particularly in stormwater drainage, are imperative.

A resilient solid waste management plan for Sangam Vihar is indispensable to avoid clogging of drains. The foundation of the proposal relies on increased public awareness regarding waste segregation and management. It is strictly required that solid waste should never be dumped into open stormwater drains under any circumstances.

Furthermore, the proper direction of stormwater runoff to low-lying open areas utilising adequate grey infrastructure is a key facet. Lastly, the operation and maintenance of the constructed wetland are equally critical for ensuring the success of the intervention.

6.4.3 Estimation of the Applied Programme

Stormwater runoff

To estimate the stormwater runoff in the catchment, "rational method"as mentioned in the Central Public Health and Environmental Engineering Organisation (CPHEEO) manual is applied (CPHEEO, 2019). The formula applied for estimating the runoff is given as below:

$$Q_p = 10 * C * I * A$$

where;

Q_p → Peak flow at the point of design, m^3/ hr

C → Runoff coefficient, dimensionless

I → Average rainfall intensity, duration of rainfall equal to the time of concentration, mm/ hr

A → Catchment area, hectares (ha)

The peak flow for the entire catchment is summarised in Table 6-02. It is observed that for sub-catchment 2, the peak runoff volume is 60,408 cu m per hour. The rainfall intensity considered is 87.20 mm per hour for a 2 year return period for a duration of 15 minutes (Gosain et al., 2018). The runoff estimate for a 5 year return period for 15 minutes duration is 77,727 cu m per hour.

Surface area of constructed wetland

To estimate the surface area of the constructed wetland (CW), two methodologies are applied, person equivalent load and hydraulic load.

Person equivalent load: The surface area of the required constructed wetland is derived in accordance with the guidelines mentioned by Hoffmann et al. (2011). The standard suggests that the required specific surface area for a CW (horizontal flow bed) is about 3-10 sq m per person depending on temperature and other local factors at site. In warm climates like Delhi, less area is required due to the higher biological activity. Although, it is ideal to consider the Bio chemical oxygen demand (BOD) loading of the wastewater as a design parameter, however, this data is not available

Sub Catchment	Area	Runoff coefficient	Rainfall Intensity (I)	
			87.20 mm /hr for 2 year return period in 15 minutes	112.22 mm /hr for 5 year return period in 15 minutes
	(A)	(C)	(Q_p)	(Q_p)
	ha	-	m^3/hr	m^3/hr
1	87.28	0.9	68,498.21	88,136.45
2	**76.97**	**0.9**	**60,408.80**	**77,727.84**
3	54.47	0.9	42,749.78	55,006.03
4	27.92	0.9	21,910.60	28,192.30
5	95.27	0.9	74,767.50	96,203.14
Total	**341.92**		**268,334.89**	**345,265.77**

Applied equation: (Q_p = 10 * C * I * A); in accordance with CPHEEO manual on stormwater drainage. Rainfall intensity data from Gosain et. al (2018)

Table 6-02: Description of sub-catchment areas in the study area

3
No of households/ building

4.5
Inhabitants/ household

3
sq m / person to determine size of CW

Sub-catchment 2							
Area	No of Buildings	No of households/ building	Inhabitants/ household	Total Population	Greywater generated/ person	Total volume of greywater	Surface area of Constructed Wetland
(m^2)	(Nos)	(Nos)	(Nos)	(Nos)	(m^3)	(m^3)	(m^2)
769,735.00 (76.97 ha)	4,086	3	4.5	55,161	0.08	4,412.88	165,483.00 (16.5 ha)
		The data is based on site interviews and certain assumptions			80 ltr per person in accordance with UN Habitat (2008)		3 m

Table 6-03: Sub-catchment 2 - estimate of required surface area of constructed wetland based on person equivalent load. Source: Hoffmann et. al (2011)

for the selected study area. In general, area requirement per person is lower when treating greywater from an average person(Hoffmann et al., 2011). Therefore, keeping in view all the conditions, a factor of 3 sq m/ per person is applied for determining the surface area of the constructed wetland (horizontal flow type).

The data regarding the population of Sangam Vihar, and in particular sub-catchment 2 is unavailable in public domain. For the purpose of approximate estimation, the total number of buildings in the sub-catchment is multiplied with total number inhabitants living in each building. It is also important to mention that each building comprises of multiple households since residential land use in the settlement is multi-family residential.

To estimate the population for sub-catchment 2, firstly, the number of buildings are counted by overlaying the Open Street Map on QGIS software, collaborated with the observations during field trips. Additionally, during the site interviews with the residents (refer Section 6.3.2), the research observed that the average size of households ranged from 5 to 7 persons per household. The number of inhabitants in each household is considered as an average of 4.5 inhabitants per household. Subsequently, since each building accommodates multiple households, a factor of 3 households per building is applied.

The total surface area for sub-catchment 2 is approximately 769,735 sq m or 76.9 ha and its total population is approximately 55,161 persons. Table 6-03 provides an overview of calculations. Details regarding the proposed sub-catchment areas along with the volume of stormwater runoff generated for each are outlined in Table 6-02.

Based on the calculations, the surface area required for the CW is approximately 16.5 ha.

Hydraulic load: The applied equation to calculate the size of wetland is based on the equation proposed by Kickuth (UN HABITAT, 2008). The formula is given as:

$$A_h = (Q_d (\ln C_i - \ln C_e)) / K_{BOD}$$

where;

A_h → Surface area of bed, m^2

Q_d →Average daily flow rate of sewage, (m^3/d)

C_i → Influent BOD_5 concentration, mg/l

C_e → Effluent BOD_5 concentration, mg/l

K_{BOD} → Rate constant, m/d

The surface area required for the CW as per hydraulic loading is approximately 15.6 ha. The basis of calculations is explained in subsequent section. The summary of calculations for the required specific size is depicted in Table 6-04.

6.4.4 Location of Constructed Wetland

Figure 6-23 provides a comprehensive overview of the topographic analysis for the area surrounding sub-catchment 2.

Notably, it is observed that the natural runoff is directed towards the existing water body located towards south-west direction. The area adjacent to this dried water body currently acts a dump site for C&D waste as well as solid waste. Additionally, a natural drain is also observed towards the western side of sub-catchment 2. It's presence provides an opportunity to direct the treated runoff into the natural path of this drain. Given these findings, it is evident that this area holds high potential for the strategic placement of the proposed intervention.

