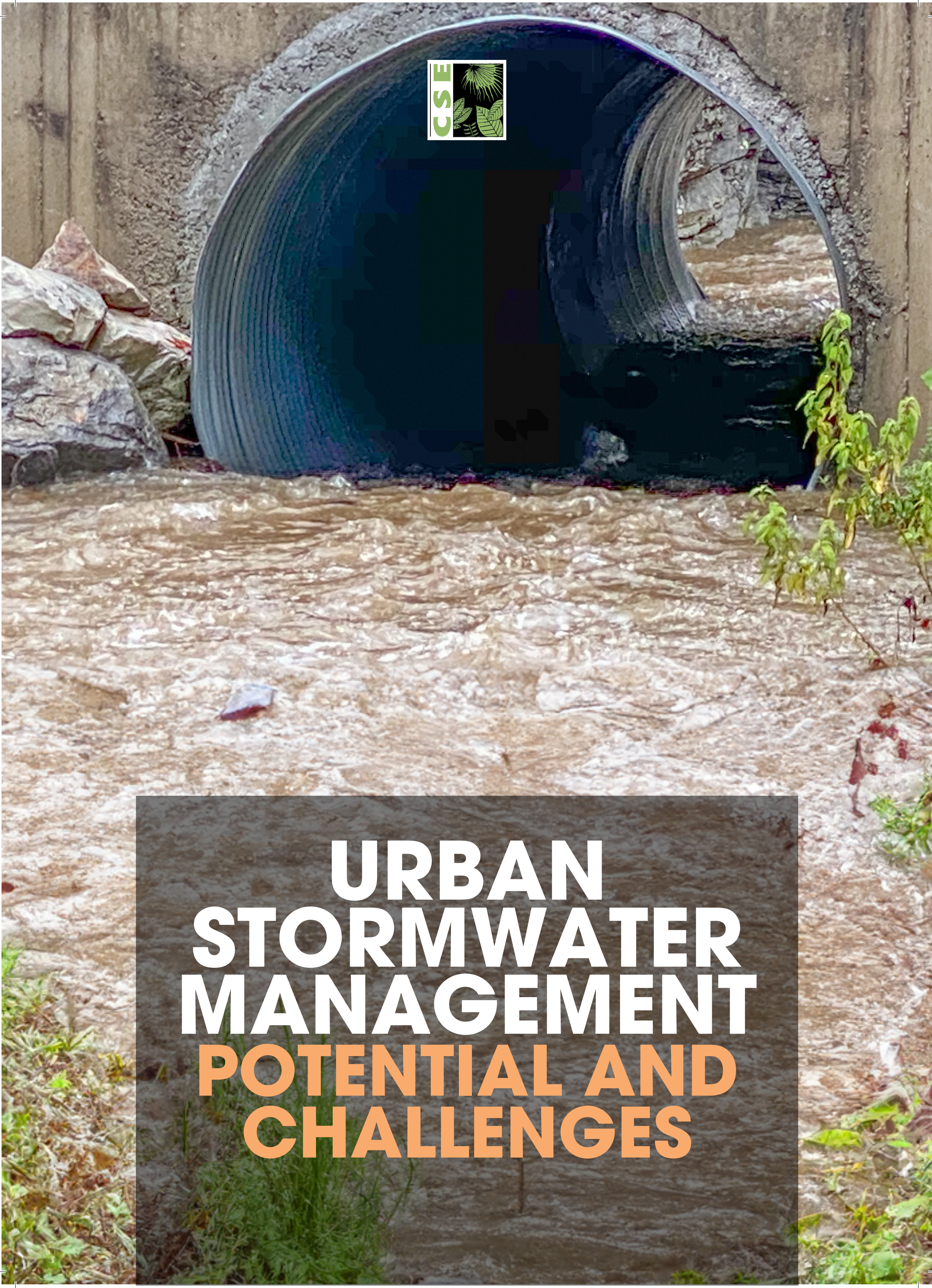


# URBAN STORMWATER MANAGEMENT
# POTENTIAL AND CHALLENGES

# URBAN STORMWATER MANAGEMENT

# POTENTIAL AND CHALLENGES

**Research direction:** Depinder Kapur

**Research support:** Dhruv Pasricha, Shivali Jainer, Shivani and Sumita Singhal

**Editor:** Akshat Jain

**Cover and design:** Ajit Bajaj

**Graphics:** Tarun Sehgal

**Production:** Rakesh Shrivastava and Gundhar Das

**We are grateful to the National Mission for Clean Ganga for its support.**



Maps used in this document are not to scale.

**Citation:** Depinder Kapur, Dhruv Pasricha, Shivali Jainer, Shivani and Sumita Singhal 2023. *Urban Stormwater Management: Potential and Challenges*, Centre for Science and Environment, New Delhi

**Published by**
**Centre for Science and Environment**
41, Tughlakabad Institutional Area
New Delhi 110 062
Phones: 91-11-40616000
Fax: 91-11-29955879
E-mail: sales@cseindia.org
Website: www.cseindia.org

# Contents

## LIST OF FIGURES

## LIST OF TABLES



## LIST OF GRAPHS



## LIST OF MAPS

## LIST OF ABBREVIATIONS

| | |
|---|---|
| AMRUT | Atal Mission for Rejuvenation and Urban Transformation |
| ARI | Average Recurrence Interval |
| CBO | Community-based Organizations |
| CGWB | Central Ground Water Board |
| CPCB | Central Pollution Control Board |
| CPHEEO | Central Public Health and Environmental Engineering Organization |
| CWC | Central Water Commission |
| DCR | Development Control Regulations |
| DPR | Detailed Project Report |
| GI | Green Infrastructure |
| GIS | Geographic Information System |
| GNCTD | Government of National Capital Territory of Delhi |
| GoI | Government of India |
| I&FC | Irrigation and Flood Control |
| ITPI | Institute of Town Planners, India |
| JNNURM | Jawaharlal Nehru National Urban Renewal Mission |
| MoEFCC | Ministry of Environment, Forests and Climate Change |
| MoHUA | Ministry of Housing and Urban Affairs |
| NAPCC | National Action Plan for Climate Change |
| NBC | National Building Code |
| NCR | National Capital Region |
| NCT | National Capital Territory |
| NDMA | National Disaster Management Authority |
| NGT | National Green Tribunal |
| NLCP | National Lake Conservation Plan |
| NPCA | National Programme for Conservation of Aquatic Eco-systems |
| NRSC | National Remote Sensing Centre |
| NWCP | National Wetland Conservation Programme |
| PHED | Public Health and Engineering Department |
| RRZ | River Regulation Zone |
| RWA | Residents' Welfare Association |
| SWMM | Stormwater Management Model |
| TCPO | Town and Country Planning Organization |
| ULB | Urban Local Body |

| | |
|---|---|
| **URDPFI** | **Urban and Regional Development Plan Formulation and Implementation** |
| **WSUDP** | **Waster Sensitive Urban Design and Planning** |
| **WSSB** | **Water Supply and Sewerage Board** |

## GLOSSARY OF TERMS

| | |
|---|---|
| **Aquifer** | A porous, water-logged sub-surface geological formation. The description is generally restricted to media capable of yielding a substantial supply of water. |
| **Baseflow** | The depth of water in a stream when the channel is fed solely by groundwater. |
| **BMPs (Best Management Practices)** | Practices or methods used to prevent or reduce amounts of nutrients, sediments, chemicals or other pollutants from entering water bodies from human activities. BMPs have been developed for agricultural, forestry, construction and urban activities. |
| **Buffer strip** | A vegetated area ordinarily situated on gently sloping ground designed to filter out insoluble pollutants in run-off. It is also known as a filter strip |
| **Catchment area** | A geographical area defined by topography from where all run-off water drains into a waterbody/ collection point. 1) An area from which surface runoff is carried away by a single drainage system. 2) The area of land bounded by watersheds draining into waterbody via sheetflow. |
| **Coefficient of runoff** | Percentage of gross rainfall which appears as runoff. |
| **Conveyance** | The transportation of water away from an area to avoid flooding. |
| **Detention time** | The time required for a drop of water to pass through a detention facility when the facility is filled to design capacity. |
| **Direct runoff** | The stream flow produced in response to a rainfall event. Equal to total stream flow minus base flow. |
| **Discharge** | Outflow; the flow of a stream, canal, or aquifer. One may also speak of the discharge of a canal or stream into a lake, river or ocean. (Hydraulics) Rate of flow, specifically fluid flow: a volume of fluid passing a point per unit of time, commonly expressed as cubic feet per second, cubic meters per second, gallons per minute, gallons per day, or millions of gallons per day. |

| | |
|---|---|
| **Drainage basin** | That portion of the earth's surface upon which all falling precipitation flows to a given location. |
| **Erosion** | The wearing away of the land surface by wind or water. Erosion occurs naturally from weather or runoff but can be intensified by land-clearing practices related to farming, residential or industrial development, road building, or timber cutting. |
| **Eutrophication** | Eutrophication is a process driven by enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, leading to: increased growth, primary production and biomass of algae; changes in the balance of nutrients causing changes to the balance of organisms; and water quality degradation. The consequences of eutrophication are undesirable if they appreciably degrade ecosystem health and/or the sustainable provision of goods and services. |
| **Evapotranspiration** | Loss of water from the soil both by evaporation from the soil surface and by transpiration from the leaves of the plants growing on it. |
| **Floodplain/Riverine area** | An area adjacent to a stream or river that experiences occasional or periodic flooding. |
| **Fluvial flooding** | Fluvial flooding occurs when rivers burst their banks as a result of sustained or intense rainfall. |
| **GIS (Geographic Information Systems)** | A geographic information system integrates hardware, software, and data for capturing, managing, analysing, and displaying all forms of geographically referenced information. GIS allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports and charts. |
| **Groundwater** | The water retained in the inter-granular pores of soils or fissures of rocks below the water table. |
| **Groundwater flow** | The movement of water through openings in sediment and rock. It occurs in the zone of saturation. |
| **Hydrology/Hydrologic cycle** | The science of hydrologic cycle is addressing the properties, distribution, and circulation of water across the landscape, through the ground, and in the atmosphere. |

| | |
|---|---|
| **Impervious surface** | A hard surface area that either prevents or retards the entry of water into the soil mantle as under natural conditions prior to development and/or a hard surface area that causes water to run off the surface in greater quantities or at an increased rate of flow from the flow present under natural conditions prior to development. Common impervious surfaces include, but are not limited to, rooftops, walkways, patios, driveways, parking lots, storage areas, concrete or asphalt paving, gravel roads, packed earthen materials, and oiled, macadam, or other surfaces that similarly impede the natural infiltration of urban runoff. Open, uncovered retention/detention facilities shall not be considered as impervious surfaces. |
| **Infiltration** | The entry of rainfall or surface water into the soil at the ground surface. |
| **Infiltration basins** | An excavated area which impounds stormwater flow and gradually exfiltrates it through the basin floor. |
| **Macrophytes** | Macrophytes are aquatic plants growing in or near water. They may be either emergent (i.e., with upright portions above the water surface), submerged, or floating. Examples of macrophytes include cattails, hydrilla, water hyacinth and duckweed. |
| **Major system** | This system provides overland relief for stormwater flows exceeding the capacity of the minor system and is composed of pathways that are provided, knowingly or unknowingly, for the runoff to flow to natural or manmade receiving channels such as streams, creeks and rivers. |
| **Minor system** | This system consists of the components of the storm drainage system that are normally designed to carry runoff from the more frequent storm events. These components include: kerbs, gutters, ditches, inlets, manholes, pipes and other conduits, open channels, pumps, detention basins, water quality control facilities, etc. |

| | |
|---|---|
| **Non-point source pollution** | Pollutants from many diffuse sources. Non-point source pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even underground sources of drinking water. |
| **Open channel** | A long, narrow excavation or surface feature that conveys surface water and is open to the air. |
| **Percolation** | The process by which water, after infiltration into the soil, moves downward or laterally through openings or fissures or fractures within the rocks in response to gravity or differences in pressure. If there is an impermeable layer of rock below, the water flows laterally and joins the stream flow. When there is no impeding layer, the water percolates into the ground and builds up the groundwater table. |
| **Pluvial flooding** | Pluvial flooding occurs when an extremely heavy downpour of rain saturates the urban drainage system and the excess water cannot be absorbed. |
| **Point source pollution** | Pollutants from a single, identifiable source such as a factory or refinery; also called single-point source pollution. Most of this pollution is highly regulated at the state and local levels. |
| **Rainfall** | The quantity of rain falling within a given area in a given time. |
| **Rainwater harvesting** | The direct capture of stormwater runoff, typically from rooftops, for supplementary water uses onsite. |
| **Retention/detention facilities** | Facilities used to control the quantity, quality and rate of runoff facilities discharged to receiving waters. Detention facilities control the rate of outflow from the watershed and typically produce a lower peak runoff rate than would occur without the facility. Retention facilities capture all of the runoff from the watershed and use infiltration and evaporation to release the water from the facility. |

| | |
|---|---|
| **Riparian habitat** | The type of wildlife habitat found along the banks of a river, stream or other actively moving source of water such as a spring. Generally refers only to freshwater or mildly brackish habitats. |
| **SCM's (Stormwater Control Measure)** | Physical structures requiring engineering design and engineered construction to remove pollutants from stormwater runoff. They also provide flood control, reduce downstream erosion, and promote groundwater recharge. The most common examples include bioretention cells, wet ponds and stormwater wetlands. |
| **Sediment** | Solid material, both mineral and organic, that is being transported or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level. Soil, sand and minerals washed from land into water, usually after rain. Sediment can destroy fish-nesting areas, clog animal habitats, and cloud waters so that sunlight does not reach aquatic plants. |
| **Shoreline** | The intersection of land with the water surface. The shoreline shown on charts represents the line of contact between the land and a selected water elevation. In areas affected by tidal fluctuations, this line of contact is the mean high tide line. |
| **Soft landscape** | Soft landscaping is the process of designing the elements of a landscape that do not involve construction. These elements include trees, shrubs, and flowers, as well as container gardens, potted plants, and hanging baskets. These areas allow infiltration of water. |
| **Stormwater** | Water resulting from natural precipitation and/or accumulation. It includes rainwater, groundwater or spring water. |
| **Storm drainage systems** | Systems which collect, convey, and discharge stormwater flowing systems within and along the right-of-way. |

| | |
|---|---|
| **Stormwater drain** | A particular storm drainage system component that receives runoff from inlets and conveys the runoff to some point. Storm drains are closed conduits or open channels connecting two or more inlets. |
| **Stormwater pollution** | Water from rain, irrigation, garden hoses or other activities that picks up pollutants (cigarette butts, trash, automotive fluids, used oil, paint, fertilizers and pesticides, lawn and garden clippings and pet waste) from streets, parking lots, driveways and yards and carries them through the storm drain system and straight to the ocean. Also included are oils, grease and metals. |
| **Stormwater runoff** | Stormwater runoff is the result of precipitation that collects on or runs off surfaces such as roofs, buildings, roads, and paved or unpaved land surfaces; that portion of precipitation which does not naturally percolate into the ground or evaporate, but flows, via overland flow, interflow pipes and other features of a stormwater drainage system, into a defined surface water body or constructed infiltration or evaporation facility. |
| **Surface water** | Water found on the surface of the earth such as a river, stream, lake, wetland, or ocean |
| **Tributary** | A river, stream, or creek flowing into a larger river or lake. |
| **Urban drainage** | Urban drainage is a method used to try and minimize stormwater flows. It is an approach to the drainage of rainwater in urban areas that aims to reduce stormwater running off into the sewers and reduce flooding. |
| **Urban run-off** | Stormwater from city streets and adjacent domestic or commercial properties that carries pollutants of various kinds into the sewer systems and receiving waters. |
| **Water (hydrologic) cycle** | The flow and distribution of water from the sky to the earth's surface and back to the atmosphere through various routes on or in the earth. The main components are precipitation, infiltration, surface runoff, channel and depression storage and groundwater. |

| | |
|---|---|
| **Water quality** | Water has two dimensions that are closely linked - quantity and quality. Water quality is commonly defined by its physical, chemical, biological and aesthetic (appearance and smell) characteristics. A healthy environment is one in which the water quality supports a rich and varied community of organisms and protects public health. Water quality in a body of water influences the way in which communities use the water for activities such as drinking, swimming or commercial purposes. |
| **Watershed** | Geographical area that drains to a specified point on a water course, usually a confluence of streams or rivers, can also be known as drainage area, catchments, or a river basin. This can also be referred to as the 'catchment basin' or 'drainage basin'. |
| **Wetland** | Wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water the depth of which at low tide does not exceed six metres. |

# Executive summary

Cities of the global south are witnessing not only rapid urbanization but also congested and dense urban habitations. South Asia is currently home to more than 23 per cent of the world's population and at least 14 per cent of its urban population.[1] India is the second largest urban system in the world with almost 11 per cent of the total global urban population living in Indian cities.[2] The built footprint of our 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 Water Sensitive Urban Design and Planning (WSUDP) measures.

As cities grow, urban areas expand geographically, converting more area from natural blue-green landscapes to paved-urban landscapes. City Master Planning is intended for residents of cities to claim their right to city development, for a reasonable quality of life including entitlement to housing, public transport and public spaces. Unfortunately, urban planning and policy making seem to have been taken over by big private builders. Real estate development has become a proxy for urban planning. Planning for basic infrastructure is ignored in favour of commercial land value appropriation. Even formal state planning is doing this. Disappearance of urban lakes and waterbodies; insufficient roads, parks and public amenities; disrupted stormwater flows; and absence of storm water drainage, are a result of this process.

Any urban water management (including stormwater management) in cities of the global south must factor in the climate and rainfall patterns of the area and existing infrastructure of combined sewers. Tropical monsoon with short intense periods of rainfall followed by dry spells, are only experienced in South Asia and a few other places. Combined sewerage and drainage infrastructure of our cities is unable to deal with even short spells of normal rainfall. Creating separate drainage systems in congested urban settlements is often not feasible. In periods of heavy rainfall, as was witnessed in Bengaluru in 2022, roads become drainage channels. The worst impacted by this are informal settlements and slums.

Impact of high-intensity rainfall attributable to climate change, coupled with the high built environment, is creating the need for better norms for stormwater drainage channels.

Stormwater management can support urban groundwater recharge, enhance liveability and reduce urban flooding. Grey infrastructure needs to be augmented to address in-situ urban flooding in cities of the global south. It will require addressing stormwater drainage design norms. The CPHEEO Stormwater Manual,[3] lists the need for new design norms for stormwater management:

*'Based on intensive research across the globe as well as those reported through IPCC, it has been established that global warming induced climate change is causing a change in rainfall precipitation pattern. Various studies in India including those by IMD also strengthen above changing pattern. It is established that rise in atmospheric temperature leads to intensifying Earth Hydrologic Cycle causing short duration heavy intensity precipitations. Each 1 deg C rise in atmospheric temperature leads to 7 % increase in water vapor in the atmosphere. Countries like the UK have already recommended an increase of 20 % in the design storm runoff to account for change in rainfall pattern due to climate change.'*

This is not to deny the value of WSUDP measures, but only to place them in the context of cities of the global south. Our monsoon climate is very different from that of the global north, our climate change impact is therefore distinctly different in terms of how much we can harvest and recharge and what we must drain out to prevent urban flooding.

The Global South Water Sensitive Cities Framework[4] made by the Centre for Science and Environment (CSE), does away with a normative understanding of urban water management and puts justice and equity at the heart of any conceptualization of Water Sensitive Cities. Four pillars/index of this Framework include a focus on stormwater management:

- ***Functional infrastructure and services:*** *Fix all existing non-functional water, sanitation and stormwater infrastructure and services to improve efficacy and treatment outcomes.*

- ***Functional and inclusive infrastructure for unserved areas:*** *Additional grey infrastructure and services will be needed for unserved informal urban settlements, that now dominate the urban landscape of cities of global south.*

- ***Substantial reuse of treated wastewater and bio-solids:*** *Reduced wastewater footprint and reuse of treated bio-solids (for agriculture) and treated wastewater.*

*This may include all measures for reuse and recharge of groundwater and prevention of pollution of groundwater, lakes and rivers inside or outside city limits.*

- ***Mitigating in-situ urban flooding:*** *Enhanced stormwater drainage dimensions/norms, to address in-situ urban flooding in cities (where built-up area has reduced groundwater recharge potential) that is witnessed in normal rainfall periods as well as in high intensity climate change induced episodes. Conserving rain water wherever possible, as contamination free as possible.*

Cities of the global south are facing twin challenges of consecutive water scarcity and urban flooding, at a scale not experienced by cities of the global north. In-situ generated urban flooding, from large paved and built areas, poses a major challenge to existing drainage systems. We need more grey infrastructure of stormwater drainage, in addition to all water conservation measures of WSUDP, especially in informal settlements. It is important to ensure equitable access to water, sanitation and stormwater drainage.

This report provides a normative approach for stormwater management, highlighting structural and non-structural challenges, deficiencies and opportunities.

Structural issues are broadly classified into planning, design, and infrastructure operation and management issues, where it is observed that urban planning and development exercises need to henceforth account for regional, city-level and local hydrology.

This report recommends taking a normative approach to water-sensitive urban design and planning for stormwater management. WSUDP strategies can be implemented in various land types in cities. These strategies can be implemented at the individual scale, neighbourhood scale and zonal/city scale, with the objective of multi-dimensional use of public open spaces and natural features in cities, transforming them from recreational infrastructure to critical green infrastructure.

In order to manage stormwater effectively, the following principles are to be implemented via short-, medium- and long-term strategies:

1. Major/minor approach: Combination of conventional systems and sustainable urban drainage system (SUDS)

2. Attenuate and infiltrate first: Control volume and peak run-off from sites by retention and detention, and preserve natural streams and waterbodies

3. Interventions at all scales: Follow the SUDS approach at individual, neighbourhood and zonal/city scales

4. Context-based interventions: Locating interventions as per city's dense urban fabric, topography and along physical features

5. Stormwater harvesting

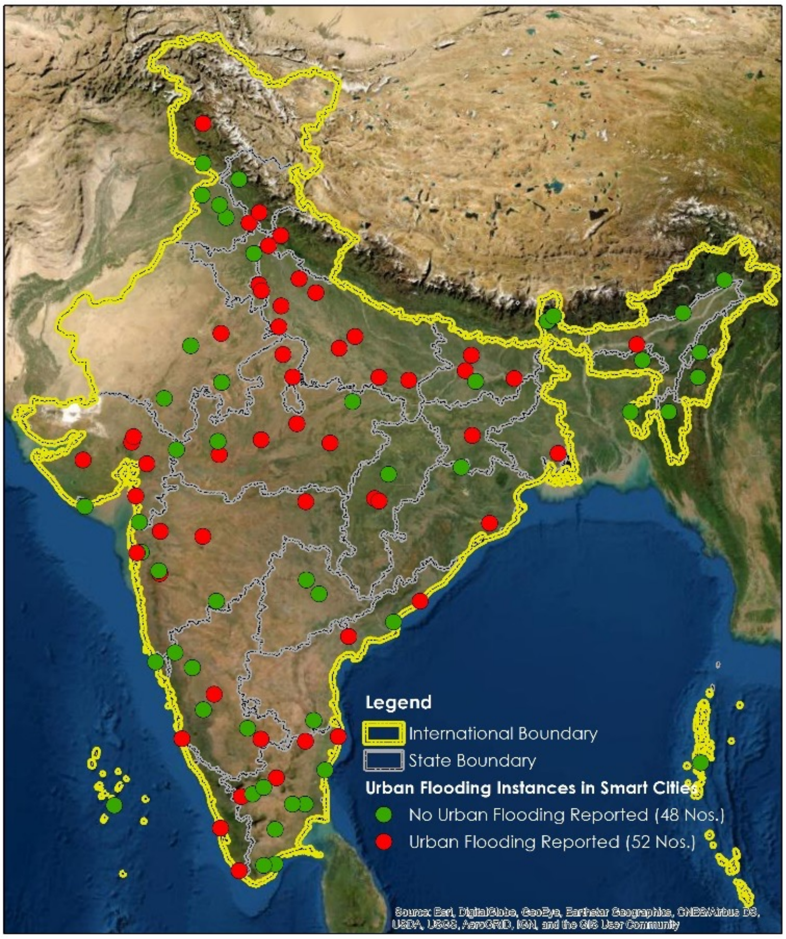
Globally, various cities and countries have implemented multi-fold stormwater management plans, projects and missions, which provide insight to augment stormwater management in India. This report lists some of them. These can be contextualized to develop innovative planning and design solutions, and develop control norms and service-level benchmarks for urban flagship missions and programmes in India.

# 1. Introduction

Floods are quite common in South Asia, with India being the second-worst flood-affected country in the world.[5] Floods do not just occur due to overflowing rivers, they are also caused by the uninformed manner in which cities are interfering with the natural water cycle. Many factors such as low-lying landscape, unplanned urbanization that does not pay heed to natural topography and hydro-geomorphology, climate change induced high intensity rainfall, and overburdened drainage systems are responsible for creating floods in urban areas.

Urban flooding needs to be addressed with a combination of water conservation and expanded drainage systems. A rapid assessment of smart cities of India shows that out of the 100 smart cities, 52 report annual urban flooding incidences during the monsoon season (see *Map 1: Status of urban flooding in smart cities of India*).

**Map 1: Status of urban flooding in smart cities of India**




Source: CSE, 2020

Urban flooding creates adverse social, physical, economic and environmental impacts. These waterlogged areas are usually also the cause of waterborne diseases as the runoff combines with solid waste and domestic wastewater. Hence, improved stormwater management is essential for overall urban planning and health of cities.

Lakes, floodplains, and buffer and green areas are neglected in the existing stormwater management process. The WSUDP approach focuses on augmenting traditional 'grey' drainage infrastructure in cities with various green infrastructure solutions. It imbibes principles of stormwater harvesting in order to address pluvial urban flooding and utilize stormwater as a resource, rather than treating it as a liability.

Stormwater harvesting is the collection and storage of rainfall run-off from urban areas in open ponds or aquifers. It's been identified as one alternative water resource that could augment urban water supplies. Stormwater harvesting is different from rainwater harvesting, which is collection and storage of run-off water from an individual property with private use – usually from the rooftops of buildings.

The WSUDP approach for stormwater management focuses on mimicking the natural water cycle in cities, and implementing stormwater harvesting strategies at various scales in different land-uses of the urban catchment. The solutions are contextualized for different urban catchments – planned areas, organic areas like urban villages, and unplanned and peri-urban areas. Traditional WSUDP measures need to be further contextualized to the specific context of global south cities with large expanses of and dense urban settlements, informal habitations and slums. In-situ rainfall runoff in these cities cannot be fully addressed with traditional WSUDP measures alone.

## 1.1 Research aims and objectives

The study is aimed at understanding the potential and challenges of current practices of stormwater management and thereby suggesting approaches which focus on lowering the hydrological impact of urbanization in Indian cities. The objectives of this study are to:

- Assess the existing stormwater infrastructure provision in India, and identify deficiencies in policy, planning and design of stormwater infrastructure.
- Identify various structural and non-structural issues and crises in stormwater management in urban India.

- Formulate and recommend principles of stormwater management for Indian cities, based on the WSUDP approach.

- Present best management practices for stormwater management, and infer key learnings and applicability in the Indian context.

The first part of the report focuses on the guiding research question—**What are the existing planning approaches and infrastructural provisions for stormwater management in Indian cities?**

The second part of the report suggests **approaches as per the existing spatial urban characteristics**. The planning approach recommended makes use of stormwater as a resource rather than a liability.

Urban stormwater management, in this document, refers to all the measures undertaken to harvest and moderate the quantity and improve the quality of the surface runoff generated by rainfall in urban areas. It includes urban planning in maintaining hydrological systems, and regulating the collection, storage and movement of stormwater runoff.

# 2. Stormwater management in India

Waterbodies like lakes and ponds were traditionally found in rural areas. They were used as measures of rainwater harvesting for agriculture purposes. As these lakes started falling within city limits, they started being used for urban stormwater management. They cannot be expected to serve the same purpose as before. Besides harvesting stormwater, lakes and wetlands also have an important but smaller footprint of flood mitigation. Now, the biggest challenge facing them is the increasing pollution load.

Urban lakes and water bodies are under threat of encroachment. In the 1960s, Bengaluru had 262 lakes. Now only ten hold water. In the last 12 years, Hyderabad has lost 3,245 ha of its wetlands. The natural streams and watercourses, formed over thousands of years due to the forces of flowing water in the respective

### HISTORY OF STORMWATER HARVESTING IN INDIA[6]

India has a tradition of stormwater harvesting which is more than two millennia old. Evidence of this tradition can be found in ancient texts, inscriptions, local traditions and archaeological remains.

Indian cities have traditionally been managed by stormwater harvesting systems, which offered the twin benefits of drainage and rainwater harvesting.

Traditionally, the design and structure of each system was decided by the terrain and rainfall pattern of the region. Hence, each eco-zone of India had unique techniques for harvesting water. Traces of them can still be found at some urban locations. A few examples are given below.

*Ahar-pynes:* Embankment catchment basin and channels, South Bihar
*Kunds/kundlis:* Underground storage tanks, West Rajasthan
*Tankas:* Underground tanks, Bikaner, Rajasthan
*Vav/Vavdi/Baoli/Bavadi:* Stepwells, Rajasthan, Gujarat, Delhi
*Paar:* Area where water has percolated, accessed by kuis, Rajasthan
*Cheruvu:* Reservoirs to store runoff, Chitoor, Andhra Pradesh
*Kere:* Series of tanks, central Karnataka
*Ooranis:* Ponds, Tamil Nadu
*Kul*: Water channel in mountain areas, Jammu, Himachal Pradesh
Naula: Small ponds, Uttarakhand
Zabo: Impounding runoff, Nagaland
*Dongs:* Ponds, Assam

watersheds, have been altered because of urbanization. As a result of this, the flow of water and wastewater has increased in proportion to the urbanization of the watersheds. Ideally, natural drains should have been widened to accommodate the increased flows.[7]

Over the years, 'drainage' solutions in India have been planned, designed and implemented through an engineering approach: making drainage channels according to peak hour rainfall. Hence, the provision of urban drainage is limited to road-side drains only.

Megacities in India have a long history of municipal drainage systems, many of which emerged during the British era. These megacities usually have century-old antiquated brick masonry conduits within core clusters. The existing stormwater collection networks in these megacities are designed to serve as a combined system for sewage as well as stormwater runoff.[8]

## INTRODUCTION AND FAILURE OF DRAINAGE SYSTEM (MASSIVE PIPE NETWORK) SINCE BRITISH ERA, INDIA

The oldest combined sewerage system in India is in Kolkata, which was the capital of the British Empire in India till 1911. In 1876, it was designed to cope with 6.35 mm/hr of rainfall with 100 per cent runoff. Later in 1970's, attempts were made to increase its capacity to 12.7 mm/hr. However, in the same year, the city of Kolkata received rainfall of 54 mm in one hour, which caused severe flooding.[9]

This approach of making linear and massive drainage infrastructure, which is still practised in urban India, often fails to avoid the flooding problems in downstream areas. This is accompanied with pollution and erosion of natural waterbodies that are receiving the runoff.

The Indian Roads Congress (IRC) guideline on urban drainage in 1999 (SP-50-1999, IRC) mentions that Mumbai drains are designed for 50 mm/hr and Chennai for 25mm/hr and yet these cities face urban flooding annually.[10] Also, these guidelines do not contain provisions for future planning of urban drainage systems for other small cities.

Over the last decade, there has been a significant increase in frequency of extreme rainfall events during the monsoon season, which are attributed to climate change. It is being witnessed that moderate to extreme rain events have become more regular; and these events are projected to increase with the altered rainfall pattern due to climate change. Indian cities urgently need to address issues of pluvial flooding through proactive stormwater management and infrastructure planning.

Urban areas of India have been experiencing increased flood events during the recent decades. In 2022 alone, India witnessed extreme weather events on 314 days. Of these, 214 were recorded as heavy rains, floods and landslides, and 185 days for lightening and storms (see *Figure 1: Incidences of heavy rainfall, floods and landslides in India in 2022*).

The landcover change associated with development not only increases the total volume of runoff, but also accelerates the rate at which runoff flows across the land. This effect is further exacerbated by drainage systems such as gutters, storm sewers and lined channels that are designed to quickly carry runoff to rivers and streams.[12]

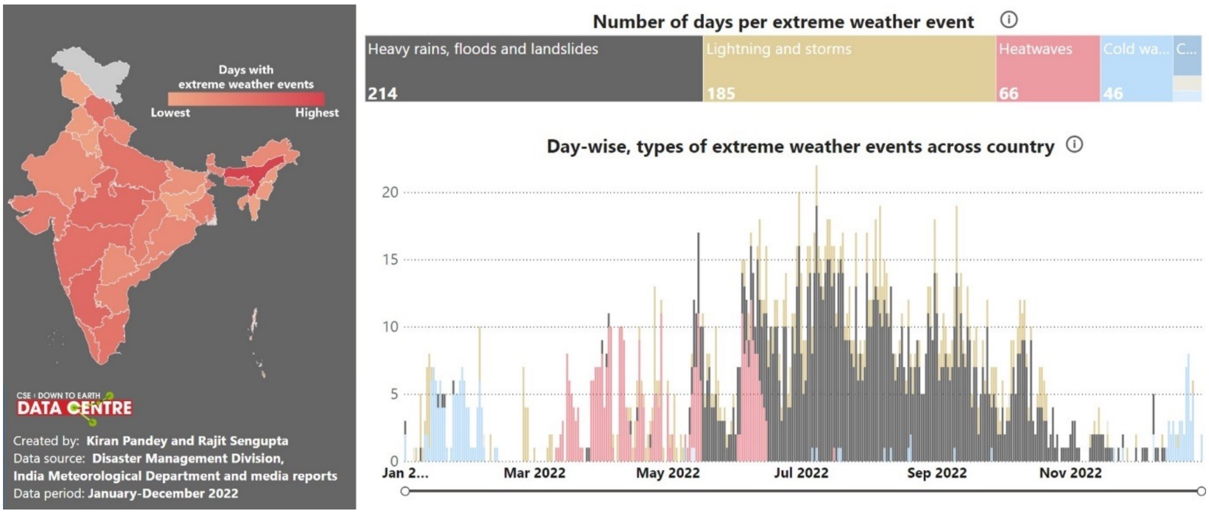
As per *Guidelines on Management of Urban Flooding* released in 2010 by the National Disaster Management Authority (NDMA), India, "*Urban flooding is significantly different from rural flooding as urbanisation leads to developed catchments which increases the flood peaks from 1.8 to 8 times and flood volumes by up to 6 times. Consequently, flooding occurs very quickly due to faster flow times, sometimes in a matter of minutes.*"[13] Typical alterations to the hydrologic regime as a result of development-associated landcover changes include the following:

- Loss of lakes and wetlands in cities
- Reduced infiltration (groundwater recharge)
- Loss of stormwater storage systems
- Increased imperviousness
- Increased runoff volume
- Increased flow frequency, duration and peak runoff rate
- Modification of the flow pattern
- Faster time to peak, due to shorter time of concentration through storm drain systems

Graph 1 shows typical pre-development and post-development streamflow hydrographs for a developed watershed.

