GREEN INFRASTRUCTURE

A PRACTITIONER'S GUIDE

Centre for Science and Environment

Ministry of Housing and Urban Affairs

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Research director and coordinator: Suresh Kumar Rohilla

Writers: Shivali Jainer and Mahreen Matto

Research support: Dhruv Pasricha

Editor: Arif Ayaz Parrey

Cover: Raj Kumar Singhj

Design: Ajit Bajaj

Production: Rakesh Shrivastava and Gundhar Das

Ministry of Housing and Urban Affairs

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41, Tughlakabad Institutional Area, New Delhi 110 062
Phones: 91-11-40616000
Fax: 91-11-29955879
E-mail: cse@cseindia.org
Website: www.cseindia.org

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List of abbreviations

AMRUT	Atal Mission for Rejuvenation and Urban Transformation
CBO	Community-based organization
CGWB	Central Ground Water Board
CPCB	Central Pollution Control Board
CPHEEO	Central Public Health and Environmental Engineering Organization
CRZ	Coastal regulation zone
CWC	Central Water Commission
DPR	Detailed project report
GI	Green infrastructure
HTL	High-tide line
ITPI	Institute of Town Planners, India
LTL	Low-tide line
MoEF&CC	Ministry of Environment, Forests and Climate Change
MoHUA	Ministry of Housing and Urban Affairs
NAPCC	National Action Plan for Climate Change
NCR	National Capital Region
NDMA	National Disaster Management Authority
NGT	National Green Tribunal
NLCP	National Lake Conservation Plan
NPCA	National Programme for Conservation of Aquatic Ecosystems
NRSC	National Remote Sensing Centre
NWCP	National Wetland Conservation Programme
PHED	Public Health and Engineering Department
RRZ	River regulation zone
RWA	Residents' welfare association
TCPO	Town and Country Planning Organisation
ULB	Urban local body
URDPFI	Urban and regional development plan formulation and implementation
WSUDP	Waster sensitive urban design and planning

Glossary

Aquifer — A porous, water-logged sub-surface geological formation. The description is generally restricted to media capable of yielding a substantial supply of water.

Buffer strip — A vegetated area ordinarily situated on gently sloping ground designed to filter out pollutants insoluble in runoff. It is also known as filter strip.

Catchment area — A geographical area defined by topography from where all runoff water drains into a reservoir. Often used as a synonym for watershed and river basin.

Eutrophication — The process by which a lake evolves into a bog or marsh and ultimately assumes a completely terrestrial state and disappears. During eutrophication, the lake becomes so rich in nutritive compounds, especially nitrogen and phosphorus, that algae and other microscopic plant life become superabundant.

Evapotranspiration — The process of loss of water to the atmosphere from the earth's surface, evaporation from the capillary fringe of the groundwater table, and the transpiration of groundwater by plants whose roots tap the capillary fringe of the groundwater table.

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.

Groundwater — The water retained in the intergranular 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.

Hypoxic condition — A condition where the oxygen content in water or air is reduced, thereby threatening the survival of aerobic organisms.

Hydrological cycle — The continuous cycle of movement of water within the earth. Water evaporates from the earth, condenses in the atmosphere, falls as rain and finally reaches the oceans as rivers, coastal runoff and groundwater flows. The entire process is driven by the energy of the sun.

Infiltration — The entry of rainfall or surface water into the soil.

Macrophytes — Aquatic plants growing in or near water. They may either be emergent (i.e., with upright portions above the water surface), submerged, or floating. Examples of macrophytes include cattails, hydrilla, water hyacinth and duckweed.

Percolation The process by which water, after infiltration into the soil, moves downward or laterally through openings, 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.

Ramsar convention The Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat is an international treaty for the conservation and sustainable use of wetlands. It is also known as the Convention on Wetlands. It is named after the city of Ramsar in Iran, where the Convention was signed in 1971. The list of wetlands of international importance included 2,266 Ramsar sites in March 2016 covering over 2.1 million square kilometres.

Riparian habitat The type of wildlife habitat found along the banks of a river, stream or any other actively moving source of water such as a spring. Generally, refers only to freshwater or mildly brackish habitats.

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.

Storm-water Water resulting from natural precipitation and/or accumulation. It includes rainwater, groundwater or spring water.

Urban heat island Built up urban areas that are hotter than nearby rural areas. Heat islands can affect communities by increasing summertime peak energy demand, air conditioning costs, air pollution and greenhouse gas emissions, heat-related illness and mortality, and water quality.

Urban runoff Storm water from streets of urban areas and adjacent domestic or commercial properties that carries pollutants of various kinds into the sewer systems and receiving waterbodies.

Watershed The upper boundary of a specified catchment area for rainfall that contributes to a given drainage area.

Wetland Land inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support (and under normal circumstance does support) vegetation (hydrophytes) typically adapted for life in saturated soil conditions (hydric soils).

Executive summary

History bears testimony to the fact that the march of human civilization has always been from the village to the city. India, too, has witnessed a gradual but unrelenting urbanization with each passing decade. As cities grow, urban areas expand geographically, characterized by impervious surfaces like roads, pavements and buildings. Rapid development and construction in these areas results in the loss of green areas. This decreases a city's capacity to absorb water, making it dependent solely on the outflow of surface water runoff. Under such circumstances, even moderate rainfall can lead to major flooding. Moreover, urban runoff increases the variety and quantity of pollutants carried into streams, rivers, and lakes. All these factors worsen the status of wetlands, decrease groundwater, cause urban flooding, and disturb the hydrological cycle.

In India, the existing urban planning paradigm lacks integration of land and water interface. Existing guidelines focusing on lakes, floodplains and coastal areas miss out the spatial analysis and recommendations regarding the role of buffer or green areas for surrounding vulnerable and watershed areas.

The need of the hour is to recognize the importance of urban green spaces in creating a naturally-oriented water cycle while contributing to the amenity of the city. This will be achieved by combining and protecting the hydrological and ecological values of the urban landscape while providing resilient and adaptive measures to deal with the eventualities of floods. Green infrastructure (GI) reintroduces the natural water cycle into urban environment and provides effective measures to manage fluvial (river), coastal, and pluvial (urban runoff or surface water) flooding.

This practitioner guide discusses GI as one of the solutions to overcome the emerging water management issues of water supply and quality regulation, and 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 purpose of this guide is to assist urban practitioners from local bodies, development authorities, town and country planning departments and other institutions to consider and understand the role of green spaces by bringing water management and GI together. The guide exhibits comprehensive approaches and strategies to integrate GI practices with urban planning for different geographical settings—inland, hilly, desert, and coastal areas, and floodplains—which are supported by relevant best management practices as case studies and research works or projects. This guide also showcases how urban areas which have adopted GI practices generate a multitude of environmental, ecological, socio-cultural and economic benefits.

On the whole, in order to mainstream the new concept of GI in Indian cities, this guide by CSE is a hands-on document serving the national urban development objectives of various policies, plans, programmes and projects related to sustainable water management. Further, it is also aligned with the United Nations Sustainable Development Goals 6 and 11, emphasizing on clean water, sanitation, and sustainable cities, including public spaces and disaster preparedness.