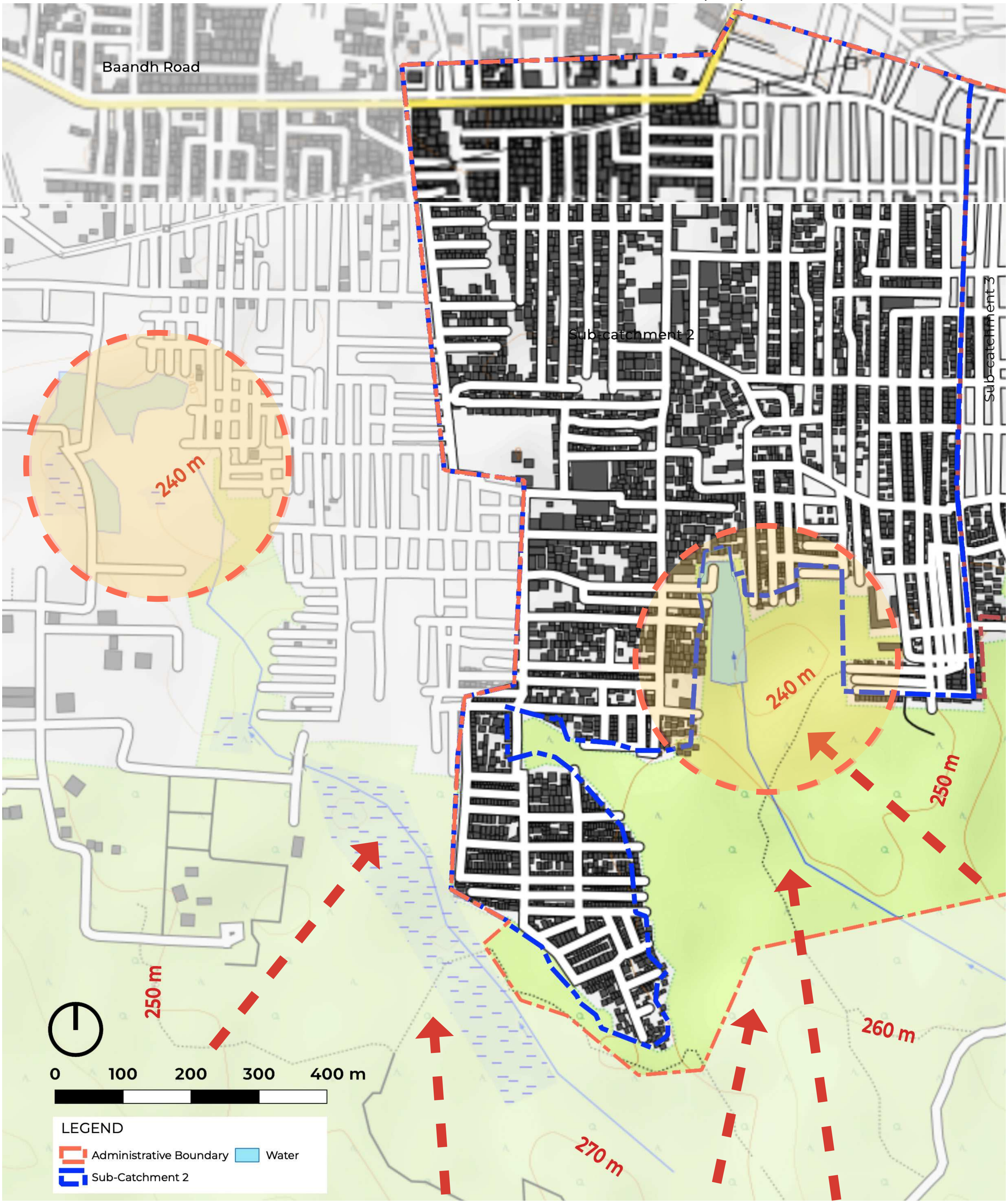


Figure 6-23: Sub-catchment 2 - slope analysis.
Source: Topographic Map(2023)

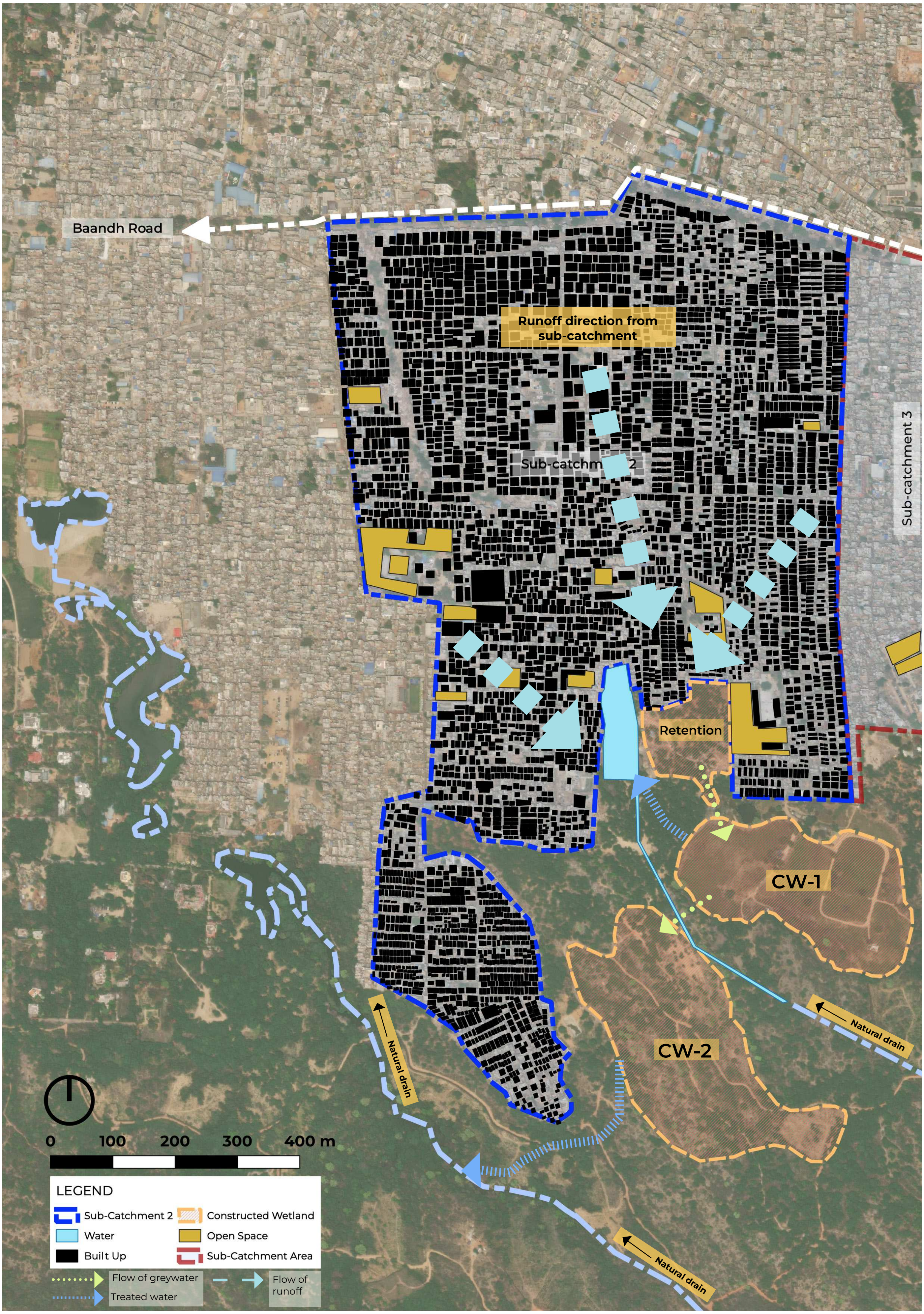


Figure 6-24: Sub-catchment 2 - proposed location of constructed wetland (CW)

6.4.5 Design of Constructed Wetland

A Constructed Wetland (CW) is a shallow basin with substrate, often sand or gravel, and planted with vegetation adapted to saturated conditions. Greywater flows through the basin, removing large waste matter in the inflow and sedimentation zone before entering the wetland/ root zone.

CWs are commonly employed as a decentralised wastewater treatment process, serving as a secondary treatment step. This implies that the wastewater undergoes primary treatment before entering the filter bed of the constructed wetland (Hoffmann et. al, 2011). The typical design of a CW includes a pre-treatment zone, inlet zone, sedimentation zone, wetland zone and an outlet zone (Figure 6-25).

The sedimentation zone requires regular cleaning, and the bottom slope should be 0.5-1 % while the filter bed depth is typically around 60 cm with additional freeboard of 15 cm for water accumulation (Hoffmann et. al, 2011). Media in the inlet and outlet zones should be 40-80 mm in diameter to minimise clogging. Properly selected vegetation with deep roots and efficient oxygen transport is crucial for optimal performance. The organic matter in the greywater is removed by bacteria on the surface of soil particles and roots of the plants.

For this research, a horizontal flow bed subsurface type CW is considered. Since the technical construction design of the CW is beyond the scope of this master's thesis, broad design features of the proposed CW are discussed.

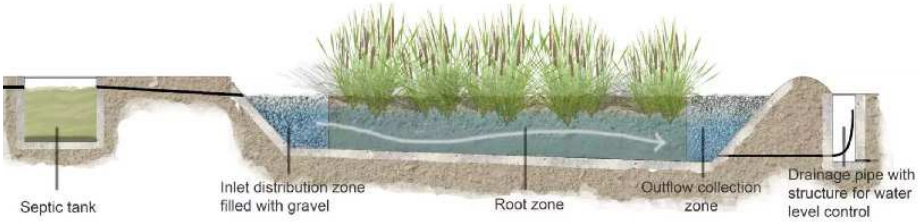


Figure 6-25: Constructed Wetland - typical cross section with pre-treatment.
Source: Moura (2015)

In principle, the design of the proposed CW is line with Figure 6-26. The runoff inflow from the sub-catchment is collected at the lowest point in the area based on natural topography and improved drainage infrastructure.

Retention pond: As a first step, a retention pond is created at this location to moderate the flow during monsoon and non-monsoon periods. Solar-powered pumps are proposed to lift water up to the pre-treatment zone. The pond with an average depth of 2 m is lined with a plastic sheet post earthwork in excavation, leveling and compaction to avoid infiltration.

Pre-treatment zone: In the second step, anaerobic treatment is suggested to remove suspended solids and organic pollutants. It is an extremely important stage to avoid clogging of subsurface flow CWs.

Inlet zone and Ephemeral zone: Partially treated greywater enters the ephemeral zone through the inlet zone. This zone is characterised by fluctuations in water levels depending on the season.

Wetland zone: This zone consists of a gravel bed and the plant media. The average depth is around 1.0 m and it contains pebbles ranging from 60 to 200 mm in size. For Delhi's context, cyperus alternifolius (Umbrella Papyrus) and Canna indica, pre-treated with natural auxins for enhanced bio-remediation efficiency, are grown as vegetation bands (Srivastava et al., 2021).

Treated water is then directed through gravity towards the natural drainage for groundwater recharge as well as towards the existing water body for its revitalisation (refer to Figure 6-29).