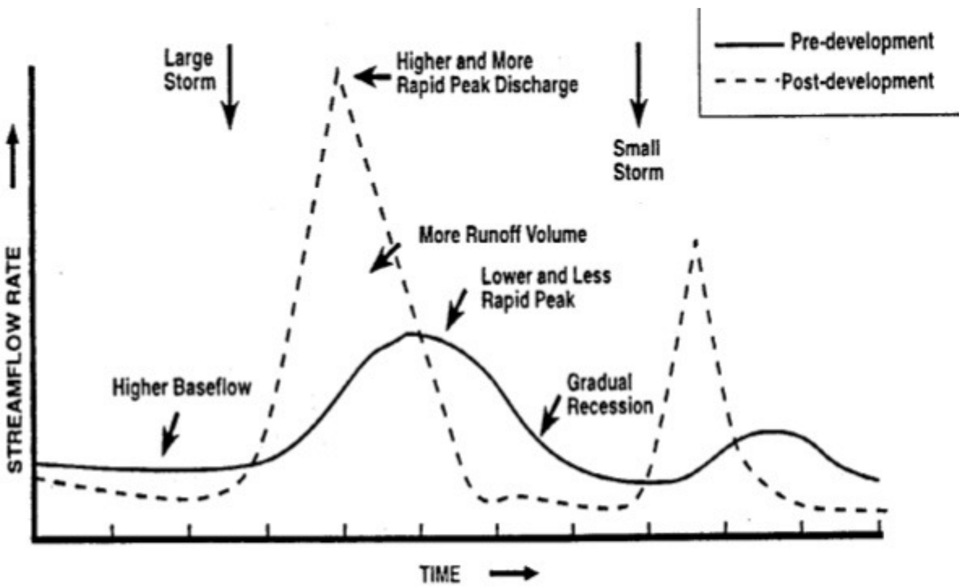
Pluvial flooding occurs when drainage systems are overwhelmed by excessive runoff, resulting in waterlogging and overland flow. While this is usually associated with short duration (up to 3 hrs) high intensity rainfall exceeding 20 mm/hr, it can also occur with lower intensity rainfall (10 mm/hr) over longer periods and can be worse in absence of waterbodies and pervious areas.

## Figure 1: Incidences of heavy rainfall, floods and landslides in India in 2022




Source: CSE – Down To Earth Data Centre, 2023

## Graph 1: Hydrograph under pre- and post-development conditions




Source: Schueler, 1992, in Metropolitan Council, 2001

Stormwater drainage design in India is based on past climate trends and is neither adaptive nor sufficient to accommodate more frequent and intense extreme storm events associated with climate change.[14]

## 2.1 Existing stormwater infrastructure in Indian cities

Stormwater infrastructure can be categorized into two typologies: Natural streams/drainage channels, and pipes and gutters which are grey infrastructure. The NDMA Guidelines classify these as major and minor drainage systems.[15]

**Major drainage systems:** Major drainage systems comprise of open nallahs and natural channels, surface drains or surface flow pathways, etc. These are generally regional systems, and form the spine of the drainage system within the city. The water from these channels is often used as a source of irrigation in peri-urban and rural areas.

**Minor drainage systems:** The minor system is the network of underground pipes and channels. Two types of minor stormwater drainage systems are 'open' channels and 'closed' pipes. These systems provide the last mile connection to various residential areas. A hierarchical distribution of these systems is observed in cities, and in most cases, these systems are laid as per the road network of the city. Water from this system is discharged into a surface waterbody, or into the major drainage system.

### Major drainage systems

Major drainage systems in Indian cities face a multitude of issues, which result from encroachment and dumping of municipal solid waste and construction and demolition (C&D) waste. It is often observed that these channels are abutted by informal settlements and JJ clusters. As these are low lying areas, they are prone to flooding, which poses a risk to the human population in these settlements. It is also observed that these drains are 'covered' in order to develop other infrastructure.

The Barapullah Drain in Delhi has been covered to develop the Seva Nagar Bus Depot. This negatively impacts the ecological processes in the drain due to absence of sunlight (see *Map 2: Construction of bus terminal on Barapullah drain, Delhi*).

### Map 2: Construction of bus terminal on Barapullah drain, Delhi

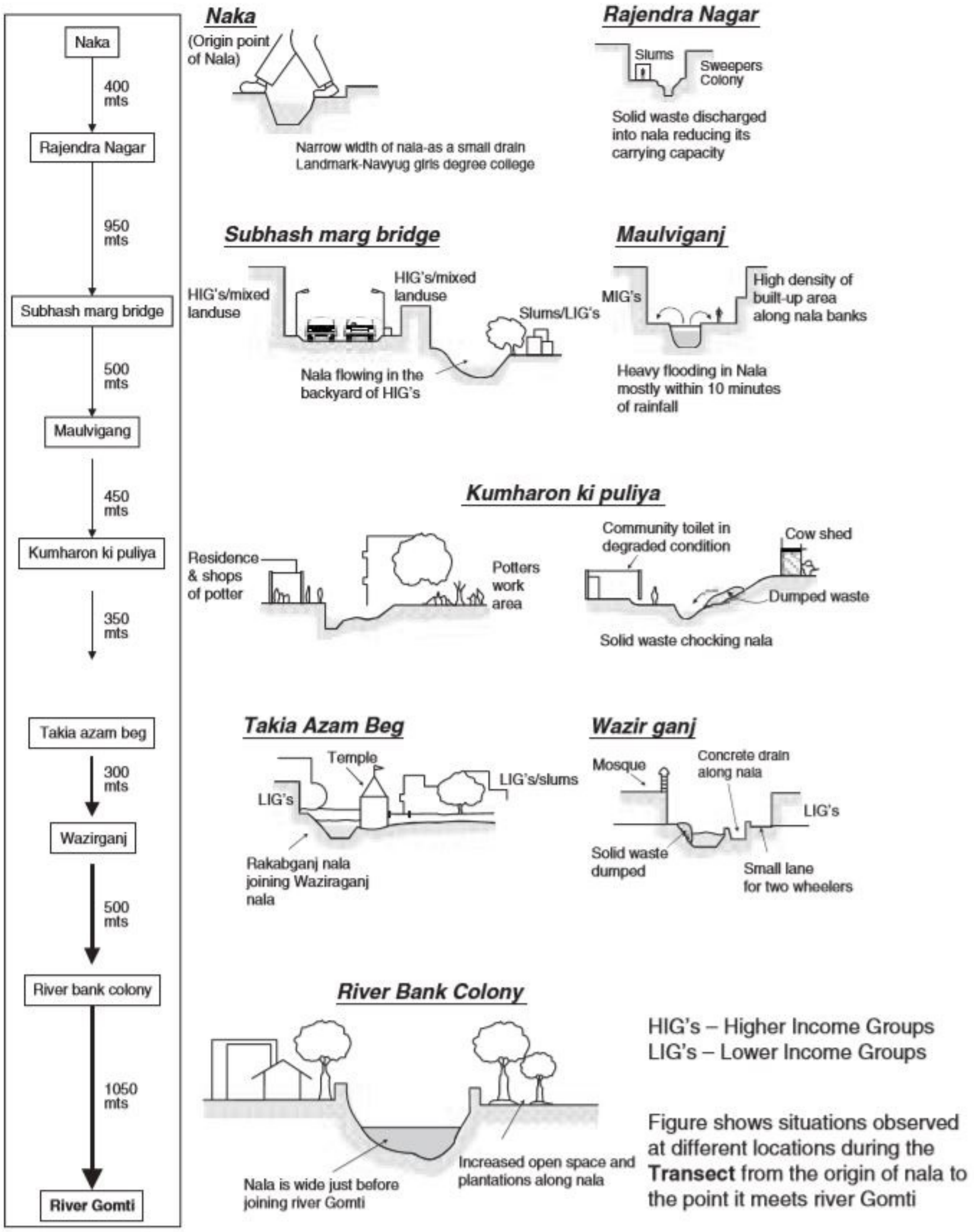

Source: CSE, 2020

Major drains also witness an inflow of treated and untreated wastewater, and in some cases, dumping of faecal sludge. Due to this, the run-off in these streams is highly polluted. For ex., the Najafgarh drain in Delhi receives treated and untreated wastewater from various point sources, and it is responsible for more than 25 per cent of the pollution load in the Yamuna River in Delhi.[16]

In many cases, it is also observed that treated and untreated effluent from industrial areas finds its way to these drainage channels, which further pollutes the water in these channels, and results in ecological deterioration of the downstream waterbody. The Kukatpally drain leading up to Hussain Sagar Lake in Hyderabad receives 15 MLD of industrial effluent.[17]

Wazirganj Drain is one of the three primary drainage channels in the city of Lucknow, which starts at Naka and meets the Gomti River. A transect walk along the drain showcases how this major drainage channel is abutted by a mix of land-uses and built forms, altering the cross-section of the drain, as well as the quality of stormwater it carries (see *Figure 2: Visual representation of a transect walk through Wazirganj drain, Lucknow*). The drain traverses through the various residential uses: high-, middle- and low-income areas, slums, recreational areas, small-scale industries, and institutional and religious buildings.

### Figure 2: Visual representation of a transect walk through Wazirganj drain, Lucknow




Source: S. Singhal and A. Kapur 2002. "Environmental management plans for the communities of Lucknow," Waterlines 20(4).

Major drainage channels carry solid waste, wastewater and faecal sludge in most urban areas, and are abutted by slums and small-scale/household industries in some cases (see *Photograph 1: Choked drain in Taimoor Nagar, Delhi*). As the floodplains of these channels are compromised for development, these are prone to flood during the monsoon, and require regular maintenance and development of appropriate embankments.

**Photograph 1: Choked drain in Taimoor Nagar, Delhi**

Source: IANS

## Minor drainage systems

Minor drainage systems can be categorized into two further types or the combination of two systems:[18, 19]

**Combined drainage systems**: These drainage systems combine domestic, commercial and industrial wastewaters. Here the stormwater is mixed with domestic and industrial effluents before being treated at a centralized wastewater treatment plant and discharged to a receiving water body.

**Separate drainage systems:** These drainage systems collect only stormwater and discharge it to receiving waterbodies with little or no treatment.

The design of Indian cities focuses on minor drainage systems, comprising of drains and channels, roadside drains, channelization, rehabilitation, rectification, enlargement of existing stormwater drainage networks and provision of cross-drainage works. These systems may also collect wastewater from various domestic, commercial and industrial activities along with the stormwater.[20]

According to the report on Indian Urban Infrastructure and Services (March 2011), published by the erstwhile Ministry of Urban Development (MoUD), the average coverage of stormwater drainage network is about 20 per cent of road network and its allied catchments. This is grossly inadequate to cater to stormwater disposal needs in the present scenario.[21] As per the 2011 Census, there is no drainage facility in 48.9 per cent households across the country, while 33 per cent households have only open drainage systems.[22]

Major drainage systems to manage stormwater are largely missing from Indian cities. Moreover, even in the minor drainage systems, separate channels rarely remain separated, leading to mixing of wastewater and effluents from septic tanks with the stormwater.

**Table 1: Sources of contaminants in urban stormwater runoff**

| Contaminant | Contaminant sources |
|---|---|
| Sediment and floatables | Streets, lawns, driveways, roads, construction activities, atmospheric deposition, drainage channel erosion |
| Pesticides and herbicides | Residential lawns and gardens, roadsides, utility right-of-way, commercial and industrial landscaped areas, soil wash-off |
| Organic materials | Residential lawns and gardens, commercial landscaping, animal wastes |
| Metals | Automobiles, bridges, atmospheric deposition, industrial areas, soil erosion, corroding metal surfaces, combustion processes |
| Oil and grease/Hydrocarbons | Roads, driveways, parking lots, vehicle maintenance areas, gas stations, illicit dumping to storm drains |
| Bacteria and viruses | Lawns, roads, leaky sanitary sewer lines, sanitary sewer cross-connections, animal waste, septic systems |
| Nitrogen and phosphorus | Lawn fertilizers, atmospheric deposition. automobile exhaust, soil erosion, animal waste, detergents |

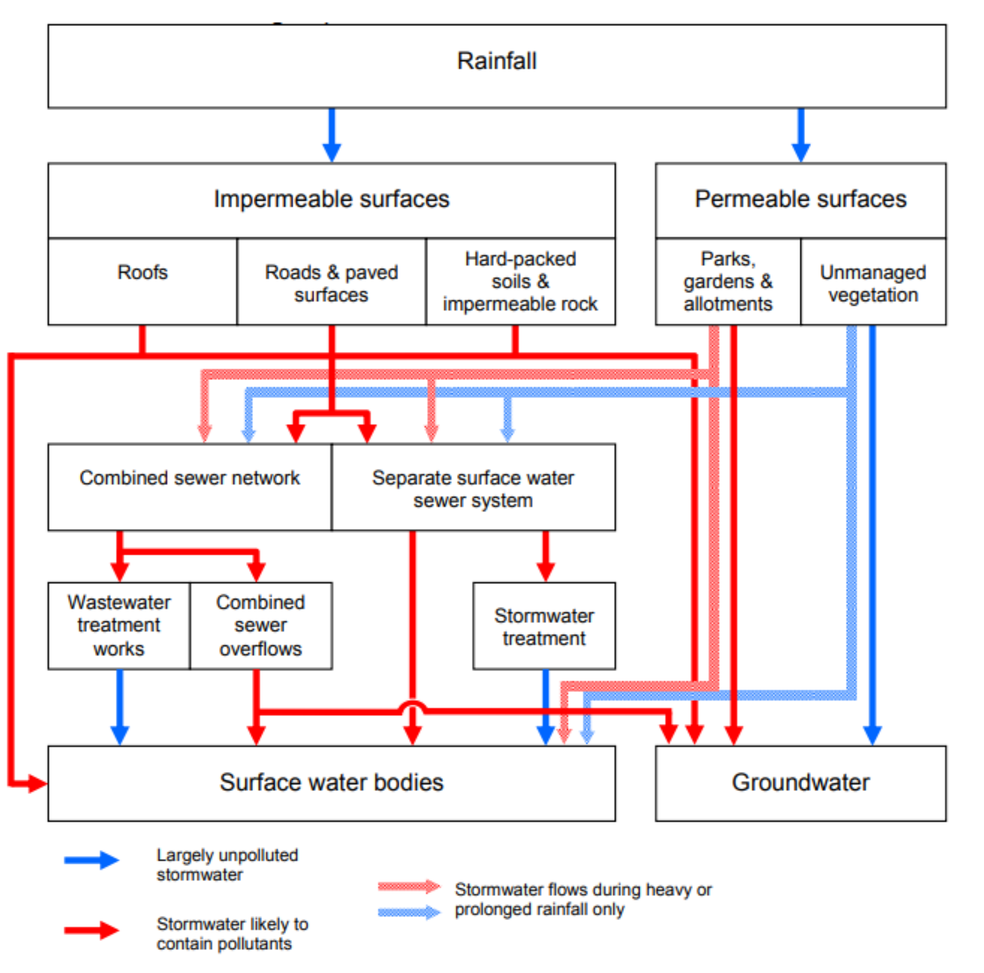
## WHAT DO STORMWATER DRAINS CARRY?

Apart from stormwater, the drain channels in a typical Indian city carry:

a) Wastewater (grey water from kitchen and bathroom, effluent from OSS, black water in absence of OSS)
b) Excreta (in case of open defecation/urination in drains)
c) Solid waste (due to littering and dumping).

As a result, a range of contaminants could be found in urban runoff which might change as per the land-use in the catchment.

### Urban stormwater flows in India




Source: SWITCH Training Kit, 2011

**Table 2: CPHEEO recommended design return periods for various urban sub-catchments**

| Urban catchment | Return period | |
|---|---|---|
| | **Class I cities**** | **Other cities***** |
| Central business and commercial | Once in 5 years | Once in 2 years |
| Industrial | Once in 5 years | Once in 2 years |
| Urban residential | Once in 5 years | Once in 2 years |
| Airports and other critical infrastructure* | Once in 100 years | Once in 50 years |

*Critical infrastructure includes railway stations, power stations, etc.
** Class I Cities are cities having population 1 Lakh and above
*** Other cities are cities having population less than 1 lakh

Source: Manual for Stormwater Drainage Systems – CPHEEO, 2019

The Manual for Stormwater Drainage Systems prepared by CPHEEO states that *'It may not be always feasible to design / retrofit the storm water drains for the recommended return period in all the cities. In cases where redesigning / retrofitting is not feasible as per recommended return period due to city profile / site constraints, efforts should be made to adopt recommended return period by adopting 'Best Management Practices, (BMP) like in-situ rainwater harvesting methods within premises / plots, along the storm water channels / conduits and storm retention/ detention structures to accommodate the excess runoff.'*

The manual also states that *'Under exceptional circumstances, a high-powered committee constituted by State / UT Government through a notification may justify the adoption of higher return period considering techno-economical and socio-environmental conditions than the one recommended in Table after exploring various other available options to meet the design requirements.'*

As rainfall patterns are altering due to climate change, higher intensity rainfall days are set to become more frequent, with reduction in rain-days. In this context, the return-period for designing stormwater drains needs to re-assessed.

The choice of return periods depends on the land-use and the potential consequence of flooding. The range for selecting the return periods should be applied as per the site context, and imbibed in the urban planning norms and standards.[23]

An indicative range of return period for various land uses are mentioned in Table 3 below.

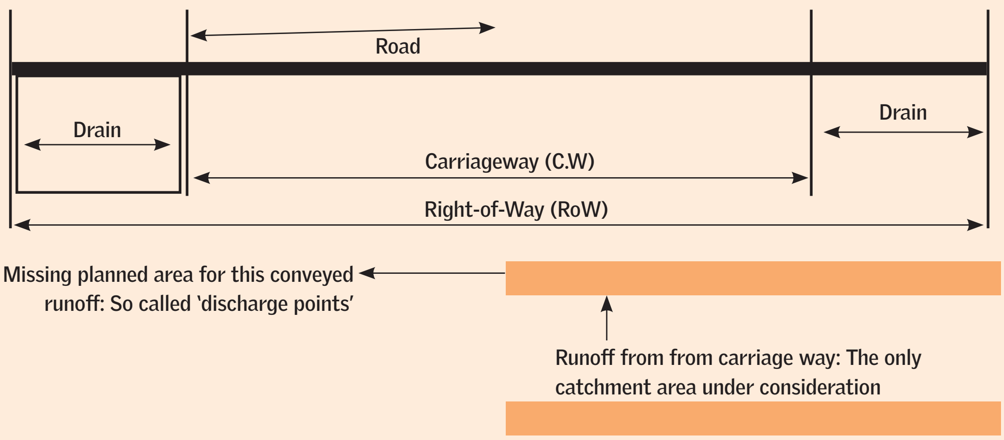
## ROADSIDE DRAINAGE SYSTEM IN INDIAN CITIES

As per the CPHEEO manual, stormwater drains should be constructed on both sides of the road and connected with cross drains across the road at suitable intervals having gratings to collect rain water from the surface of the roads. These drains are constructed for removal of stormwater runoff from the carriageway, just to avoid waterlogging.

Hence the design is focused towards directing runoff away from roads (which may or may not reach a water course or an open area). As per IRC: SP:42-2014, roadside drains must drain the surface and subsurface water away from the roadway and dissipate it in a way that prevents the excessive collection of water in unstable areas and subsequent downstream erosion.

While designing the cross-section of these drains, even the inlet sizing is determined to cater to runoff from half-road catchments. That means, the provision of urban drainage is not designed as per city's density, landcover or designated catchment area but is only limited to roadside drains.

### Drainage components of a typical road in Indian city




Source: Compiled from Draft Manual on Stormwater Drainage by CPHEEO

### Roadside drains (a) Covered drain in Noida; (b) Open drain in Bijnor

Source: CSE, 2018

Source: CSE, 2018

**Table 3: Guideline flood return frequencies for design of urban drainage systems**

| Land use | Return period (years) |
|---|---|
| Public spaces | 1 to 2 |
| Suburban residential districts | 2 to 5 |
| Higher-density residential areas | 5 to 10 |
| City centres and high value districts | 10 to 20 |
| High-risk areas | 20 to 50 |

Source: J. Parkinson and O. Mark 2005. Urban stormwater management in developing countries. IWA publishing.

## 2.2 Stormwater management and urban planning

Sustainable stormwater management requires greater emphasis on urban drainage as an integral component of urban development.

### Planned and unplanned encroachments

Any land or waterbody is seen as a 'wasted resource' under neo-liberal economic thinking unless it is put to some economic use and monetized. Real estate oriented urban planning exercises often end up using critical green-blue infrastructure spaces as 'land' for other uses: residential, commercial, industrial, transportation, etc.

Indian cities lack effective urban planning measures. Urban waterbodies and streams have been encroached by 'planned' development. 'Planned' encroachments are those where the development plan has formally changed the land-use of the lake and its catchment area. For instance, as per a report tabled in the Karnataka State Assembly in 2017, approximately 25 per cent of lake area in Bengaluru has been encroached by the Bengaluru Development Authority and Bruhat Bengaluru Mahanagar Palike. Other departments have also encroached upon lake areas and developed residential layouts, bus terminals, etc.[24]

Apart from 'planned' encroachments, most Indian cities are plagued with informal developments and unauthorized colonies. These settlements are located on floodplains, along urban drainage channels, open areas and low-lying areas. It is estimated that approximately 50 per cent of residents of Delhi reside in informal settlements of various typologies. These informal settlements impact the overall hydrological regime of the city, and are prone to urban flooding and associated vulnerabilities.

### Inadequate development control norms

While preparing masterplans and land-use plans, the impact of site design and land-use on the overall hydrological cycle is seldom considered. These impacts are reflected in the Development Control Regulations (DCR). The URDPFI Guidelines recommended that DCRs should be limited to floor area ratio, ground coverage, building height and setbacks. The DCRs fail to incorporate retention basins and other rainwater harvesting features in site design. Doing that would ensure that run-off generated within the site is not allowed to burden city-level infrastructure.

### Lack of catchment area planning

Urban planning jurisdictions are based on administrative boundaries of planning authorities and municipalities. The jurisdiction of these areas is based on revenue boundaries, and seldom adhere to geographical catchment boundaries. It is often observed that the functions of natural drainage paths are not considered while preparing land-use plans. The catchment and sub-catchment plans within city limits are not prepared. Land-use zoning, with urban sub-catchments as elements, is not practiced in Indian cities.

For instance, the city of Delhi is divided into three distinct urban drainage catchments (as per the Drainage Master Plan for Delhi): Najafgarh Basin, Barapullah Basin, Trans-Yamuna Basin and two smaller basins. However, the draft Master Plan for Delhi-2041 does not identify these catchments as planning units. The zones in Delhi are based on physical features such as roads, population densities and distribution of non-residential land-uses. Therefore, the natural drainage paths and their functions have negligible correlation with the urban developments in these catchments, which the Zonal Development Plans fail to address.

## 2.3 Extreme rainfall events: Is it climate change?

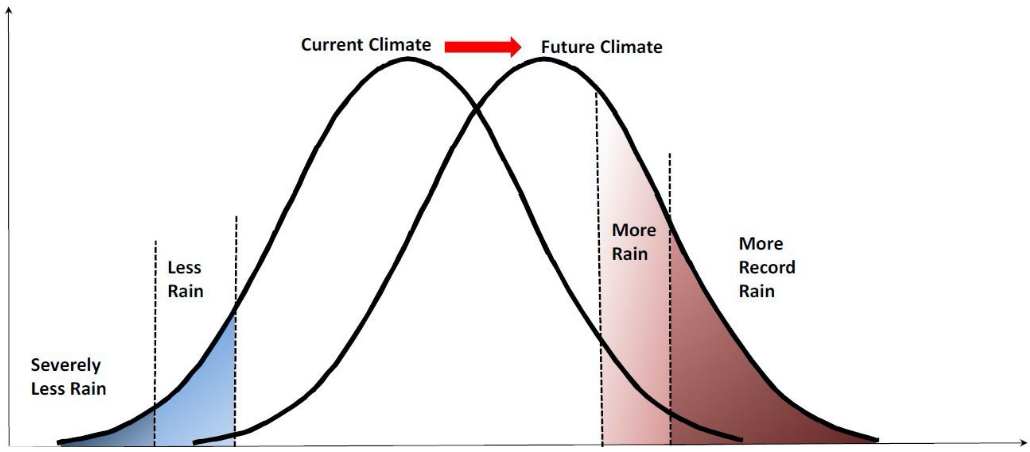
Rainfall (water drops of size 0.5–6 mm) is the major form of precipitation that causes stream flow as well as flood flow in rivers. Variation in magnitude and duration of rainfall in different parts of the country leads to potential of flooding of urban areas where the drainage systems are inadequate. Based on the magnitude, the rainfall is classified as:[25]

- Very light rain: 0.1–2.4 mm/day
- Light rain: 2.5–15.5 mm/day
- Moderate rain: 15.6–64.4 mm/day
- Heavy rain: 64.5–115.5 mm/day
- Very heavy rain: 115.6–204.4 mm/day
- Extremely heavy rain: >204.5 mm/day

As per the Inter-governmental Panel for Climate Change (IPCC), there is evidence of change in some climate extremes, based on the data gathered from 1950. In terms of precipitation, it is likely that there have been statistically significant increases in the number of heavy precipitation events (see *Graph 2: Projected rainfall distribution pattern in (a) short-term; (b) long-term*).[26]

Various studies have been conducted to understand the altering rainfall pattern in India. Analysis of rainfall data from 1951–2003 shows statistically significant increasing trends in extremes of rainfall over many parts of India, consistent with the indications from climate change models and the hypothesis that the hydrological cycle will intensify as the planet warms.[27]

**Graph 2: Projected rainfall distribution pattern in (a) short-term; (b) long-term**




Source: Climate Change and India: Adaptation Gap (2015) - A Preliminary Assessment. Working paper of Indian Institute of Management Ahmedabad (IIMA)

Urban flooding in Indian cities has become an annual affair during the monsoon season. Though the average rainfall remains the same, fewer rain days are witnessed now, which have high intensity rainfall. Therefore, there is more likelihood to have 10-year, 15-year and 20-year rainfall events more frequently.

This means that our existing drainage systems have to be redesigned to accommodate the increased flow-levels. This can be done by resizing the drains and by judiciously integrating the best management practices into the drainage infrastructure.[28] Countries like the UK have already recommended an increase of 20 per cent in the designed storm runoff to account for change in rainfall patterns due to climate change.[29]

Presently, the design of our stormwater infrastructure is not based on run-off generated because of such high intensity rainfall events. CPHEEO designed drains for 1-year or 2-year rainfall events. Add to this the fact that urban stormwater infrastructure covers only 20 per cent of road length in cities on an average.[30] Further, most of these drains are clogged due to siltation and solid waste.

## 2.4 Evolution of stormwater management in India

Stormwater management in India has evolved in the following phases of urbanization.

### Ancient India and medieval India: 3,000 BC to 1,500 C.E.

Planning for stormwater management has been an integral part of ancient and medieval cities of the Indian subcontinent. Evidence of designed stormwater drains have been found in ruins of pre-historic cities of the Indus Valley Civilization like Lothal, Dholavira and Mohenjo-Daro.[31,32] Cities established in north India under the Mauryan Empire and cities in Deccan India under the Marathas, Cholas, etc. were planned and designed on the basis of the *Arthashastra*.[33,34] It is considered as the first document on urban planning in India, and informs about the importance of a series of tanks and canals for water supply, irrigation and drainage patterns. It recommended largely nature-based systems as per the natural topography of the city.

Some famous examples of this approach are Udaipur in 1559 under Maharana Udai Singh II, Vijaynagar in 14–16 century CE, Jaipur in 1726 under Maharaja Jai Singh II, and Bengaluru in 1799 under the Kingdom of Mysuru.

### British India: 16th to 19th century

The British era saw the introduction of various structural and non-structural changes in urban water management in India. With the development of cantonment areas, the British introduced Victorian engineering methods for development of urban areas. They designed combined sewer and stormwater drains, and saw stormwater as a possible threat for pluvial flooding. Thus, it had to be drained away as soon as possible. This has resulted in a broken network of urban streams and waterbodies.

### Post-British to 1990s

Post-British India witnessed a slew of town planning interventions in various states in India. The model Town and Country Planning Act was passed in 1960, based on which all states of India adopted their own town and country planning acts, and set-up institutions for urban planning. New cities were developed, like Chandigarh in 1949-60 and Gandhinagar in 1965, which tried to maintain the links between local and regional drainage. The first masterplan for Delhi was notified in 1962, which also maintained local and regional drainage links.

During the same period, government institutions like PWD, PHED, I&FC, etc. were also established to design and develop stormwater infrastructure. While PWDs and ULBs focused on construction and maintenance of roadside drains, I&FC and PHED focused on the natural *nallahs* of cities and potential threats of (fluvial) flooding.

The first drainage masterplan for Delhi was prepared by I&FC Dept., GNCTD in 1976.[35] The plan focused on two broad objectives: protection of Delhi from flooding and stormwater drainage along roads of Delhi. It led to the design and construction of embankments along the Yamuna River, and other city-level drains like Supplementary Drain, Bawana Escape Drain, etc. under the control of the PWD, GNCTD.

The first attempt at regional planning in India was undertaken when the National Capital Region Planning Board (NCRPB) was set-up in 1985, with the initial objective of establishing satellite towns. The NCR Plan provides for functional plans for the sub-region, one of which was the functional plan on drainage. This provided the first instance of guidelines and strategies for planning regional and urban drainage.

The URDPFI Guidelines were released in 1996 by Institute of Town Planners, India (ITPI) with a focus on planned urban development. However, those guidelines did not address the potential issues of pluvial flooding and focussed on drainage along roads as the only infrastructure associated with stormwater management.

CSE published the SOE Report on Floods, Floodplains and Environmental Myths in 1992. The study focused on the causes and effects of floods in the floodplains and river valleys of the Ganga and Brahmaputra. The report, citing scientific studies and field reports, stunned environmentalists by arguing that floods in these regions can be controlled through better management of the rivers' floodplains themselves. It established a need for incorporating land-use interventions for flood mitigation in urban India.

## Post-2000

In 2005, the Ministry of Urban Development launched the Jawaharlal Nehru National Urban Renewal Mission (JNNURM), which set Service Level Benchmarks (SLBs) for various sectors. The SLBs for drainage infrastructure were set as: 1.) 100% coverage of stormwater drains along length of *pucca* roads. 2.) Zero incidences of waterlogging.

In 2010, the National Disaster Management Authority (NDMA) released the guidelines on Management of Urban Flooding, which provided post-flooding strategies. It also called for better urban planning and infrastructure development to prevent urban flooding.

With growing knowledge of implementation and success of techniques such as SUDS, the Indian Roads Congress (IRC) released guidelines for designing urban drains (IRC:SP:50-2013)

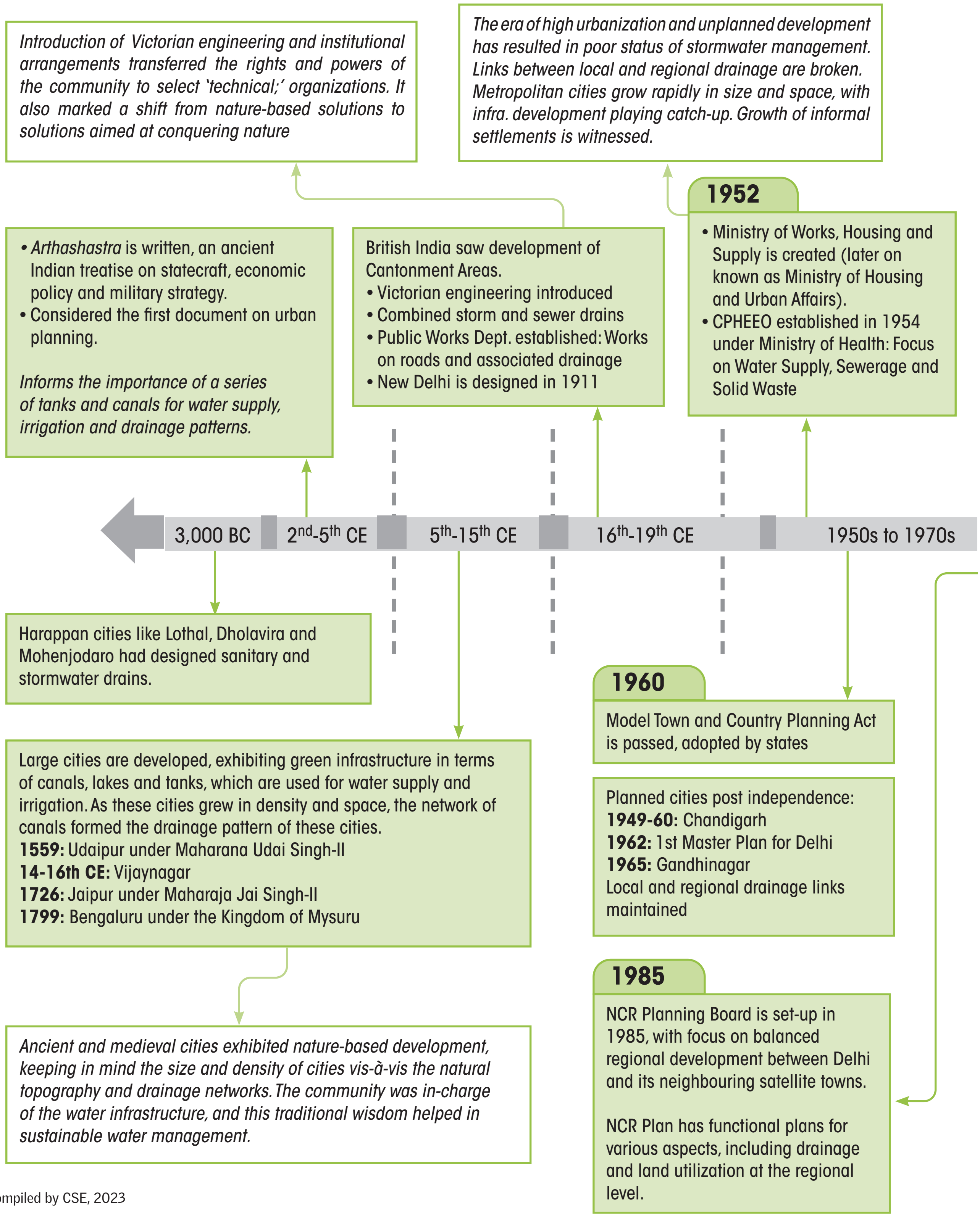
The revised URDPFI Guidelines released in 2014 are silent on the requirement of a separate City Drainage Plan or Drainage Masterplan. They recommend SLBs, as utilized in JNNURM. In 2015, the Ministry of Housing and Urban Affairs (MoHUA) launched the AMRUT mission under which 'Stormwater drainage to reduce flooding' is one of the thrust areas. However, the SLBs for urban drainage are the same as used in JNNURM.