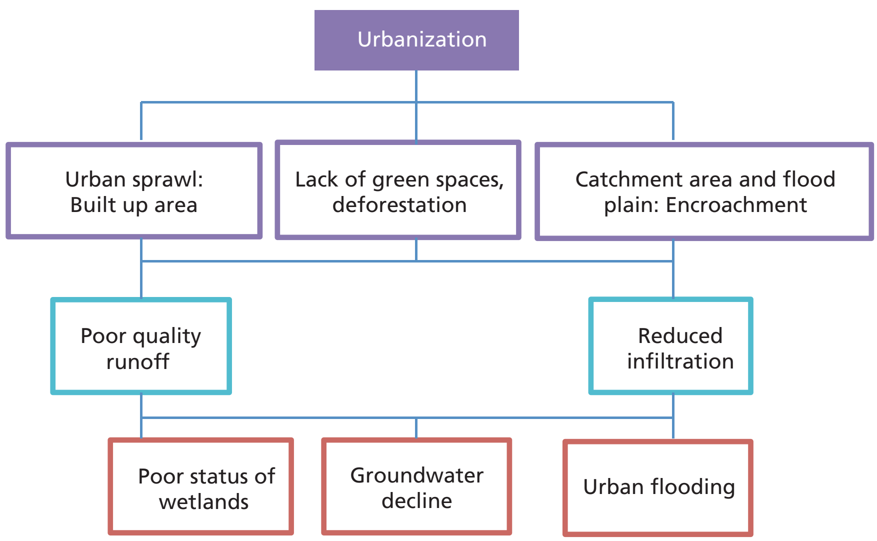
1. Introduction

The world is increasingly an urban environment. An urban population that is aware of the factors that improve quality of living puts pressure on the environment with respect to dependable utilities, water distribution and sewerage systems, and complicates efforts to maintain the sustainability of the environment and the limited urban sprawl. This pressure extends to green spaces and recreational areas, aesthetics and conservation of heritage sites, and efficient use of real estate and public space within the urban environment.[1&2] The problem is exacerbated by lack of availability of space needed for developing new functions or relocating and improving existing ones (see *Figure 1.1: Effect of urbanization on natural water resources*).[3]

In India, population and urbanization have increased manifolds in recent times. The 2011 Census provides a glimpse of these changes—with a population base of more than 1.22 billion, urban housing deficit is touching 23 million. Migration to urban areas has increased phenomenally, as the annual rate of economic growth has hovered around the 8 per cent mark. There are 31 cities with more than 10 lakh population.[4]

Out of India's total geographical area of 329 million hectares (mha), more than 40 mha is flood prone. The average annual flood damage from 1996 to 2005 was Rs 4,745 crore, as compared to the corresponding average of Rs 1,805 crore for the previous 53 years. On an average, every year 75 lakh hectares of land are affected and 1,600 lives are lost in India due to floods. In the past few years, the frequency of major floods has increased to more than one in five years.[5] This can be attributed to many reasons, including a steep increase in population coupled with global warming and, of course, brisk urbanization and increased economic activities in floodplains.

Figure 1.1: Effect of urbanization on natural water resources



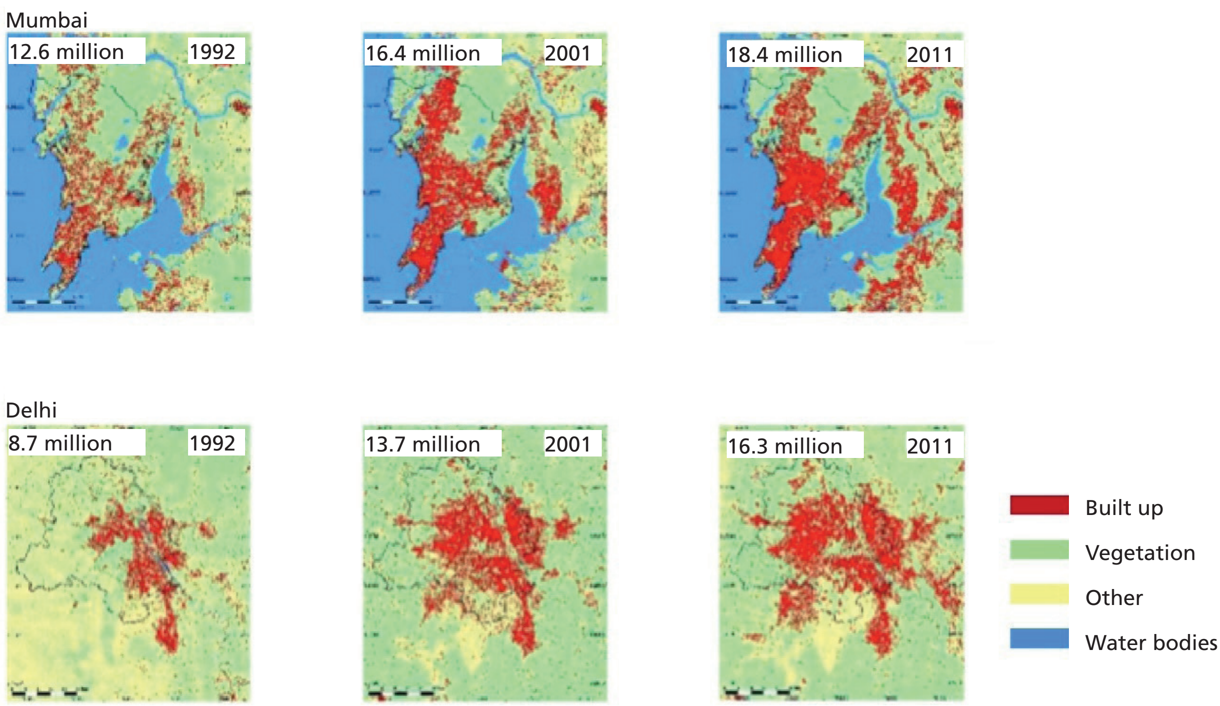
Source: CSE, 2017

Rapid urbanization puts a lot of pressure on land and, as a result, habitations encroach on floodplains, low-lying areas and drainage channels. Encroachment in the immediate upper catchments has also been a cause of serious flooding in the floodplains of cities surrounded by hills. Moreover, urban areas are characterized by impervious surfaces like roads, pavements and buildings (see *Figure 1.2: Urbanization and increase in built up area in select Indian cities*). Rapid development and construction in these areas results in the loss of green spaces. This decreases a city's capacity to absorb water, making it solely dependent on the outflow of surface water runoff, and increases the demand for storm water drainage systems.[6] As a result, even moderate precipitation results in flooding, which is why 'urban flooding' is recognized as a disaster significantly different from riverine flooding.[7] (See *Appendix 1: Impact of flooding in urban areas*).

India has a large network of rivers and all major Indian cities are located on the banks of one or the other river. These rivers provide water for various uses including human consumption, irrigation, transportation, hydropower generation etc.[8] However, floodplain resources, including wetlands, are being squeezed for the needs of development. Also, deforestation within catchment areas leads to increasing magnitude and frequency of runoff events and reduced base flow, increased pesticide contamination, erosion and sedimentation of streams and river.