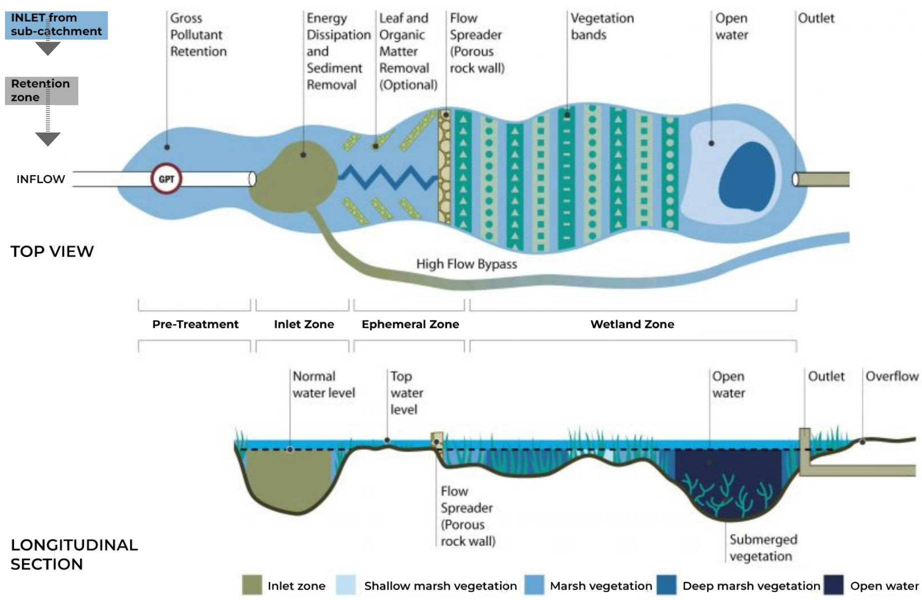
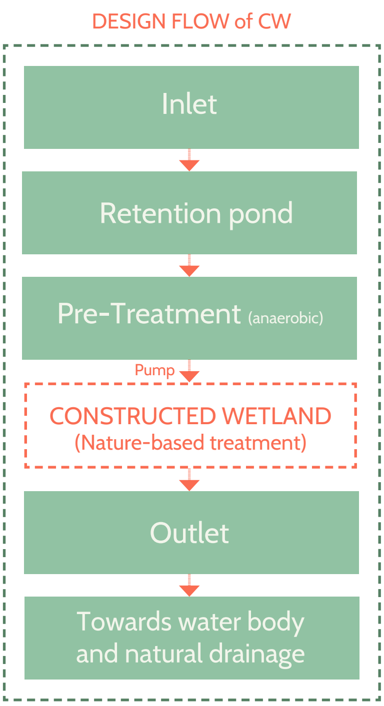


Figure 6-26: Constructed Wetland - schematic top view and section
Source: Adapted from Melbourne Water (n.d.)

Figure 6-27: Concept design - zoning of intervention. Source: Google Earth (2023)



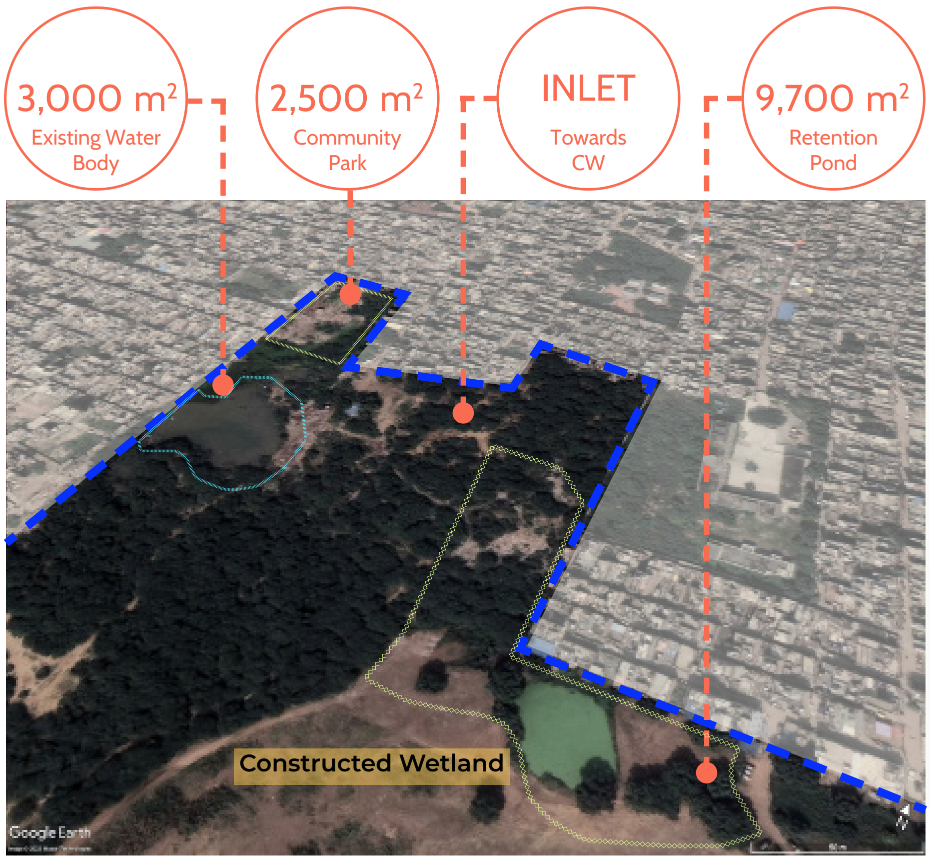


Figure 6-28: Concept design - proposed key features. Source: Google Earth (2023)

Sub-catchment 2						
Area	**Total volume of greywater/ day**	**Peak runoff rate (Q_d)**	**Surface area of Constructed Wetland (A_h)**		**Volume of retention pond**	**Surface area of retention pond**
(m^2)	(m^3/ day)	(m^3 / hour)	(m^2)	(m^2)	(m^3/ day)	(m^2)
769,735.00	4,412.88	60,408.80	483,270.42	156,120.65	19,515.08	9,757.54
(76.97 ha)			(48.3 ha)	(15.6 ha)	(4,412 + 15,102)	
	Greywater volume generated per day	Rainfall rainfall intensity of 87.20 mm/hr for 2 year return period for 15 mins duration	Greywater volume per day + 100% of stormwater volume for 1 hour	Greywater volume per day + only 25% of stormwater volume generated during peak monsoons (2 year return period) is considered due to available area at site		Considering an average depth of retention pond as 2.0 m

Applied equation for the size of wetland: $A_h = (Q_d (\ln C_i - \ln C_e)) / K_{BOD}$; in accordance with Kickuth equation (UN HABITAT, 2008)

$\ln C_i = 100$ mg/l ; $\ln C_e = 30$ mg/l ; $K_{BOD} = 0.15$

Rainfall rainfall intensity of 87.20 mm/hr for 2 year return period for 15 minutes duration is considered

Table 6-04: Sub-catchment 2 - estimate of required surface area of constructed wetland based on hydraulic load. Source: UN HABITAT (2008)

Sub-catchment 2 generates a total of 4,412 cu m of greywater daily (refer to Table 6-03). Due to lack of availability of accurate data from Sangam Vihar, it is assumed that each person generates 80 litres of greywater daily (UN HABITAT, 2008). This is the volume of runoff generated within the sub-catchment during non-monsoon period. However, during monsoons (july to september), the total volume of runoff would be higher as a considerable amount of stormwater is generated as well.

It is observed that the peak stormwater runoff volume is 60,408 cu m per hour. The rainfall intensity considered is 87.20 mm per hour for a 2 year return period for a duration of 15 minutes (Gosain et al., 2018). This implies that the specified intensity is statistically expected to occur once every two years. Furthermore, the duration considered for this intensity is 15 minutes. The exact data regarding the frequency and the exact duration of such intense rainfall is not available. On substituting this volume to Kickuth's equation (to estimate the size of CW), the surface area required for the CW is 48.3 ha.