While the various planning documents and guidelines have been silent on land-use strategies for sustainable drainage solutions, the National Capital Region Plan-2021, under the Functional Plan for Drainage recommends 2–5 per cent of municipal area to be under waterbodies for flood mitigation. This remains the only planning document providing for land-use interventions for stormwater management and urban flooding.

In 2017, CSE as a Centre of Excellence with the ministry released a practitioner's guide on *Water-Sensitive Urban Design and Planning*. These guidelines provided scale-specific measures for sustainable stormwater management for Indian cities, to aid practitioners and city managers to plan for stormwater drainage.

In 2018, GNCTD along with IIT Delhi revised the Drainage Master Plan for Delhi. The revised plan focused on re-establishing the links between local and regional drainage networks of Delhi. As stormwater management became a pressing urban issue, the CPHEEO in 2019 released the draft manual on stormwater drainage. This is aimed at aiding practitioners and city officials in planning and designing sustainable stormwater infrastructure. Both these documents are still in the draft stage.

**Figure 3: India's stormwater management timeline**




Source: Compiled by CSE, 2023

**1976**
1st Drainage Master Plan for Delhi

**1980**
National Commission for Urbanisation is set-up, in order to inform policy on urban and regional development, with focus on migration, housing and other urban issues

**1992**
CSE publishes SOE Report on Floods, Floodplains and Environmental Myths

)s | 1970s to 1990s | Late 1990s to early 2000s | Late 2000s to present

**1996**
UDPFI Guidelines

**1999**
INTACH Report on Blueprint for Water Augmentation in Delhi

*Concept of floodwater and stormwater harvesting is introduced*

**2001**
Under NCR Plan 2021, Functional Plan for Drainage recommends allocating 2-5% of municipal area for water bodies, for flood mitigation and stormwater management.

**2005**
JnNURM launched, focused on urban infra. development. SLBs:
- % coverage of drains along roads
- Incidences of water-logging

*Unprecedented investment in urban infra. Sectors eligible for assistance included: Construction and improvement of drains and stormwater drains*

**2010**
NDMA Guidelines on Management of Urban Flooding

*As cities grow, incidences of pluvial flooding increase. Nature-based approach to address the same is being developed by various organizations*

**2013**
IRC Guidelines for Urban Drainage IRC : SP : 50 - 2013

**2014**
URDPFI Guidelines do not recommend preparation of City Drainage Plan/ Drainage Masterplan

National Mission for Sustainable Habitat: Recommends 2-5% of municipal area be reserved for water bodies and flood mitigation

**2015**
AMRUT launched. Thrust area includes Stormwater Drainage to reduce flooding

**2017**
CSE prepares Guidelines on Water Sensitive Urban Design and Planning and Green Infrastructure

**2018**
Draft Drainage Master Plan for Delhi prepared by IIT Delhi
*Linking of regional and local drainage*

**2019**
Draft manual on Stormwater Drainage by CPHEEO

## 2.5 Existing policy framework for urban flooding and stormwater management

As per the 7th Schedule of the Constitution of India, both 'Land' and 'Water' fall under List II, and are state subjects. However, the central government provides vision, technical support and funding through various policies, programmes and projects. The existing policy framework at the level of the central government, state government and local government is explained here.

At the national level, there is no separate policy for drainage and stormwater management. The various policies, plans and programmes with respect to drainage are listed below.

### Guidelines on Management of Urban Flooding, 2010

Prepared by the National Disaster Management Authority (NDMA) in response to increasing number of flood events, the guidelines provide a nine-point approach for urban flood management. The recommendations deal with institutional arrangements, data collection and planning principles to address the issue of urban flooding. The key action points under the guidelines are:

1. Ministry of Urban Development will be the Nodal Ministry for Urban Flooding
2. Establishment of the Urban Flooding Cell in Ministry of Urban Development (MoUD), State Nodal Departments and ULBs
3. Establishing a Technical Umbrella for Urban Flood Forecasting and Warning both at the National Level and State/UT levels
4. IMD will establish a 'Local Network Cell'
5. Establishment of Local Network of Automatic Rainfall Gauges (ARGs) for Real-time Monitoring with a density of 1 in every 4 sq km in all 2,325 Class I, II and III cities and towns
6. Strategic Expansion of Doppler Weather Radar Network in the country to cover all Urban Areas for enhanced Local-Scale Forecasting Capabilities with maximum possible lead time
7. India Meteorological Department (IMD) will develop a Protocol for Sub-Division of Urban Areas on the basis of Watershed and issue Rainfall Forecast on Watershed-basis
8. Establishing Urban Flood Early Warning System
9. Catchment will be the basis for Design of Stormwater Drainage System
10. Watershed will be the basis for all Urban Flooding Disaster Management Actions
11. All 2,325 Class I, II and III cities and towns will be mapped on the GIS platform
12. Contour Mapping will be prepared at 0.2 - 0.5 m contour interval
13. Inventory of the existing stormwater drainage system will be prepared on a GIS platform

14. Future Stormwater Drainage Systems will be designed with a Runoff Coefficient of up to 0.95 in using Rational Method taking into account the Approved Land-use Pattern
15. Pre-Monsoon De-silting of Drains will be completed before March 31 every year
16. Involve the Residents' Welfare Associations (RWAs) and Community Based Organisations (CBOs) in monitoring this and in all Urban Flood Disaster Management (UFDM) actions
17. Every building shall have Rainwater Harvesting as an integral component of the building utility
18. Encroachments on Drains and in Floodplains will be removed by providing alternative accommodation to the poor
19. Better Compliance of the Techno-legal Regime will be ensured
20. Establish the Incident Response System for Coordinated Response Actions
21. Capacity Development at the Community and Institutional level to enhance UFDM capabilities
22. Massive Public Awareness programmes covering Solid Waste Disposal, problems of Encroachments, relevance of Techno-legal Regime besides all other important aspects
23. Involve elected Public Representatives in Awareness Generation

## National Mission for Sustainable Habitat, 2014

This is one of the eight missions under the National Action Plan for Climate Change. Amongst other objectives, the mission seeks:

*"To improve the ability of habitats to adapt to climate change by improving resilience of infrastructure, community-based disaster management and measures for improving advance warning systems for extreme weather events."*

In addition to SLBs followed in AMRUT, it recommends the following SLBs, in order to measure and better manage stormwater infrastructure:

- Construction of new drains and conversion of *kuccha* drains to *pucca* with 20 per cent extra discharge capacity
- Cleaning and draining of drains twice a year
- Incidences of people affected in vulnerable areas and property damaged during flooding
- Rejuvenation of waterbodies once in two years
- Stormwater drainage cess on property tax
- Provision of pumping arrangement in low lying areas or areas which experience waterlogging

- Imposition of penalty on defaulters who dump solid and untreated liquid waste in drains
- Extent of rainwater harvesting in buildings

These SLBs are comprehensive, with additional focus on the preventive approach of rejuvenating water bodies. However, these were never adopted and incorporated in the mainstream urban infrastructure development missions like AMRUT and Smart Cities.

## Smart Cities Mission, 2015

The Smart Cities Mission was launched with the objective to promote sustainable and inclusive cities that provide core infrastructure with the application of 'Smart' solutions to give a decent quality of life to its citizens with a clean and sustainable environment. Unlike AMRUT, this is an area-based mission, where selected cities will prepare area-based development strategies and pan-city initiatives.

As of August 2018, a total of Rs 18,861 crores have been allocated under 'Water and Sanitation'. Out of that, Rs 1,878 crores is for drainage projects. Given the infrastructure deficiency in Indian cities, these funds are also utilized for infrastructure projects under other (and older) schemes.[36]

## Atal Mission for Rejuvenation and Urban Transformation (AMRUT), 2015

The aim of AMRUT is to provide basic services (water supply, sewerage, urban transport) to households and build amenities in cities which will improve the quality of life for all, especially the poor and the disadvantaged. One of the thrust areas in the mission is 'Stormwater drainage to reduce flooding'.

The mission has set SLBs to assess infrastructure provision in cities. The SLBs for drainage are:

- % coverage of stormwater drains along length of roads. Target set is 100%.
- Incidences of sewerage mixing in the drains. Target set is 0 (zero).
- Incidences of waterlogging. Target set is 0 (zero).

## Standard Operating Procedure (SOP) on Urban Flooding, 2017

The SOP on Urban Flooding was prepared by the Ministry of Urban Development (now MoHUA), taking a cue from the Guidelines on Management of Urban Flooding-2010, prepared by NDMA. The SOP on urban flooding focuses on preparation of a basic plan for engagement and coordination in the times of crisis management after a disaster. In terms of disaster response, the SOP focuses on the following aspects:

- Pre-monsoon phase: Preparedness for disaster reduction
- Monsoon phase: Early warning, effective response and management, and relief planning and execution
- Post-monsoon phase: Restoration and rehabilitation

The SOP provides for broad institutional responsibility for planning, mitigation and relief activities.

At the local (city) level, various stakeholders are involved in urban planning, construction and O&M of stormwater infrastructure, protection of waterbodies, etc. In terms of stormwater drainage infrastructure, a total of 69 projects had been implemented in 2019, amounting to a total expenditure of Rs 9,245.45 crore. These are individual projects, implemented in isolation.

No city in India has prepared a comprehensive strategy or plan or programme for urban flooding and stormwater management, except for the NCT of Delhi. GNCTD and IIT Delhi prepared the Drainage Masterplan for Delhi in 2019, which is a review of the 1976 document. However, this is the only instance of a city-level policy, plan or programme for urban flooding and stormwater management. Deficiencies in the policy framework at various levels of governance are depicted below:

| Policy / Plan / Programme | Water policy | Urban flooding | Stormwater management |
|---|---|---|---|
| National level | | | |
| State level | | | |
| City level | | | |

Policy / Plan / Programme exists    Policy / Plan / Programme does not exist

## AMRUT 2.0, 2022

AMRUT 2.0 aims to make cities water secure. Under this mission, states and ULBs are required to prepare City Water Balance Plans and City Water Action Plans. The three key components of these are water supply, septage/sewerage and rejuvenation of water bodies, and development of parks and green spaces. While there is no separate focus on stormwater management and drainage, there is an opportunity to conserve and develop critical green infrastructure assets as stormwater management projects: water bodies, parks, open spaces, etc.

## 2.6 Institutional set-up for stormwater management in India

In most situations, it is the responsibility of the local government and municipal agencies to develop and implement urban runoff and flood control strategies. The main decisions related to urban stormwater management are made by local governmental institutions and water-related companies, whereas for regional issues, federal government and ministries take over the full responsibility.[37]

Stormwater infrastructure in Indian cities is of two categories: natural drains (*nallahs*) and roadside stormwater drains. While roadside drains are generally within municipal limits (except in cases of National Highways, State Highways and District Roads), natural drains are regional in nature. The institutional setup for design, construction and O&M of these infrastructures is explained below:

### Natural drains (*Nallahs*)

Historically, natural drains have been used as canals for irrigation, and have been a potential source of flooding. For this reason, they fall under the jurisdiction of either the Irrigation and Flood Control Dept., Drainage Board, or the Public Health and Engineering Dept. Some examples are:

- NCT of Delhi: Irrigation and Flood Control Dept.
- Bhopal and Indore (Madhya Pradesh): Public Health and Engineering Dept.
- Mathura, Vrindavan and Agra (Uttar Pradesh): Public Health and Engineering Dept.

These departments are responsible for construction and maintenance of embankments along these drains, and the general upkeep of the drains. In some metropolitan cities, these natural drains are under the jurisdiction of the ULB, within the urban limits. The city of Bengaluru exhibits this model.

- The city of Bengaluru is known for various tanks and ponds, which are interconnected through canals, locally known as Raj Kaluve. Within municipal limits, these drains are under the jurisdiction of the Bruhat Bengaluru Mahanagar Palike (BBMP).

### Roadside drains

The design, construction and O&M of urban drainage infrastructure is the responsibility of the ULBs as per the 12th Schedule of the Constitution of India. However, due to inadequate financial and technical capacity in most ULBs across India, various line departments and parastatal organizations also work on stormwater infrastructure.

In most cities across India, roadside drains have a mixed institutional set-up, between the PWD, the ULB and other development authorities.

- In Delhi, stormwater drains along roads are under the jurisdiction of the PWD, and all roads with right-of-way of more than 60 ft fall under the jurisdiction of the PWD.
- Areas developed by the respective development authorities in cities are responsible for design, construction and O&M of drains.
    - Hyderabad: Hyderabad Metropolitan Development Authority
    - Bhopal: Bhopal Development Authority
    - Delhi: Delhi Development Authority
    - Bengaluru: Bengaluru Development Authority

**Urban water bodies:** Lakes and ponds play an important role in maintaining the hydrological regime, and have high potential for run-off control, among other uses such as water supply, groundwater recharge and recreation.

## Institutional setup for urban lakes and ponds

For urban lakes and ponds, three models of ownership exist in India depending upon the size, ecological importance and location of the lake. The three models are:

- State-level Lake Conservation Authority is the custodian/nodal agency for lakes. Rajasthan, Karnataka, Madhya Pradesh and Jammu & Kashmir have constituted lake authorities. Objectives:
    - Develop an inventory of waterbodies in the state
    - Prepare action plans for conservation projects
    - Prevent lakes from getting polluted and encroached upon
- Separate Lake Conservation Authority for designated lakes is constituted, in cases of important lakes, Ramsar Sites, etc.
- ULB / Development Authority / Parastatal Organizations / Land Dept. has the ownership of lakes. This is the most common scenario in urban areas.
    - ULB has the ownership of lakes within its limits in Bengaluru
    - Hyderabad Metropolitan Development Authority has the ownership of the Hussain Sagar Lake, and other lakes in Hyderabad
    - Delhi Jal Board has ownership of various small ponds in Delhi
    - Generally, in peri-urban areas and outskirts of small and medium towns, the Revenue Dept. has the ownership. Ex. Bodhgaya

Apart from design, construction and O&M of stormwater infrastructure, it is imperative to identify organizations which provide technical inputs, pollution control and complaint redressal mechanisms. This is important to identify the soft infrastructure details of stormwater management, as they are key in sustainable implementation (see *Table 4: Institutional setup for soft infrastructure with respect to stormwater management in India*).

**Table 4: Institutional setup for soft infrastructure with respect to stormwater management in India**

| Role | Organization |
|---|---|
| Design standards | Central Public Health and Environmental Engineering Organization (CPHEEO)<br>Indian Roads Congress (IRC)<br>National Building Code (NBC) |
| Water quality in natural drains | State Pollution Control Board |
| Early warning system and complaint redressal system | No authority. In most places, Traffic Police records incidences of water logging, as reported to it by the citizens |
| Preparation of city drainage plan | No specific authority. Institutional/legislative framework does not exist for preparation of such a document |

Source: Compiled by CSE, 2020

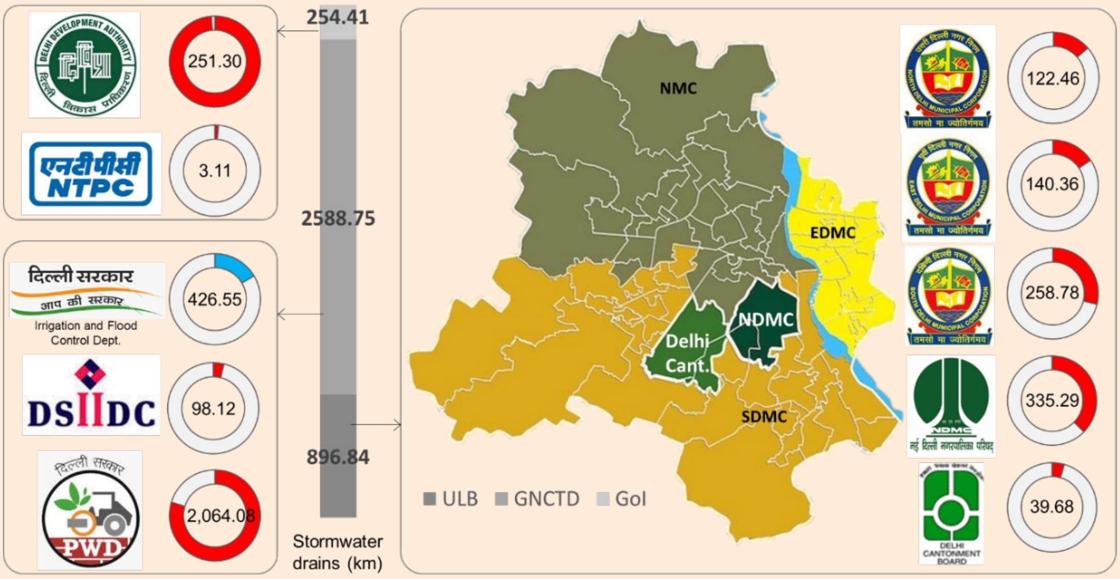
The design standards for roadside/engineered stormwater drains are prepared by CPHEEO, under the Draft Manual for Stormwater Management. Additionally, cross-section designs for urban drainage are prepared by IRC, under the IRC – SP:50-2013 Codes. Drainage standards for buildings are prepared by NBC under the Model Building Bye-laws.

For water quality management in these natural drains, the PCBs take cognizance and can direct relevant authorities to act. In case of municipal solid waste and C&D waste, they direct the ULBs to act. In case there is wastewater/faecal sludge mixing in the stormwater infrastructure, the WSSB is responsible.

It is also observed that there is no designated department/authority/organization for complaint redressal and form an early warning system in case of failure of stormwater infrastructure. In most cases, incidences of waterlogging are reported to the Traffic Police. Citizens don’t have any medium to register complaints.

## INSTITUTIONAL SETUP FOR STORMWATER MANAGEMENT IN THE NCT OF DELHI

Stormwater drains in Delhi: 3,740 km (3,313.45 km of engineered drains, 456.55 km of natural drains)




## OWNERSHIP, DESIGN, CONSTRUCTION, O&M

- As many as eight organizations across the local, state and central governments are involved in stormwater management for Delhi. In terms of ULBs, 24 per cent of total length of engineered stormwater drains are governed by the various local governments in the city.
- The GNCTD owns 69 per cent of all the stormwater infrastructure in the city, including 426.55 km of natural drains, under the Irrigation and Flood Control Department. The Public Works Department of GNCTD owns 62 per cent of engineered stormwater drains in the city. Stormwater drains in industrial estates are under DSIIDC.
- The Delhi Development Authority (DDA) is responsible for stormwater drains in various DDA developments in residential, institutional, commercial and other projects, which amount to 8 per cent of total engineered drains in the city. Apart from this, NTPC has 3.11 km of stormwater drains under their jurisdiction. In addition to this, approximately 311 m of the Agra Canal is owned by the UP Irrigation Deparment.

## WATER QUALITY, COMPLAINT REDRESSAL

- In terms of the quality of water in natural drains, DPCC and CPCB are the authorities which take cognizance, and can direct relevant authorities to maintain the water quality, including the issue of disposal of municipal and C&D waste.
- There is no authority/organization/department under any level of administration which is responsible for early warning systems, complaints and redressals in case of waterlogging issues and other issues related to the breakdown of stormwater infrastructure.
- However, Delhi Traffic Police records incidences of waterlogging, as reported to it by the citizens.

Source: CSE, 2020 (Compiled from data retrieved from Draft Drainage Master Plan for Delhi, and other sources)

## 2.7 Stakeholders for stormwater management in India

Stormwater management and urban flooding involve a diverse group of stakeholders. Due to its strong linkages with other urban services and urban planning, it is important to identify and involve these stakeholders for preparation and implementation of stormwater management strategies (see *Table 5: Stakeholders for stormwater infrastructure provision*).

**Table 5: Stakeholders for stormwater infrastructure provision**

| Area of work | Organization(s) |
|---|---|
| Construction, O&M of roadside drains | ULB: Municipality, Municipal Corporation<br>Public Works Department<br>State Infrastructure Development Corp. |
| Construction and O&M of natural drains and embankments | Irrigation and Flood Control Dept.<br>Public Health and Engineering Dept. |
| Management of urban water bodies | Lake Conservation Authority<br>ULB: Municipality, Municipal Corporation<br>Development Authority<br>Revenue Dept. |
| Water quality in natural drains, waterbodies | Central / State Pollution Control Board |
| Design standards | CPHEEO<br>Indian Roads Congress |
| Rainfall data | Indian Meteorological Dept. |
| Urban flood mitigation | National / State Disaster Management Authority<br>ULB: Municipality, Municipal Corporation |

Source: Compiled by CSE, 2020

The stakeholder groups that are integral for stormwater management and urban flooding are mentioned in Table 6.

**Table 6: Stakeholders for urban planning and other urban services**

| Area of work | Organization(s) |
|---|---|
| Preparation of Master Plan / Development Plan | Town and Country Planning Department<br>Development Authority<br>ULB: Municipality, Municipal Corporation |
| Implementation of master plan and monitoring for encroachments | ULB: Municipality, Municipal Corporation<br>Development Authority |
| Municipal solid waste management | ULB: Municipality, Municipal Corporation |
| Sewage and sanitation services | Water Supply and Sewerage Board<br>ULB: Municipality, Municipal Corporation<br>Public Health and Engineering Dept. |

Source: Compiled by CSE, 2020

Involvement of local stakeholders and consultation with communities is an integral component of the planning process.[38] The various other stakeholder groups which we need to incorporate in planning and awareness strategies are mentioned in Table 7.

**Table 7: Stakeholder groups with their interests and priorities in urban drainage planning**

| Stakeholder group | Interests and priorities |
|---|---|
| Public and community leaders | Largest community of residents and service users/beneficiaries |
| Slum dwellers | Low-income communities who often inhabit areas which are at risk from floods |
| Land developers | Construction of new developments for new housing or industry |
| Farmers | Peri-urban community with agricultural interests |
| Environmentalists | Protection of quality of water resources and conservation of natural habitat |
| Local politicians | Priority issues responding to local constituents' demands |
| Councilor and civil servants | Trade-off between cost-benefits in relation to municipal expenditure |
| Architects and land planners | Planning and design of urban space |
| Private sector, and the business community | Protection of industrial and commercial interests |

Source: Urban Stormwater Management in Developing Countries

## 2.8 Data management and urban information system

Planning and designing for stormwater management and urban drainage is highly data-intensive, requiring multi-sectoral information on geographical features, land-use and historical data.

In order to analyse all this data in a single model and prepare strategies, it is important to establish an urban information system which uses GIS and remote sensing techniques to fill data gaps, and can also run analysis and simulations for preparation of stormwater management strategies. Only a handful of cities in India have established an urban information system (152 towns under NUIS, apart from other metropolitan towns). However, the availability of data at the appropriate scale is a challenge faced by local authorities. Some of these challenges are explained below:

### Rainfall data

Rainfall data in India is provided by the Indian Meteorological Department (IMD), which records it through its 3,879 rain gauges across the country. However, IMD does not provide spatially disaggregated rainfall data for urban areas. As the amount of rainfall in a city is not evenly distributed, cities require spatially disaggregated data for rainfall in order to appropriately design drainage infrastructure. NDMA Guidelines on urban flooding recommend a rain gauge (or weather station) density of one per square km. Cities in India don't meet this criterion.

## Land-use and land cover data

Land cover data provides information on the proportion of hard and soft surfaces in the city. This information is essential in estimating run-off generation and formulating drainage strategies. With rapid urbanization, the land-use and land cover change need to be recorded in a periodic manner. Local authorities don't have access to this data, which is to be prepared at various scales. Land-use and land cover maps need to be prepared at 1:1,000 (for the purpose of infrastructure and utilities); 1:2,000 (for the purpose of zonal plan and town planning schemes); and 1:10,000 (for the purpose of city-level planning for stormwater management and urban drainage).[39] In addition to this, data for waterbodies, streams and open spaces needs to be regularly updated.

## Topography and drainage basins

In order to manage urban drainage, we need information on regional and local drainage basins, and their inter-linkages. Catchment area planning for urban drainage is negatively impacted due to the absence of data on urban sub-catchments, as the estimation of run-off flows and linkages are not established.

Topography data is required to delineate local sub-catchments, and identify low-lying areas and areas prone to flooding. Periodically updated local topography maps are required because with periodic changes in landuse and landcover, the local topography is altered. Toposheets obtained from Survey of India are not updated frequently, and freely available remote sensing data is not at an appropriate scale for analysis at the local level. LiDAR data is increasingly being used; however, the cost of procurement of LiDAR data from private organizations is high. Data on water utilities and infrastructure is also not readily available with local authorities. These should include updated network, details of flow, quality of water, invert level, etc.

### SUMMARY OF ISSUES WITH RESPECT TO STORMWATER MANAGEMENT IN INDIA

**STRUCTURAL ISSUES**

*Planning issues*

- Absence of designated waterbodies and open spaces to support stormwater runoff.
- No comprehensive strategy for stormwater management through a city drainage plan or drainage masterplan.
- Unplanned laying of drains leads to random outfall throughout the city—open fields, vacant plots, low lying areas, etc.
- Unplanned and planned construction in catchment of waterbodies and flood plains (Polluted run-off: Sheet flow).

- Inadequate/poor strategies for dense urban fabric and low-lying areas
- Inadequate drainage network
- Proposed land-use, use zones (at city and zonal level) and DCRs do not address issues in run-off control measures
- Urban planning exercise fails to identify sub-catchments and flood prone areas in cities. Due to no knowledge of stormwater flows and flood risks, proposed land-uses don't address flood vulnerability concerns

*Design issues*
- Design standards developed by statutory organizations have not incorporated effects of climate change: Need to design for moderate and extreme rainfall events, at least in greenfield development and planned areas
- Design standards for dense urban fabric and low-lying areas are not developed.
- Design standards for SUDS techniques like swales, rain-gardens, etc. for urban areas not prepared.

*Infrastructure and management issues*
- Poor O&M of stormwater infrastructure in cities
- Poor structural condition
- Irregular desilting activities
- Poor condition of stormwater drains due to dumping of municipal solid waste and C&D waste

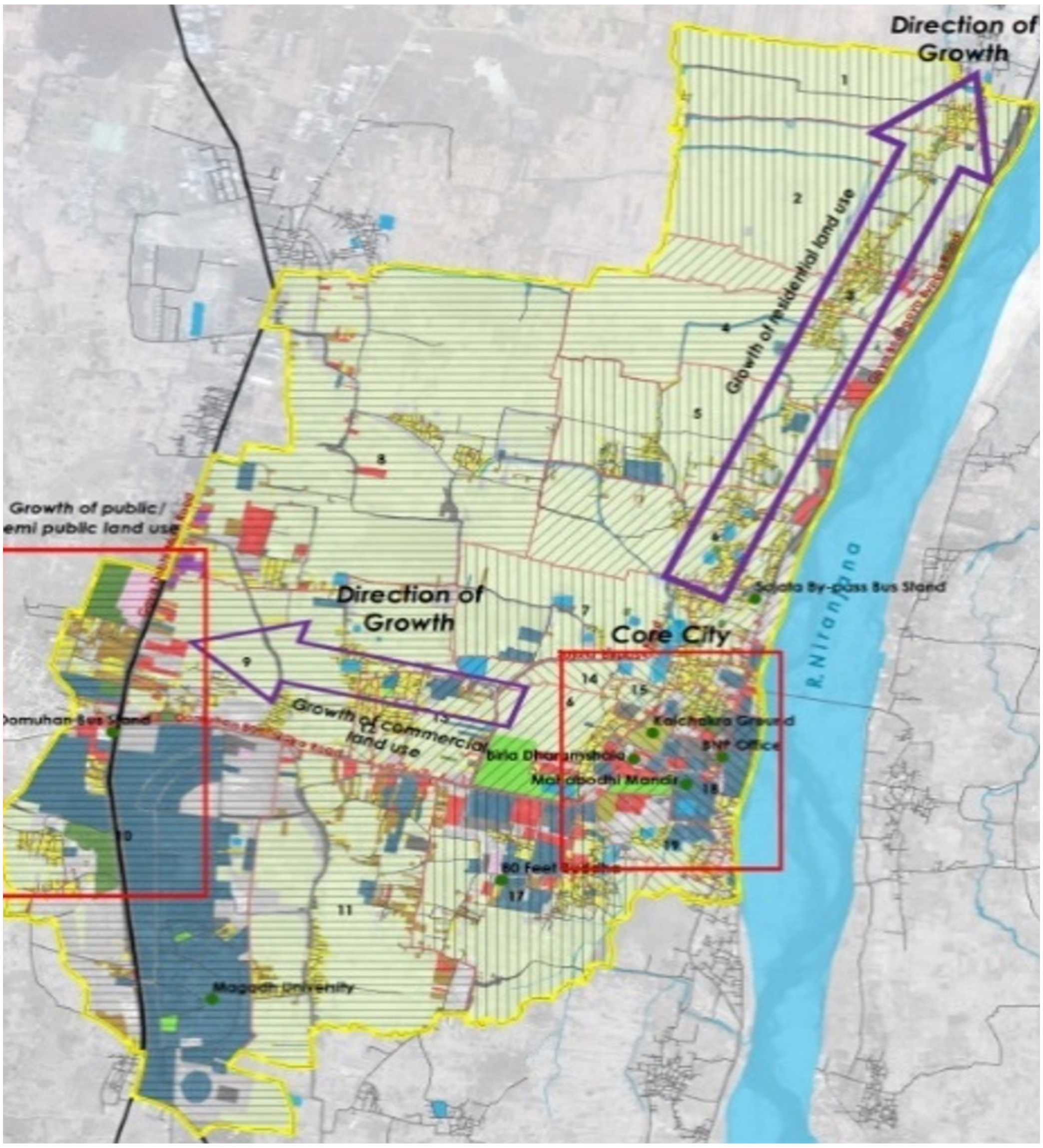
**NON-STRUCTURAL ISSUES**

*Policy framework*
- A policy/plan/programme for sustainable stormwater management does not exist in India. Majority of stormwater infrastructure projects are implemented through urban infra. improvement schemes like AMRUT and Smart Cities.
- The SLBs provided under AMRUT are inadequate in addressing the issues related to stormwater infrastructure. The SLBs and indicators under the National Mission on Sustainable Habitat are comprehensive. However, these are not implemented as of now.
- The recommendations made under the Guidelines for Management of Urban Flooding are not yet implemented by the various organizations.

*Institutional setup and stakeholder engagement*
- Absence of a nodal agency/organization for preparing stormwater and drainage policy/plan at national/state level
- Uncoordinated actions between master planning exercise and stormwater infrastructure development
- Multiplicity of authorities for provision of stormwater infrastructure, with little or no coordination
- Negligible coordination between organizations involved in preparing master plans (including land-use plans and DCRs) and those preparing strategies for urban drainage and providing stormwater infrastructure
- No institutional/legislative/administrative framework for:
    - Preparation of City Drainage Plan or Drainage Masterplan
    - Identification of flood-prone areas and chronic points for waterlogging
    - Grievances and complaint redressal
- Lack of enforcement of relevant regulations with respect to:
    - Encroachment of catchment area: Masterplan norms, building bye-laws, etc.
    - Pollution issues with respect to water quality in natural drains: Water (Prevention and Control of Pollution) Act, Environment (Protection) Act, etc.
    - Inadequate civic services with respect to dumping of municipal solid waste and C&D waste in natural and engineered stormwater drains: Solid Waste Management Rules

# CASE STUDY
# Class III city, stormwater management issues in Bodhgaya, Bihar

## Urban fabric of Bodhgaya




Source: City Sanitation Plan for Bodhgaya - 2033

Bodhgaya in Bihar, India is a small but internationally renowned city with a population of 38,439 people. It is famous for Lord Buddha having attained enlightenment here more than 2,000 years ago.

The town is concentrated around the Mahabodhi temple complex on an east-west and north-south axis. It is surrounded by agricultural fields and small settlements.

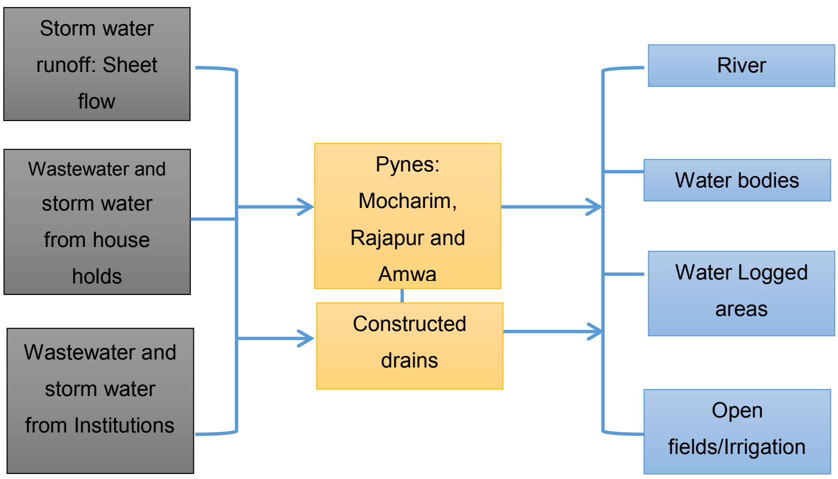
The traditional pynes (open unlined channels allowing infiltration and also acting as canals) in the city act as the only drainage system and are the major recipient of the surface run-off of the town. In Bodhgaya, around 23 per cent of roads are covered with the drainage network.