More surface water than groundwater is available in India. However, owing to the decentralized availability of groundwater, it is easily accessible and forms the largest share of India's agriculture and drinking water supply. About 89 per cent of the extracted groundwater is used in the irrigation sector, making

Figure 1.2: Urbanization and increase in built up area in select Indian cities



Source: Urban India 2011: Evidence, Indian Institute for Human Settlements. 2012 it single largest consumer in the country. This is followed by groundwater for domestic use, which is 9 per cent of the extracted groundwater. Industrial share of groundwater use is 2 per cent. About 50 per cent of urban water requirements and 85 per cent of rural domestic water requirements are also fulfilled by groundwater.[9]

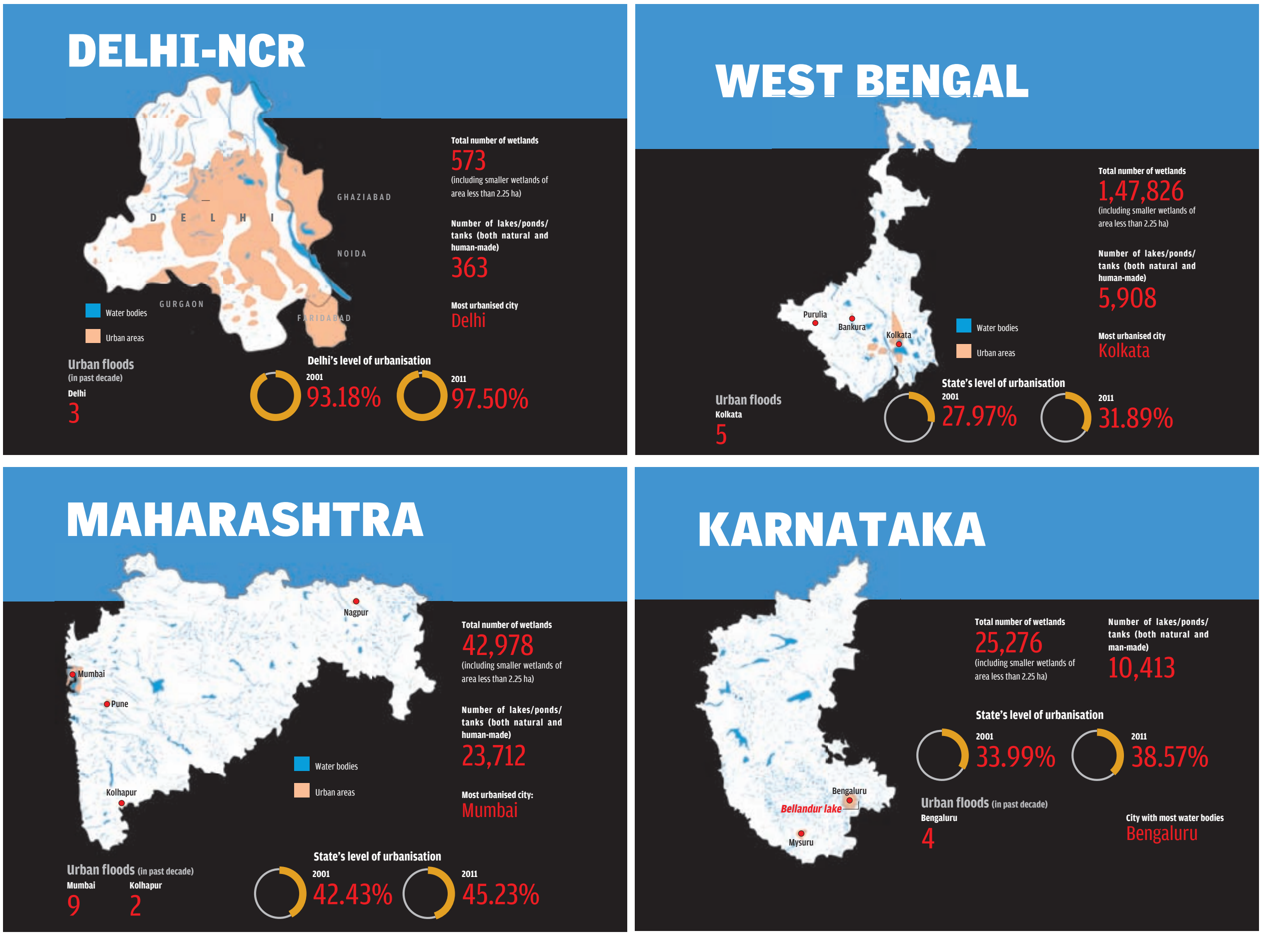
How is this water replenished? The overall contribution of rainfall to the country's annual groundwater resource is 68 per cent, and the share of other resources, such as canal seepage, recharge from tanks, ponds and water conservation structures taken together is 32 per cent. Due to increasing population, the national per capita annual availability of water has reduced from 1,816 cum in 2001 to 1,544 cum in 2011. This is a reduction of 15 per cent.[10] It is clear that rain is the major factor in India's water cycle. Since rain is a periodic and (in many parts of the country) a mostly seasonal phenomenon, this also implies that many areas get their water in short spurts of torrential rains.

This complicates the situation for burgeoning urban centres. For example, Guwahati, a low-lying city on the bank of the Brahmaputra river, faced unprecedented flooding in 2016. Flooding in Delhi due to overflow of the city's 18 major drains has become a common phenomenon. Heavy rain in the Yamuna's upstream increases its water level in Delhi, due to which the drains in the city experience reverse flow. Floodplain areas in National Capital Region (NCR) have undergone rapid urbanization in recent years. The number of water bodies in the region have been reduced from 800 to 600 due to encroachment.[11] As more and more farmlands and green areas are being urbanized, the amount of surface area for water percolation is reduced. As a result, all the runoff flows on the land, without being absorbed. This increases the chance of floods. Major flooding events in Delhi include the flooding in 2010, when the water level in Yamuna crossed the 207 m mark. In 2013, 117.8 mm rain was recorded in four hours. Losses, including the damage to crops, houses and public utilities was estimated at Rs 176.1 million. Flooding on roads caused severe traffic issues in the city. Before that, the 1988 floods had affected approximately 8,000 families and the 1995 floods had rendered around 15,000 families homeless.[12]

Kolkata and Chennai have witnessed massive construction in recent decades, reducing soil cover and vegetation. While other cities can expand into adjoining areas, Mumbai cannot due to its peculiar peninsular topography and long coastline. The city was built by merging seven islands and hilly areas.[13] Nearly 60 per cent of Mumbai's population lives in poorly built temporary settlements. The most devastating flooding event in Mumbai was the mega flood of July 2005, caused by 944 mm of rain in 24 hours. A total of 1,094 lives were lost, all major suburbs were affected, train and bus services, and airport operations were suspended for about 30 hours. A total loss of Rs 5,500 million was incurred in two days.[14]

The negative economic, social, and environmental consequences of declining water quality in wetlands are also an issue of concern for India. The problem of deteriorating water quality is particularly more alarming in the case of small water bodies such as lakes, tanks and ponds. India has a wealth of wetland ecosystems that support diverse and unique habitats. In the past, these water sources performed several economic (fisheries, livestock and forestry), social (water supply), and ecological functions (groundwater recharge, nutrient recycling, and biodiversity maintenance).[15] Despite all these benefits, many decision-makers and even many of the primary stakeholders consider them as

Figure 1.3: Status of waterbodies in a few Indian states



Source: S. Narain and S. Sengupta. 2016 'Why urban India floods—Indian cities grow at the cost of their wetlands', Centre for Science and Environment.

wastelands. Every one claims a stake in them, as they are in the open access regime, but rarely are willing to pay for this extractive use. Many freshwater wetlands ecosystems are threatened and others are already degraded and lost due to urbanization, population growth, and increased economic activities.[16] (See *Figure 1.3: Status of waterbodies in a few Indian states*.)