A significant portion of the wildlife sanctuary is characterised by dense vegetation. The designated area for the CW spans approximately 16 hectares or 160,000 sq m. In this context, only 25 % of the stormwater volume generated within the sub-catchment is allocated for greywater treatment, along with accounting for the daily greywater generation. The CW's total daily capacity is calculated at 19,515 cu m, as detailed in Table 6-04. This capacity is distributed between 4,412 cu m of daily greywater generation and 15,102 cub m of stormwater directed to the CW. Any excess beyond this capacity is channeled into the drainage infrastructure. This volume is firstly directed into a retention pond

Figure 6-29 offers an insightful depiction of the proposed intervention. The runoff inlet strategically aligns with the natural topography, directing water towards the lowest point in the sub-catchment. A designated zone with a sieve serves to filter out solid waste before allowing greywater into a retention pond, moderating the flow into the CW. Greywater undergoes pre-treatment in a specially designated zone, removing suspended solids and organic pollutants through anaerobic treatment. The CW cells, thoughtfully integrated into the topography of the green field area, require minimal cut and fill, showcasing informed placement. Employing a nature-based treatment process, the greywater follows a meandering path through gravity within the CW. The treated water is then directed, again through gravity, towards a natural drain on the western side and the existing water body as indicated. Additionally, a community park is planned near this water body, transforming a current Construction and Demolition (C&D) dump site into a vital community space. Considering that 90 % of the surface area in the sub-catchment is built-up, with limited open and unsealed spaces primarily allocated to schools or religious places, this intervention plays a pivotal role. Beyond treating greywater before its recharge to significantly mitigate flooding events, it also serves as a valuable breathing space within the densely populated settlement. This shared community space fosters a sense of ownership and collectively contributes to the well-being of the residents.

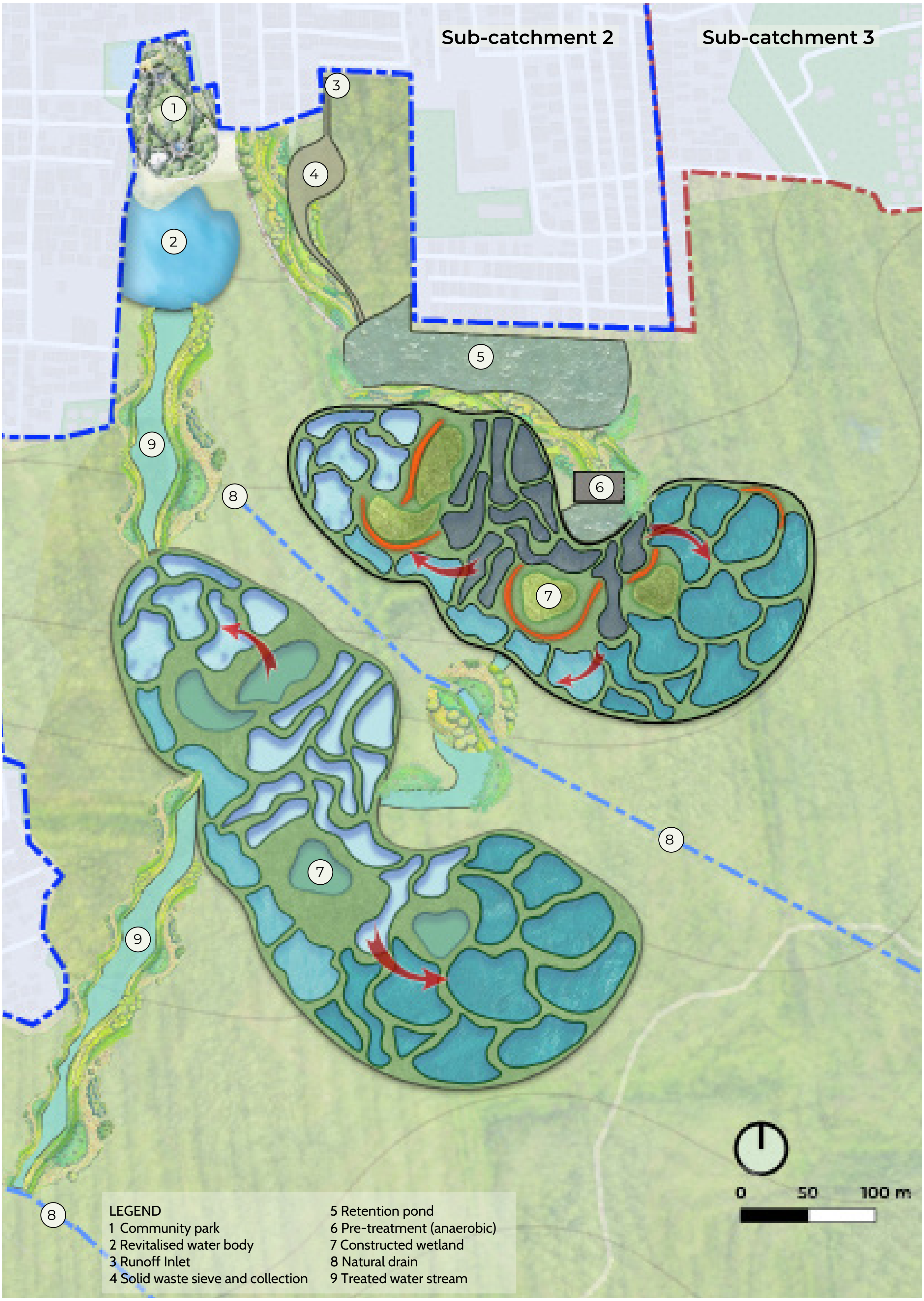


Figure 6-29: Concept design: site plan of the proposed intervention (community area and the constructed wetland)

07 CONCLUSION

7.1 Answers To The Research Question and Sub-Questions

Chapter 5, titled 'Framework Guidance for Indian Cities,' presents the essential principles for a Water Sensitive Planning (WSP) framework tailored to Indian cities. The chapter delves into the goals, projected outcomes, and impacts of this framework for Indian cities.

Which design principles of the WSP framework can be applied to dense urban settlement in Sangam Vihar, New Delhi to mitigate urban flooding risk?

In Chapter 6, titled 'Concept Design: Framework Implementation,' the focal point is the dense unplanned settlement of Sangam Vihar, New Delhi, serving as a case study to address and mitigate urban flooding risks. The intervention is grounded in the key principles of the Water Sensitive Planning (WSP) framework, emphasising a comprehensive analysis. The design proposal aligns with the framework's rationale, as depicted in Figure 5-02, emphasising the need to supplement highly dense unplanned settlements with adequate grey infrastructure and affordable services. Simultaneously, low-density planned settlements should prioritise recharge and reduce dependence on piped infrastructure.

The application of WSP framework principles in Sangam Vihar is organised into short-term, mid-term, and long-term categories based on priority and feasibility. Short-term principles play a crucial role in mitigating flooding risks and decreasing their recurrence within the settlement, primarily by enhancing existing grey infrastructure, particularly in stormwater drainage. Robust solid waste management infrastructure is also deemed imperative to prevent stormwater drain clogging. This step is complemented by reinforcing statutory urban planning norms, emphasising the importance of accurate baseline data. Regular updates of this data are essential for informed decision-making. The mid-term goal involves establishing an efficient separate stormwater and wastewater network, prioritising water reuse and treatment through decentralised methods. Land use zoning should underscore water availability, conservation, and the intricate relationship between water availability, demand, and pollution.

Principles categorised as long-term, such as sustainable urban drainage, permeable surfaces, and safeguarding water commons, contribute to a broader intervention at the Delhi planning level. While these may not have a direct impact on Sangam Vihar, they promise long-term benefits, including enhanced water security and reduced dependence on centralised networks. The interdependence of WSP principles is significant. Figure 7-01 provides a summarised depiction of the key principles for Sangam Vihar.

Moreover, strengthening the legislative framework for implementing the WSP framework in Delhi involves establishing a single institution responsible for managing stormwater citywide. This consolidation aims to enhance accountability, streamline coordination, and minimise inter-departmental conflicts, ultimately fostering more efficient and effective stormwater management practices.