These pynes also carry: a) wastewater (grey water from kitchen and bathroom, effluent from onsite sanitation system (OSS), and black water in absence of OSS); b) excreta (in case of open defecation/urination in drains); c) solid waste (due to littering and dumping).

The following key issues arise from the current situation:

1. Polluted stormwater (in constructed drains and pynes) leads to unhygienic conditions throughout Bodhgaya which results in increased exposure of population to various health hazards and environmental pollution.
2. Inefficient stormwater management leading to waterlogging in low lying areas.
3. Pollution of waterbodies leads to ecological and economic loss, along with degradation of the aesthetic environment.

**Existing stormwater management in Bodhgaya**




Source: City Sanitation Plan for Bodhgaya, 2033

**Institutional setup**

The responsible agency for stormwater management in Bodhgaya is Bodhgaya Nagar Parishad (BNP). However, there is no dedicated team and structured institutional setup for stormwater management. Safai karamcharis only carry out de-silting. An effective complaint redressal system is also absent.

Source: CSE, 2018

*Wastewater and solid waste in stormwater drains and pynes, Bodhgaya*

**O&M of stormwater**

The task of regular O&M needs to be performed as a preventive approach in order to attain sustainability. However, presently, the O&M of stormwater drainage network is only limited to de-siltation which includes: monthly cleaning of minor drains manually; cleaning of pynes once in two months through cranes.

Source: CSE, 2018

*Waterlogged area in ward no. 17, Bodhgaya*

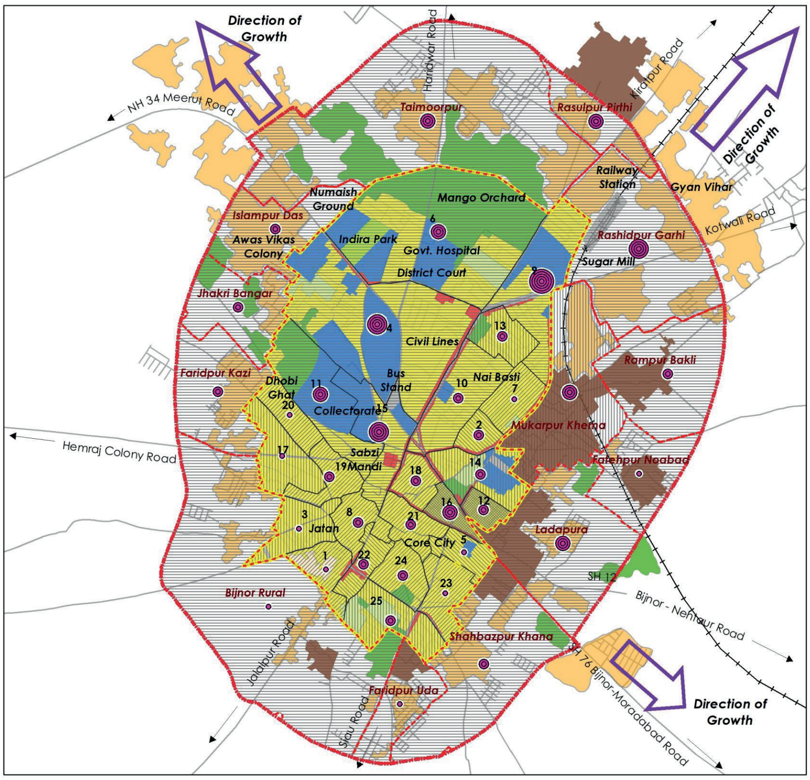
In Bodhgaya, unplanned development with inadequate drainage network regularly causes waterlogging in many areas of the city. Poor runoff from urban areas, that includes wastewater and solid waste, is a severe issue as this results in contamination of the existing watercourses, thus creating an unhealthy environment in low lying areas.

Waterlogging in Bodhgaya happens due to the following reasons:

- Unregulated growth in immediate catchment of pynes leads to overflow and/or backflow from pynes
- Wastewater from buildings, hand pumps and public/community toilets gets collected in low lying areas
- Sheet flow of stormwater also gets collected in low lying areas

# CASE STUDY:
# Class II city, stormwater management issues in Bijnor, Uttar Pradesh

### Urban fabric of Bijnor




Source: City Sanitation Plan for Bijnor, 2033

The city of Bijnor, district headquarters of Bijnor district of Uttar Pradesh, lies in the upper Indo-Gangetic plain. The municipal boundary of Bijnor Nagar Palika Parishad (BNPP) encompasses 25 wards and occupies an area of 3.65 sq. km.

The city limits were recently extended to include Bijnor Extended Area (BEA) covering nearby 14 villages having a cumulative area of 7.4 sq. km. Currently, the total area under BNPP is 11.05 sq. km.

The old city is concentrated around the centrally located wards. All other wards situated around the old city are in the southern part—establishing the core of the city. Sabzi Mandi, which is the main vegetable wholesale market of the city, is also located in this area.

The overall density of this area is high with narrow lanes and cluttered housing with mixed land-use. It has been observed that the area comes under relatively low-income group settlements followed by rural setting towards the south-west.

On the eastern part of this area, the prevalent settlement is called Abdai. It is in the low-lying part of the city, prone to frequent waterlogging.

In BNPP, most of the roads are covered with the drainage network and about 70 per cent of the drains are covered. However, the existing drainage network is designed along the roads as per road width and not corresponding to the catchment areas. Moreover, few wards with high population densities are characterized by impervious surfaces like roads, pavements and buildings.

Apart from stormwater, the drains carry: a) wastewater (grey water from kitchen and bathroom, effluent from OSS, black water in absence of OSS); b) excreta (in case of open defecation/urination in drains); c) solid waste (due to littering and dumping).

## Institutional setup

The agency responsible for stormwater management in Bijnor area is Nagar Palika Parishad or ULB. However, there is no dedicated team and structured institutional setup for stormwater management. Safai karamcharis only do de-silting. There is also no complaint redressal system in place.

## Operation and maintenance

The task of regular O&M needs to be performed as a preventive approach in order to attain sustainability. However, presently, the O&M of stormwater drainage is only limited to de-siltation, which includes daily cleaning of minor drains and weekly cleaning of major drains.

Unplanned development with inadequate drainage network and construction of new colonies in Bijnor Extended Area (BEA) results in the loss of green spaces and decreases the city's capacity to absorb water, making it solely dependent on the outflow of surface water runoff; this increases the demand for stormwater drainage systems. This scenario, exaggerated due to uncontrolled dumping


*Wastewater and solid waste in stormwater drains, Bijnor*

of solid waste into drains, results in waterlogging even in the case of moderate precipitation. Moreover, there is no officially designated/maintained waterbody to support the stormwater infrastructure in Bijnor Nagar Palika Parishad, hence the drains carrying the polluted stormwater from the city end in low lying areas/ vacant plots in BEA.


*Waterlogged area, Bijnor*

# 3. Sustainable stormwater management

There is a growing realization at both the central and state levels that the risk of not addressing water management in the early stages of planning and design causes constraints to new development or (re)development.

The missing link is not taking into consideration the context of the whole catchment area, including consideration of the flows upstream and downstream of the planned unit area, in the existing stormwater management approach. This can be supported with the following 3Ms for every spatial unit, from a single lot and building block up to a neighbourhood and the whole city:[40]

(1) **M**inimize the difference in runoff volume leaving the area after development as compared with the volume before it.

(2) **M**inimize the difference in discharge leaving the area after development as compared with the discharge before it.

(3) **M**inimize the pollutant load in the runoff leaving the developed area.

This can be achieved by planning urban development through:

- **Protecting local waterbodies** (lakes, ponds and wetlands) which act as sponges in high rainfall events, hence reducing the volume of rainwater runoff and lowering the risk of flooding and waterlogging.

- **Promoting rainfall infiltration** into the soil at public places, including open areas in cities through elements of landscape design like vegetated swales and bio-retention systems. (Swales are linear vegetated channels with a flat base that encourage sheet flow of water through grass or other robust vegetation. Bio-retention areas and rain gardens are planted areas designed to provide a drainage function as well as contribute to the soft landscape.)

This approach which considers quantity, quality and amenity issues is referred to as Sustainable Drainage Systems (SUDS). SUDS approach assures that runoff quantity and quality is addressed. It provides an integrated and balanced approach

## FACTORS AFFECTING RUNOFF

**Infiltration** is the process by which rainwater percolates through the soil surface. The amount of infiltration which occurs depends upon the soil type, moisture content, organic matter present, vegetation cover, depth of the groundwater table and rainfall intensity. In many cases, infiltration is considered the largest, if not the only surface runoff loss.

*Principle: Minimizing change in post-development hydrology by reducing impervious areas and preserving more trees and meadows to reduce storage requirements to maintain the pre-development runoff volume.*

**Surface retention**, or depression storage is that portion of rainfall which collects in natural or man-made depressions or ponds, and remains within the basin after a runoff event has effectively concluded. Surface retention is considered a runoff loss.

*Principle: Providing retention storage for volume and peak control, as well as water quality control, to maintain the same storage volume as the pre-development condition.*

**Time of concentration (Tc)** is defined as the time required, during a storm, for the entire basin area to contribute to the surface water outflow. It is a useful basin characteristic which is used in several analyses. The time of concentration is affected by the watershed's surface conditions (such as vegetation types and land-use), land slopes, soil types, and surface water management.

*Principle: Maintaining the pre-development Tc in order to minimize the increase of the peak runoff rate after development by lengthening flow paths and reducing the length of the runoff conveyance systems.*

to help mitigate the impacts of stormwater quality on receiving systems and the changes in stormwater runoff flows that occur as land is urbanized (see *Table 8: Approach for stormwater management: Conventional vs SUDS*).

SUDS is a broad area with a wide range of practices at different scales, including:

- Maintaining and protecting the natural water cycle by managing the water balance (groundwater and surface water runoff).
- Reducing runoff and peak flows from urban developments by employing local retention measures and minimizing impervious surfaces.

The main objective of stormwater management here is to integrate stormwater drainage systems into the landscape, creating multiple use corridors that maximize the visual and recreational amenity of urban development through SUDS. Factors taken into consideration for catchment development are mentioned in Table 9.

### Table 8: Approach for stormwater management: Conventional vs SUDS

| Aspect of stormwater | Conventional approach – stormwater as a 'nuisance' | Alternative approach – stormwater as a 'resource' |
|---|---|---|
| Quantity | Stormwater is conveyed away from urban areas as rapidly as possible. | Stormwater is attenuated and retained at source allowing it to infiltrate into aquifers and flow gradually into receiving waterbodies. |
| Quality | Stormwater is treated together with human waste at centralized wastewater treatment plants or discharged untreated into receiving waterbodies. | Stormwater is treated using decentralized natural systems such as soils, vegetation and ponds. |
| Recreation and amenity value | Not considered | Stormwater infrastructure is designed to enhance the urban landscape and provide recreational opportunities. |
| Biodiversity | Not considered | Urban ecosystems are restored and protected by using stormwater to maintain and enhance natural habitats. |
| Potential resource | Not considered | Stormwater is harvested for water supply and retained to support aquifers, waterways and vegetation. |

Source: CSE, 2020

### Table 9: Factors for catchment development in SUDS

| Approach for catchment development | Scope of development |
|---|---|
| Time of concentration—Increase | Lengthening flow paths and conveyance systems. Diverting the drainage flow to bigger areas and open swales. |
| Runoff volume—Decrease | Reducing or minimizing imperviousness, preserving more trees and meadows. Tree plantation along channels as recreational areas. |
| Peak discharge—Reduce | Retention storage for volume and peak control, natural drainage patterns, off-channel storage by depressions and through SUDS features. |
| Water quality—Improve | Catchment land use, sand filters, retention areas, filter strips |
| Flooding—Controlled | Use of additional runoff, use of floodwater in low-lying area |

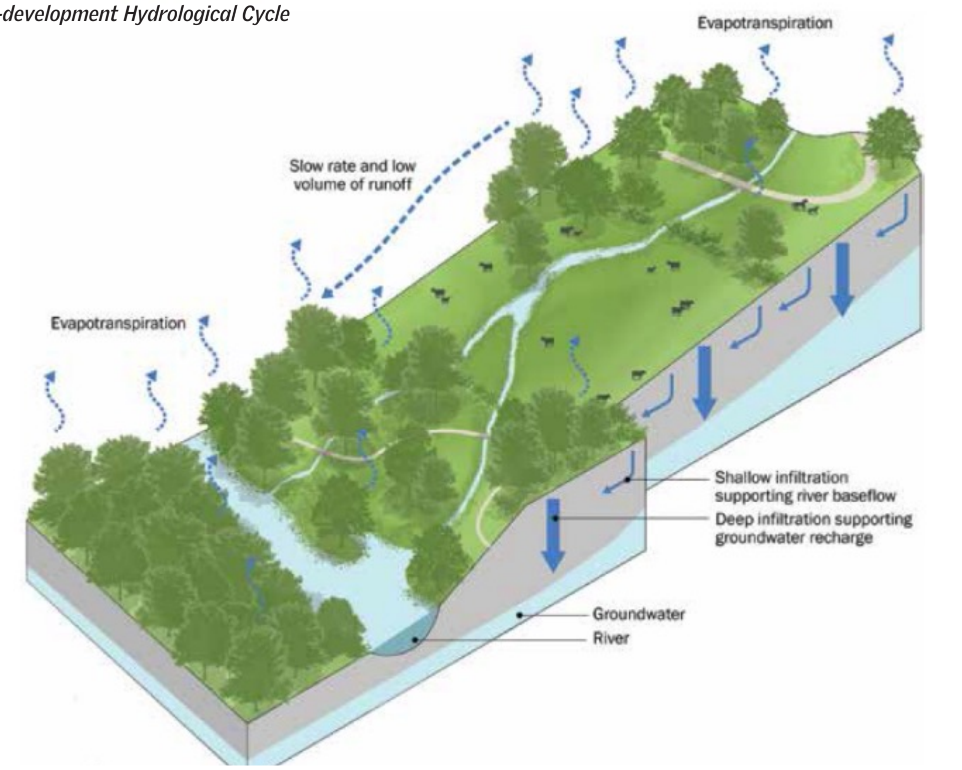
Source: CSE, 2020

The SUDS approach encourages consideration of water quality, water quantity and amenity/biodiversity. By considering all three functions, it is possible to provide adequate, well-designed systems that offer water quality treatment through natural processes inherent in the system, encourage infiltration where appropriate, attenuate peak flows, and provide a liveable habitat for those using the area, including the local community and wildlife.

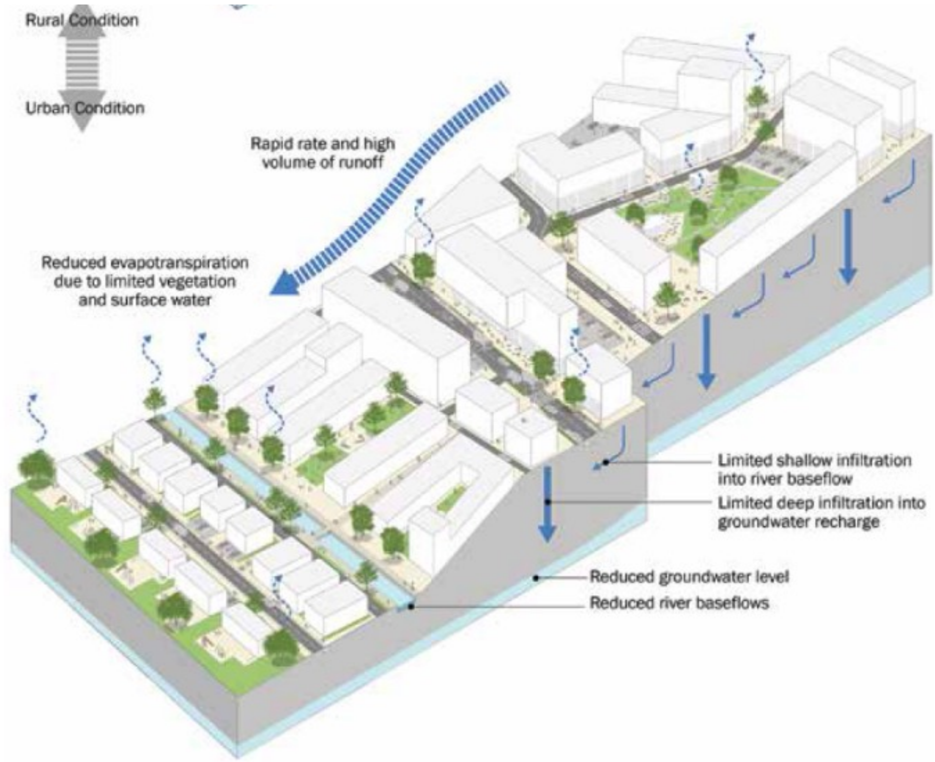
Figure 4 describes the altering hydrological cycle due to land cover change, and how introduction of SUDS manages the surface water run off.

## Figure 4: Altering hydrological cycle due to land cover change, and introduction of SUDS

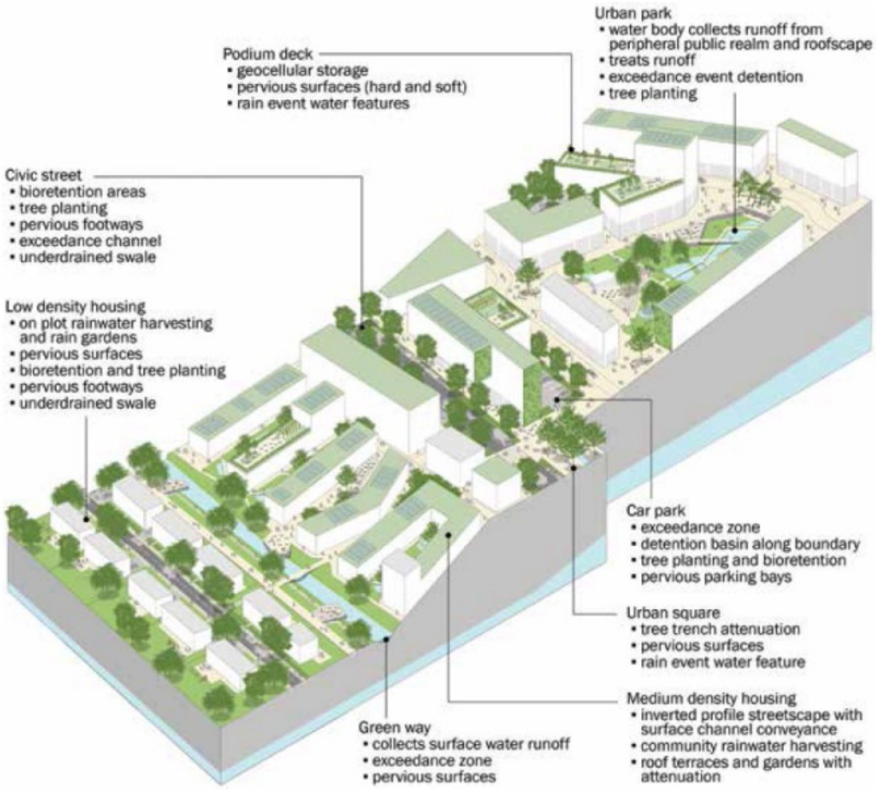
*Pre-development Hydrological Cycle*




*Impact of Urbanization on Catchmnet*



*SUDS Approach to Manage Surface Water Runoff*




*Source: The SUDS Manual 2015 (Guide technique No. C753). London: CIRIA*

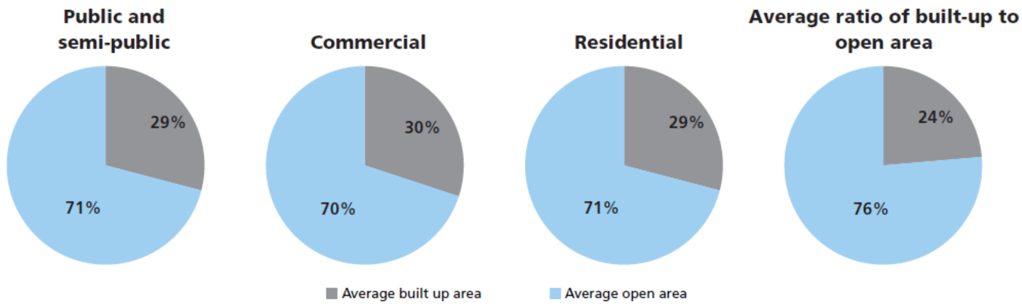
## 3.1 Feasibility of this approach in the Indian context

According to Guidelines from Urban and Regional Development Plans Formulation & Implementation (URDPFI), released in 2016, the maximum percentage of land in all kinds of urban centres—metropolises to small towns—is allotted to residential areas. Residential clusters which occupy the largest share (35 to 45 per cent), along with recreational areas (18 to 20 per cent), of land-use in cities and towns comprise building rooftops, sidewalks, paved parking spaces, pervious areas that could be gardens or just open land and accessible roads.

The URDPFI guidelines provide ground rules for the percentage of maximum allowable ground coverage for each land-use in India. According to the guidelines, the average ratio of built-up area to open area in an urban area is 76:24 (see *Graph 3: Average built-up area in various land-uses).*

CSE has come up with two practitioner's guides, namely 'Water Sensitive Urban Design and Planning (WSUDP)'[41] and 'Green Infrastructure (GI)'[42] which give

**Graph 3: Average built-up area in various land-uses**




Source: URDPFI Guidelines by MoHUA, Govt. of India

comprehensive solutions for mitigating floods at different scales and in different agro-climatic regions of India. The WSUDP guide aims to assist practitioners involved in sectors related to water management as well as urban designing and planning in India. The focus moves to water-sensitive urban designs and then individual-level designs.

The GI guide discusses green infrastructure as one of the solutions to overcome the emerging water management issues of supply and quality regulation, along with moderation of extreme flood events. GI practices are demonstrated through relevant strategies which can be applied within the existing urban fabric of a city or region. The GI concept reintroduces the natural water cycle into the urban environment and provides effective measures to manage fluvial (river), coastal, and pluvial (urban runoff or surface water) flooding in Indian cities. Besides coverage of drainage network, it is essential to assess other components (see *Table 10: List of indicators to check efficiency of stormwater management*) leading to effective drainage, which includes resilience, quality, efficiency and governance.

The existing public open spaces in Indian cities can be designed for collecting runoff, in order to avoid flooding in the entire city (see *Table 11: Scope of SUDS interventions as per existing provisions*). This can be in the form of waterbodies/ponds, parks and other green areas which can be used for other recreational activity for the rest of the year while serving the purpose of flood attenuation during monsoon. The public open spaces in India, after being planned and designed correctly, can help achieve a sustainable balance between overall development and natural environment. There is a need to include public open spaces within the urban fabric in the form of stormwater management infrastructure, thus helping our cities to transform from flood affected cities to water-sensitive cities.

**Table 10: List of indicators to check efficiency of stormwater management**

| Infrastructure | Resilience | Quality | Efficiency |
|---|---|---|---|
| • Coverage of stormwater drainage system<br>• Cleaning of structures<br>• Designated waterbodies<br>• Use of open areas | • Waterlogging incidences<br>• Green space or stormwater infiltration<br>• Rainwater harvesting (RWH) | • Quality of stormwater in drains<br>• Quality of waterbodies | • Change in groundwater level<br>• Use of stored rainwater<br>• Frequency and number of O&M activities |
| **Governance** | | | |
| • Redressal of user complaints<br>• Legislative action for water resource management<br>• Citizens' perception on water resource<br>• Stakeholder engagement<br>• Accountability of allotted budget and its expenditure for water resource management in the city<br>• Any development authority created for monitoring of waterbodies<br>• Any incentives offered for water sustainable initiatives<br>• Capacity building of staff and users<br>• GIS mapping of drains, waterbodies and green areas | | | |

Source: CSE, 2020

**Table 11: Scope of SUDS interventions as per existing provisions**

| Scale | Spatial opportunities for interventions |
|---|---|
| City level: Open spaces—parks and waterbodies, road infrastructure (planning stage) | • Waterbodies, parks, recreational areas, green areas, public transport<br>• Future locations of stormwater management facilities along roads: Swales, detention basins |
| Zone level (planning and designing stages) | • Parking lots, roads, parks, open space blocks and stormwater management facilities defined in planning documents<br>• DPRs for stormwater drainage: Swales, bio-retention areas |
| Individual level (designing stage) | • Site-specific pervious areas<br>• Rainwater harvesting features |

Source: CSE, 2020

## 3.2 Principles of stormwater management for Indian cities

As stated in Table 12, CSE recommends five principles to cater to urban drainage planning issues:

**Table 12: Principles for stormwater management in Indian cities**

| Principle I | Principle II | Principle III | Principle IV | Principle V |
|---|---|---|---|---|
| The major/minor approach to urban drainage | Attenuate and infiltrate first | Interventions at all scales | Locating interventions as per city's urban fabric and natural physical features | Stormwater harvesting |

Source: CSE, 2020

## Principle I: The major/minor approach to urban drainage

*Combination of conventional system and SUDS*
Frequent storms can be managed by the major drainage system. This conventional system collects storm runoff from roads and buildings and routes it into curbs and channels, which discharge into stormwater inlets. From there it is transported via drainage channels toward outfalls joining receiving waters.

As per CPHEEO manual, urban drains (minor system) are recommended to have a design capacity of 1-to-5-year Average Recurrence Interval (ARI) storms as per different land-uses and city type (see *Table 2: CPHEEO recommended design return periods for various urban sub-catchments*). These systems could be useful to prevent nuisance flooding, thereby allowing safe use of infrastructure such as roads and footpaths.

However, there is a need to design the major drainage system to convey runoff that would otherwise exceed the capacity of the minor system (now that this frequency is increased due to climate change). This design capacity could be of the order of a 10-year ARI or greater depending on the infrastructure it is protecting.

These distributed stormwater systems could typically include roadways, walkways and certain public open spaces, which are designed to convey water away from built infrastructure, whilst ensuring that velocity/depth conditions are below prescribed limits to allow for safe traffic conditions. Major flows are then conveyed to receiving waters. The minor system still contributes to flood and flow management during a major storm, but it conveys only a small proportion of the peak discharge.

**Figure 5: Schematic representation for distributed stormwater management**

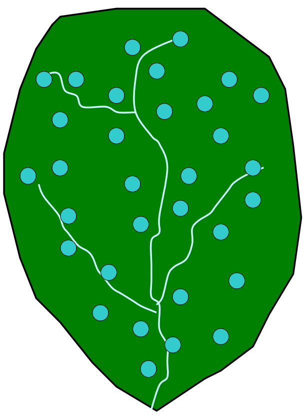
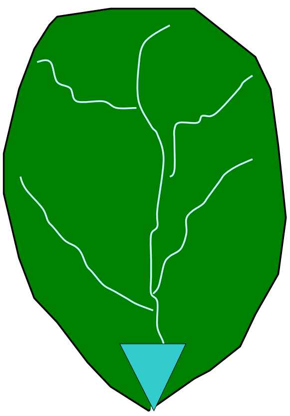


**Figure 6: Schematic representation for regional drainage management**



Source: CSE, 2020

## SHOWCASING PRINCIPLE I: BARAPULLAH BASIN, DELHI

The city of Delhi consists of three major drainage basins, namely the Najafgarh Basin, the Barapullah Basin and the Shahadra (trans-Yamuna) Basin. The Barapullah Basin is spread across an area of 376 sq km. It is the second largest basin amongst the three. The total population residing in the basin is approximately 3.4 million. The basin forms a triangular shape, abutted by the river Yamuna on the eastern edge, the Delhi Ridge on the western end and Asola Wildlife Sanctuary and southern ridge on the southern side.

In terms of land-use, around 30 per cent of the basin area is built-up. The built-up area is spread across the basin, except in the southern part where agriculture fields and forest areas are found. It has a mix of formal and informal areas, along with institutional areas like universities, hospitals, embassies and government offices. The basin also includes Lutyens' Delhi, Shahjahanabad and the Mehrauli Archaeological Complex, Delhi Ridge, and other notable areas. The basin exhibits different hierarchies of open spaces, ranging from neighbourhood-level green areas to city forests.

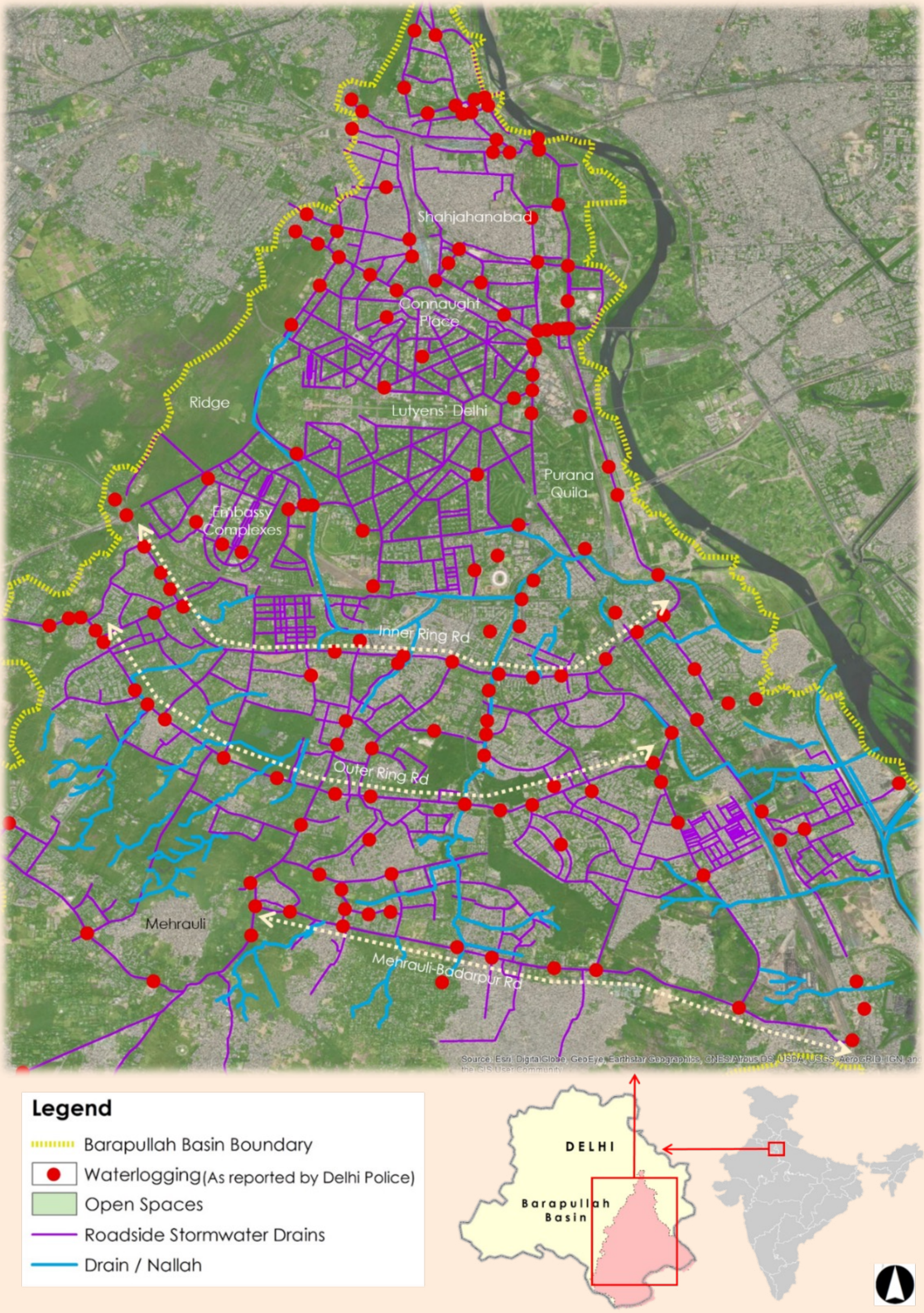
Despite adequate stormwater infrastructure, the basin is riddled with waterlogging issues at all major junctions and roads. Even planned areas in south and central Delhi face the issue of waterlogging. Connaught Place and Lutyens' Delhi also have considerable instances of waterlogging.

The way the city has grown, it has been observed that waterbodies and natural drains have either been encroached upon, or have been covered for other built uses. Two bus depots are developed covering the Barapullah Drain.

**Stormwater management: A combination of conventional systems and SUDS**
The basin has high potential of an integrated approach for stormwater management. The abundant open space can be used to plan and design SUDS features, especially in areas in and around the Outer and Inner Ring Roads, Lutyens' Delhi and the Mehrauli Archeological Complex.

Instead of using only the roadside stormwater drains to collect run-off, there is a potential to utilize the abundant open space available for various SUDS features. The distribution of these features would reduce pressure on the trunk networks, especially along the Inner and Outer Ring Roads and the Mehrauli–Badarpur Road, which witness seasonal waterlogging for longer durations. Lutyens' Delhi has the highest open space-to-built up ratio, and these areas have high potential for almost all SUDS features.

## Stormwater infrastructure in Barapullah Basin




Source: CSE, 2020 (Compiled from information retrieved from Draft Drainage Master Plan for Delhi, 2014; Satellite Image dated 2 Jan., 2020 from Sentinel 2A, retrieved from USGS Earth Explorer)

## Principle II: Attenuate and infiltrate first

*Control the volume and peak runoff rates from the site: concept of retention and detention*

Peak runoff rates from the site (i.e., how fast the runoff is allowed to leave the site after development has taken place) should be controlled by maximizing opportunities to capture runoff and slow down flow rates through attenuation and flow controls (for ex. by using retention and detention basins). Managing surface water runoff at or close to source helps prevent high rates and volumes of runoff being conveyed to large downstream attenuation systems.