These freshwater bodies are often subject to changes in land use in their catchments leading to reduction in in-flows and deteriorating quality of the runoff traversing through agricultural fields and urban areas. On the other hand, many of them act as a 'sink' for untreated effluents from urban centres and industries. Encroachment of reservoir areas for urban development and excessive diversion of water for agriculture is another major problem.[17] A study found that out of 629 water bodies identified in the National Capital Territory (NCT) of Delhi, as many as 232 cannot be revived on account of large scale encroachments.[18] Floodplains of the River Yamuna in parts of Delhi, New Okhla Industrial Development Area (Noida) and Faridabad of NCR, are characterized by decline in groundwater and quality detrition of the groundwater system that are related to the land use and land cover pattern.[19]

Green spaces and other open spaces like pavements and parking are the major components which define the livability of the urban built environments.[20] In

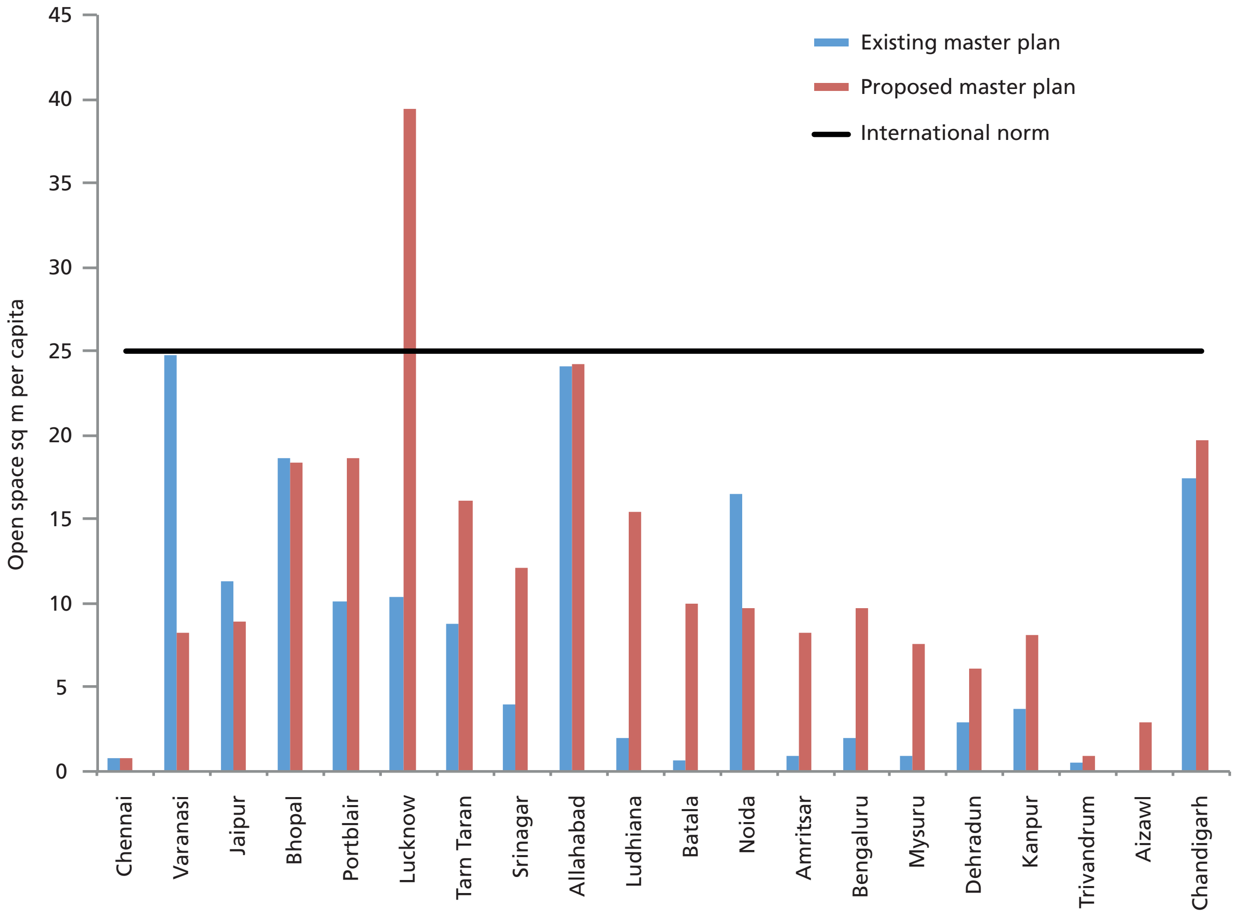
India, the term 'urban green space' is used as a comprehensive term comprising trees in all urban parks, forests and along roads and canals etc., which contribute greenery to the city. Three main components of the urban forest and green spaces are *patch* (urban domestic gardens, public and private parks, gardens, urban forest patches, etc.), *corridor* (roadside avenues, walkaway and urban green ways, etc.) and *network structure* (layout of all the patches and corridors connecting the patches).[21]

From a global perspective, although there are wide variations both in coverage as well as per capita availability of green spaces, cities in the world renowned for their urban green spaces often have 20–40 per cent green coverage, and 25–100 sq m urban green spaces per capita. Most Indian cities are far behind in quality as well as quantity of urban open spaces than their counterparts in Australia, Europe and North America (see *Figure 1.4: Green areas in select Indian cities as per master plans*).[22]

The master plans of cities in India specifies 'the proposed' recreational or open space as part of different urban land uses. It has been observed that the range of designated land use for green open spaces ranges from 0–15% per cent irrespective of the typology of the city. (See *Figure 1.5: Percentage of recreational areas in select Indian cities*).