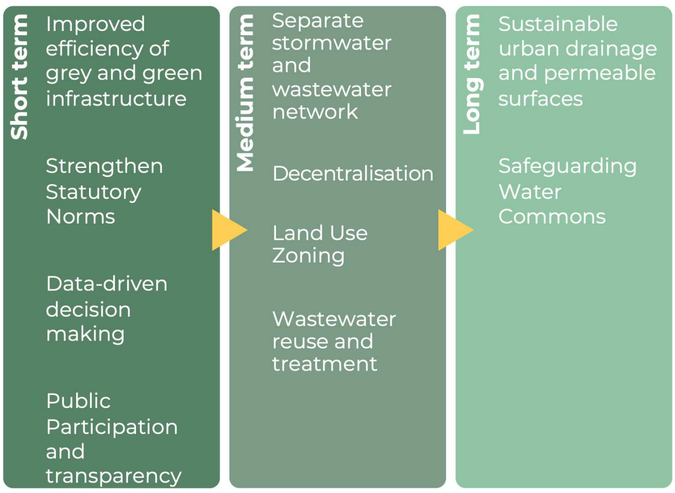


Figure 7-01: Key WSP principles application for Sangam Vihar

S No	Outcome	Indicator	Unit	Measure	Addressed through the intervention
1	Hybrid approach to sanitation and wastewater infrastructure	Percentage of households or areas implementing hybrid systems.	%	NA	No
2	Urban flooding mitigation	Reduction in the frequency and volume of urban flooding events	Number and Volume	2 nos. in sub-catchment; 15,102 m^3/ day	**Yes**
3	Stormwater reuse	The volume of stormwater captured and reused for non-potable purposes, such as landscaping and irrigation, compared to the total stormwater generated.	litres/ m^3	19,515 m^3/ day	**Yes**
4	Addressing infrastructure gaps in less privileged areas	The number of underserved communities with improved water, wastewater, and drainage infrastructure, as well as the extent of coverage of incremental planning in these areas.	Number; %	100 % of the sub-catcment; 22.5 % of Sangam Vihar	**Yes**
5	Efficiency of existing wastewater facilities	Percentage increase in the operational efficiency of existing wastewater treatment plants.	%	NA	No
6	Incorporating stormwater drainage standards	The number of infrastructure upgrades that have incorporated stormwater drainage.	Number	Cannot quantify at this moment	**Yes**
7	Enhanced water planning for security	Progress in aquifer mapping, water recharge policies, and strategies developed and executed to enhance water security.	%	NA	No
8	Mitigating water pollution	Reduction in pollution levels in both surface and groundwater sources.	Number; %	Cannot quantify at this moment	**Yes**
9	Energy efficiency	Energy savings achieved through reduced electricity consumption.	%	Cannot quantify at this moment	**Yes**
10	Substitution with groundwater	Increase in the use of groundwater as a substitute for long-distance water supply.	%	NA	No
11	Wastewater reuse	Volume of treated wastewater and biosolids reused within and outside the city.	litres	NA	No
12	Knowledge and awareness	The number of citizens and stakeholders engaged through open-source platforms and information systems.	Number	Cannot quantify at this moment	**Yes**

Table 7-01: Measuring the outcomes of the proposed intervention using the WSP framework indicators

The proposed intervention in sub-catchment 2 aims to reduce flooding events in Sangam Vihar by diverting excess stormwater and greywater outside the catchment for local treatment, promoting decentralisation. This process facilitates the creation of a community park and revitalises arid water bodies, emphasising groundwater recharge. Due to site constraints, the designated area for the proposed constructed wetland (CW) spans approximately 16 ha. In this context, only 25 % of the stormwater volume generated within the sub-catchment and 100 % of the daily greywater generated is directed towards the CW for treatment, total daily capacity is calculated at 19,515 cu m (refer to Table 6-04).

Subsequently, a few of the intervention's desired outcomes align with WSP framework indicators from Table 5-01. While focusing on greywater reuse and stormwater runoff, certain WSP outcomes, like a hybrid approach to sanitation and wastewater infrastructure, extend beyond this thesis. Measurement feasibility for outcomes such as pollution reduction, energy efficiency and stakeholder engagement is currently limited. This is summarised in Table 7-01.

Challenges for framework implementation

For a dense unplanned settlement such as Sangam Vihar, implementing a WSP framework can present additional challenges apart from space and existing grey infrastructure constraints. Some potential challenges are:

- Land Tenure Issues: Sangam Vihar is an unauthorised colony, predominantly occupied agricultural land that originally belonged to the villages of Tigri, Deoli, Tughlaqabad, and Khanpur. It is currently undergoing formalisation under a phased manner, however the land use map for MPD-2041 still categorises it under an unauthorised colony (refer to Annexure-4). There is an uncertainty regarding land tenure, making it difficult to enforce regulations and implement changes without proper community engagement and collaboration.

- Public Awareness and Participation: Engaging the public and stakeholders in unplanned settlements can be challenging due to lack of awareness, or distrust in the planning process.

- Data Availability and Infrastructure Mapping: Lack of accurate and up-to-date data on the existing infrastructure, hydro-geographical features, and population density can hinder effective planning and decision-making for water sensitive initiatives.

- Enforcement of Regulations: Strengthening statutory norms and enforcing regulations related to urban planning and stormwater management may face resistance and require significant efforts in unplanned settlements.

Addressing these challenges in dense unplanned settlements requires a holistic approach, involving collaboration between local communities, government bodies, and relevant stakeholders to develop context-specific solutions.

Application of framework for Indian Cities

Applying the Water Sensitive Planning (WSP) framework to other Indian cities with a similar context involves adapting the principles and strategies to the specific conditions and challenges of each city. While Indian cities share certain common trends in urban expansion, informality, population density, inequity, surface water pollution, and inadequate drainage, there are noticeable differences.

Common strategies for water sensitive planning in all Indian cities include community engagement, gathering accurate and up-to-date data, and data-driven approaches to inform decision-making. This engagement is crucial for the successful implementation and acceptance of the framework. Investing in capacity building for local government officials, community leaders, and technical professionals, including training on water sensitive planning practices, sustainable urban drainage, and decentralised water management solutions, is essential.

Implementing small-scale pilot projects tests the feasibility of WSP principles in the local context. Evaluating the effectiveness of different strategies and gathering feedback from the community informs adjustments and scalability. Advocating for supportive policies at the regional and national levels, and collaborating with government agencies, NGOs, and academic institutions, creates an enabling environment for the adoption of water-sensitive planning practices.

Lastly, establishing a robust monitoring and evaluation framework is crucial for assessing the impact of WSP initiatives over time. Regularly reviewing progress, identifying challenges, and making necessary adjustments will improve the overall effectiveness of the framework.

7.2 Remarks

In this research, the examination of Water Sensitive Urban Design (WSUD) in India unveils a discourse predominantly rooted in best practices from developed countries or Global North cities, driven by their scholars. While the literature advocates the potential for developing countries to leapfrog toward a Water Sensitive City (WSC), a closer look at India, particularly in the context of Delhi, reveals intricate challenges. Notably, approximately one-third of Delhi's population resides in densely unplanned settlements lacking basic services and grey infrastructure, challenging the feasibility of leapfrogging (Roychowdhury & Das, 2021). This necessitates the creation of adequate grey infrastructure, especially in dense unplanned settlements.

Delhi's current status, including climatic conditions, urban water cycles, stakeholders, informality, and legislative frameworks for stormwater management, highlights the city's twin challenges of water scarcity and urban flooding.

While the Master Plan of Delhi (MPD-2041) introduces Water Sensitive Urban Design (WSUD) discourse, the outlined strategies lack a clear pathway. The draft Drainage Master Plan of Delhi (DMP-2018) sidestepped a comprehensive flood prevention strategy by focusing on quantifying surplus runoff and proposing measures through various simulation scenarios. The plan prioritised enhancing the efficiency of existing stormwater infrastructure to mitigate the city's flooding issues. Consequently, Delhi relies on a 50-year-old drainage system, underscoring the immediate need for planning-level enhancements to address current urban and climatic challenges.

The research underscores the urgency for a Water Sensitive Planning (WSP) framework tailored for Indian cities, grounded in inclusive planning, that addresses both planned and unplanned areas in Indian cities. The key principles of the WSP framework include safeguarding water commons, strengthening statutory norms, prioritising water availability in land use zoning, improving the efficiency of existing grey infrastructure, sustainable urban drainage, separate stormwater and wastewater networks, wastewater reuse and treatment, decentralisation, data-driven decision-making, and public participation and transparency. The main indicators are listed in Table 5-01 (Outcomes of WSP framework along with their indicators). By establishing a robust monitoring and evaluation framework, cities can assess the impact of WSP initiatives over time and make necessary adjustments to improve overall effectiveness.

In conclusion, the research asserts that a successful transition to a Water Sensitive City (WSC) in the context of Indian cities requires the integration of nature-based solutions (NBS) alongside robust development of grey infrastructure, not as a substitute but as a complementary strategy. Challenges unique to Indian cities, including concentrated monsoon rainfall and the large presence of densely unplanned settlements, present significant hurdles in this transition. In Delhi, challenges are compounded by the ineffective governance of water utility organisations and city planning agencies, underscoring the imperative for a unified institutional commitment to implement sustainable urban water management practices.

7.3 Further Recommendations

This master's thesis focuses on proposing a Water Sensitive Planning (WSP) framework tailored for Indian cities, with a specific emphasis on flooding mitigation in dense urban settlements in Delhi. The comprehensive analysis of Sangam Vihar serves as the basis for the concept design; however, certain limitations exist. Notably, the technical design of the proposed constructed wetland is beyond the scope of this thesis. Additionally, the proposed intervention is dependent on specific boundary conditions.

One critical condition assumes the presence of a robust solid waste management plan in these unplanned settlements. This assumption presents an opportunity for further in-depth research into solid waste management plans for dense, unplanned settlements within the context of Indian cities. A focal point at the site is the issue of clogged drains due to solid waste accumulation; addressing this concern can significantly enhance the effectiveness of stormwater management.

Furthermore, it presents an opportunity for researchers to explore topics closely related to stormwater management in Indian cities, such as the provision of safe sanitation services and the treatment and reuse of wastewater in Indian cities.