Retention-based measures are defined as those that intercept and permanently hold the water or divert it for another purpose, effectively preventing water from entering the downstream drainage system. Examples of retention storage include rainwater tanks and infiltration systems.

Detention systems are those that temporarily hold runoff in a storage system and release stored water into the downstream drainage system, usually at a restricted flow rate through an orifice or similar structure. At the single dwelling allotment scale, "on-site detention" is typically implemented in the form of a detention tank. For larger development sites, such as larger commercial sites and residential subdivisions, detention is generally applied in the form of detention basins or detention ponds.

The design goals of detention systems, as well as some retention systems, are to ensure that post-development runoff rates from an urban development remain equal to, or less than, the pre-development peak flow rates for one or more target ARIs. The target ARIs are typically set by local or state government and range from 1 to 10 years in residential areas.

There are likely to be many areas within the built-up development that could potentially be combined with the delivery of attenuation storage—beneath permeable paving or recreation facilities, within small detention zones, ponds or channel conveyance routes. Distributing the storage areas across the site within multi-functional spaces can be effective in terms of land-take, potentially reducing the need for a large downstream attenuation facility.

Open spaces provide the opportunity to combine the function of public open space with habitat retention (trees and watercourses) and stormwater management. The utilization of these open spaces can be used to control and reorganize flow discharges to avoid flooding. About 5–10 per cent of the area can be made into regional or district parks which can be dedicated to cater to pluvial flooding/ flood storage, alongside being used for leisure activities in non-monsoon days. For example, in planned developments, local authorities may adopt a policy that encourages infiltration, restricts runoff by limiting allotment of impervious area, encourages vegetation in upstream areas, and/or ensures that natural streams are protected in the development planning process. A public education campaign about WSUD concepts is also an important non-structural measure to justify or support public investment.

## SHOWCASING PRINCIPLE II: BODHGAYA, BIHAR

Stormwater infrastructure in the city is a mix of traditional pynes and roadside stormwater drains. Apart from this, the city has 44 small ponds. The total area of these waterbodies and pynes is 330 Ha, which is 16.8 per cent of the city area.

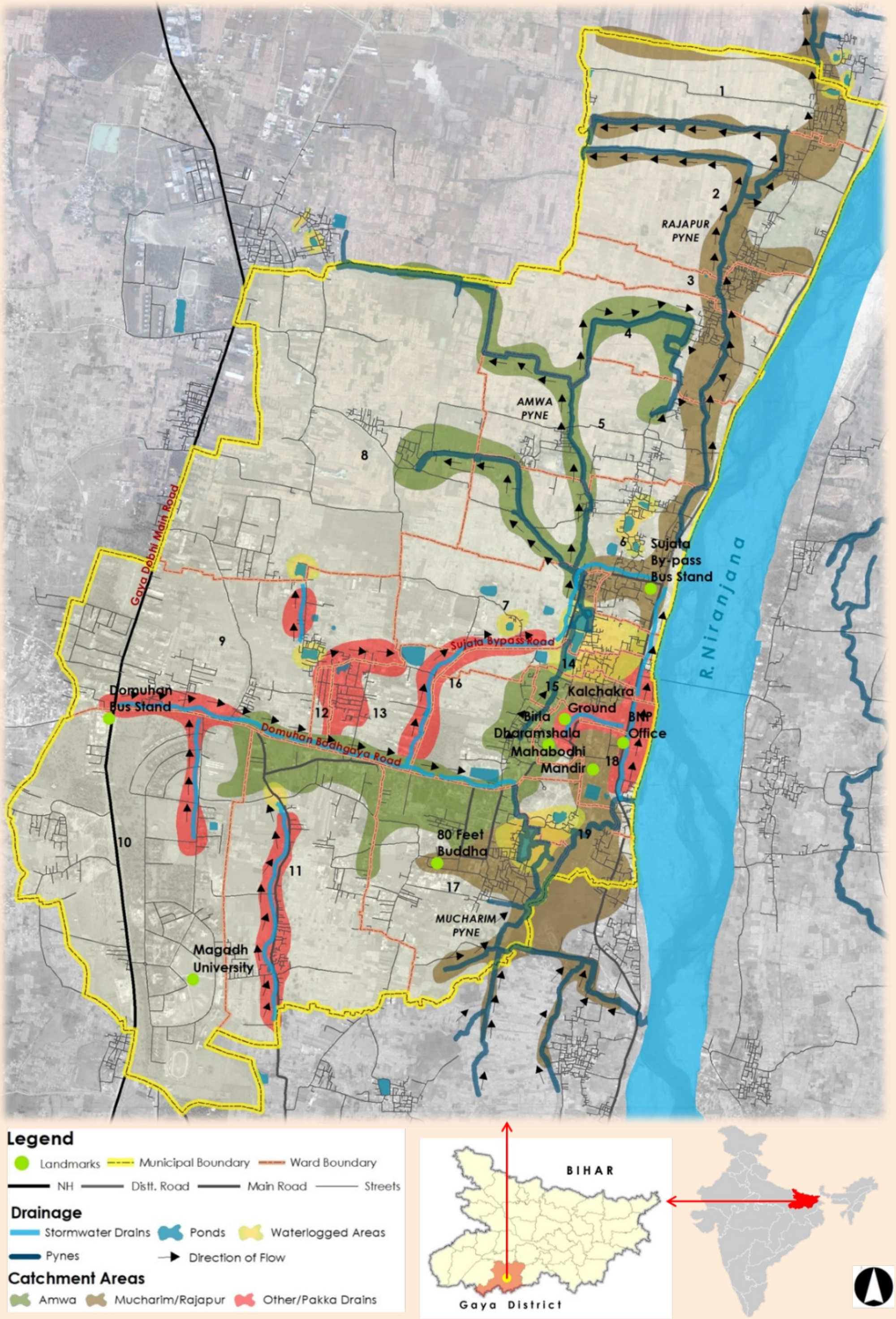
### Stormwater infrastructure in Bodhgaya

<table>
<tr><th>Stormwater infrastructure</th><th>Length (km)</th><th>Catchment area (Ha)</th></tr>
<tr><td>Amwa pyne</td><td>9.28</td><td>205.34</td></tr>
<tr><td>Mocharim and Rajapur pyne</td><td>10.51</td><td>255.59</td></tr>
<tr><td>Pucca drain</td><td>31.96</td><td rowspan="3">117.22</td></tr>
<tr><td>Covered pucca drain</td><td>19.68</td></tr>
<tr><td>Kuccha drain</td><td>2.90</td></tr>
</table>

Source: City Sanitation Plan 2033 for Bodhgaya

As a city in the nascent stages of physical development, it serves as an appropriate example to conserve the traditional drainage system, and execute the principle of attenuate and infiltrate. The catchment areas of these pynes and waterbodies need to be protected, and these in combination with the roadside drains can evolve into a sustainable drainage network. Instead of adopting a 'Don't Build' approach for these areas, there is a need to adopt a 'Build Better' approach, in which the principles of attenuation and infiltration can be accommodated, thus providing sustainable infrastructure.

### Potential areas for attenuation and infiltration in Bodhgaya




Source: City Sanitation Plan 2033 for Bodhgaya

## CITY-SCALE GREEN OPEN SPACE AVAILABLE

1. City and district parks: It is a designated term as per the hierarchy of green spaces in a city. A district park is a prominent recreation space and is developed to provide vital lungs for the city airshed.

2. Community park: It is developed at the community level and acts as a link between the neighbourhood and city-level green areas. It is generally centrally located in settlements and has direct links with other natural systems.

3. Multi-purpose ground: It is provided at the city, district and community levels. It is generally meant for active and passive recreation and other community activities.

4. Neighbourhood and housing area park: It is developed at the neighbourhood level for a population of 10,000. The park is conveniently located within the developed residential areas at walking distance from all the households.

5. Playground: It is normally provided in educational institutions and neighbourhoods. It is specifically meant for active recreational activities.

6. Totlot: The lowest level in the hierarchy of green areas, it is located in residential premises and is specifically meant for recreational activities of children.

7. Green belt (buffer): Includes spaces like a green girdle, park belt, rural belt, rural zone, agriculture belt, country belt and agriculture green belt. A green belt is defined as an area of land predominantly agricultural in character and located around the proposed urban limits.

8. Green strip: It is developed on vacant land; for example, land under high tension power supply lines. It is also developed along the arterial roads separating residential areas from other areas.

For urban green spaces, recreational areas are provided on the basis of planning norms. These norms are as per the Master Plan for Delhi, 2021 and are accepted as a reference point in the URDPFI Guidelines.
As per URDPFI Guidelines, 2014, open spaces can include the following three categories:

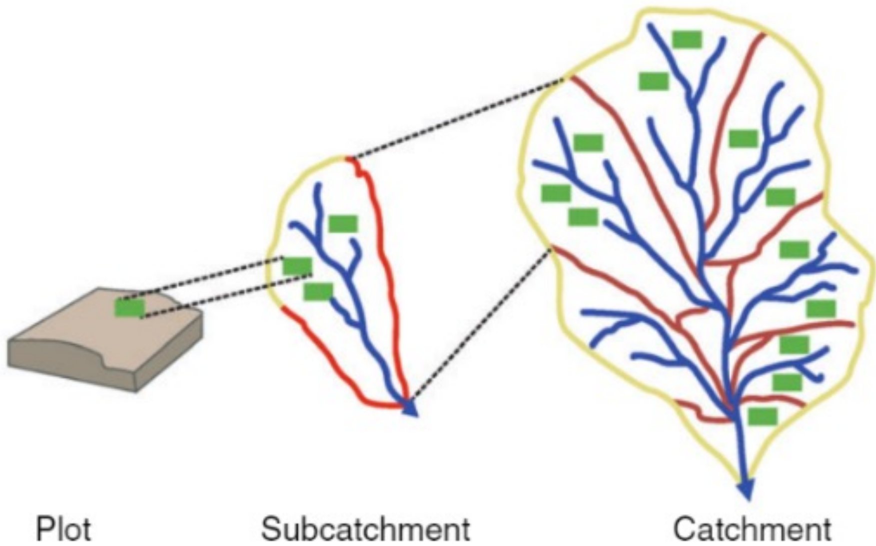
- Recreational space
- Organized greens
- Other common open spaces (such as vacant lands or open spaces including floodplains, forest cover, etc.)

## Principle III: Interventions at all scales

*Follow the SUDS train: Individual / Neighbourhood / City*

A central design concept for this approach is the management train. The management train starts with prevention (preventing runoff by reducing impermeable areas) and reducing pollution; and progresses through local source controls to larger downstream sites and regional drains.

**Figure 7: Schematic representation of stormwater management at various scales**




Source: CSE, 2020

In the context of Indian cities, wherever possible, runoff should be managed at source (i.e., close to where the rain falls) with residual flows then conveyed downstream, when required. Following this, neighbourhood level components can be designed in a number of different ways. For example, the same component can either be lined to prevent infiltration, or have a permeable base. These can be part of landscape features to look appropriate in a contemporary setting. Components can often be used to both convey and store runoff, usually depending on the size of the runoff event (for example: swales). This will help in overall reduction of volume and to control the rate of surface runoff.

The SUDS interventions at different scales create a sequence of components that collectively provide the necessary processes to control the frequency of runoff, the flow rates and the volumes of runoff, and to reduce concentrations of contaminants to acceptable levels. SUDS interventions are not independent; however, one component may provide two or more functions (see *Table 13: SUDS components and their applicability at various scales*).

Stormwater management in parks and open spaces of various scales have been successful in moderating extreme run-off, through principles of retention and infiltration. Interventions in parks and open spaces at various scales are mentioned in Table 14 along with their estimated benefits in terms of run-off volume reduction and peak flow reduction. The values are based on globally implemented solutions.

While these interventions provide a range of ecological, social and economic benefits, it is to be noted that these nature-based interventions are not resource-intensive, are easy to maintain and monitor, and they require only 1–5 per cent of the total park area.

**Table 13: SUDS components and their applicability at various scales**

| SUDS component | Individual scale | Neighbourhood/ institutional scale | City/zonal scale |
|---|---|---|---|
| Rainwater harvesting | Y | | |
| Filter strip | Y | | |
| Swale | Y | Y | |
| Filter drain | | Y | |
| Pervious pavements | Y | | |
| Bioretention | Y | Y | |
| Green roof | Y | | |
| Detention basin | Y | Y | Y |
| Pond | | Y | Y |
| Wetland | | Y | Y |
| Infiltration system (soakaways/trenches/ blankets/basins) | Y | Y | Y |

Source: CSE, 2020

**Table 14: Techniques for stormwater harvesting in parks and open spaces**

| Measure | City | Area (sqm) / Vol. (cum) | Reduction in | | Co-benefits |
|---|---|---|---|---|---|
| | | | % run-off | % peak flow | |
| Rain garden | Japan | Area: 1.862 | 36 to 100 | | • Increased biodiversity<br>• Increased property value<br>• Aesthetics |

| Measure | City | Area (sqm) / Vol. (cum) | Reduction in | | Co-benefits |
|---|---|---|---|---|---|
| | | | % run-off | % peak flow | |
| Vegetated swale | Beijing, China | Vol.: 157 | 0.3 to 3 | 2.2 | • Increased biodiversity<br>• Reduced concentration of pollutants |
| | Hai He, China | Vol: 1,500 | 9.6 | 23.56 | |
| Rainwater harvesting | Melbourne, Australia | Vol: 1 to 5 | 57.8 to 78.7 | | Improved water quality:<br>• TN reduced by 72–80% |
| Dry-detention pond | Selangor, Malaysia | Area: 65,000 | | 33 to 46 | Recreational benefits |
| Detention pond | Texas, USA | Vol.: 73,372 | | 20 | • Increased biodiversity<br>• Recreational benefits |
| | Joinville, Brazil | Vol.: 9,700 | 55.7 | 43.3 | |
| Bio-retention | Beijing, China | Vol.: 946 | 10.2 to 12.1 | | Improved water quality:<br>• Reduced TSS<br>• Reduced TP |
| | Hai He, China | Vol.: 1,708 | 9.10 | 41.65 | |
| | Calgary, Canada | Vol.: 48 | 90 | | |
| Infiltration trench | Hai He, China | Vol.: 3,576 | 30.8 | 19.44 | • Reduction in pollutants<br>• Improved surface water quality |
| | Joinville, Brazil | Vol.: 34,139 | 55.9 | 53.4 | |
| Detention pond and rain garden | Joinville, Brazil | Area: 18,327 | 70.8 | 60 | Aesthetics |
| Detention pond and infiltration trench | Joinville, Brazil | Area: 18,327 | 75.1 | 67.8 | Improved surface water quality |

Source: L. Ruangpan et al.: Nature-based solutions for hydro-meteorological risk reduction: a state-of-the-art review of the research area, Nat. Hazards Earth Syst. Sci., 20, 243–270

## SHOWCASING PRINCIPLE III: DWARKA SUB-CITY, DELHI

Dwarka is a sub-city, planned and developed by the Delhi Development Authority (DDA). It's population of 1.1 million is spread across an area of 56.48 sq. km. It is bound by the Najafgarh drain on the west, airport on the east, high density residential development (Uttam Nagar) in the north and an agricultural green belt in the south.

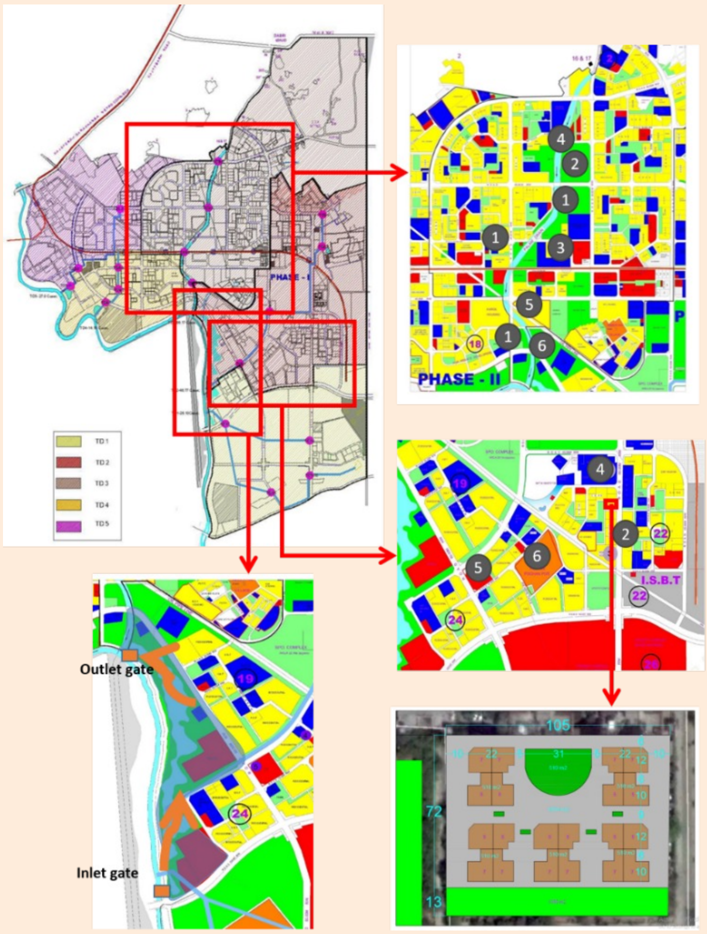
The sub-city is planned on the sector-neighbourhood concept, with a mix of land-uses, providing various amenities to the residents within the sector. The sub-city has a network of open spaces of various scales, covering 17.81 per cent of the total area. In terms of water infrastructure, the sub-city has a separate system for conveyance of stormwater and sewage. There are five trunk drains running through Dwarka, discharging the stormwater into the Najafgarh drain. These drains have their separate catchment areas mapped out as shown in the figure below.

Various interventions can be made in Dwarka, depending on the scale of application. In this study, three neighbourhood areas have been selected and analysed for potential SUDS interventions.

The above strategies were applied at following scales:

- Neighbourhood scale: Bye-laws were proposed for rainwater harvesting and minimum green area provision in different plot areas.

## SUDS interventions for Dwarka





| SUDS FEATURE | |
|---|---|
| Open space | Pond and Wetland<br>Infiltration and Retention Basin<br>Filter Strip<br>Swale<br>Rain Garden (bio-retention Area)<br>Filter Drain<br>Canal and Rill |
| Road | Filter Strip<br>Swale<br>Rain Garden (bio-retention Area)<br>Filter Drain |

**KEY**

1. Detention Pond
2. Bio-retention Area
3. Gully and Trench
4. Check Dam
5. Filter Strip
6. Grassed Swale

Source: CSE

- Catchment scale: Various natural drainage structures (like swales, bio-retention area, ponds, trenches, etc.) are proposed to be designed according to identified public open spaces of Palam drain catchment area.

- Regional scale: Potential areas for regional flood water harnessing were identified. Series of ponds are proposed to carry additional flood water (6 MCM annually). The harnessed water is to be used for horticulture and construction purpose.

It is estimated that the overall composite run-off coefficient of Dwarka can be reduced from 0.62 to 0.40. This amounts to approximately 22 per cent reduction in peak discharge for the major drains, which can be achieved by implementing only the coefficient reduction strategies. In addition to these, if retention strategies are implemented, covering an area of 5–10 per cent of the public open spaces, 100 per cent reduction in peak discharge can be achieved.

## Principle IV: Location of interventions as per city's dense areas and topography

*The urban fabric along with natural physical features are considered*
Constraints and opportunities for SUDS delivery include any likely change in permeability of the site following development, proposed land-use, site contamination levels, infiltration potential, public open space/green space/amenity provision requirements, local biodiversity characteristics and street types.

If one observes the city's urban fabric, usually there are high density informal colonies which do not have any space to follow the SUDS train. In such cases, the exceedance runoff flows (i.e., runoff in excess of those for which the system is designed) need to be managed safely by identifying above-ground space near that area such that risks to people and property can be avoided.

Where space is limited, this often means directing excess flows into a low-lying area adjacent to the high density area—parks, urban forest, open ground, etc. These '*provisional safe storage zones*' and conveyance channels for extreme events can be included as part of road or car park designs using raised kerbing or speed bumps as containment features. Civic spaces such as pocket parks, squares and plazas can also be designed to function as exceedance storage zones.

Another approach would be to find the '*end of catchment areas*' which are intended to manage flood flows from a much larger catchment and therefore tend to be situated near the end of a development/catchment. These include large detention basins, retention/infiltration basins and wetlands. These could be designated spaces allotted to cater to high peak runoff load in the monsoon season by local/state authorities where public land is available to meet the needs of a developed catchment.

## SHOWCASING PRINCIPLE IV: SANGAM VIHAR, DELHI

Sangam Vihar is an unauthorized colony located in South Delhi. It is spread across an area of roughly 5 sq. km and has a population of nearly 1 million. It is bound by the Mehruali–Badarpur (MB) road (R/W 45 m) on the north and the Asola Wildlife Sanctuary on the east and south-east. On the west and north-west, it is bound by the urban villages of Deoli, Khanpur and Tigri. The colony is abutted by Tughlaqabad Air Force Station and ITBP Camp on the north, along the MB road.

Sangam Vihar developed organically on the agricultural lands of these villages in the late 1970s and early 1980s, due to the influx of people who worked as construction labourers when Delhi hosted the Asian Games and for the development of Okhla Industrial Area. With time, Sangam Vihar has also grown spatially, and the built-up has amalgamated with the neighbouring urban villages. The continuous built-up area is now approximately 6.23 sq. km, with a population of approximately 1.4 million.

The settlement has approximately 95 per cent built-up area, with little open spaces, which are used as car parking, and are a dumping site for municipal solid waste and C&D waste.

Residents of Sangam Vihar deal with the issue of waterlogging very frequently. They mention that the roads are flooded for days in the monsoon season. Frequent cases of waterlogging are also reported in non-monsoon seasons, primarily due to clogged stormwater drains. The main roads (Tigri Road, Bandh Road, Mangal Bazaar Road and Raitya Marg) with wider stormwater drains are frequently flooded and waterlogged. It's an annual monsoon battle for shopkeepers and residents abutting these roads to keep their premises dry.

The major issues regarding stormwater management in Sangam Vihar and the nearby villages are:

- Stormwater infrastructure in Sangam Vihar is grossly inadequate. The drains on local streets (R/W 6 m) convey the stormwater to the main drains, which eventually join the trunk drain along MB road. Due to a high volume of stormwater from a large catchment, frequent waterlogging occurs on MB road during monsoons.

- The drains carry water from three sources: Stormwater from streets and houses, greywater from households (HHs) and industrial effluent from HH industries. Due to influx of greywater, the quantity of water carried in these drains is also high.

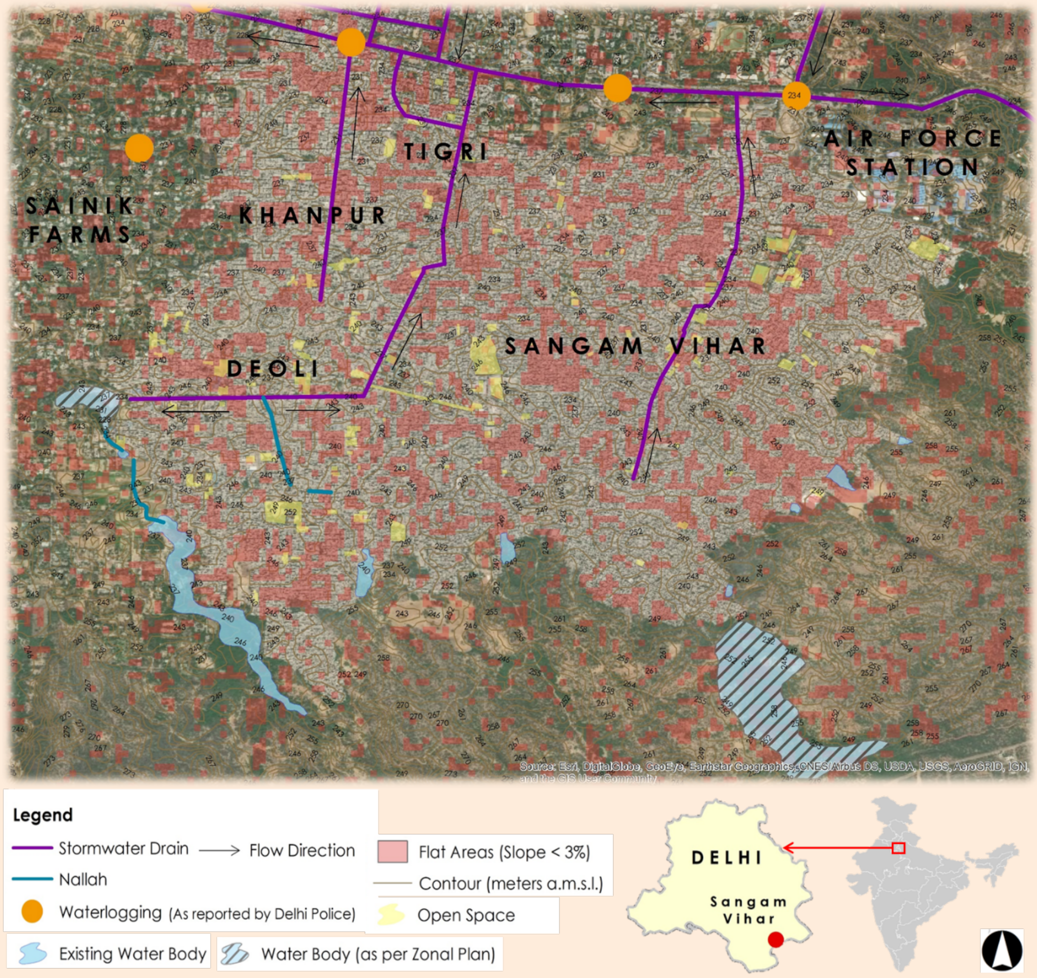
- The design of drains does not account for the cumulative stormwater. As one moves north, there are higher incidences of waterlogging.

- Natural drains and waterbodies are encroached upon, and in a dilapidated state, as these areas act as dumpsites for municipal solid waste and C&D waste.

- Stormwater infrastructure, wherever available, is clogged due to dumping of municipal solid waste and C&D waste generated within Sangam Vihar. Poor coordination between PWD Dept., GNCTD (responsible for drainage), South Delhi Municipal Corporation (responsible for solid waste management) and residents (who are responsible to transport their C&D waste to the nearest collection point) has resulted in gross mismanagement of urban waste, thus affecting other infrastructure in the settlement.

Planning for stormwater in such settlements needs an innovative approach. The concept of conveying all the stormwater through a piped network to the nearest trunk line is not sufficient. There is a need to consider the continuous built-up area as one catchment, and understand the sub-catchments using their natural topography.

### Potential areas for stormwater management in Sangam Vihar




Source: CSE, 2020

The right approach would be to direct excess stormwater into open low-lying areas, which are 'provisional safe storage zones'. In case of Sangam Vihar, the western part slopes towards the waterbodies, with a depression along the natural drains. The fringe areas slope towards smaller waterbodies, whereas the northern part of the built-up area slopes towards MB road. The waterbodies and low-lying areas are spread across 35 Ha, and can cater to 50 per cent of peak rainfall intensity during monsoon season. Another 30 Ha can be made available using the open spaces.

As the stormwater is polluted, these spaces can also be used to provide decentralized treatment facilities. Tertiary treatment through planted filter beds can be used to treat the greywater, which will also elevate the aesthetics of the open spaces. Additionally, chronically waterlogged areas can be identified based on slope analysis, and pumping infrastructure can be installed for peak monsoon seasons, which can pump the stormwater to the nearest open space/low lying area. A load reduction of 50–65 per cent of peak rainfall intensity on the MB road trunk drain can be achieved by these measures, aided with better coordination.

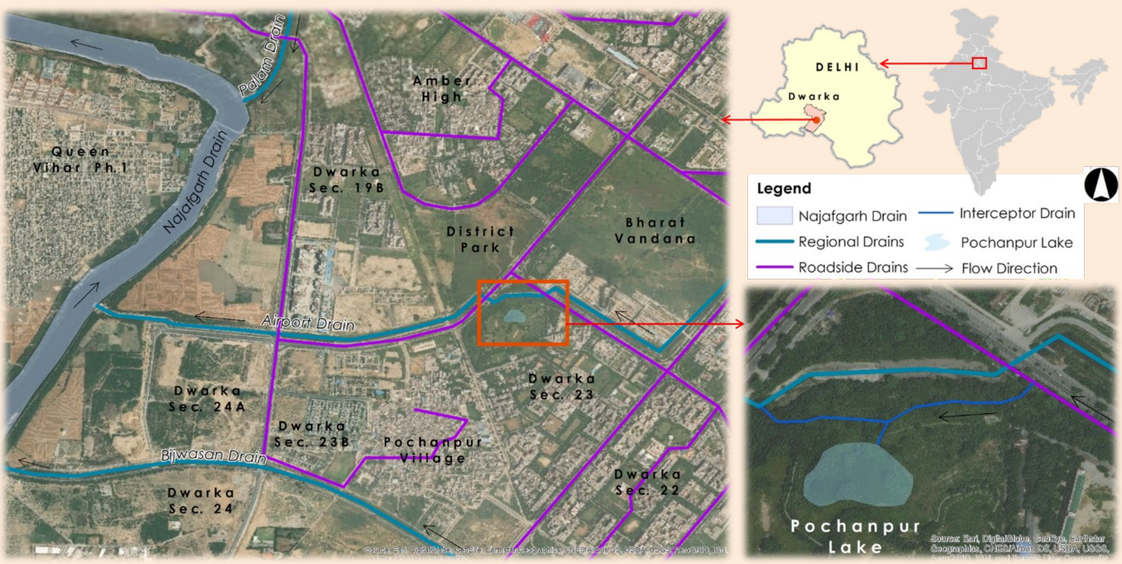
## Principle V: Stormwater harvesting

The primary objective of stormwater harvesting is to capture as much water as possible during a runoff event, so that it is available for use when needed. The location, type and capacity of a storage system are of fundamental importance in determining the success of a harvesting scheme. Providing substantial storage in an urban environment is usually a major and costly challenge to urban stormwater harvesting and can easily limit the capacity or financial viability of a scheme. In many cases, harvesting has only been possible where natural or man-made storage opportunities already exist; for example, if a lake or a disused quarry is located in or near the catchment, or suitable aquifers exist in close proximity. In other cases, specific opportunities exist that have allowed construction of a storage mechanism to be integrated into the site landscaping or development; for example, buried storage beneath a playing field or recreation park.

### SHOWCASING PRINCIPLE V: POCHANPUR LAKE, DWARKA

Pochanpur is an urban village near Sector 23 in Dwarka, surrounded by planned development. A dried-up village pond has been revived using stormwater harvesting. As depicted in the map below, the roadside stormwater drain (which used to empty in the Airport drain, and eventually into the Najafgarh drain) is intercepted, and channelized to feed the lake. A by-pass system is constructed, for peak monsoon season.

#### Stormwater harvesting at Pochanpur Lake, Dwarka




Source: CSE, 2020

The lake is spread across an area of 1.6 acres, and is 8–10 feet deep. It has a capacity to harvest 1.9 million litres of stormwater. The lake has had a positive impact on the local groundwater levels, improving the groundwater table and the quality of groundwater. The improvements in groundwater levels and TDS are mentioned in the table below.

### Performance with respect to groundwater in Dwarka Sec. 23, Delhi

| Parameter | 2015 | 2017 |
|---|---|---|
| Pre-monsoon GW level (mbgl) | 19.5 | 17.4 |
| Pre-monsoon TDS (mg/L) | 2,099 | 1,105 |
| Post-monsoon TDS (mg/L) | 1,228 | 469 |

Source: Tests conducted by University of Delhi

Apart from improvements in groundwater, the lake has improved the aesthetics of the place, enhanced the micro-climate and it also acts as a biodiversity island in the heart of the city. The de-silted mud is used to create nesting islands for birds, and mounds around the lake. A grassland buffer is provided, which is an essential nesting habitat for various birds and butterflies. Birds, butterflies, dragonflies and other terrestrial species are a common sight in and around the lake.

In terms of institutional set-up, the lake area is owned by DDA. However, the lake revival has been undertaken and executed by the community residing in Dwarka. They also take the responsibility of the up-keep and maintenance of the surroundings and the lake.

Due to a planned network of stormwater infrastructure and open spaces, Dwarka sub-city has a high potential for stormwater harvesting using this model. Based on the success of the Pochanpur Lake, two more sites have been identified in Bharat Vandana and Sector 24 for lake revival using stormwater harvesting.

*Pochanpur Lake, Dwarka*

Source: CSE, 2019

## 3.3 Proposed stormwater master planning approach

Although stormwater management is considered a priority by a majority of residents in most cities, this issue is not always prioritized by public authorities. The following are the key factors in the Indian context which would promote an innovative approach towards stormwater management in cities:

### 1. Need for 'stormwater master plans' with planning aligned to local capacities

Only one 'drainage master plan' has been developed for the capital city, Delhi. Stormwater management plans must contain an inventory of existing and planned public parks, open spaces and waterbodies. This important information about preserving natural features like waterbodies and watershed areas should be supported with a list of evaluated alternatives such as using traditional drainage channels or grey infrastructure versus more efficient and economically sustainable low-impact green infrastructure.

The stormwater masterplan should also identify areas more prone to flooding, at various moderate and extreme rainfall intensities. Risk and Vulnerability Assessment should be included as an essential part of the stormwater masterplan, which will inform regarding the following:

- Flood-prone areas
- Chronic waterlogging locations
- Vulnerable residential areas and potential population which can be impacted due to floods

These assessments aid preparation of stormwater management strategies, and inform which areas need attention on a priority basis.

### 2. Increased knowledge on innovative methods and tools

Although pluvial flooding has been clearly identified as a major issue in cities during monsoons, the authorities responsible often lack the knowledge and tools required to deal with stormwater management.

### 3. Promoting collaboration between different stakeholders

Stormwater management is rarely dealt with by a dedicated department, and responsibility for its design, planning and financing is instead usually dispersed among the different development, road or sanitation departments. As there is no clear legal and institutional segmentation, stormwater management does not strictly constitute a sector.