However as per URDFI guidelines, 2014 about 25–35 per cent of a city's

Figure 1.4: Green areas in select Indian cities as per master plans



Source: Urban Green Guidelines, 2014, Town and Country Planning Organization, Government of India, Ministry of Housing and Urban Affairs, India

Figure 1.5: Percentage of recreational areas in select Indian cities

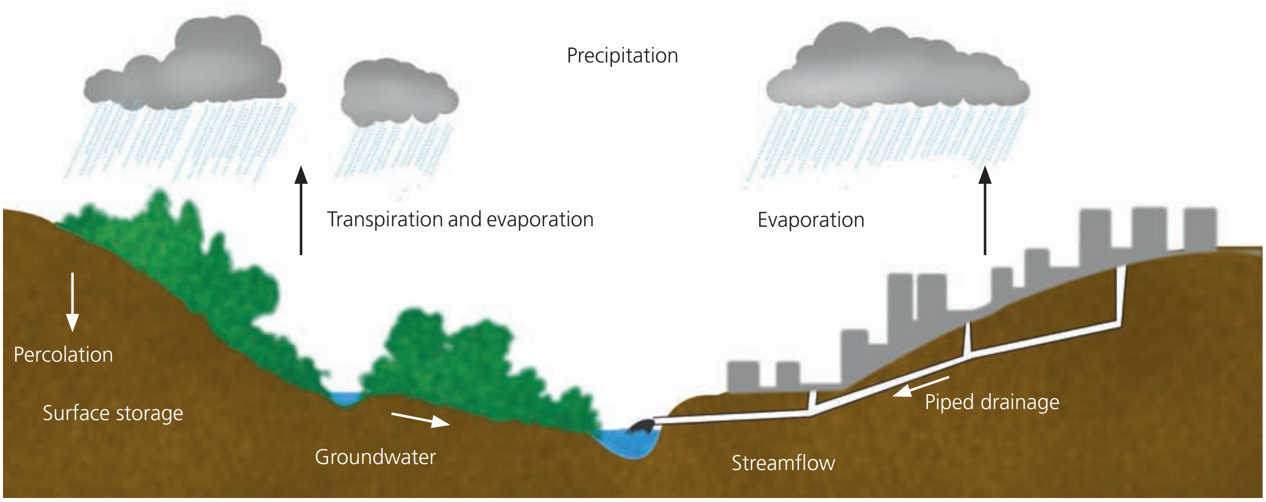
Source: Urban and regional development plans formulation & implementation (URDPFI) guidelines (2014) Ministry of Housing and Urban Affairs.

area should be earmarked as recreational and open spaces, in addition to environmentally sensitive areas, which must be protected.

It can be concluded that the high percentage of impervious surfaces in urban areas alters runoff and drainage patterns, making natural events of rain an enabling pathway for oil, grease, toxins, pathogens, nutrients, and other pollutants to reach nearby waterways. Storm flows of high volume and velocity cause additional adverse environmental consequences, such as flooding and riparian habitat loss. Impervious surfaces prevent rainwater from seeping into the ground, thereby preventing groundwater recharge. This results in degradation and depletion of water bodies and groundwater resources in urban areas (see *Figure 1.5: Comparison between natural and urban hydrological cycles*).[23]

This guide enumerates comprehensive approaches and strategies to integrate GI practices with urban planning for different geographical settings—inland, hilly, coastal and desert areas, and floodplains—supported by relevant best management practices as case studies and research work or projects.

Figure 1.6: Comparison between natural and urban hydrological cycles



Source: Girling, C. and Kellett, R., 2005. Skinny streets and green neighborhoods: design for environment and community. Island Press.

1.1 Need for a guide

Urban green spaces are a major contributor to both the quality of environment and to human well-being, hence GI provides a new concept evolving as a 'smart' method for natural conservation and urban planning. It is high time we realize that open green spaces are not a frill but a necessity.[24]

Conventionally, storm water management has been focused on drainage systems via underground pipes. However, these conventional approaches have been found inadequate in many cases, most particularly in dealing with extreme rainfall. The frequency of extreme rainfall events is expected to increase with projected climate change, which will make reliance on only conventional storm water management systems increasingly untenable.

Augmenting urban green spaces is considered to be an effective approach to reducing the adverse impacts of urbanization on the hydrological cycle. Green spaces improve the natural hydrological systems in urban areas and dampen peak flows from storms that can lead to flooding. Expansion of urban green spaces is not only an economical and environmentally-friendly approach to deal with storm water runoff and urban flooding, but can also improve the resiliency and sustainability of cities.[25&26]

Objectives of the guide are:
1. To sensitize practitioners about the need and concept of GI for urban areas.
2. To provide GI approach and strategies for analyses with regard to planning for different urban typologies.
3. To present case studies in support of GI principles across the world.

1.2 How to use the guide

This guide focuses on identifying issues and opportunity of a select area by spatial analyses, thereby demarking the zones of conservation, preservation and development. The approach used in this guide is an extension of the concept used in the practitioner guide on Water Sensitive Urban Design and Planning (WSUDP) prepared by CSE in 2017 for Ministry of Housing and Urban

Affairs, Government of India. The guide provides appropriate methods and strategies under WSUDP as per different scales of urban planning like city or zonal, neighbourhood or institutional, and individual scale.[27] The GI guide, on the other hand, focuses on regional, city and zonal scales with reference to urban typologies, e.g. inlands, coastal, hilly and desert areas, and floodplains. This will further be enhanced with landscape planning and designing solutions for green spaces and flood or storm water management. The guide will also be supported with examples of good practice to show impact of GI solutions in terms of number of environment benefits.

Target group

The target audience for this guide comprises city officials from urban local bodies (ULBs) and development authorities from target states, such as urban planners, landscape and other architects, town planning officers, engineers, and others involved in preparing and enforcing regional and master plans, zonal plans, city development plans and city sanitation plans and various local design standards.

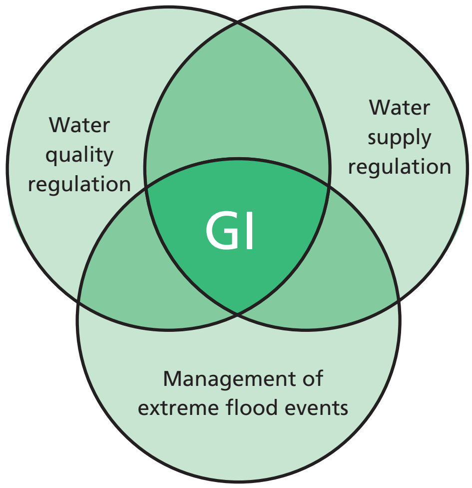
Scope of the guide

This guide provides an overview of the key water management issues that can be addressed by the GI approach. It also showcases the relevant GI solutions that can be used to achieve desired improvements.

The wide spectrum of GI solutions for key water management issues include

- Water supply regulation
- Water quality regulation
- Moderation of extreme flood events

Figure 1.7: The GI convergence



Source: CSE, 2017

Table 1.1: Objectives of the guide

Objective 1	Objective2		Objective3	
Introduction	**Understanding green infrastructure**	**Green infrastructure approach**	**Value of green infrastructure**	**Appendixes**
• Urban India issues focusing on green spaces • Need for a practitioner's guide • Target group for this guide • How to use the practitioner's guide	• What is GI and what are its multiple benefits • Evolving international knowledge on GI • Evolving Indian knowledge on GI • Scope of GI interventions in Indian cities	• Understanding the geographical typologies, e.g., inlands, deserts, hilly, coastal and riverine areas and floodplains • Planning targets and measures in alignment with different typologies of urban areas, supported by case examples	• Stakeholder analysis • Other benefits of GI solutions • Case studies	• Definitions and benefits of GI recognized across the globe • Existing tools and practitioners guides on GI across the world