Recognising the interconnected nature of water sensitive planning, recommendations stemming from this research include the integration of WSP principles into existing urban development policies, fostering public-private partnerships, and investing in ongoing research and innovation in the field.

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Annexure - 1: Questionnaire for residents of Sangam Vihar

02.03.2023

Question	Answer
1. Name, Age, Occupation?	
2. How long have you been living here? How many people live in your household?	
3. What are the challenges facing the neighborhood?	
4. How do you see yourself contributing to the challenges/problems?	
5. How would you describe the neighborhood development over the last 20 years?	
6. What opportunities do you see rising in the neighborhood?	
7. How do you see yourself benefiting from this?	
8. Describe the water situation at Sangam Vihar? Does the water come from the municipal supply or Borewell or any other source? Is the water supply reliable?	
9. Do you have a toilet inside your home? If yes, do you use flush toilets?	
10. Do you know where wastewater this discharge goes?	
11. Describe the sewage management infrastructure at Sangam Vihar? What is your opinion about it?	
12. Does this infrastructure pose any threat to health/life security?	
13. Do you observe flooding at Sangam Vihar? Is it only during Monsoons? Can you describe it?	
14. What mode of transport do you use? Bus/ Car/ Bike/ Rickshaw/ Walk ?	
15. Do you have any solid waste management systems? How and where do you dispose of Garbage?	
16. Do you know about solid waste segregation before disposal? Do you practice it?	
17. Do you get an electricity bill? Who pays your Electricity Bills?	
18. How difficult is it to get a meter/connection for electricity? Is the process transparent?	
19. How difficult is it to get a water supply connection? Is the process transparent? Are you okay with paying for the water supply?	
20. Do you know what rainwater harvesting is?	
21. What is the biggest issue you face as a resident of Sangam Vihar	
22. Do you think the government is doing enough in terms of water supply, wastewater, and stormwater management?	
23. What do you think can be better? Any suggestions for the policymakers?	
24. Has any NGO or other public organization reached out to them with anything related to the topic of energy/electricity.	

Annexure - 2: Questionnaire for Experts and Stakeholder - Ms Pratima Joshi

Question 1: Name

Answer: Ms. Pratima Joshi

Question 2: Current practice/ role

Answer: Founder of Shelter Associates. Shelter Associates (SA) was founded in 1994 as a Non-Profit Organization with a passion for ensuring equitable access to essential services for the underserved. SA follows a Data-driven, Multistakeholder approach to designing and implementing community-centric solutions around Sanitation and Social housing issues. Ms. Joshi completed her Masters-in-Architecture from Bartlett School of Architecture and Planning in London. She is the only Indian to receive the 'Google Earth Hero Award'. An Ashoka fellow, she is recognised by BBC as a leading 'Slum architect of India'.

Question 3: What are the challenges that Indian cities face in terms of urban flooding?

Answer: The biggest challenge is to protect our natural waterways from encroachment as well as unplanned and haphazard development. We must plan according to the natural gradient and flow of the river. These rivers took centuries to form, we are instead straightening the canals and natural stormwater channels. Over concretisation of these channels has only made the situation worse in terms of urban flooding. Climate change and intensification of natural water cycle has overwhelmed us.

Question 4: What is the role of informality/ informal settlements in these cities?

Answer: Informal settlements usually come up along with rivers or water bodies as availability of water is of paramount importance. Access to water ensures that their daily needs are met. These are the people that help in functioning of our cities in more than one way. However, they are often neglected when it comes to planning and by and large remain unauthorised and unrecognised.

Question 5: What is the role of data in planning?

Answer: Data is of utmost importance. Without numbers, there cannot be efficient planning. "How can we plan our cities if we do not know who and how many are we planning for" ? Reliable data collection and its analysis are essential components for planning our cities. Furthermore, this data must be updated consistently as our cities are growing rapidly.

Question 6: Does the informality provide an opportunity for urban planners?

Answer: Already answered

Question 7: What is your opinion on existing grey infrastructure in Indian cities?

Answer: Our cities have a fragile grey infrastructure as most of these were planned around 1980's, roughly 50 years ago. Since then, our cities have expanded and are growing at an intense pace. The infrastructure is already overwhelmed even in planned parts of the city during monsoons. Unfortunately, the low income groups and informal settlements are impacted the most.

Question 8: Do Nature-based solutions for stormwater management provide an alternative to grey infrastructure development?

Answer: NBS provides our cities with an alternative, however these cannot replace the basic need of infrastructure. Water supply, sanitation, and stormwater management infrastructure provision cannot be overlooked. The government of India claims that access to WASH (Water, Sanitation and Hygiene) facilities will be provided to all the citizens. However, this seems like a distant reality.

Question 9: What other factors impact planning decisions for effective stormwater management?

Answer: Public participation, Stakeholder engagement and management are also important. Usually, most projects are implemented with a top-down approach and people are neglected. This needs to change. For instance, at Shelter associates, during the planning and concept stage, we ensure that we include the citizens, the municipality, and all other stakeholders at every stage of the project.

Question 10: Do Indian cities need a new approach for WSUD?

Answer: Yes. Data driven approach towards planning is the right way forward. Any planning guideline must be relooked at least once in a 5 year time period as our cities are growing rapidly. Necessary revisions must be made in order to cater to the needs.

Question 11: What is your suggestion to urban planners regarding stormwater management in cities?

Answer: Sensitive planning should be the starting point. Planners need to respect the existing green infrastructure (water bodies, open spaces, natural slopes) and plan in line with it. Planners must not over concretise our cities.

Question 12: Do you think the government is doing enough to provide grey infrastructure or tackle urban flooding?

Answer: Not really. They need to involve urban planners, architects, engineers, and all other stakeholders for planning our cities.

Annexure - 2: Questionnaire for Experts and Stakeholder - Mr Dhruv Pasricha

Question 1: Name

Answer: Mr. Dhruv Pasricha

Question 2: Current practice/ role

Answer: He has a Master's degree in Planning and Environmental Planning from the School of Planning and Architecture in New Delhi. Having contributed to more than 30 WASH publications, he was an integral part of the Centre for Science and Environment's (CSE) Water Program in New Delhi from 2018 to 2023.

Question 3: What are the challenges that Indian cities face in terms of urban flooding?

Answer: The biggest challenge is that our manuals and guidelines are still restricted to the management of stormwater at the roadside drain level. The idea is primarily to dispose of the runoff away from the cities as fast as possible. Additionally, combined sewers pose a huge challenge to re-use stormwater due to high pollutant load. Another challenge is the lack of presence of drainage infrastructure. The urban density of our cities is another challenge. Large parts of our cities are unplanned and are missing drainage. Even in planned areas of the city, the designed capacity of stormwater infrastructure is not as per the current rainfall patterns. However, the larger challenge that I see is in our approach. The current approach is a 'Reactive' approach. We can manage our stormwater better by having a 'Proactive' approach. The design approach must be sensitive to both the planned and the unplanned settlements in our cities. In a good scenario, we need a tiered approach to manage stormwater – Regional, Urban, Zonal, and Neighbourhood scale, and the strategies are different at each level, however, implemented in a holistic manner.

Question 4: What is the role of informality/ informal settlements in these cities?

Answer: They are an integral part of our economy and system. They provide our cities with services, income, and goods. A lot of our informal industrial clusters are present in these informal settlements. People living in these areas are not just numbers. They contribute significantly to our social and economic development which is also documented well enough. The importance is unquestioned.

Question 5: What is the role of data in planning?

Answer: Data is the most important aspect of Planning. Poor data leads to poor plans and ill-informed solutions. Good documentation of a cities' natural features/ topography and manmade infrastructure would help to prepare better management plans as these are primarily based on existing geographical conditions of a city. Good data would result in good policies which would in turn result in cost effective solutions. We must not limit data just to maps/GIS and numbers but also include data on people. Without involving people, stakeholder engagement and awareness in our strategies/ policies, there is a huge risk that the strategies might fail.

Question 6: Does the informality provide an opportunity for urban planners?

Answer: Yes, they do. From a planner's perspective, the challenge and the opportunity lie in possible interventions to convert our informal settlements or Slums into Neighbourhoods. This would essentially mean upgrading their living conditions with provision of basic services like safe water supply and sanitation.

Question 7: What is your opinion on existing grey infrastructure in Indian cities?

Answer: In terms of Water supply, Delhi's current demand is around 1,200 mgd (million gallons per day) as per Delhi Jal Board (DJB). DJB supplies approx.. 960 mgd. About 85% of this water is brought in from outside the city limits. To close or reduce this gap, the city must identify local water resources. For sewage management, the existing infrastructure would never be able to keep up with the speed of urban housing development. DJB needs to look at decentralised solutions which they rightly seem to be in the process of. The above holds true for Delhi's stormwater drainage network.