### KEY SPECIALISTS REQUIRED TO BE INVOLVED IN STORMWATER MANAGEMENT

1. Architect/Urban designer, 2. Planner, 3. Landscape architect
Stormwater management will not only help meet runoff targets and water efficiency targets, but will also support great placemaking and add value for communities.

4. Ecologist, 5. Hydrologist, 6. Academicians
Stormwater management needs to be done with a technical approach on the ground.

7. Engineer, 8. Contractor
The applicable civil work to be implemented on site requires the right skills for overall workability of the selected project (swale, bio-retention areas, etc.)

9. Local authorities
Once the right stormwater management approach is in place, the authority is responsible for its O&M to check the overall sustainability of the project.

10. RWAs, 11. Local residents
The open areas which are used for stormwater retention can be much more interesting and engaging places for local people. People help in creating a peaceful and natural landscape in urban areas, especially for the elderly and kids.

## 4. Watershed study

Suggested aspects which need to be covered under '**Watershed planning**' for a particular city/urban area:

✓ ***Runoff volume***: The plan should aim to reduce the amount of water that becomes runoff from a site. In forests and other natural areas, most rainfall infiltrates into the ground. In urban regions, where there are large expanses of impervious areas (paved roads, for example) and minimal amounts of pervious areas (parks, green areas for example), much less rainfall is able to infiltrate and this results in large amounts of stormwater runoff.

✓ ***Runoff rate:*** The plan should aim to slow the flow of runoff leaving a site. With greater expanses of impervious areas connected together, such as along roads, runoff flows faster and can erode streams and other pervious areas that are not able to withstand the runoff velocity.

✓ ***Runoff quality***: The plan should aim to remove pollution from urban stormwater runoff. As runoff flows across roads and other impervious areas, it picks up sediments and sometimes mixes with sewage and transports them to the nearest stream. Polluted runoff adversely affects streams and wetlands by decreasing these water bodies' ability to support aquatic life.

- ✓ ***Ecosystem health, recreation and aesthetics***: The plan should look into possibilities of enhancing the ecological and aesthetic value of the urban environment in line with existing flora and fauna with potential reuse as a water resource in society. The proposed solutions need to include measures to preserve natural streams and water bodies.

- ✓ ***Integration with urban design***: The plan should focus on developing a comprehensive stormwater drainage map which is in line with the existing land-use development patterns and future expansion areas.

- ✓ ***Cost*:** The plan should focus on reducing the construction and maintenance costs of the proposed stormwater infrastructure.

## 5. Stormwater modelling

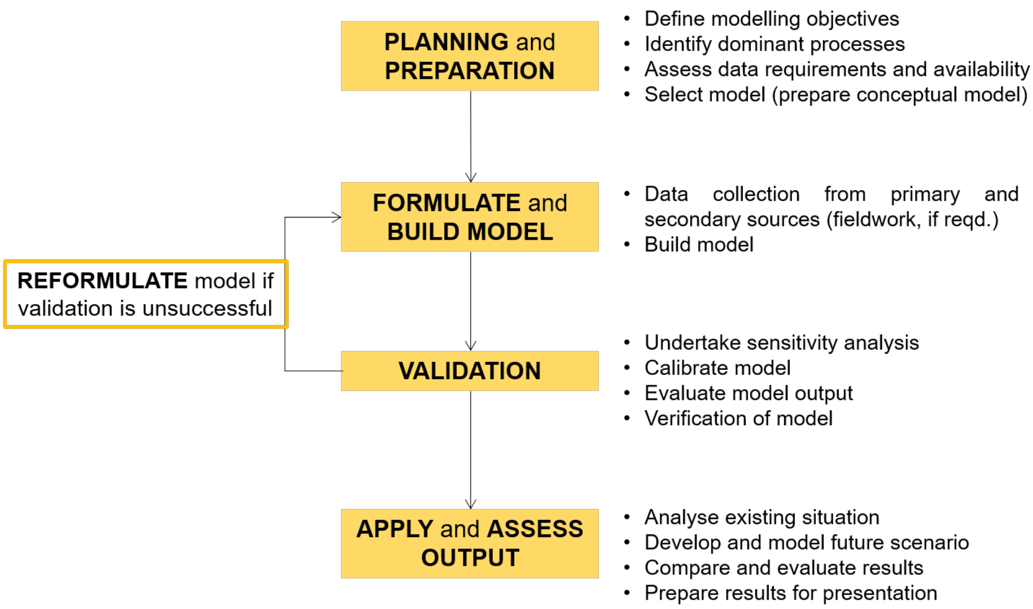
Stormwater models provide versatile tools to help understand the hydrological and hydrodynamic processes in a catchment. They can also be used to evaluate the impacts of future development scenarios and assess the implications of possible changes to the existing situation and/or proposed physical interventions.

The models can be used for the following activities:

- Designing storm events and performance analysis
- Design of new systems
- Analysis of existing systems – identification of flooding and urban drainage problems
- Analysis of optimization of existing system – input of Low Impact Development (LID) interventions
- Flood vulnerability assessment
- Provision of information for operation and real-time decision making support (ex. for flood-response strategies)
- To provide input to economic analyses of the impacts of flooding
- Analyse flooding scenarios to assist in the development of flood-response strategies

Figure 8 lists out the various steps to follow for the stormwater modelling procedure.

### Figure 8: Steps for stormwater modelling procedure




Source: Adapted from Urban Stormwater Management in Developing Countries

## STORMWATER MANAGEMENT MODEL (SWMM)

SWMM was first developed by USEPA in 1969–71, and has been regularly upgraded ever since. SWMM is a dynamic rainfall run off and sub-surface run off simulation model. It can be used to simulate water flows within a network of systems, as well as for processes like infiltration, evapouration and groundwater connections. The main compartments of the model are:

**Atmosphere compartment:** Used for quantification and spatial mapping of precipitation. It uses rain gauge objects to input rainfall into the system.

**Land compartment:** Represented by one or more sub-catchments, it receives precipitation from the atmospheric compartment, and sends its outflow of water to the groundwater compartment (through infiltration) and transport compartment (water and pollutant loading, through run-off generation).

**Groundwater compartment:** This receives inflow from infiltration, and this component is also used for aquifer mapping.

**Transport compartment:** This compartment contains a network of conveyance elements (channels, pipes, pumps, etc.). The inflows can come from any of the other three compartments. This component is modelled using links and nodes.

**The capabilities of SWMM include:** Hydraulic modelling; accounting for hydrological processes; pollutant load estimations; and add-in tool for climate projections. SWMM 5.0 has also incorporated LID components such as Green Infrastructure controls.

**Applications of SWMM are:**

- Designing and sizing of drainage system components for flood control.
- Sizing detention facilities and their appurtenances for flood control and water quality protection.
- Mapping flood plains of natural channel systems.
- Designing control strategies for minimizing combined sewer overflows.
- Evaluating the impact of inflow and infiltration on sanitary sewer overflows.
- Generating non-point source pollutant loadings for waste load allocation.
- Controlling site runoff using green infrastructure practices such as low LID controls.
- Evaluating the effectiveness of best management practices and low impact development for reducing wet weather pollutant loadings.

**Model for Urban Stormwater Improvement Conceptualization (MUSIC)**

MUSIC has been developed by eWater Ltd., which is an Australian Govt. owned not-for-profit, working in urban water management. MUSIC developers and planners devise water sensitive urban designs and integrated water-cycle management capability to manage urban stormwater. In some states, MUSIC is mandatory for designing new urban developments. Applications of MUSIC include:

- Simulate stormwater flows and detention from lot-scale to suburb-scale
- Estimate the potential for stormwater harvesting and reuse, and the effects on downstream flows and water quality
- Model pollutants including suspended solids, total phosphorus and total nitrogen, and estimate the impacts of various treatment options
- Model water balance
- Compare the quantity and quality of water and conduct a cost vs benefit analysis of employing alternative treatment scenarios
- Plan entire stormwater systems

**Polish Atlas of Rains Intensities (PANDa)**

PANDa is a digital rainfall atlas developed for 930 cities of Poland. It has been developed by the Polish consultancy firm Retencjapl Sp., and provides information about the rainfall intensities of Polish cities. The PANDa system gathers data recorded by over 100 rain gauges for the last 30 years across Poland, which meet the Polish measurement standards.

The model is an improvement on the pre-existing Błaszczyk formula, and can provide more accurate granular data and predictions of rainfall intensities. The model is capable of monitoring precipitation of up to 4,320 minutes, thus creating a glocalization effect. The rainfall atlas provided by PANDa is capable of providing information for:

- Managing stormwater in the city or a commune
- Designing dewatering systems
- Forecasting floods and other hydrological hazards

Apart from these examples, various other models have been developed for evaluating and designing nature-based solutions for stormwater management. Web-based applications for green-blue design tools include Atelier GROENBLAUW (the Netherlands) and PEARL-KB (Germany and USA). In addition to these, various GIS-based models have been developed to evaluate and design nature-based solutions. Some of these include SuD Selection and Location (SUDSLOC), Urban Biophysical Environments and Technologies Simulator (UrbanBEATS), Long-

Term Hydrologic Impact Assessment-Low Impact Development (L-THIA-LID), Adaptation Support Tool (AST), MIKE packages, Soil and Water Assessment Tool (SWAT), Urban Water Optioneering Tool (UWOT), Benefits of SuDS Tool (BeST), etc.[43]

### 6. Other areas to strengthen

✓ **Operations and maintenance:** Operations and maintenance activities can include cleaning and maintenance of catch basins, drainage swales, open channels, storm sewer pipes, stormwater ponds, and water quality BMPs.

A clear assignment of inspection and maintenance responsibilities, whether they be accomplished by the local government, land owners, private concerns, or a combination of these, is essential to ensuring that stormwater management systems function as they were intended.

✓ **Complaint redressal:** It has been observed that there is no mechanism of reporting for stormwater management issues. This will benefit in the following ways:

- It will improve complaint redressal and delivery of services with respect to stormwater management
- This also provides a feedback mechanism to inform stormwater management strategies. The data collected through this cell would contribute to risk assessment and will also provide information on modelling exercises
- No. of complaints received and addressed can also be added as a SLB to assess delivery of services over time.

## 3.4 Recommended policy framework

A comprehensive policy framework should:

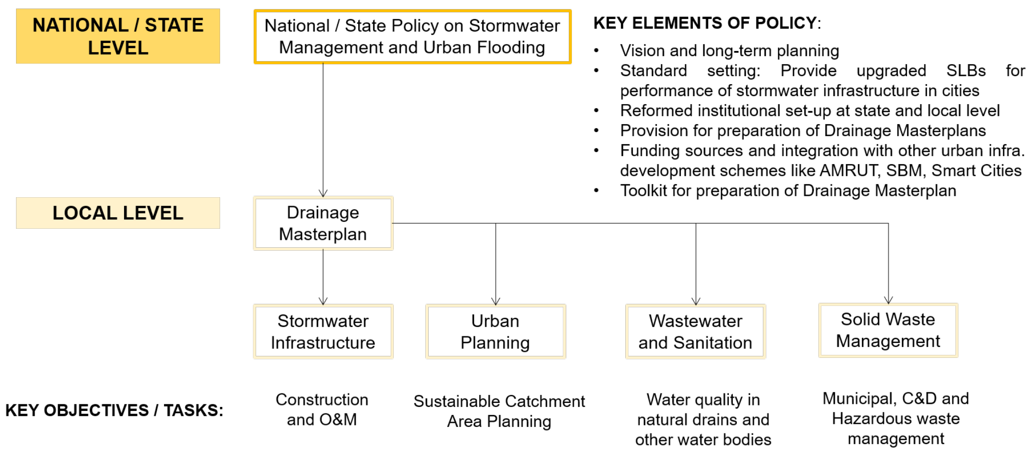
- Provide a broad vision, with long-term planning at the national and state levels.
- Establish a comprehensive set of SLBs in order to ascertain the performance of development works
- Identify the tasks and objectives at different levels of governance

- Provide clear designation of responsibilities for different stakeholders, and it should provide an overall platform of coordination amongst various state and non-state stakeholders.

- Provide funding mechanisms, which focus on source of funds, as well as how these funds shall be transferred between various stakeholders

Using these principles, the recommended policy framework for stormwater management and urban flooding is shown in Figure 9.

**Figure 9: Proposed policy framework for stormwater management and urban flooding**




Source: CSE, 2020

At the national and/or state level, there is a need to frame a policy on stormwater management and urban flooding. This policy shall provide the vision and long-term planning for stormwater management, focussing on principles of circular economy, water balance and catchment area treatment. The policy should also recommend improved standards and SLBs, which can be implemented through urban infrastructure development schemes, masterplans, and other urban service delivery mechanisms.

In addition to these, the policy framework should provide for the preparation of Drainage Masterplan for cities. These can be prepared for five years, under the aegis of Special Purpose Plans, as recommended under the URDPFI Guidelines. The policy should prepare guidelines and toolkits regarding the methodology for preparation, data requirements and expected outputs.

At the local level, local entities are responsible for preparation of the stormwater management plan, like a nodal committee consisting of state and non-state actors. The local entities are also responsible for the implementation of the proposals, including O&M. They should also have the power for collection of appropriate fees from public and private stakeholders for provision of services.

Based on the delineation of responsibilities, local organizations should prepare strategies based on the objectives of the policy. Urban planning authorities should prepare desired Development Control Regulations (DCRs) and focus on sustainable catchment area planning, while organizations responsible for other urban services should focus on water pollution (run-off and waterbodies) and up-keep of stormwater infrastructure and waterbodies.

## 3.5 Formulating a stormwater management or urban drainage plan

One of the major aspects of a drainage plan for a city is the identification of time-specific spatial strategies. The recommended timeframes for these categories are:

- Short-term: 0–3 years
- Medium-term: 3–7 years
- Long-term: 7+ years

### Stormwater and urban drainage infrastructure

The drainage plan needs to identify infrastructure gaps with respect to provision of roadside drains for both present and future development (based on city master plan / ULB data). Depending on the size of the city, and the infrastructure gap, these measures can be short- to medium-term.

Natural streams in the city need to be protected, and embankments need to be constructed and lined. These infrastructure development works come under short- to medium-term strategies, depending upon the gaps.

The O&M of stormwater infrastructure is a routine activity. Scheduled activities include seasonal de-silting of drains, clearing out solid waste and maintaining civil structures. Unscheduled activities include repairs, in case the infrastructure is damaged.

Upgradation of stormwater infrastructure is required, in cases when old infrastructure is redundant and needs to be modified. Such instances are generally observed in old city areas, or in case of upgradation of design standards for stormwater drains.

## Catchment area planning

As the masterplan/zonal plans are long-term, regulation of catchment area land-use is a long-term strategy, which can be formulated with short-term goals and indicators.

Upgradation of DCRs in order to incorporate run-off control measures is a short-term strategy. This would ensure that new developments employ run-off control measures.

The drainage master plan should provide information regarding potential flood hotspots, and assess the vulnerability of these hotspots. Various urban drainage strategies emerge out of this information. Hence, flood vulnerability mapping is a short-term strategy.

The drainage masterplan should provide an inventory of all waterbodies and open spaces, with associated details, as a short-term strategy.

Once these water bodies and open spaces are identified, these need to be protected by non-structural and structural measures. Structural measures include regulation of land-use through buffer area management, restricting hard-infrastructure-based activities in these areas, and encroachment removal. Non-structural measures include identification and protection of these areas under the masterplan and preparing use zone guidelines for the same. Depending on the scale of protection required, these strategies are categorized as short- to medium-term.

Indian cities (and cities in the Global South) witness formal and informal encroachments in open spaces, wetlands and waterbodies. Identification of critical encroachments (floodplains, low-lying areas, etc.), and relocation and rehabilitation of the same is essential in order to reduce flood vulnerability and enhance the natural drainage infrastructure. Such strategies are medium- to long-term, depending on the scale of encroachment, and the possibility of relocation. However, prevention from further encroachments is a periodic strategy, which shall be part of the monitoring framework of the plan.

## Integration with urban services

Water quality issues in waterbodies, natural drains and roadside drains are dependent on various parameters, specifically wastewater and faecal sludge discharge and urban fabric of areas. Strategies for improving the water quality are categorized as medium- to long-term, depending on the infrastructure conditions of other services.

Ensuring zero-discharge of wastewater in drains is essential for maintaining the water quality of the run-off. A cleaner run-off has higher potential of reuse and harvesting, at a lower cost. Ensuring zero-discharge of wastewater in stormwater infrastructure is categorized as a medium- to long-term strategy.

While O&M of stormwater infrastructure is a periodic activity, it is important to formulate strategies for zer dumping of solid waste and faecal sludge in stormwater infrastructure. Due to the high possibility of decentralized solutions, which require less civil work (compared to that for wastewater discharge), strategies for zero dumping of solid waste and faecal sludge are categorized as short- to medium-term.

Suggested measures for short-, medium-, long-term, and periodic activities are summarized in Table 15.

**Table 15: Short-, medium-, long-term and periodic activities for drainage masterplan**

| Strategy | Short | Medium | Long | Periodic |
|---|---|---|---|---|
| *Stormwater and urban drainage infrastructure* | | | | |
| Construction of roadside drains | | | | |
| Embankment and lining of natural drains | | | | |
| Upgradation of stormwater infrastructure | | | | |
| O&M of roadside drains | | | | |
| | | | | |
| *Catchment area planning* | | | | |
| Regulate land-use in urban catchment | | | | |
| Upgrade development control regulations | | | | |
| Flood hazard vulnerability mapping | | | | |
| Inventory of water bodies and open spaces | | | | |
| Relocation and rehabilitation of encroachments | | | | |
| Preventing further encroachments | | | | |
| Protection of water bodies and open spaces | | | | |
| | | | | |
| *Integration with urban services* | | | | |
| Water quality in roadside and natural drains | | | | |
| Ensure wastewater free drains/nallahs | | | | |
| Ensure zero dumping of solid waste | | | | |
| Ensure zero dumping of faecal sludge | | | | |

Source: CSE, 2020

# 4. Stormwater management around the world

In the past few decades, the frequency and intensity of extreme weather events (ex. high intensity rainfall) caused by climate change have continued to increase, floods have become frequent, and water pollution has become increasingly serious. These events have led to increased attention on water-related research. *Pluvial flooding*—rain-driven flooding that results from the exceedance of natural or engineered drainage capacity—has emerged as a critical issue in urban water management.

Many contemporary cities are vulnerable to pluvial flooding and its associated risks are projected to increase as the global climate changes, urban populations grow and existing infrastructure ages. To address the same, the concepts of slow, spread, sink, and store with respect to runoff have been adopted by many cities to manage high rainfall events and to prevent urban surfaces from turning into waterlogged areas. Such cities opted for bio-swales, rooftop gardens, retention ponds and permeable pavements, which can reduce half to nearly all runoff. The efforts are known as Water-Sensitive Urban Design (WSUD) in Australia, Low-Impact Development (LID) in North America and Sustainable Urban Drainage Systems (SUDS) in Europe. These concepts generally represent more holistic approaches with more attention for urban planning, ecological quality and local conditions.

In the wake of climate change, many countries are now beginning to consider the necessity for such practices in their cities and settlements. Addressing technical integration problems, legislative constraints, social equity, and community acceptance will be necessary for the development of Water Sensitive Cities.

Cities in East Asia have been undergoing rapid urbanization over the past 40 years, often accompanied by increased flooding, especially in China. In 2013, China introduced new urban policies which included the concept of *Sponge Cities* where "stormwater can be naturally conserved, infiltrated, and purified" for potential reuse, thereby reducing flood risks and increasing water availability. Construction guidelines were issued accordingly. Thirty major cities are participating as pilot cities. Each is eligible for central government subsidies.[44]

## 4.1 Selected best management practices

With increasing need for sustainable drainage systems, cities across the world are demonstrating the implementation of innovative and affordable practices focusing on a holistic and integrated approach to stormwater management. A review of select cases was undertaken on a global scale to analyse the applicability and feasibility of such best management practices (BMPs). The review focuses on key benefits of stormwater management strategies, and their applicability/potential/takeaway for Indian cities.

The BMPs showcased in this section focus on innovative stormwater management interventions in terms of planning and designing stormwater features, methodology for addressing pluvial flooding, national level programmes for sustainable urban drainage, and comprehensive stormwater management strategies including O&M and public awareness.

# CASE STUDY
# Water Square Benthemplein, Rotterdam, the Netherlands

## Year of implementation: 2013

### Background

Rotterdam is a coastal city located in South Holland province next to the North Sea, within the Rhine-Meuse-Scheldt delta. It is the second largest city in the Netherlands, with a population of 0.65 million (2020). It covers an area of 319 sq. km, out of which 206.44 sq. km is the land area. It is the largest port city in Europe and is often known as the 'Gateway to Europe'. Rotterdam was voted as European City of the Year 2015 by the Academy of Urbanism.

Rotterdam is highly vulnerable to extreme events arising out of climate change as it is a coastal city which is below sea level in parts. As an initiative to build resilience against climate change, Rotterdam has been designing ways to manage floods due to extreme rainfall and rise in sea levels. The various initiatives include roof gardens, green roofs, floating buildings and water squares, also commonly known as Water Plazas or 'Waterplein' in Dutch.

### Project details

Water plazas are areas specifically designed to flood, thereby collecting water and discharging it at a slower rate. Most of the time the water square will be dry and in use as a recreational space. The design is divided into two main parts: a sports area and a hilly playground. The space is surrounded by a green frame of grass and trees (see *Figure 10: Concept plan for water square*).

When heavy rains occur, rainwater that is collected from the neighbourhood will flow visibly and audibly into the water square. Water storage tanks are located beneath the square's surface, and the square's design allows rainwater to flow into the tanks through a system of drains and channels. Short cloudbursts will only fill parts of the square. When the rain continues, more and more parts of the water square will gradually be filled with water. The rainwater is filtered before running into the square.

The rainwater is held in the square until the water system in the city has enough capacity again. Then it can run off to the nearest open water. The water square is therefore also a measure to improve the quality of the open water in urban environments. After it has been in use as buffering space, the water square is cleaned (see *Figure 11: Technical working of water square*).

The water square is designed to manage different levels of flooding based on different seasons and anticipated extreme events (see *Figure 12: Seasonal flooding in water square*).

**Figure 10: Concept plan for water square**

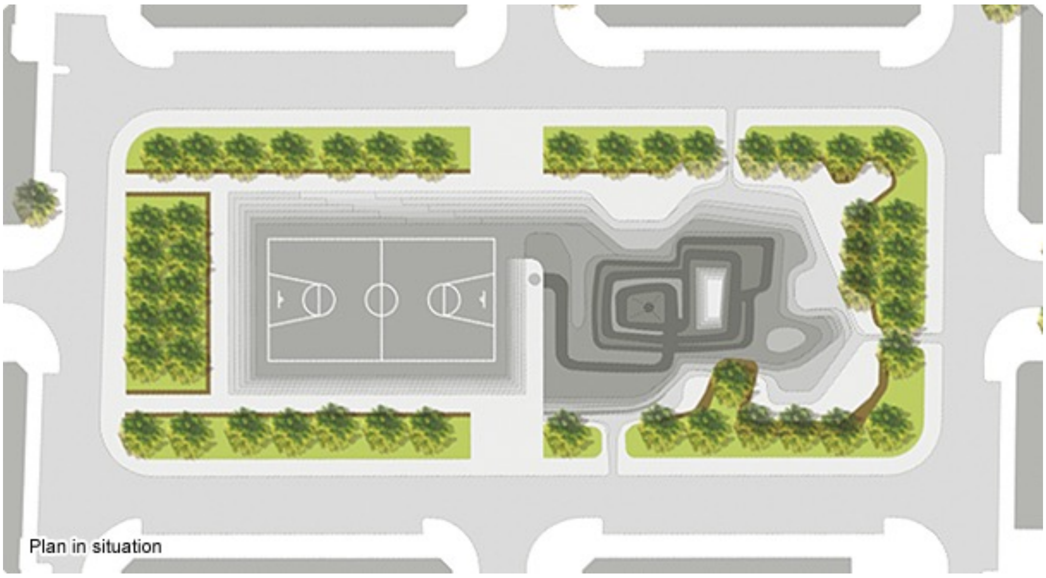
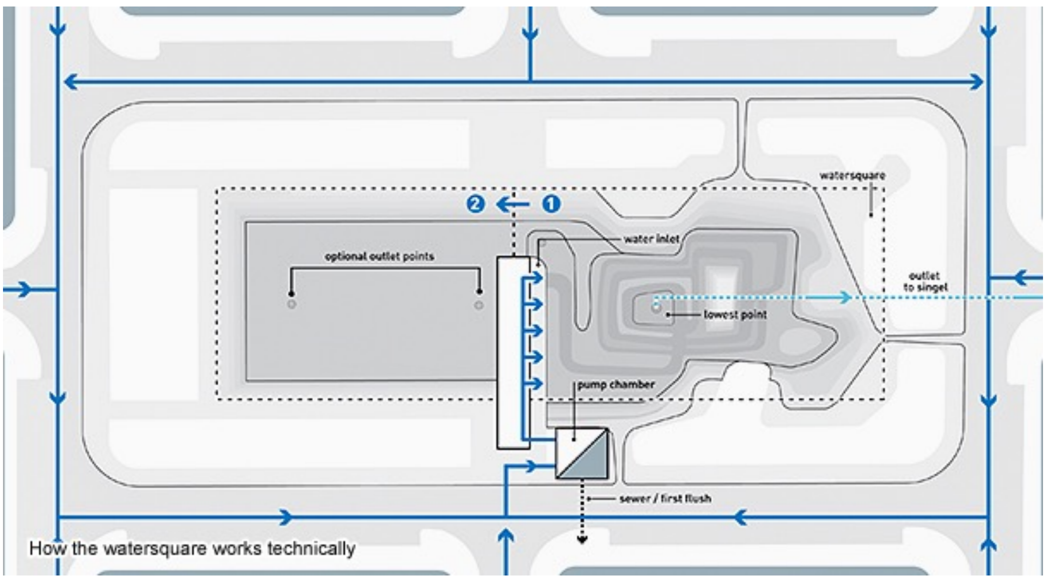



**Figure 11: Technical working of water square**



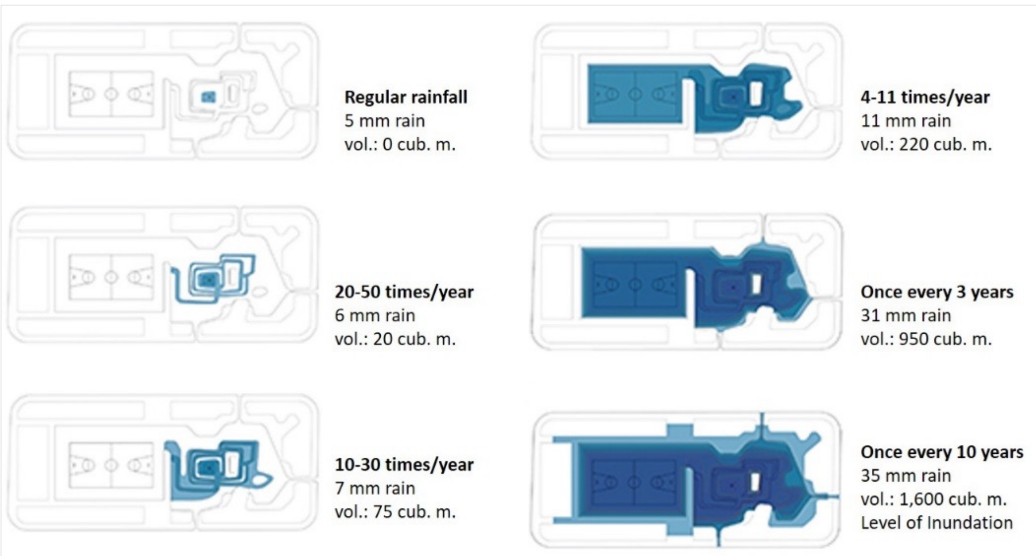
## Figure 12: Seasonal flooding in water square

Dry situation

Medium rainfall

Once a year

## Figure 13: Space capacity for different amounts of rainfall



## Key takeaways

Water plazas are an innovative solution to provide temporary storage to stormwater. Such plazas have the potential to be located in various commercial centres and central business district areas in a city. Large commercial plazas are generally located along major arterial and collector roads. These spaces fulfil the infrastructure requirements to design a plaza: open space within a dense neighbourhood, planned stormwater infrastructure in abutting land-uses, large number of users of the space. Moreover, various plazas have a high degree of imperviousness, which can be evolved as a design strategy for water plazas.

## References


- D.E. Urbanisten 2013. “Water square Benthemplein in Rotterdam, the Netherlands,” *Landscape Architecture Frontiers* 1(4), pp.136-143
- Rotterdam Climate Initiative RCI (17 Sept 2017). *Water plaza Benthemplein Rotterdam* [Video File]. Retrieved from: https://www.youtube.com/watch?v=kujf4BTL3pE&t=2s

# CASE STUDY
# Cloudburst management plan for Copenhagen, Denmark

## Year of formulation: 2011–12

### Background

Copenhagen is the capital city of Denmark, having a population of 0.79 million (2020), and spread across an area of approximately 89 sq. km. It is situated on the coast of the Øresunds region that connects the North Sea with the Baltic Sea. The city is vulnerable to rising sea levels, warmer weather and more weather extremes in the future, including heavy rain events.

Spurred by a series of highly damaging cloudburst events, including the July 2011 cloudburst that caused damages worth close to €1 billion, Copenhagen needed a better way to manage the water inundating the city during these downpours. In 2011, the City of Copenhagen adopted the Copenhagen Climate Adaptation Plan, later complemented by the Cloudburst Management Plan (2012) detailing the methods, priorities and measures related to adaptation to extreme rainfall events. The plan focuses on blue-green solutions to address urban resilience issues.

### Project details

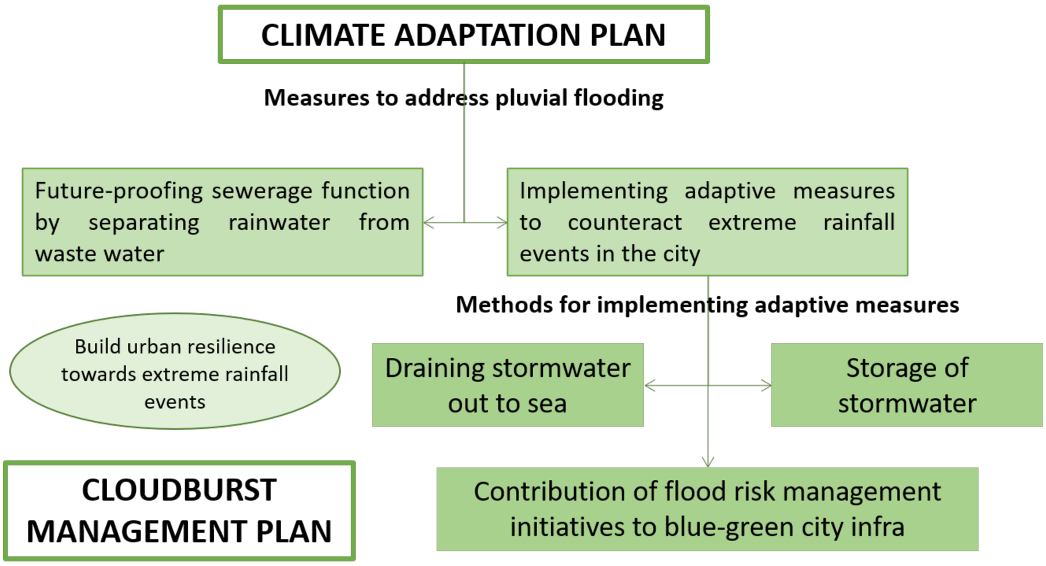
The objective of the Climate Adaption Plan and the Cloudburst Management Plan is to build urban resilience against extreme rainfall events by adopting measures to prevent pluvial flooding (see *Figure 14: Objective and strategies for urban resilience in Copenhagen*).

The overall process is divided into six steps, including risk analysis, blue-green infra planning and design, stakeholder review and cloudburst economics (see *Figure 15: Methodology for Cloudburst Management Plan*). The focus is on integration of various physical development processes.