Source: CSE

Table 1.2: Target audience of the guide

Primary users	
Organizations	**Technical staff and decision makers**
Government bodies	Urban planners: Chief town planner, senior town planner, junior town and assistant planner
Development authorities State urban development agencies Town and country planning (state-wise) Regional planning authorities Flood and irrigation departments	
Municipal corporations Municipalities Other ULBs	Engineers: Superintending engineer, executive engineer, assistant engineer, environment engineer, project officer
Public health engineering departments Water supply and sewerage boards Urban shelter improvement boards	Director, secretary, chairman, engineers
Engineering, architectural and planning colleges and institutes under the following courses	Students and teachers: B.E. or B. Tech (Civil) or environmental—future engineers in this sector Landscape architectural students Planning students Urban design students
Postgraduate course in public health engineering, environmental engineering, short-term courses in public health engineering and environmental engineering and refresher courses on various aspects of water sensitive design and planning	
Private organizations	Technical staff
Consultants Landscape firms Private organizations	
Secondary users	
Non-governmental organizations Community-based organization: RWA and residents	

Key messages

- Increase in the spread of impervious surfaces in urban areas alters runoff and drainage patterns leading to storm flows of high volume and velocity causing additional adverse environmental consequences, such as flooding and riparian habitat loss.
- Impervious surfaces prevent rainwater from soaking into the ground, thereby preventing groundwater recharge.
- Increasing urban green spaces is considered to be an effective approach to reducing the adverse impacts of urbanization on the hydrological cycle.
- The range of designated land use for green open spaces in a typical Indian city ranges from 5–15 per cent, irrespective of its typology.
- GI aims to recreate a naturally-oriented water cycle while contributing to the amenity of the city by bringing water management and GI together.

2. Understanding green infrastructure

Infrastructure can be defined as 'the substructure or underlying foundation, especially the basic installations and facilities on which the continuance and growth of a community depends' and the term 'green' is akin to conservation and is related to ecology and environment.[1]

The first definition of GI was given by Mark Benedict, USA as 'an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife.'

In Indian cities, urban greens refer to any area within the city limit which has been created and preserved for the purpose of growing plants.[2] However, urban landscapes have evolved under extremely complex influences of changing land uses and management practices, sustaining some habitats and fundamentally altering others.[3]

As per Green Infrastructure Work Group, US, 'GI is an interconnected network of waterways, wetlands, woodlands, wildlife habitats, and other natural areas; greenways, parks and other conservation lands; working farms, ranches and forests; and wilderness and other open spaces that support native species, maintain natural ecological processes, sustain air and water resources and contribute to the health and quality of life for communities and people.'

The Town and Country Planning Association, UK defines GI as 'the sub-regional network of protected sites, nature reserves, green spaces, and greenway linkages.' The linkages include river corridors and floodplains, migration routes and features of the landscape which are of importance as wildlife corridors.

As per the latest definition of Natural England, GI is 'a strategically planned and delivered network comprising the broadest range of high quality green spaces and other environmental features. It should be designed and managed as a multifunctional resource capable of delivering ecological services and quality of life benefits required by the communities it serves and needed to underpin sustainability.'

Various definitions and guides on GI have been prepared across the world and can be referred for further understanding of the subject (see *Appendix 2: Definitions of green infrastructure across the world* and *Appendix 3: A few practitioner's guides on green infrastructure developed by other countries*).

CSE's proposed definition of GI

Green infrastructure refers to natural or semi-natural ecosystems that provide water resource management by introducing the natural water cycle into urban environments. It provides effective measures to manage urban flooding, water supply and quantity regulation, at the same time generating multiple environmental benefits.

2.1 Evolution of GI in India

The evolution of GI in the Indian sub-continent started in the pre-historic era in the floodplains of Indus Valley Civilization (around 3,000 B.C.). The city of Mohenjo-Daro can be considered as the first example of a designed water management system, exhibiting GI solutions at the city scale.

Historically, most cities incorporated GI as an essential element of human settlements. For example, Udaipur (established in 1559 A.D.) had artificial lakes designed around the city to fulfill the water demand. The area around these lakes also served recreational purpose; Jaipur (established in 1726 A.D.), designed on the basis of the traditional Hindu writings of Shilpa Shastra, had an open space network; Bengaluru (established between 1799 to 1809) is considered to have had various water bodies and adjoining areas for recreation activities. Examples of GI were also witnessed during the Mughal Era in complexes like Humayun's Tomb, New Delhi; Taj Mahal, Agra, and the Shalimar Gardens of Kashmir.

The last city designed in British era India was New Delhi (1913–31). British and American styles of open space design influenced the layered hierarchies of greens in the city, but links between green spaces and natural drainage network were not observed in the spatial design of New Delhi.

In the post-British era, planning and design of various cities exhibited a broad network of GI. For example, Chandigarh, designed by Le Corbusier in 1950s; the first Master Plan for the National Capital of Delhi in 1962, prepared on the principles of American Land Use Planning; Gandhinagar plan, based on the concept of Chandigarh in 1965 etc. The common feature in all these cities was a visible link between various hubs of green spaces and natural runoff pattern at different hierarchies, from city level to the neighbourhood level (see *Figure1.4: Green areas in select Indian cities as per master plans* in *Chapter 1*).

In order to facilitate urban planning for various developing centres, The Model Town and Country Planning Act was drafted in 1962 by Town and City Planning Organisation (TCPO), based on which a majority of states established various TCPOs. Master plans for various medium and large towns were developed, incorporating design and distribution of open spaces. However, the link between green spaces and natural drainage patterns were broken or absent due to poor planning and implementation and lack of technical know-how. This resulted in major deviations from GI as practiced in traditional settlements.

Metropolitan cities like Delhi, Hyderabad, Chennai, Mumbai, Kolkata and Bengaluru, and large cities like Pune, Mysuru, Magarpatta, Auroville, and Noida also suffered from such deviations from the 1970s–90s. At the regional level, planning has been limited to metropolitan regions, as observed in the case of Delhi, Mumbai, Chennai and Kolkata. The master plan for the NCR was the first to identify regional green links, paving the way for a regional-level GI.

To further supplement the preparation of master plans for the growing urban settlements, UDPFI Guidelines were published in 1996 by the Institute of Town Planners (ITPI), which mandated a minimum of 15 per cent of total urban area for green or open spaces. After a review in 2014, the URDPFI Guidelines were published, further supplementing the requirement for green space with an additional norm of 10–12 sq m green area per capita. The Atal Mission for Rejuvenation And Urban Transformation (AMRUT) and Service-level Benchmarks (SLBs) of 2014 concurred, specifying that ULBs would have to ensure the availability of 10-12 sq m green area per capita. However, the concept of GI is not specifically discussed in these Guidelines.

The Ministry of Environment, Forest and Climate Change (MoEF&CC) was established in 1985, following which the Environment Protection Act, 1986 was notified. This is an umbrella act which ensures the protection of all dimensions of the natural environment. This, along with other acts related to quality of water resource, air, forests, biodiversity, etc., mention the importance of green areas. However, no law or legislation specifically mentions the protection and enhancement of green areas and GI. It is understood that these are to be dealt with at the local level.

The deadly combination of absence of legislative focus on GI and the loopholes in the preparation of master plans and implementation witnessed from 1970s onwards has resulted in unsustainable urban settlements, which are the motors of the country's economy, but are increasingly becoming vulnerable in terms of water management and green spaces. For cities like Bengaluru, Chennai, Gorakhpur and Delhi, issues of annual urban flooding, diminishing water bodies and depleting ground water table require immediate action (see *Figure 2.1: India's green infrastructure timeline*).