Question 8: Do Nature-based solutions for stormwater management provide an alternative to grey infrastructure development?

Answer: Indian Cities need to look at solutions with a combination of Grey and Green Infrastructure. They need to complement each other. In fact, people often misunderstand this concept. The idea is not to replace one with the other, instead it is for their co-existence, however giving more importance to NBS or decentralised solutions. Considering Delhi's urban density, amount of impervious surfaces and intensified rainfall patterns, the width of drain channels may surpass the available right of way of streets in some scenarios.

Question 9: What other factors impact planning decisions for effective stormwater management?

Answer: Some of the factors that would help in effective stormwater management include: Circular economy approach in stormwater management – looking at stormwater as a resource. Proactive design approach. New age technology/ AI tools need to be implemented to create vulnerability maps so that appropriate action can be taken based on reliable data. Interventions (design guidelines and infrastructure) at each scale - Regional, Urban, Zonal, and Neighbourhood scale for effective stormwater management should include the cost, governance, and it's life cycle/ management as well. These must fit the City/ State's budget.

Question 10: Do Indian cities need a new approach for WSUD?

Answer: We certainly need manuals or guidelines that would improve upon the previous centralised/ conventional approach for stormwater management at the Planning level. The WSUDP requires some modifications as we learn from experience. However, I strongly believe that more emphasis needs to be given to decentralised solutions. SuDS are often misunderstood; they are just one aspect of WSUDP principles. The approach must be to manage drainage locally as much as possible. Neela Hauz lake rejuvenation to a Bio diversity park near JNU campus in Delhi is a perfect example of how to locally manage your waste/ discharge. Drain from nearest STP, NBS solutions to treat water and supply to nearby villages through groundwater recharge.

Question 11: What is your suggestion to urban planners regarding stormwater management in cities? **Answer: Already answered**

Question 12: Do you think the government is doing enough to provide grey infrastructure or tackle urban flooding?

Answer: The Delhi government's initiative with the 'City of Lakes' is a good step in management of city's water supply. The idea is to fill the water supply gap of approx. 300 mgd through creating new lakes, reviving old lakes, constructing wetlands, and thereby increasing the ground water level through recharge. In terms of lake management and water supply, Delhi is making progress. Unfortunately, for stormwater drainage, the progress is almost negligible. The drainage masterplan is as old as 1976 and the most recent masterplan prepare by IIT Delhi in 2018 was completely rejected by the government. The governance system of drainage management is disjointed and involves almost 10 agencies. This causes bureaucratic issues, but the larger issue is that there is no 1 organisation that can be held accountable in case of urban flooding. This seems to be a collective failure.

Annexure - 2: Questionnaire for Experts and Stakeholder - Ms Shambhavi Gupta

Question 1: Name

Answer: Ms. Shambhavi Gupta

Question 2: Current practice/ role

Answer: An urban planner, currently a student of Master of Public administration at Columbia University. She is one of the co-authors of 'Water Sensitive Planning for the Cities in the Global South', an article that was published by MDPI in January 2023. She is interested in areas related to inclusive planning, sustainable development, environmental planning, public policy research and formulation, and resilient cities.

Question 3: What are the challenges that Indian cities face in terms of urban flooding?

Answer: The biggest challenge is evident from the rainfall data and abnormal rainfall patterns with a recurrence period of 50 years. Additionally, in the case of Delhi, approximately 90% of the water supply is met through inter-state governance, and this is a huge challenge. Delhi was developed with a piecemeal approach, be it pre-colonial, colonial period, or be it now. Most of our housing typologies lack basic drainage or sewage systems. The groundwater level is rising in the settlements next to the Yamuna river. We are hampering the natural systems of the city in a systemic manner. It reflects on the stormwater management and mismanagement of the city.

Question 4: What is the role of informality/ informal settlements in these cities?

Answer: It is the biggest last-mile connection we have regarding the provision of grey infrastructure and related services. Delhi Jal Board (DJB) claims that it shall provide water to even unauthorised colonies. However, the situation is extremely political in nature, it is alarming to see that most of these areas are supplied with water through a private water tanker system that involves a water mafia. Depending upon the number of voters residing in a specific area, political parties indulge in favouritism leading to mismanagement of water supply in the absence of a planned network.

Question 5: What is the role of data in planning?

Answer: I would want to know how many people are residing in the area that I am planning for. Baseline data for a city is most important and unfortunately, even in the new 2041 Master plan of Delhi, the baseline data of the city is missing.

Question 6: Does the informality provide an opportunity for urban planners?

Answer: Yes, they do. The role of an urban planner is also to be the facilitator between the government and the citizens and this is not happening currently. This eventually leads to us criminalising the informality as we are not able to recognise these settlements.

Question 7: What is your opinion on existing grey infrastructure in Indian cities?

Answer: It has a lot of grey areas. The DJB does not have a city level map of its water supply network in Delhi. The same holds true with stormwater and sewerage network maps.

Question 8: Do Nature-based solutions for stormwater management provide an alternative to grey infrastructure development?

Answer: I believe they are more of a complimentary system to the present infrastructure network. We should not look at NBS as an alternative since that would mean undermining the existing infrastructure. One might then perhaps consider discarding the present and start something new.

Question 9: What other factors impact planning decisions for effective stormwater management? **Answer: Already answered**

Question 10: Do Indian cities need a new approach for WSUD?

Answer: We don't need a new approach to Urban Design, instead we need a new approach to Urban Planning. If we don't look at it from this perspective, we might then miss the whole picture. Both (UD and UP) are very different each other and one is part of the other. I see Urban Design as a part of Urban Planning. Urban Planning is something which guides the city through policy interventions.

Question 11: What is your suggestion to urban planners regarding stormwater management in cities?

Answer: We need to place Water in the centre of Planning and make policies and frameworks in consideration with that. We also need to look at the compatibility of land uses in terms of low water and high water intensive land uses.

Question 12: Do you think the government is doing enough to provide grey infrastructure or tackle urban flooding?

Answer: The draft Water Policy (prepared by INTACH) is a good start. The report is unfortunately still at draft stage due to political reasons. The biggest challenge they face is the lack of data or accurate data.