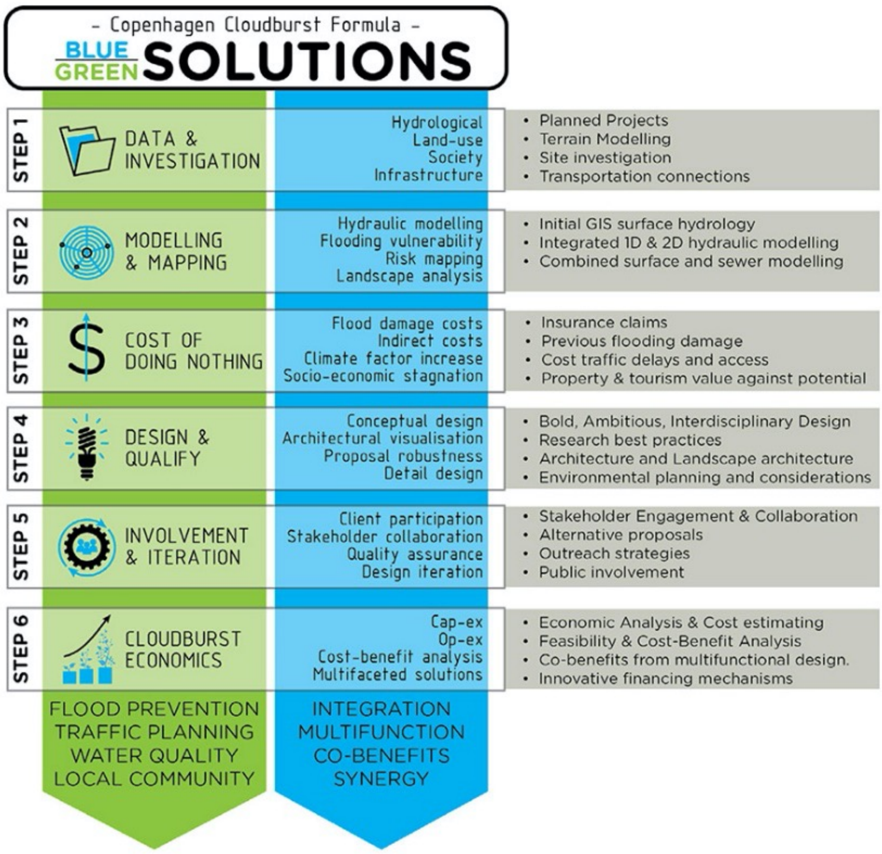
The City of Copenhagen has neither the capacity nor the economy to implement all the measures at once. Hence there is a need for ranking the initiatives in order of priority. Essential elements for deciding the order of priority are:

- High risk areas
- Areas where measures are easy to implement
- Areas with on-going urban development projects
- Areas where synergistic effects can be gained

### Figure 14: Objective and strategies for urban resilience in Copenhagen




### Figure 15: Methodology for Cloudburst Management Plan

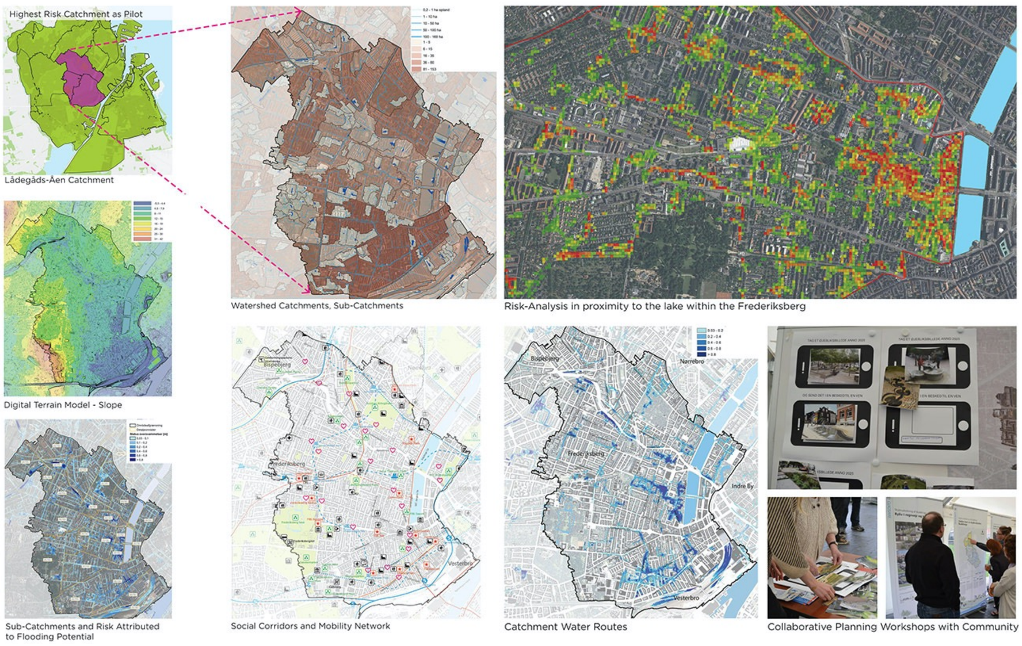


The city of Copenhagen has been divided in 26 water catchment areas, all of which eventually drain in the sea (see *Figure 16: Selection of catchment, risk analysis mapping*). The Lådegåds-Åen catchment was selected as a prototypical test area due to its high risk to flooding and sea surges. Comprehensive site analysis led to establishing the Copenhagen Cloudburst Formula and a Cloudburst Toolkit of urban mitigation strategies and components.

Within the Lådegåds-Åen catchment, a system of Cloudburst boulevards follow the 'fingers' of the existing river network, identifying opportunities for investment along green corridors where surface solutions ensure mitigation is visible and interactive. Figure 17 illustrates the detailed site analysis carried out, revealing the complex existing situations and identifying areas most at risk to flooding which can be the potential sites of catalyst pilot projects.

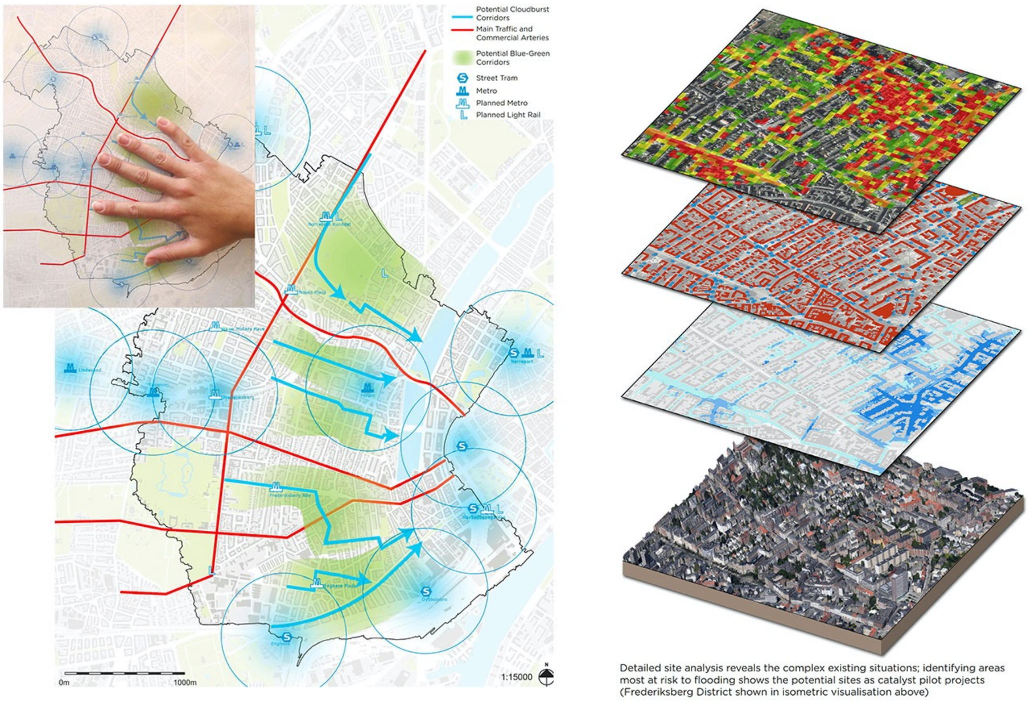
Based on the blue-green potential map, risk and vulnerability analysis, flow rates and volumes as per rainfall events, potential intervention areas are identified, as illustrated in Figure 18. These development options are evaluated for long-term sustainability. It was observed in the masterplan that highest concentration of Blue-Green Tools and reduced pipe sizes results in higher quality open spaces, lower investment costs, and more flexible mitigation strategies. Resiliency necessitates combining the best of existing infrastructure with low tech solutions.

**Figure 16: Selection of catchment, risk analysis mapping**



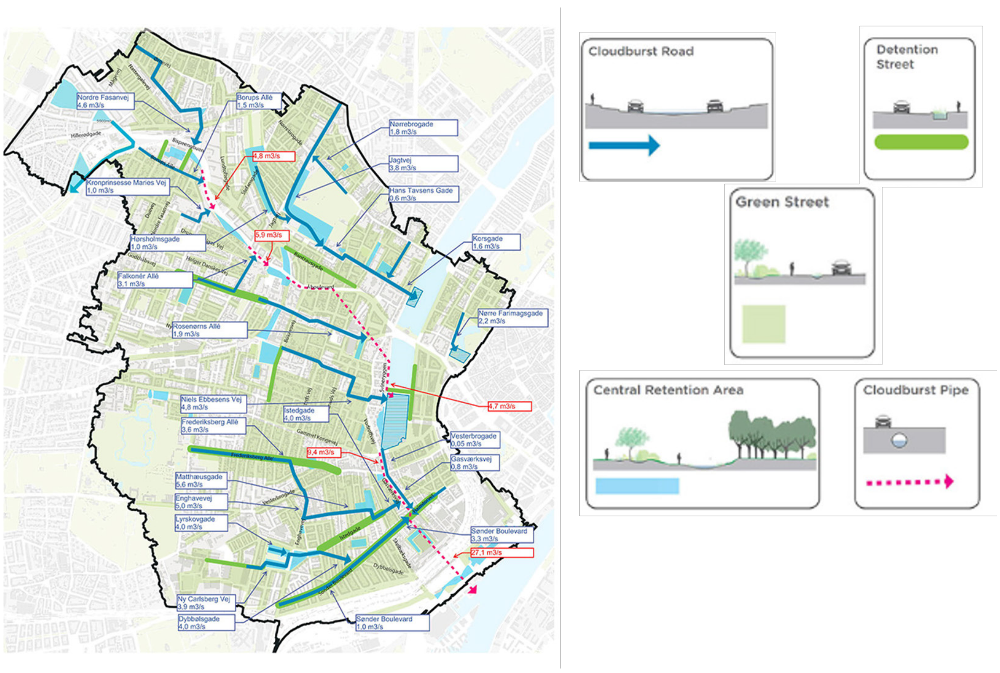

Source: https://www.asla.org/2016awards/171784.html

## Figure 17: Vulnerability analysis and blue-green infrastructure potential map




Source: https://www.asla.org/2016awards/171784.html

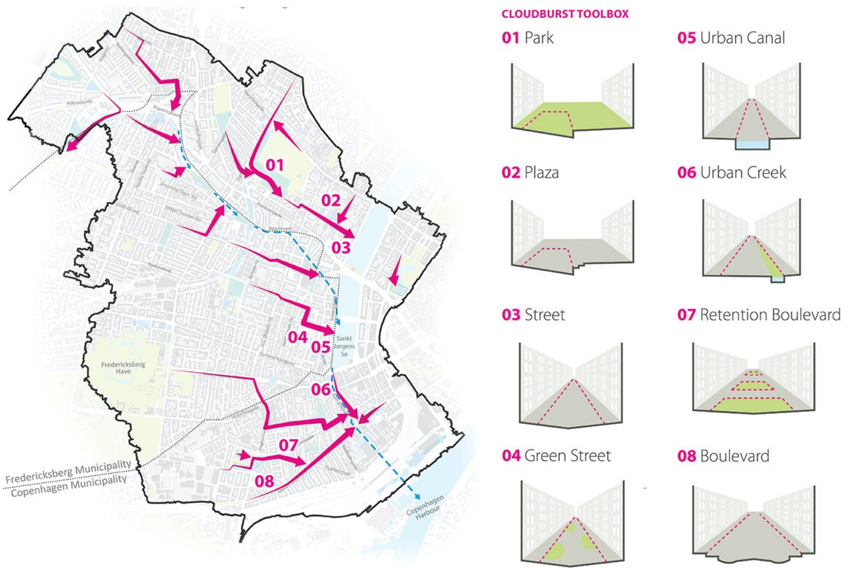
## Figure 18: Evaluation of development options for blue-green infrastructure in Copenhagen




Source: https://www.asla.org/2016awards/171784.html

Based on the analysis, the City of Copenhagen prepared a Cloudburst Toolbox, providing solutions for various parts of the city (see *Figure 19: The cloudburst toolbox)* The Cloudburst Toolkit combines hydraulic engineering (the 'Grey') with urban ecological engineering (the 'Blue-Green'), establishing a model for universally-applicable flood mitigation strategies. Eight Urban Intervention Tools were developed to mitigate common urban typologies - streets, parks and plazas. These interventions provide solutions based on three scenarios: dry weather, rainfall event (normal to moderate rainfall events) and cloudburst event (extreme rainfall event).

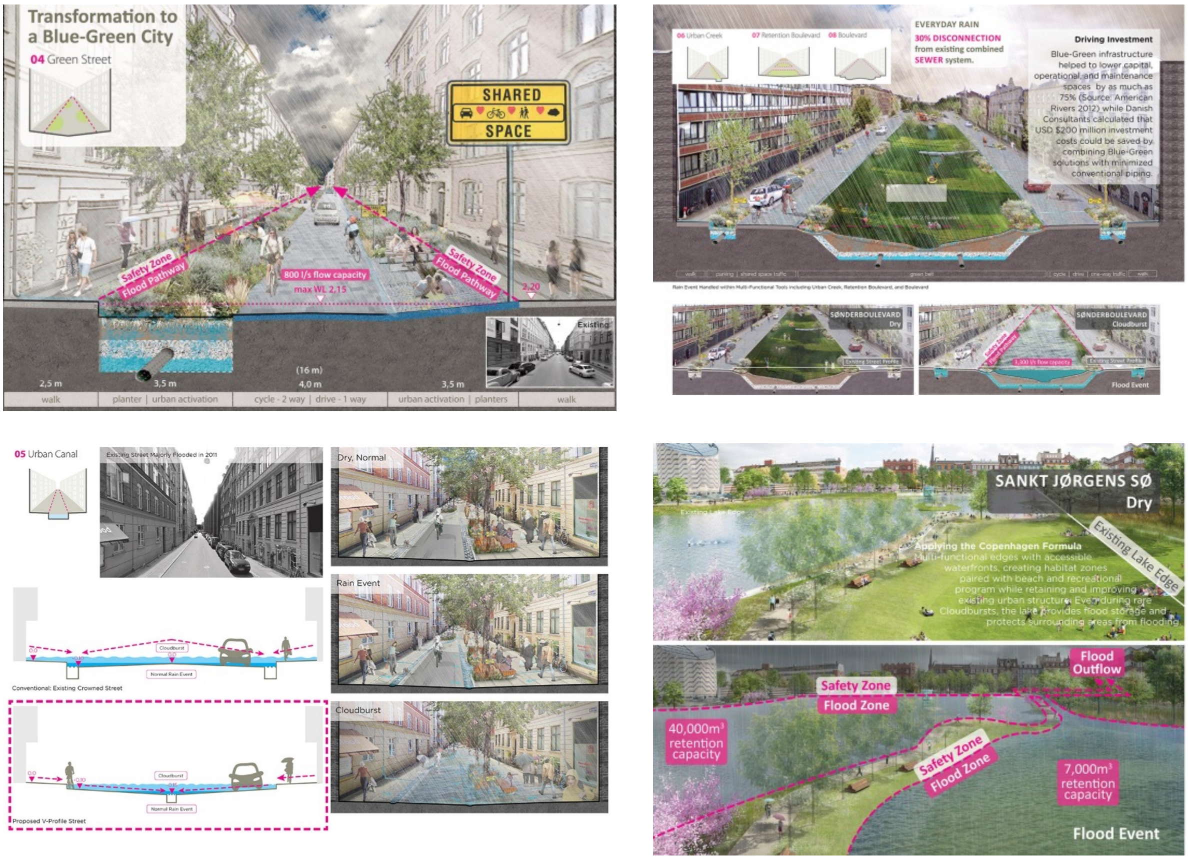
**Figure 19: The cloudburst toolbox**




Source: https://www.asla.org/2016awards/171784.html

Illustrations for the interventions showcase how these spaces can be transformed during extreme rainfall events to accommodate stormwater and provide temporary storage zones (see *Figure 20: Illustrations showing stormwater management initiatives adopted in various spaces in Copenhagen*). During dry days, these are public spaces which improve the quality of life of the residents, and positively impact the economy of these neighbourhoods.

**Figure 20: Illustrations showing stormwater management initiatives adopted in various spaces in Copenhagen**




Source: https://www.asla.org/2016awards/171784.html

## Key takeaways

The Cloudburst Management Plan provides an effective methodology for preparation of a City Drainage Plan / Stormwater Master Plan, in terms of technical analysis. It also showcases how urban resilience can be built in the wake of climate change. In terms of Indian cities, area-based Development Plans under the Smart Cities Mission provide an appropriate opportunity to customize, design and implement various aspects of the Cloudburst Management Plan. In addition to that, cities focussing on building urban resilience, under various international collaborations like C40 (Delhi), 100 Resilient Cities (Pune, Indore, Chennai, Surat, Gorakhpur) and UN Sustainable Cities (Noida and Greater Noida) are appropriate examples.

The methods adopted for risk and vulnerability assessment, cost and benefit analysis and stakeholder reviews can be customized and adopted by various municipal corporations and development authorities in metropolitan cities (and other small and medium towns) for better stormwater management.

## References


- Anon 2012. *Cloudburst Management Plan*, City of Copenhagen, Denmark
- Anon 2016. *The Copenhagen Cloudburst Formula: A Strategic Process for Planning and Designing Blue-Green Interventions.* American Society of Landscape Architects (ASLA), 2016 ASLA Professional Awards. Retrieved from: https://www.asla.org/2016awards/171784.html
- Anon 2016. C40 Cities Good Practice Guides: Copenhagen - Cloudburst Management Plan. Retrieved from: https://www.c40.org/case_studies/c40-good-practice-guides-copenhagen-cloudburst-management-plan
- Anon 2016. *The economics of managing heavy rains and stormwater in Copenhagen – The Cloudburst Management Plan*, Climate ADAPT. Retrieved from:https://climate-adapt.eea.europa.eu/metadata/case-studies/the-economics-of-managing-heavy-rains-and-stormwater-in-copenhagen-2013-the-cloudburst-management-plan

# CASE STUDY
# Sponge Cities Project, China

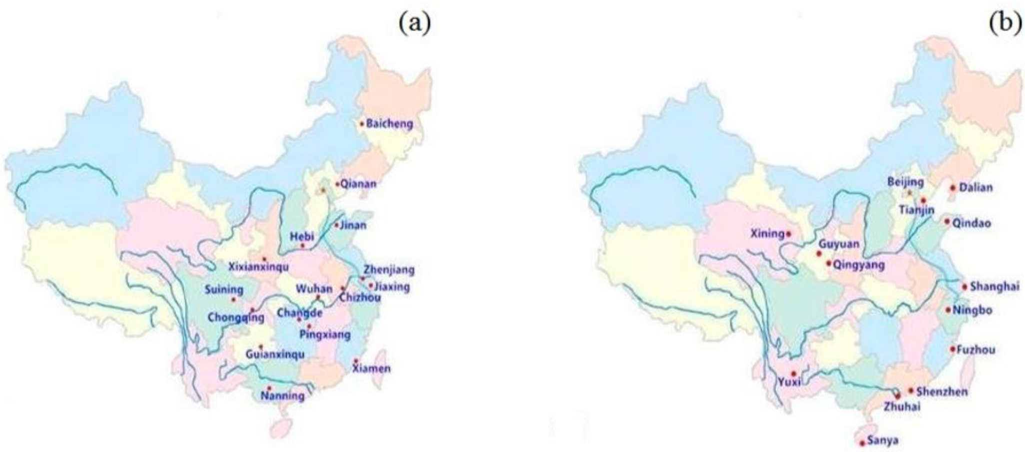
## Year of implementation: 2014–15

### Background

Chinese cities have witnessed intense urbanization over the past three decades due to rapid economic development. As China's global economic dominance grows, challenges to Chinese cities in terms of environmental degradation and infrastructure failure also increase exponentially. It is estimated that more than 600 Chinese cities are exposed to frequent flooding, which has a huge social, economic and environmental impact.

As waterlogging is considered to be one of the major underlying causes of these impacts, the management of urban drainage is a big challenge for both researchers and government authorities. In order to address these issues, the Chinese government launched the Sponge Cities Project in 2014, and selected 16 pilot cities for the same under phase one and 14 pilot cities in phase two.

**Map 3: Model sponge cities in China under (a) Phase 1; (b) Phase 2**




### Project details

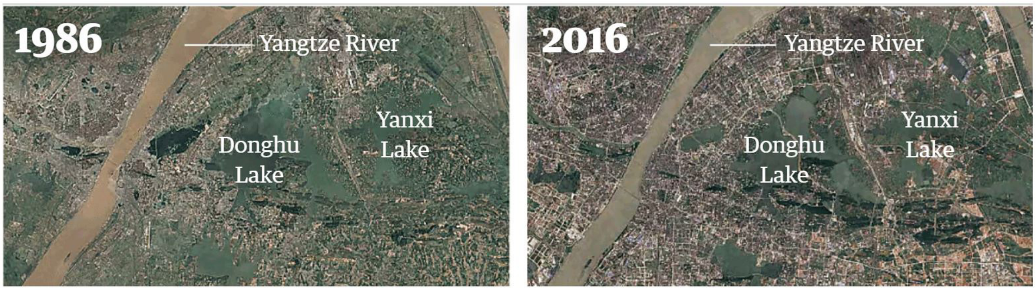
The objective of the sponge cities project is to use permeable surfaces and green infrastructures to mimic the natural water cycle in urban areas and build resilience, as conventional engineering solutions cannot address the modern issues related to urban drainage and water management. The idea is to build the city as a 'sponge' which absorbs water, which would recharge the groundwater, reduce flood risks, and enable reuse of rainwater and stormwater for various domestic and urban purposes.

Sponge features include permeable pavements, green roofs, and SUDS techniques like swales, detention ponds, bio-retention areas, rain gardens, wetlands and other green infrastructure solutions.

## Wuhan Sponge City Project

The city of Wuhan is in eastern China, and has a population of 10.1 million (2018). It is spread across an area of 860 sq. km. It is located at the confluence point of the Yangtze and Han rivers. Wuhan was once known as the 'City of 100 Lakes', with 127 lakes located in the central area alone in the 1980s. This number had reduced to 30 by 2016.

**Map 4: Increase in built-up area in Wuhan, 1986 to 2016**




The Sponge City Project in Wuhan has identified a total of 228 projects in the pilot districts of Qingshan and Sixin to retrofit public spaces, schools and residential areas with sponge features. Most of the drainage infrastructure in China and Wuhan is designed to cater to 1-in-10-year storms. Once the sponge projects in Wuhan are completed, the city should be able to handle a 1-in-30-year storm, whereas some select spaces would be able to handle even larger storms.

Xinyuexie Park is a proposed park in a densely populated area that will serve as a multipurpose space for stormwater management. The park's design incorporates a range of features that will help manage stormwater runoff and prevent flooding in the surrounding area. Some of the proposed improvements in Xinyuexie Park include:

**Rain gardens:** The park will include rain gardens, which are planted areas that help absorb and filter stormwater runoff. The rain gardens will be designed to capture and treat runoff from surrounding streets and buildings.

**Green roofs:** The park's buildings will be designed with green roofs, which are planted roofs that help absorb and retain stormwater. Green roofs will help reduce the amount of stormwater runoff that enters the park's drainage system.

**Permeable pavements:** The park's walkways and other paved areas will be made with permeable pavements, which allow stormwater to pass through and be absorbed into the ground.

**Stormwater storage tanks:** The park will include underground stormwater storage tanks, which will help capture and store excess stormwater during heavy rainfall events. The stored water can then be slowly released back into the surrounding area once the storm has passed.

**Bioswales:** The park will feature bioswales, which are planted areas designed to capture and filter stormwater runoff. Bioswales will be designed to direct runoff away from buildings and other sensitive areas, and towards the park's stormwater management features.

Overall, the proposed improvements in Xinyuexie Park demonstrate how urban parks can serve as effective stormwater management tools, while also providing valuable green space for local communities. By incorporating a range of innovative features, the park will help reduce the risk of flooding in the surrounding area, while also providing a functional and attractive public space for residents to enjoy (see *Figure 21: Proposed improvements in Xinyuexie Park: Designed as a multi-purpose*).

These projects are subsidized and funded by the government, and implemented under the direction and support of Ministry of Housing and Rural-Urban Development, Ministry of Finance and Ministry of Water Resources, Govt. of China.

**Figure 21: Proposed improvements in Xinyuexie Park: Designed as a multi-purpose space for stormwater management**

## Key takeaways

The Sponge City Project has been initiated by the Government of China in order to build urban resilience and strengthen urban infrastructure, so that it is able to sustain extreme rainfall events and cope with climate change related weather changes. The project is focussed on a particular urban infrastructure delivery service.

The Indian Government is in the middle of implementing flagship urban development projects under AMRUT, Smart Cities Mission, Swachh Bharat Mission, etc. These flagship programmes can be modified using more applicable SLBs. Additionally, various state governments with higher urban population like Maharashtra, Gujarat, Karnataka, Kerala, etc. can formulate a scheme on the lines of the Sponge Cities Project to mainstream sustainable stormwater practices.

In terms of cities, Kochi has been selected as India's first Sponge City Project site. Additionally, Sponge City Toolkit for the city of Chennai has also been prepared. These toolkits can be used to identify, plan and design distributed stormwater features across various Indian cities.

## References


- L. Jing 2019. *Inside China's leading 'sponge city': Wuhan's war with water*, The Guardian. Retrieved from: https://www.theguardian.com/cities/2019/jan/23/inside-chinas-leading-sponge-city-wuhans-war-with-water
- Z. Li et al 2018. "Objectives and indexes for implementation of sponge cities—a case study of Changzhou City, China," *Water* 10(5). Retrieved from: https://www.mdpi.com/2073-4441/10/5/623#citedby
- Anon 2019. *This man is turning cities into giant sponges to save lives | Pioneers for Our Planet*, World Economic Forum. Retrieved from: https://www.youtube.com/watch?v=U37gst79pGc
- A. Biswas and K. Hartley 2019. *THROWBACK: How China's 'sponge cities' aim to re-use 70% of rainwater*, DownToEarth. Retrieved from: https://www.downtoearth.org.in/news/water/throwback-how-china-s-sponge-cities-aim-to-re-use-70-of-rainwater-65399

# CASE STUDY
# Stormwater management in Singapore

## Year of implementation: 1970s to present

### Background

Singapore is an island city-state located in south-east Asia, south of Malaysia. It has a population of 5.6 million (2018), and it is spread across an area of 725.7 sq. km. The city-state is a torch-bearer of sustainable development technologies, and is considered as the 'City of Gardens and Water'.

The city has high vulnerability towards climate change effects, due to sea-level rise and extreme rainfall events. The city is also dependent on importing water to meet its domestic needs, due to unavailability of adequate fresh water sources within the city. Hence, Singapore aims to reuse and harvest as much wastewater and stormwater as possible to cater to its domestic demands and address issues arising out of climate change.

Singapore uses two separate systems to collect rainwater and used water. With two-thirds of Singapore as water catchment, rainwater that falls in these areas is collected through an extensive network of drains, canals, rivers, stormwater collection ponds and reservoirs before it is treated for drinking water supply. In 2014, the water agency of Singapore, PUB, adopted the 'Source-Pathway-Receptor' approach for stormwater management, which looks at catchment-wide solutions to achieve higher flood protection.

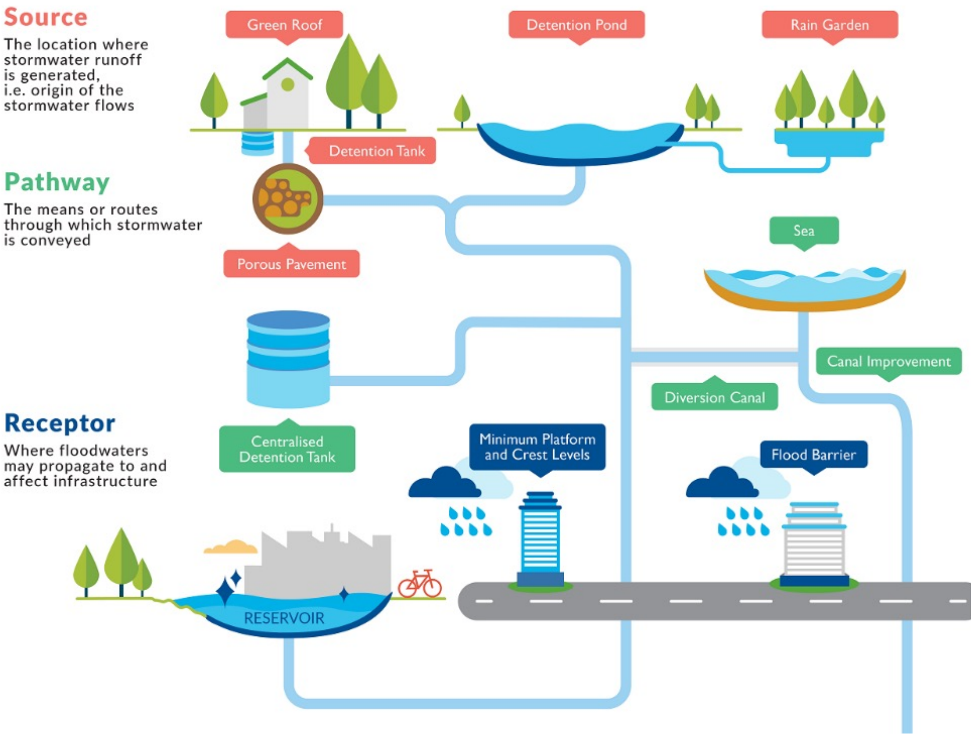
### Project details

The holistic approach introduces flexibility and adaptability to Singapore's entire drainage system, addressing not just the drains and canals through which stormwater travels (Pathway), but also in areas generating stormwater runoff (Source) and areas where floods may occur (Receptor) (see *Figure 22: 'Source-Pathway-Receptor' approach for urban drainage in Singapore).*

### 'Source' solutions

All new developments and re-developments of 0.2 ha or more are required to implement 'source' solutions to slow down stormwater runoff entering the public drainage system. Measures include detention tanks or rain gardens and bio-retention swales.

**Figure 22: 'Source-Pathway-Receptor' approach for urban drainage in Singapore**




## 'Pathway' solutions

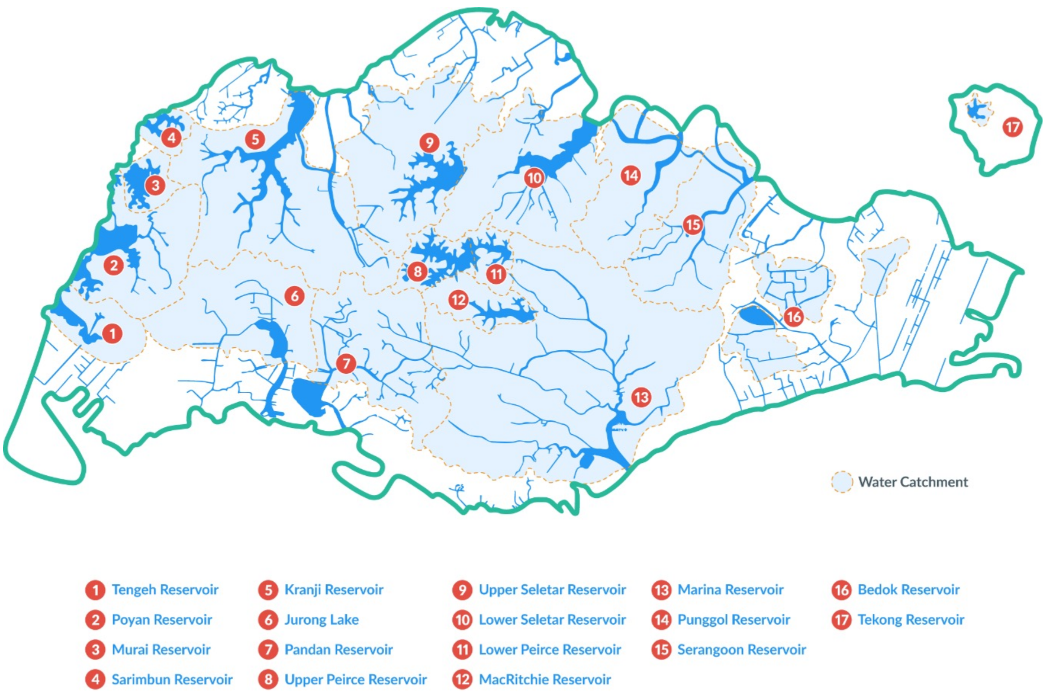
PUB raised the design standards in 2011 for drains to cater to more intense rainfall events. Depending on the size of the catchment, this could mean an increase of between 15 and 50 per cent in drainage capacity.

## 'Receptor' solutions

These strategies aim to provide additional flood protection for buildings and key infrastructure. Some of these measures include setting minimum platform and crest levels and placing flood barriers to prevent floodwaters from entering buildings.

Singapore is divided into three broad catchments (eastern, central and western watershed), from which the water flows into the 17 reservoirs or the sea (see *Map 5: Reservoir map of Singapore*).

**Map 5: Reservoir map of Singapore**




PUB has adopted three key strategies for stormwater management in Singapore:

1. Providing adequate drainage ahead of new developments
2. Implementing flood protection measures
3. Continual drainage improvement

To support the nation's urbanization and development needs, planning for new drainage infrastructure and upgrading of existing drains is done in consultation with key planning agencies and authorities. These organizations include Urban Redevelopment Authority, Building & Construction Authority, Land Transport Authority, Housing & Development Board, and JTC Corporation. PUB continuously monitors upcoming developments and upgrades the drains and canals promptly to:

- Alleviate flooding – identify and remove constrictions/bottlenecks in existing drains/canals
- Meet current drainage standards – cope with the needs of increased runoff from developments
- Rehabilitate drains – fix deteriorating drains

Efforts of PUB over the decades have yielded results. Singapore used to witness widespread flooding in the 1960s and 1970s, with approximately 3,200 ha area identified as flood-prone (low-lying areas). This has reduced to 30.5 ha of flood prone area in 2016, despite increased urbanization.

**Map 6: Flood prone areas in 1970s vs 2016 in Singapore**


Under the 'Source-Pathway-Receptor' approach, PUB has taken the following measures to comprehensively address stormwater management in Singapore:

- **Improved design standards**
  The Code of Practice on Surface Water Drainage has been revised to raise the standards of flood protection, as well as to enhance the flexibility and adaptability of Singapore's drainage systems to cope with storms of higher intensities. PUB has introduced compulsory on-site detention basins. This measure alone is estimated to reduce peak run-off by 25–35 per cent.

- **Preparation of action plans for drainage improvement**
  As many as 302 projects (completed and ongoing) have been undertaken by PUB to enhance urban drainage. These projects include SUDS interventions, protection of surface waterbodies, upgradation and rehabilitation of drains, and canal works. These projects are undertaken in areas which have previously flooded, in areas in anticipation of development, and areas which require upgradation.

- **Restoring regional drainage**
  A major component of the action plan is to restore regional drainage channels to their natural courses. Alexandra Canal, Rochar Canal, Stamford Canal, Kallang River, Geyland River, Bedok Canal, etc. are some of the projects which work on regional drainage solutions.

**Photographs 2, 3 and 4: Kallang River Restoration**


Kallang River @ Bishan-Ang Mo Kio Park, before (left) and after (right) improvement works.


The "naturalised" stretch of the Kallang River has brought people closer to water and is a popular destination for families.