2.2 Water management services addressed by GI

GI aims to recreate a naturally-oriented water cycle while contributing to the amenity of the city by bringing water management and GI together. This is achieved by combining and protecting the hydrological and ecological values of the urban landscape while providing resilient and adaptive measures to deal with floods, generating a multitude of environmental, ecological, socio-cultural and economic benefits. GI favours a holistic approach and aims for interdisciplinary cooperation in water management, urban design, and landscape planning.[4]

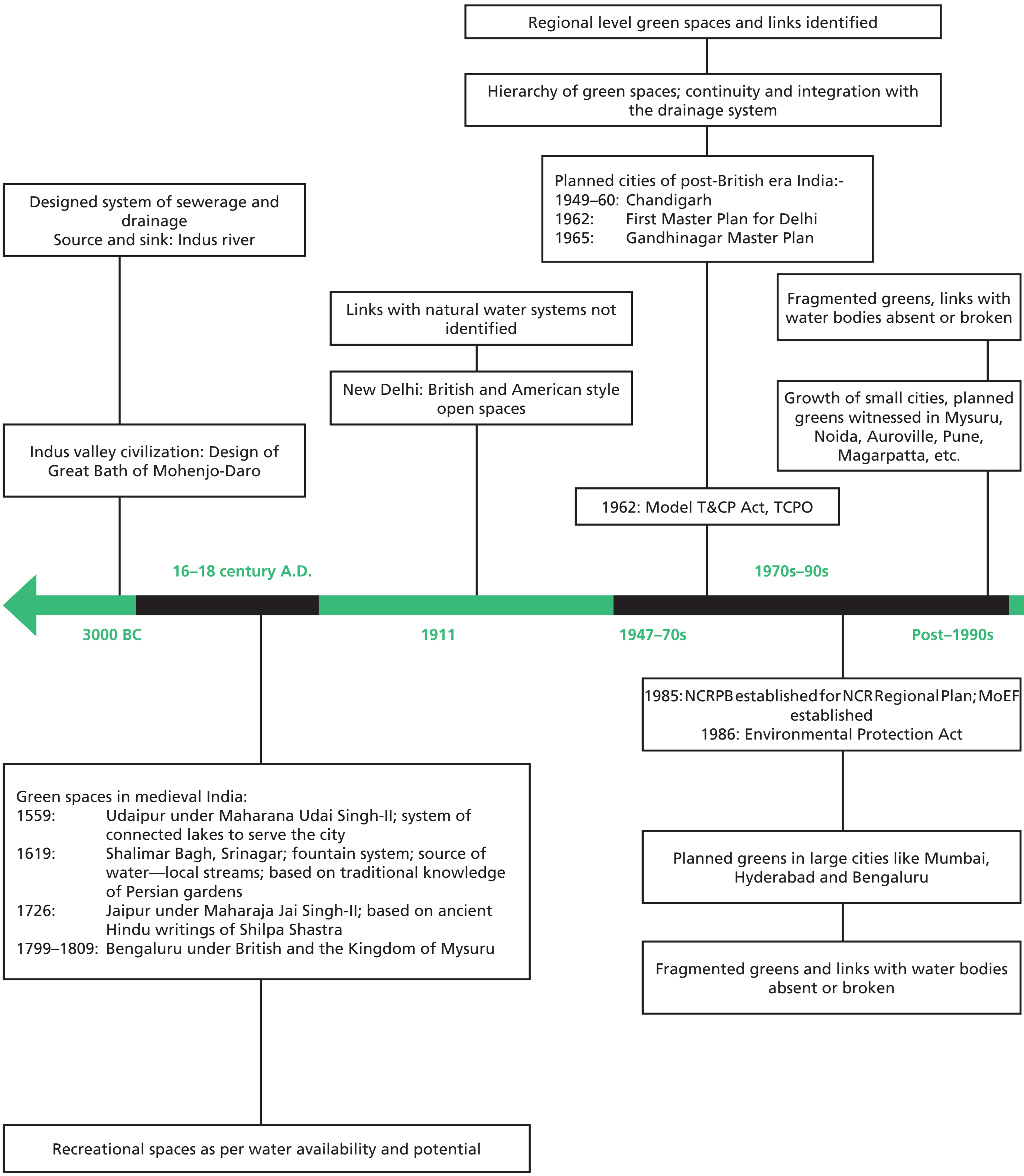
It is instructive to distinguish between grey infrastructure and GI. Grey infrastructure is more conventional and engineered, while GI is inspired by and draws from nature.[5] One of the most evident drawbacks of grey infrastructure is that it tends to be capital intensive to build, operate, maintain and replace. Furthermore, as grey infrastructure is often designed to address a specific water management problem, it can serve to shift amplified risks to other locations. For example, conventional flood management infrastructure can disconnect rivers from floodplains and reduce or eliminate services such as flood control, groundwater recharge, pollution control and supply regulation.[6] We need a combination of both (grey and green) to support resilient and vibrant places[7] (see *Figure 2.2: Distinguishing between grey and green infrastructure* and *Figure 2.3: Comparison of attributes of a conventional and green urban area*).

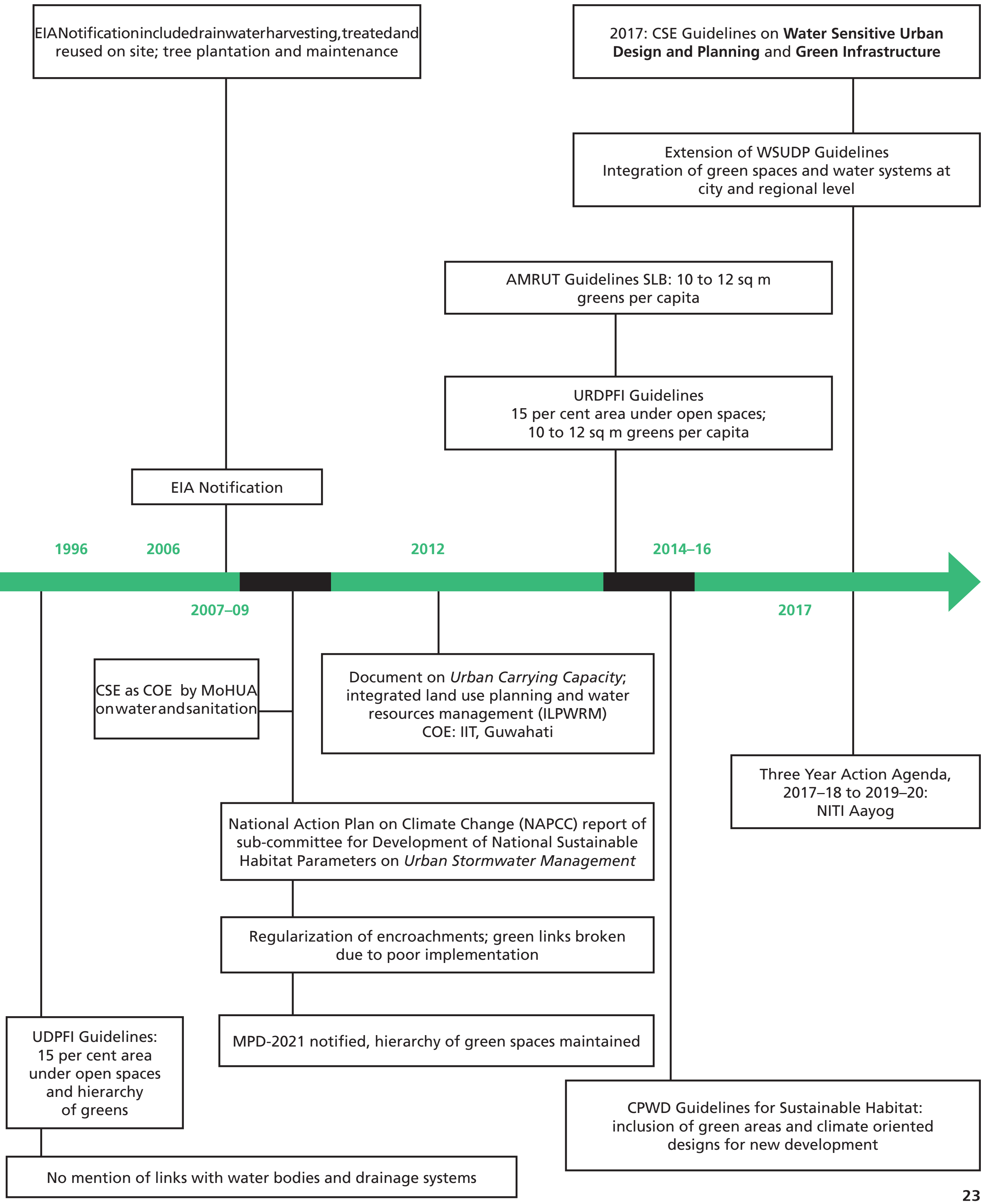
The key water management issues that can be addressed by utilizing GI are water supply and quality regulation, and moderation of extreme events.