Annexure - 3: Stakeholder Register

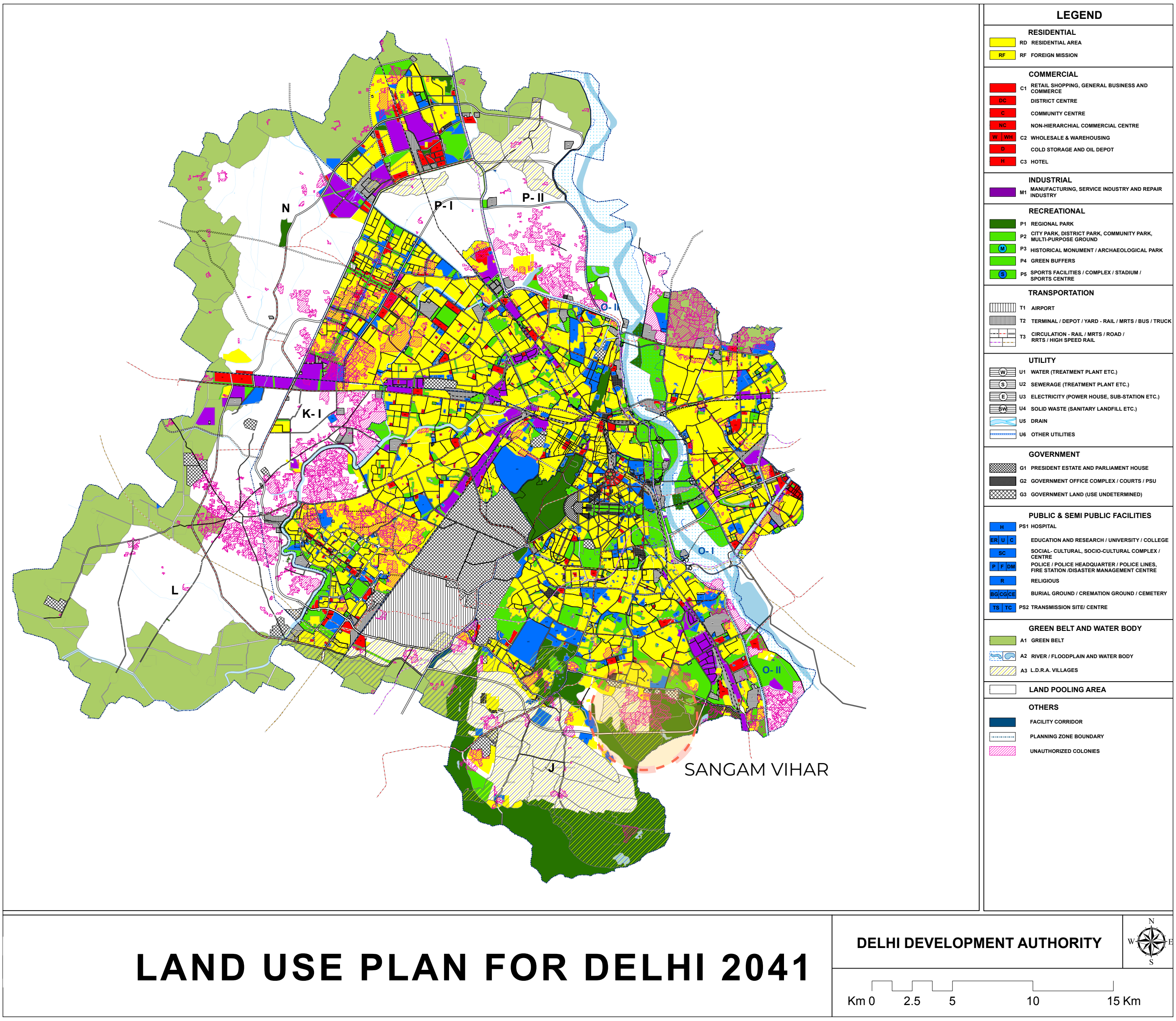
	Stakeholder description	Stakeholder (acronym)	Stakeholder's Focus area	Stakeholder's duties & responsibilities	Stakeholder Interest ?	Stakeholder Power ?	How to manage this stakeholder ?
Central & State Authorities, Public Institutions and associations	Irrigation and Flood Control Department - NCT Delhi	IFCD	Stormwater drainage network	Construction & maintenance of stormwater drains; Maintenance of greenary; Urban flooding risk mitigation	**7**	**9**	Provide context oriented, efficient and feasible solutions suitable to Delhi which can manage stormwater, mitigate flooding risk and improve quality of stormwater discharging into surface water bodies
	Delhi Jal Board	DJB	Water supply & Sewage Disposal	Construction & maintenance of water supply and septage network; Urban flooding risk mitigation	**6**	**8**	Provide efficient and feasible solutions which can manage wastewater and avoid reverse flow of sewer drains during events of rainfall
	Municipal Corporation of Delhi (including New Delhi Municipal Corporation)	MCD	Executive governing body to create civic amenities in Delhi	Construction & maintenance of streets, bridges, flyovers,transport and related infrastructure; Urban flooding risk mitigation and immediate welfare during such events. Crucial role in implementing and enforcing regulations	**6**	**8**	Provide context oriented, efficient and feasible solutions suitable to Delhi which can manage stormwater, mitigate flooding risk and improve quality of stormwater discharging into surface water bodies
	Public Works Department - Delhi	PWD	Construction & maintenance of public infrstructure	Construction & maintenance of streets, bridges, flyovers,transport and related infrastructure; Urban flooding risk mitigation	**5**	**8**	
	Delhi Development Authority	DDA	Masterplan development	Development for roadmap for Delhi's holistic landuse and infrastructural development	**5**	**7.5**	Provide context oriented, efficient and feasible solutions that can be implemented for the masterplan
	Central Ground Water Board	CGWB	Regulation of ground water resources	Providing scientific inputs for monitoring, assessment, and regulation of ground water resources	**4**	**5**	Provide latest tools & technology for accurate data collection regarding ground water level
	Delhi Disaster Management Authority	DDMA	Manage disaster including floods	Formulating policies and plans to manage and respond to various disasters, including floods	**7.5**	**7**	Provide state of the art equipment and tools for effective disaster management; Knowledge sharing workshops urban local bodies
	Ministry of Housing and Urban Affairs	MoHUA	Executive authority for uban development for India	Economically, socially & environemntally sustainable city development following the legislative framework	**6**	**9**	Provide context oriented, efficient and feasible solutions suitable to Delhi which may be applied to other Indian cities as well
	Ministry of Jal Shakti	MoJAL	Executive authority for water resource development and management for India	Sustainable development, maintenance of quality and efficient use of water resources to match with the growing demands	**5**	**8**	
	Political Party - Ruling	AAP	Governing the city of Delhi	Deliver on the election mandate and address the issues of the citizens	**6**	**7.5**	Provide context oriented, efficient and feasible solutions for flooding risk mitigation
	Political Party - Opposition	OPP	Desire to govern the city	Question the ruling party with regards to their shortcomings; Raise awareness regarding the issues of the citizens	**5.5**	**6**	
	Delhi Traffic Police	Traffic Police	Manage and control traffic	To ensure that emergency services can access all areas and provide services; Manage overall traffic	**6**	**3**	Provide solutions that can assure minimization of traffic jams during flooding events

Annexure - 3: Stakeholder Register (continued)

	Council of Architecture; The Institute of Engineers; Plumbing Association of India	EXP	Regulation of the profession, practise and education of architecture	To assist and provide solutions for urban flooding risk mitigation to the state authorities; Development and implementation of the	**5**	**3.5**	Provide beneficial, efficient solutions towards/ and a new framework for 'Water Sensitive Urban Design for Indian Cities'
	Indian Institute of Technology - Delhi	IITD	Research & development towards science and technology	Research towards the solving the issues of the citizens & assisting the urban local bodies	**7.5**	**3.5**	Provide relevant data, methods, tools applicable to hydrometeorological researches
Non for Profit/ NGO	Centre for Science & Environment	CSE	Research and environmental advocacy with a high professional capacity	Generation of reports and scientific studies highlighting environement related issues in Delhi and Indian cities; Impacting decision making towards environemntal related issues; organaise workshops and spread of knowledge to urban local bodies	**9**	**4**	Provide reliable data from government sources for more accurate generation of reports and knowledge; Provide relevant projects, methods, tools and contemporary ideas for urban planning; Provide opportunities to knowledge sharing through stakeholder workshops
Non for Profit/ NGO	National Institute of Urban Affairs	NIUA	Think tank and research organization with a network of urbanists	Generation of knowledge about cities in general and Delhi in particular; Impacting decision making towards environemntal related issues	**8**	**4**	
Non for Profit/ NGO	Centre for Urban & Regional Excellence	CURE	Building resilient communities & cities	Preparation of city wide slum upgradation and environemental resilience plans	**7.5**	**3.5**	

	Stakeholder description	Stakeholder (acronym)	Stakeholder's Focus area	Stakeholder's duties & responsibilities	Stakeholder Interest ?	Stakeholder Power ?	How to manage this stakeholder ?
Private	Property Developers/ Builders	Builder	New construction and rebuilding of damaged infrastructure	Profitable investment with an acceptable payback	**6**	**6**	Provide feasible solutions to flooding risk mitigation. Provide incentives to follow framework and guidelines
Media	National/ State (TV/ newspapers, radio etc.)	Media	Inconsistent coverage to public issues	Relevant news with facts and actual site situation	**5**	**6**	Provide relevant information and recommendations for improving the situation
Media	Independent (Internet)	Independent Media	Informing the public	Relevant news and fact checking	**6**	**4**	Provide relevant information and actual site situation
Individuals	Residents of Sangam Vihar	Residents	Inhabitants of the neighbourhood	No illegal disposal of blackwater into stormwater drains; Correct disposal of solid waste	**9**	**3.5**	Provide solutions to flooding risk mitigation; Inform about their roles and responsibilities
Individuals	Citizens of Delhi	Citizens	Residents in the city	Same as above	**5**	**3**	Inform about alternate urban development strategies and its benefits for the whole city
Individuals	Activists	Activists	Active citizens with a desire of liveable city	Raise awareness & highlight issues; Empower residents using dialogue	**7**	**6**	Provide solutions to flooding risk mitigation, networking and collaborations
Individuals	Local representative	MLA	Appointed leader by the neighbourhood	Problem solving approach towards the issues of the residents	**7**	**8**	Provide solutions to flooding risk mitigation; Inform about alternate urban development strategies and its benefits
International Organisations	United Nations	UN	Issues related to climate change and sustainable development	Implementation of international agreements; Enabling the national and state level urban bodies for integrating Planning into 'Water Sensitive Design Urban Design Framework'	**5.6**	**7**	Provide corelation of the importance of flooding risk mitigation in Delhi and the UNDP sustainability goals in Delhi - India
International Organisations	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH English: German Agency for International Cooperation GmbH	GIZ	Financial support for pilot projects that may reduce flooding impact in the neighbourhood	Compliance for and towards environmental and social sustainability. Providing technical assistance and support for capacity building	**7**	**8**	Provide facts and scientific evidence towards flooding risks in dense urban settlements in Delhi and the relevance of a new Water Sensitive Urban Design Framework for Indian cities

Annexure - 4: Land Use plan for Delhi as per Master Plan of Delhi - 2041



HafenCity
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MSc. Resource Efficiency in Architecture and Planning
Master's thesis by Abhishek Sharma
November 2023