- **Collaboration and capacity building**
  PUB recognizes that urban drainage not only requires detailed scientific analysis, but is also largely dependent on other aspects of urban planning and development. In order to successfully prepare and implement its action plans, PUB works closely with organizations like Institution of Engineers, Singapore; Association of Consulting Engineers, Singapore; Singapore Institute of Architects; Singapore Institute of Landscape Architects as well as public agents to prepare manuals and conduct seminars and training programmes to develop a community of practitioners. It also works closely with the Department of Public Cleanliness to ensure cleaning of public drains

- **Enhancing public preparedness**
  PUB, along with the National Environment Agency, has developed an SMS alert system to provide early warnings of heavy rains and rising water levels in drains and canals during heavy storms. PUB has also installed 200 water level sensors and 200 CCTV cameras, out of which 49 CCTV feeds are available for public viewing. It has also prepared a 'MyWaters' application for further outreach, apart from providing updates on social media platforms like Twitter and Facebook.

## Key takeaways

Stormwater management in Singapore is an apt example of a comprehensive stormwater management system, which addresses the various issues and challenges pertaining to climate change, planning, design, institutional set-up, O&M and collaboration with various organizations. The key highlights are:

- Singapore has one organization responsible for the delivery of water infrastructure, the PUB. Indian cities face the issue of multiplicity of authorities, which often leads to poor and inequitable stormwater management infrastructure and strategy. A refined institutional setup for urban water systems will benefit not only drainage systems, but other water-related infrastructure.

- Singapore has addressed issues related to inadequate design standards for stormwater drains, as well as use of various public spaces for implementation of SUDS techniques. The integration of grey and green infrastructure is achieved in most places in Singapore. As Indian cities develop under the various urban development missions, it is imperative to modify design standards for drains, and integrate the same with various GI solutions.

- Focus on regional drainage channels and protection of urban waterbodies is an important aspect of urban stormwater management, which can be achieved through catchment management via sustainable urban planning practices. Development Authorities and ULBs in India need to integrate stormwater masterplans with development plans in order to address regional drainage issues.

- Enhanced monitoring, complaint redressal and early warning systems are essential to address infrastructure failures and improve O&M of drains and other stormwater infrastructure. Indian cities can only benefit from such measures, which can be funded through AMRUT and Smart Cities Mission.

## References


- Anon 2014. *Managing Stormwater for our Future*, PUB: Singapore. Retrieved from: https://www.pub.gov.sg/Documents/ManagingStormwater.pdf
- Anon (n.d.). Stormwater Management, PUB: Singapore. Retrieved from: https://www.pub.gov.sg/drainage/stormwatermanagement

# CASE STUDY
# Stormwater management in Melbourne, Australia

## Year of implementation: 2000 onwards

### Background

The coastal city of Melbourne falls in Victoria province. Spread across an area of 9,993 sq. km, it has a population in excess of 5 million. It is the second largest city in Australia and is considered one of the most liveable cities in the world. The term 'Water-Sensitive Urban Design' and associated concepts can be traced back to Australia. The city has an established stormwater management framework right down from the regional scale to site specific water-sensitive projects.

In the year 2000, the Agriculture and Resource Management Council of Australia and New Zealand released the Australian Guidelines for Urban Stormwater Management, under the National Water Quality and Management Strategy. The document introduced the terms 'Water Sensitive Urban Design', and principles of stormwater resource management through green infrastructure and nature-based solutions. As a guiding document, they shaped the regional stormwater management framework for the state of Victoria and the city of Melbourne

### Programme and project details

Melbourne Water is the organization which manages and protects the city's water resources. It is responsible for drinking water supply, sewerage management, wastewater recycling, management of waterways and provision of integrated drainage and flood management services.

## Planning framework for stormwater management

### State Planning Guidelines

The enabling framework for stormwater management for residential sub-divisions are mentioned under 'Clause 56.07-4' of the Victorian Planning Provisions prepared by the Department of Environment, Land, Water and Planning, Govt. of Victoria. These objectives are:

- To minimize damage to properties and inconvenience to residents from stormwater.

- To ensure that the street operates adequately during major storm events and provides for public safety.
- To minimize increases in stormwater and protect the environmental values and physical characteristics of receiving waters from degradation by stormwater.
- To encourage stormwater management that maximizes retention and reuse.
- To encourage stormwater management that contributes to cooling, local habitat improvements and provision of attractive and enjoyable spaces.

The provisions also state that '*The stormwater management system should be integrated with the overall development plan including the street and public open space networks and landscape design*'; and that the local drainage network should *'Include water sensitive urban design features to manage stormwater in streets and public open space. Where such features are provided, an application must describe maintenance responsibilities, requirements and costs.*'

## Municipal Integrated Water Management Plan

The City of Melbourne has prepared a strategic framework for implementation of integrated water management across the municipality. The Municipal Integrated Water Management Plan sets the foundation of water management across the municipality, using a place-based and catchment-based approach. The plan, prepared in 2017, aims to build upon the Total Watermark 2014 successes in urban water management. The vision of the plan is 'A health city in a healthy catchment', and the objectives are:

- Adaptation and flood risk embedded into the strategic planning process
- Reduction in the municipality's exposure to flood risk and impacts
- Creation of an aware and prepared community
- Embedding water and liveability in the strategic planning processes
- Providing access to waterways and public open spaces to support a healthy population
- Healthy and clean major waterways
- Maintaining soil moisture for a healthy urban forest
- Optimizing stormwater quality
- Optimizing fit-for-purpose water use
- Planning water supply infrastructure for current and future demand
- To mimic the natural water cycle by retaining more rainwater in the upper catchment and reducing runoff

The municipal area is divided into eight catchments, targets for which are set in the plan. To be achieved by 2030, they focus on flood protection, health of water bodies, provision for stormwater management, etc. Some specific targets are:

- Make a minimum of 20 per cent area of each catchment permeable by 2030
- All habitable finished floors must be free from flooding, outside the 100-year flood level from all council (regional) drains
- Minimum 20 per cent (city level) and 50 per cent (municipal level) of all water use must be from alternative sources

The document provides key issues and opportunity areas, supplemented by a detailed action plan for each catchment focussing on stormwater management, use of water from alternate sources, and implementation of WSUD projects. The document also mentions the various stakeholders and their roles and responsibilities for implementing the integrated management plan.

## Stormwater strategy

In order to realize the provisions under Clause 56.07-4, Melbourne Water has prepared the 'Stormwater Strategy' for managing urban and rural stormwater run-off in Melbourne. It is a regional and city level stormwater management strategy, which focuses on reviving and naturalizing waterbodies including lakes, ponds and streams, and their floodplains and buffer areas, using the WSUD approach for planning and designing local drainage networks. The strategy also recommends improving overall stakeholder engagement for managing stormwater, while providing a toolbox which can be used for identification of priority areas, and for planning and realizing investments.

Developers need to apply for a 'Stormwater Harvesting Licence' if their properties are connecting to new or modified stormwater drains, watercourses or open channels, or harvest any quantity of stormwater from a waterway controlled by Melbourne Water. The licence requirements include a detailed plan for stormwater management in the property, providing details of connectivity with the local drainage system, harvesting structures, etc.

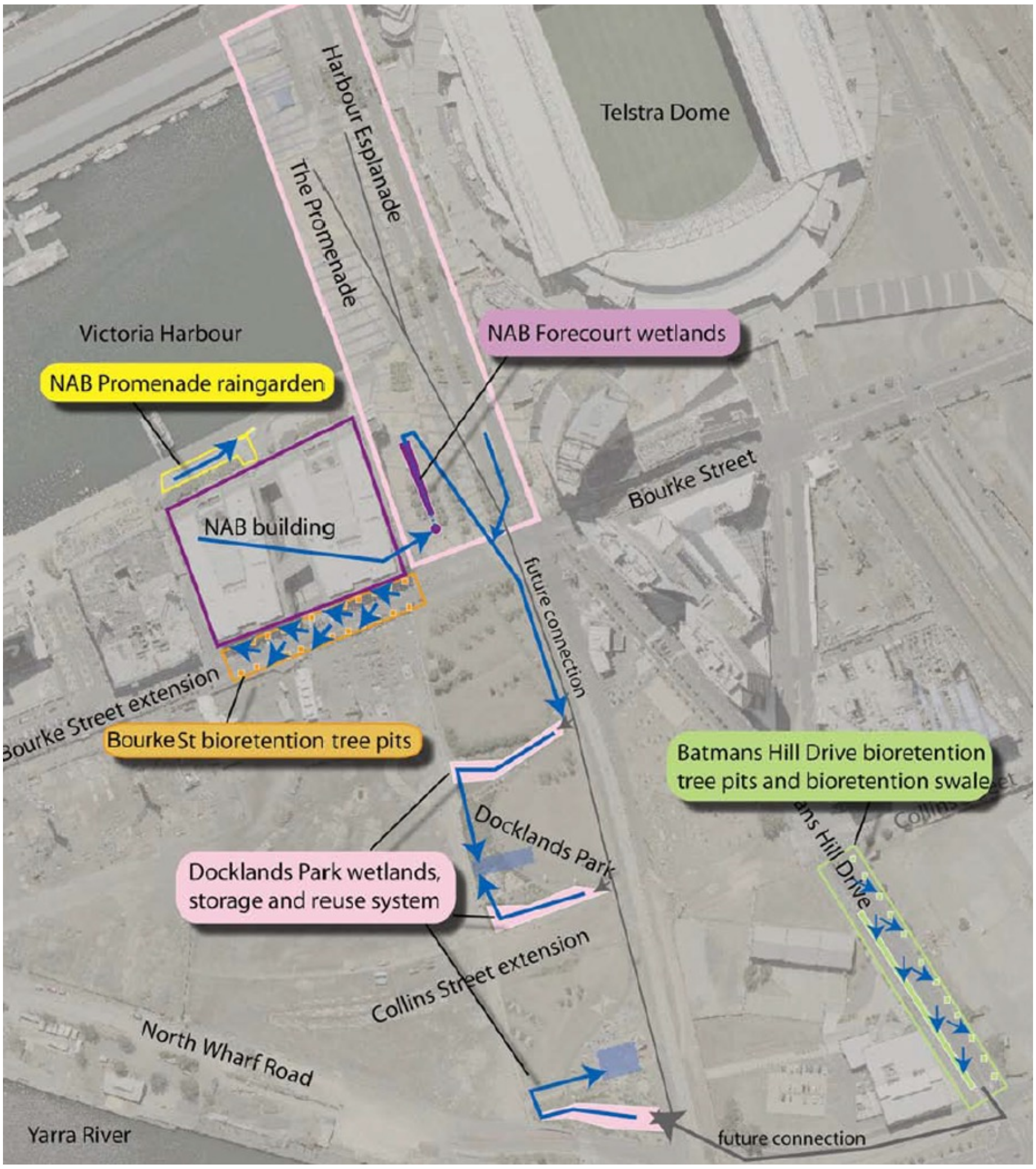
Melbourne Water has provided various solutions for implementing WSUD through rainwater tanks, raingardens, sedimentation ponds, wetlands and swales. The design standards, cost, O&M schedule and other related details are available on their webpage for reference and use by various stakeholders. In addition to these resources, they also provide various online tools like MUSIC and STORM for stormwater calculations. These can be used by all stakeholders for designing of plans for their stormwater licences.

## Stormwater management projects

### WSUD in Melbourne Docklands

Various multi-scale WSUD interventions have been implemented in the Melbourne Docklands area, with the objective to protect downstream environments from flooding and to produce water of suitable quality for reuse.

**Figure 23: WSUD features in Melbourne Docklands**



A series of wetlands are constructed to treat the run-off generated in the precincts, which are estimated to harvest enough stormwater to meet 80 per cent of the estimated annual horticulture demand for the Dockland Parks.

In addition to this, various tree pits and vegetated swales are located along roads, to add to the run-off management areas. A raingarden is also constructed in the NAB Promenade to temporarily store additional run-off.

The WSUD design for the precinct takes into account future developments in the area, and provisions have also been made to manage run-off from future developments.

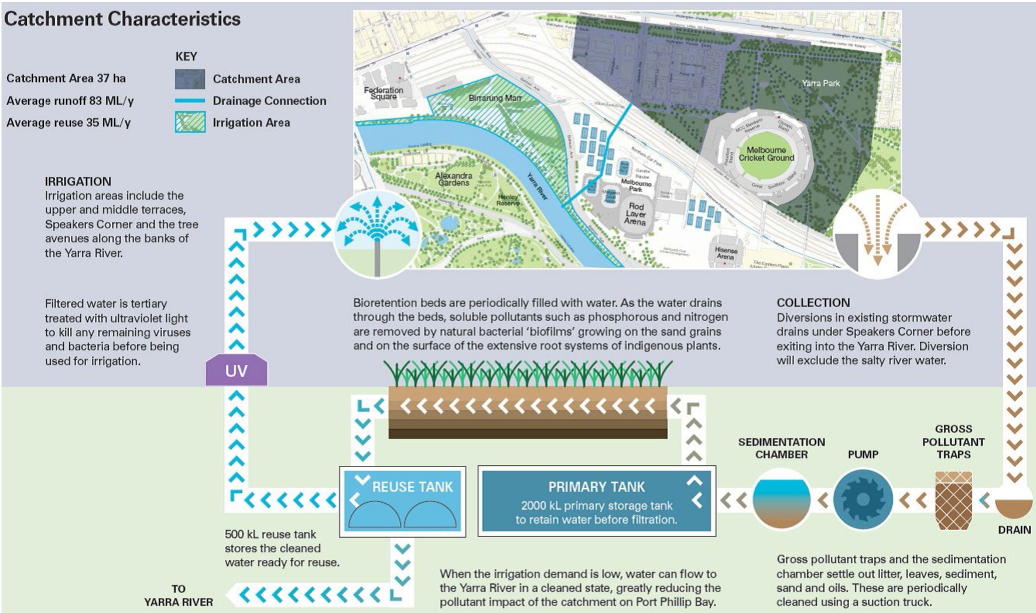
### Birrarung Marr Stormwater Harvesting System

Birrarung Marr is an 8.3 ha park located on the northern bank of the Yarra River, next to Federation Square. Transformed from a rail yard into parkland in 2002, Birrarung Marr is the newest large park in the inner Melbourne area. The popular and versatile space is home to many events throughout the year, from Circus Oz to Moomba to sporting events and festivals. The park is also a major thoroughfare for millions of pedestrians. It links the city centre to the MCG and the Melbourne Park sporting precinct.

Birrarung Marr has three separate terraces stepping up from the river, connected by a central pedestrian bridge. The park's 6 ha of vegetated space requires approximately 45 million litres of irrigation water each year. The Birrarung Marr stormwater harvesting system captures, treats and stores stormwater for irrigation reuse in the park. This has reduced use of potable water for irrigation by 70 per cent.

The park is located between the Yarra River and several busy roads and multi-storey buildings. It plays a crucial role in intercepting polluted stormwater runoff before it enters the river. The project has estimated to be saving 35 million litres of drinking water per year, contributing 2.1 per cent of the Council's 30 per cent alternative water use target by 2018 under the Total Watermark Strategy. It has also reduced pollutant levels of nitrogen, phosphorus, heavy metals and sediment entering the Yarra River and Port Phillip Bay, along with facilitating landscaping upgrades, including the flowering meadow at the storage tank site (see *Figure 24: Stormwater management strategy for Birrarung Marr*).

## Figure 24: Stormwater management strategy for Birrarung Marr




## Raingarden tree pit programme

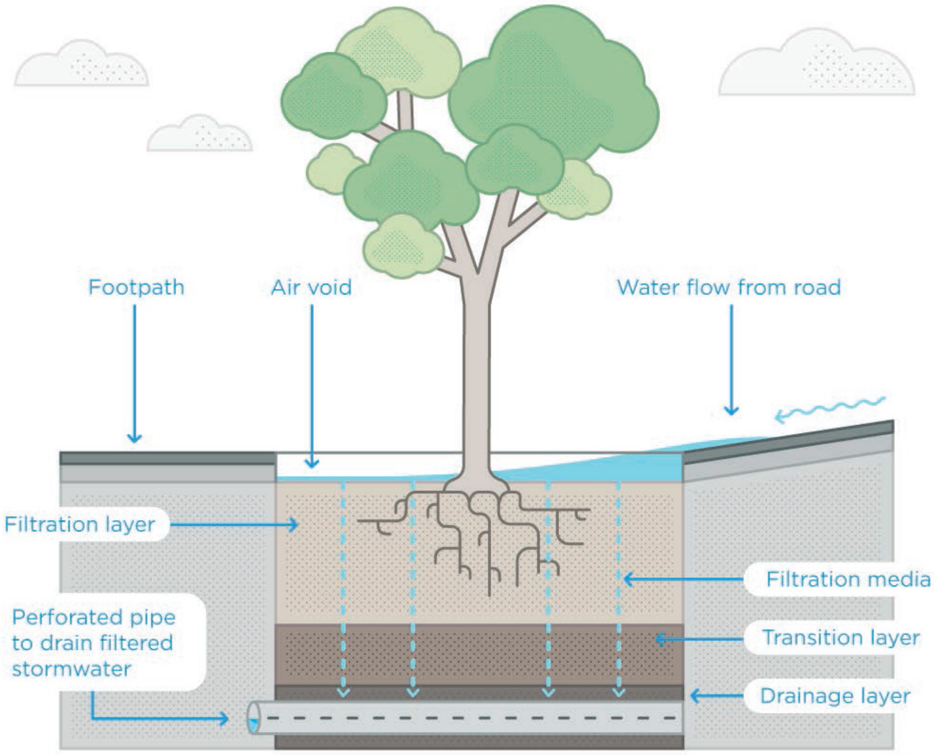
The tree pits are positioned adjacent to roads. They intercept stormwater runoff that would otherwise flow directly into the stormwater drains.

This stops pollution and litter from entering our rivers and bays.

In addition to cleaning the water, tree pits also provide passive irrigation for trees, reducing the need for manual watering (see *Figure 25: Schematic cross-section of raingarden tree-pit*).

Since the program began in 2006, the City of Melbourne has installed over 200 raingarden tree pits across the city.

**Figure 25: Schematic cross-section of raingarden tree-pit**




## Howard Street Raingardens

Howard Street is a short residential street in North Melbourne. In 2011, the City of Melbourne closed a part of the road and turned it into parkland. The new public open space includes three raingardens that capture and clean stormwater runoff. They placed two large raingardens at the intersection of Howard and William Streets. They capture water running down the gutters on Howard Street, before it reaches the stormwater drains. The third raingarden captures runoff from William Street.

In addition to these projects, there are various WSUD projects across the city like stormwater harvesting in Fitzroy Gardens, Queen Victoria and Alexandra Garden; Trin Warren Tam-Boore Wetland systems; urban greening projects; permeable footpaths in neighbourhoods, etc.

## Key takeaways

Stormwater management in Melbourne provides an apt example of integrating WSUD principles at the policy level, planning level, and implementation in projects at various scales and land-uses. In addition to this, the institutional roles and responsibilities are clearly defined with respect to planning organizations at the regional level (Department of Environment, Land, Water and Planning. Govt. of Victoria) and city level (Melbourne Water for provision for water infrastructure), and Municipality (City of Melbourne).

Furthermore, various non-state stakeholders—consultants, local community, consortium of think-tanks and universities, etc.—play an integral role in planning, designing, advocating and creating awareness for WSUD and its role in stormwater management. The integrated water management plan for the city provides an effective approach for realizing multi-dimensional objectives of WSUD. The catchment approach provides a suitable context for effective solutions for these areas.

## References


- Anon 2018. Victorian Planning Provisions. Dept of Environment, Land, Water and Planning. Govt. of Victoria: Melboure. Retrieved from: https://planning-schemes.delwp.vic.gov.au/__data/assets/pdf_file/0007/481723/VPPs_All_Clauses.pdf
- Anon 2017. Municipal Integrated Water Management Plan. City of Melbourne: Melbourne. Retrieved from: https://www.melbourne.vic.gov.au/SiteCollectionDocuments/municipal-integrated-water-management-plan-2017.pdf
- Melbourne Water Web-portal: https://www.melbournewater.com.au/building-and-works/stormwater-management/introduction-wsud
- Cooperative Research Centre for Water Sensitive Cities (CRCESC) Web Portal: https://watersensitivecities.org.au/case-studies-by-location/ accessed 21 Sept, 2020

# 5. Way forward

Stormwater needs to be considered a resource and should be attenuated and retained at source, allowing it to infiltrate into aquifers and flow gradually into receiving waterbodies. However, in existing spatial planning processes, the focus on lakes, floodplains and buffer or green areas for surrounding vulnerable and watershed areas is neglected.

The need of the hour is to recognize the importance of waterbodies and urban green spaces in creating a naturally-oriented water cycle while contributing to the amenity of the city. To implement the same, a detailed spatial planning study is required to get the exact figures on space availability and respective runoff generated to be treated and retained from identified locations. There is a need to look at the bigger picture which reflects the urban settlements as part of a larger drainage basin while conserving the natural topography and using natural features as opportunity areas for retention and attenuation.

There is also a need to give up the techno-managerial approach to urban water management. Equity and justice should be made central to any initiative of stormwater management, lake rejuvenation and rainwater harvesting in order to give substance to the discourse of green-blue infrastructure promotion.

## Global South Water Sensitive Cities (GSWSC) Framework[45]

### Goal statement

*Cities commit to "Just and Equitable Access, Use, Reuse" of water supply, and sewerage/septage and stormwater management.*

The framework, prepared by CSE, recognizes inequity in urban settlements as the basis of planning and design interventions for water sensitive cities. There is no "leap frogging" possible without addressing infrastructure deficiencies, specially for the less privileged residents of our cities. Climate change impacts everyone but the less privileged are impacted more severely. Therefore, we need to strengthen urban planning and not look for only design interventions, place making and beautification as outcomes of water sensitive cities.

## Principles

- **Larger and long-term vision (firmly rooted in the equity, rights and justice goals).** Not just in projects. Inter-city and urban-rural contextualization of interventions.
- **Climate change exacerbates already existing water scarcity and flooding risks of cities.** Mitigation measures should not increase inequity.
- **"Design" consciously for Equity and Justice.** Abandon a normative, techno-managerial approach to "design" interventions for water sensitive cities.
- **Reducing conflicts.** Recognize existing and future conflicts around water and waste. Address them to the extent possible in programs and policy.
- **Improving functionality and efficiency of grey and green infrastructure.**

## Planning and design considerations

- **Water Sensitive Urban Planning and Design.** Statutory city development plans (Master Plans) need to have water sensitive city planning with clear aims and objectives.
- **Fixing responsibility and accountability.** Water supply, stormwater and wastewater management (including septage management) cannot be entirely left to the market and outside the formal statutory urban planning ambit.
- **Both grey and green infrastructure provisioning is needed.** Without grey infrastructure improving the living conditions, green infrastructure may have a limited impact.
- **Adapting to climate change.** Grey infrastructure needs to be planned keeping in mind both floods and droughts that impact our cities with intensification of water cycle as a result of climate change.
- **Look beyond urban "place making" and "beautification".**
- **Monitor city level gains.** Electricity pumping cost of transporting water and wastewater over hundreds of kilometres to the cities and to treatment plants, can certainly be reduced.

This framework does away with a normative understanding of urban water management and puts justice and equity at the heart of any Water Sensitive Cities conceptualization. The four pillars/index of this Framework include a focus on stormwater management:

- ***Functional infrastructure and services.*** *Fix all existing non functional water, sanitation and stormwater infrastructure and services. To improve efficacy and treatment outcomes.*

- ***Functional and inclusive infrastructure for unserved areas.*** *Additional grey infrastructure and services will be needed for unserved informal urban settlements that now dominate the urban landscape of cities of global south.*

- ***Substantial reuse of treated wastewater and bio-solids.*** *Reduced wastewater footprint and reuse of treated bio-solids (for agriculture) and treated wastewater. This may include all measures for reuse and recharge of groundwater and prevention of pollution of groundwater, lakes and rivers, inside or outside the city limits.*

- ***Mitigating in-situ urban flooding.*** *Enhanced stormwater drainage dimensions/norms, to address in-situ urban flooding in cities (where built-up area has reduced groundwater recharge potential) that is witnessed in normal rainfall periods as well as in high intensity climate change induced episodes. Conserving rain water wherever possible, as contamination free as possible.*

# 6. Annexure 1: List of resource persons interviewed

| List of resource persons interviewed | | |
|---|---|---|
| **Resource person** | **Organization** | **Expert inputs** |
| Prof. A.K. Gosain | IIT Delhi, India | Spatial planning in stormwater management India |
| Vijay Chaurasia | CPHEEO, MoHUA, Govt. of India | Stormwater management guidelines in India |
| Somnath Sen | IIT Kharagpur, India | SUDS approach in stormwater management |
| Sahana Goswami | World Resources Institute (WRI), Bengaluru, India | Stormwater management in Hyderabad |
| Prof. Kapil Gupta | IIT Bombay, India | Urban flooding and stormwater management in urban India |
| Prof. Kalyan Das | OKD Institute of Social Change and Development, Guwahati, India | Urban drainage and flooding issues in Guwahati |
| Prof. Paweł Licznar, | Wroclow University of Science and Technology, Poland | Initiatives from Poland for developing models on stormwater |
| Jacek Zalewski | RetencjaPL, Poland | European stormwater management initiatives |

# References


1. Peter Ellis and Mark Roberts 2016. *Leveraging Urbanization in South Asia: Managing Spatial Transformation for Prosperity and Livability*, World Bank.

2. Anon 2021. *Reforms in Urban Planning Capacity in India*, NITI Aayog. Accessed at https://www.niti.gov.in/sites/default/files/2021-09/UrbanPlanningCapacity-in-India-16092021.pdf

3. https://cpheeo.gov.in//cms/manual-on-storm-water-drainage-systems---2019.php

4. Depinder S Kapur 2023. *Water Sensitive Cities Index*, CSE. Accessed at https://www.cseindia.org/water-sensitive-cities-index-handbook-for-ranking-in-ganga-basin-cities-11694

5. S.S. Nandargi and A. Shelar 2018. "Rainfall and flood studies of the Ganga River Basin in India," *Ann Geogr Stud* 1(1). Accessed at https://www.sryahwapublications.com/annals-of-geographical-studies/pdf/v1-i1/4.pdf , as accessed on 20 August 2021

6. Anil Agarwal and Sunita Narain (eds.) 1997. *Dying Wisdom: Rise, fall and potential of India's traditional water harvesting systems*, CSE.

7. Sushmita Sengupta 2016. *Why urban India floods*, CSE.

8. Anon 2019. *Manual on Stormwater Drainage Systems Volume I, Part A: Engineering Design, First Edition*. CPHEEO, Ministry of Housing and Urban Affairs. Accessed at http://164.100.117.97/WriteReadData/userfiles/Volume%20I%20Part%20A%20Engineering%20Design.pdf

9. K. Gupta 2005. "The drainage systems of India's cities," *Waterlines* 22-24. Accessed at https://www.jstor.org/stable/pdf/24684703.pdf?refreqid=excelsior%3A0c1e880d7f4c48de090b20b4e284ada1

10. Anon 2010. *National Disaster Management Guidelines*, Government of India. Accessed at https://ndma.gov.in/images/guidelines/management_urban_flooding.pdf

11. S. Basu and J. Singh 2014. *The peculiarity of urban floods: What are urban floods and why are we witnessing them?* Down To Earth, New Delhi

12. Anon 2016. *Georgia Stormwater Management Manual Volumes 1 & 2*, Atlanta Regional Commission, Atlanta: USA

13. Anon 1999. *Low-Impact Development Hydrologic Analysis*. Department of Environmental Resources, Programmes and Planning Division, Prince George's County, Maryland. Accessed at https://www.princegeorgescountymd.gov/DocumentCenter/View/87/Low-Impact-Development-Hydrologic-Analysis-PDF

14. B.R. Rosenzweig, L. McPhillips, H. Chang et al 2018. "Pluvial flood risk and opportunities for resilience," *WIREs Water*; 5:e1302. https://doi.org/10.1002/wat2.1302

15. Anon 2010. *National Disaster Management Guidelines: Management of Urban Flooding*, National Disaster Management Authority, Government of India. Accessed at https://ndma.gov.in/images/guidelines/management_urban_flooding.pdf

16. A. Nema and L. Agrawal 2003. "Wastewater Management in Najafgarh Drainage Basin–Key to Water Quality Improvement In River Yamuna," *Indian Association of Environment Management, Annual Conference*. Foundation for Greentech Environmental Systems: New Delhi. Accessed at http://green-ensys.org/site/publications/Wastewater%20management%20in%20Najafgarh%20drainage%20basin.pdf

17. Interview with Sahana Goswami, WRI India, dated 10 February 2020

18. R. Philip, B. Anton and A. Loftus (eds.) 2011. *SWITCH Training Kit- Integrated Urban Water management for the City of Future: Module 4: Stormwater-Exploring the Options*, ICLEI European Secretariat GmbH, Freiburg: Germany. Accessed at https://switchtraining.eu/fileadmin/template/projects/switch_training/files/Modules/Module_reduced_size/Switch_Training_Kit_Module_4.pdf

19. J. Parkinson and O. Mark 2005. *Urban stormwater management in developing countries*, IWA publishing.

20. Ibid.

21. Anon 2019. *Manual on Stormwater Drainage Systems Volume I, Part A: Engineering Design, First Edition*. CPHEEO, Ministry of Housing and Urban Affairs. Accessed at http://164.100.117.97/WriteReadData/userfiles/Volume%20I%20Part%20A%20Engineering%20Design.pdf

22. S. Kumar and N. Joseph 2012. "Drainage and sewerage system in urban India: Need for action," *Indian journal of occupational and environmental medicine* 16(3). Accessed at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3683187/

23. J. Parkinson and O. Mark 2005. *Urban stormwater management in developing countries*, IWA publishing.

24. A. Urs 2017. *Nearly one-fifth of lake area in Bengaluru encroached*, The Hindu: Business Line. Accessed at https://www.thehindubusinessline.com/news/national/nearly-onefifth-of-lake-area-in-bengaluru-encroached/article9969980.ece#

25. Anon 2019. *Manual on Stormwater Drainage*, CPHEEO. Accessed at https://cpheeo.gov.in//cms/manual-on-storm-water-drainage-systems---2019.php

26. IPCC, 2012: Summary for Policymakers. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [C.B. Field et al (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 3-21.

27. C. K. B. Krishnamurthy, U. Lall and H. H. Kwon 2009. "Changing frequency and intensity of rainfall extremes over India from 1951 to 2003," *Journal of Climate* 22(18). Accessed at https://journals.ametsoc.org/doi/pdf/10.1175/2009JCLI2896.1

28. Interview with Dr Kapil Gupta, IIT Bombay by PIB, Govt of India. Accessed at https://pib.gov.in/newsite/printrelease.aspx?relid=153050

29. Anon 2019. *Manual on Stormwater Drainage*, CPHEEO. Accessed at https://cpheeo.gov.in//cms/manual-on-storm-water-drainage-systems---2019.php

30. Anon 2019. *Draft Manual on Stormwater Drainage Systems*, CPHEEO, Govt. of India.

31. N. Zubair 2017. *Mohenjo-daro Street with Drains*. Accessed at https://www.harappa.com/blog/mohenjo-daro-street-drains

32. D. Shukla (n.d.). *Lothal: Sanitary drainage at the acropolis*. Accessed at https://www.harappa.com/lothal/14.html

33. S.M. Deshkar 2010. "Kautilya's Arthashastra and its relevance to Urban

Planning Studies," *Institute of Town Planners India Journal* 7(1).

34. S. Singh and S. R. Tiwari 2016. *Eco-city and Other Ecological Approaches in Urban Planning: A Review of the State-of-the-Art*. In Proceedings of IOE Graduate Conference (pp. 253-263).

35. D. Nath 2017. *Delhi's drainage master plan ready to take off*, The Hindu. Accessed at https://www.thehindu.com/news/cities/Delhi/delhis-drainage-master-plan-ready-to-take-off/article19131661.ece

36. Anon 2017. *Policy Brief – An overview of the Smart Cities Mission in India*, Centre for Policy Research: New Delhi

37. I. Andjelkovic 2001. *Guidelines on non-structural measures in urban flood management*, International Hydrological Programme (IHP), United Nations Educational, Scientific and Cultural Organization (UNESCO).

38. Urban Stormwater Management in Developing Countries

39. Anon 2006. *National Urban Information System (NUIS) Scheme - Guidelines for Implementation*, Ministry of Urban Development, Govt. of India: New Delhi

40. N. Carmon and U. Shamir 2010. "Water-sensitive planning: integrating water considerations into urban and regional planning," *Water and Environment Journal* 24(3).

41. S.K. Rohilla et al 2017. *Water-Sensitive Urban Design and Planning: A Practitioner's Guide*, Centre for Science and Environment, New Delhi

42. S.K. Rohilla et al 2017. *Urban Water Sustainability: A template*, Centre for Science and Environment, New Delhi

43. L. Ruangpan et al (n.d.). *Nature-based solutions for hydro-meteorological risk reduction*

44. A. Sharma, T. Gardner and D. Begbie (eds.) 2018. *Approaches to Water Sensitive Urban Design: Potential, Design, Ecological Health, Urban Greening, Economics, Policies, and Community Perceptions*. Woodhead Publishing.

45. Depinder S Kapur 2023. *Water Sensitive Cities Index*, CSE. Accessed at https://www.cseindia.org/water-sensitive-cities-index-handbook-for-ranking-in-ganga-basin-cities-11694

**Floods are quite common in South Asia, with India being the second-worst flood-affected country in the world. Floods do not just occur due to overflowing rivers, they are also caused by the uninformed manner in which cities are interfering with the natural water cycle.**

**The study is aimed at understanding the potential and challenges of current practices of stormwater management and thereby suggesting approaches which focus on lowering the hydrological impact of urbanization in Indian cities.**

**The first part of the report focuses on the guiding research question—What are the existing planning approaches and infrastructural provisions for stormwater management in Indian cities?**

**The second part of the report suggests approaches as per the existing spatial urban characteristics. The planning approach recommended makes use of stormwater as a resource rather than a liability.**

**Centre for Science and Environment**
41, Tughlakabad Institutional Area, New Delhi 110 062
Phones: 91-11-40616000 Fax: 91-11-29955879
E-mail: cseindia@cseindia.org Website: www.cseindia.org