2.2.1 Water supply regulation

Sufficient water supply is a precondition for the functioning of any community, industrial and economic activity, as well as for the health of ecosystems. Grey infrastructure (including water treatment plants and distribution pipes) is essential in providing water to large populations. However, water supplies invariably originate from the broader landscape of watersheds and aquifers, so

Figure 2.1: India's green infrastructure timeline




EIA Notification included rainwater harvesting, treated and reused on site; tree plantation and maintenance
2017: CSE Guidelines on **Water Sensitive Urban Design and Planning** and **Green Infrastructure**
Extension of WSUDP Guidelines Integration of green spaces and water systems at city and regional level
AMRUT Guidelines SLB: 10 to 12 sq m greens per capita
URDPFI Guidelines 15 per cent area under open spaces; 10 to 12 sq m greens per capita
EIA Notification
1996
2006
2012
2014–16
2007–09
2017
CSE as COE by MoHUA on water and sanitation
Document on *Urban Carrying Capacity*; integrated land use planning and water resources management (ILPWRM) COE: IIT, Guwahati
Three Year Action Agenda, 2017–18 to 2019–20: NITI Aayog
National Action Plan on Climate Change (NAPCC) report of sub-committee for Development of National Sustainable Habitat Parameters on *Urban Stormwater Management*
Regularization of encroachments; green links broken due to poor implementation
UDPFI Guidelines: 15 per cent area under open spaces and hierarchy of greens
MPD-2021 notified, hierarchy of green spaces maintained
CPWD Guidelines for Sustainable Habitat: inclusion of green areas and climate oriented designs for new development
No mention of links with water bodies and drainage systems

natural ecosystems are the foundation of sustainable water supplies. Therefore, GI solutions that affect hydrological processes such as runoff and infiltration positively enhance the supply potential of a watershed.[8]

GI can help:

- Sustain supplies by increasing water infiltration and storage capacity of both wetlands and dry land, and increasing recharge of aquifers.
- Mitigate droughts through the release of water from natural storages, including groundwater, surface water and aquifers.

2.2.2 Water quality regulation

Instead of the traditional approach to storm water management of capture, convey, and treat, GI manages rain where it falls, recognizing it as a valuable resource. Under GI, soil and vegetation are allowed to absorb and cleanse rainwater. The water is then reused or allowed to flow back into surface water resources or to recharge groundwater. Decentralized storage and infiltration approaches, including the use of permeable pavements, rainwater harvesting, and reuse of rainfall for irrigation or other non-potable onsite uses often accompany GI. Constructed wetlands help improve the quality of water, as they can treat and remove pollutants before they enter urban water bodies.[9]

This reduces the volume of water entering the combined sewer and storm water systems, thus reducing the need for infrastructure and treatment costs at wastewater treatment plants, while enhancing the general aesthetics of urban areas.

GI can help:

- Purify polluted water from both point and non-point sources by trapping and containing sediments, and pollutants in sediments, soils and vegetation (filtration and chemical conversion).
- Protect groundwater from contamination by removing sediments, heavy metals and other pollutants from the infiltration water.
- Relieve pressures on existing water treatment infrastructure via bio-retention and infiltration practices that support water capture and infiltration, and slow down release of contaminants.

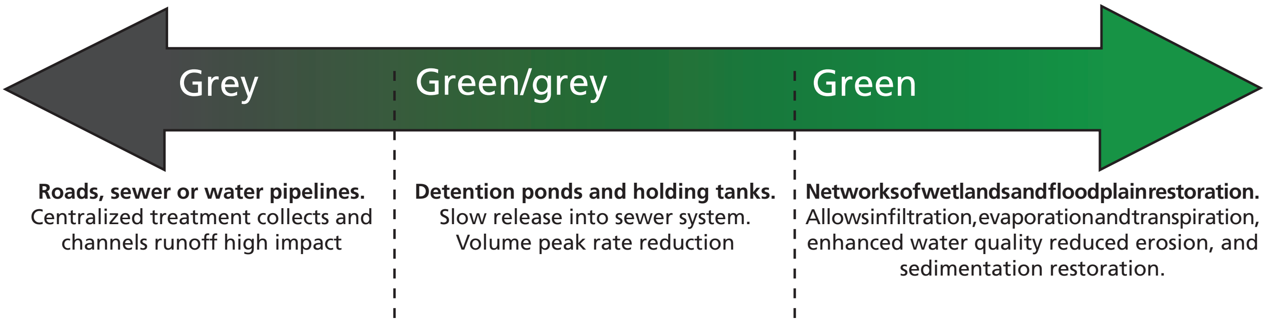
2.2.3 Moderation of extreme events

Floodplains are disturbance-dominated ecosystems characterized by rich habitats and ecosystems. Urbanization results in the stripping off of vegetation and layering with artificial impervious surfaces (in the form of buildings, roads, parking lots, etc.) in the floodplains. This reduces the natural storage capacity of the soil and channels of seepage are blocked. Constructed storm water drains alter the existing hydrology and flow regimes, such that precipitation flows rapidly across the surface in short, intense, high-volume bursts rather than sinking into the soil.[10]

Urban areas will have to cope with increased rainfall that will occur due to climate change. Directing more rain into surface water drainage systems will often overload them, causing floods. GI provides a sustainable solution to this problem by:[11]

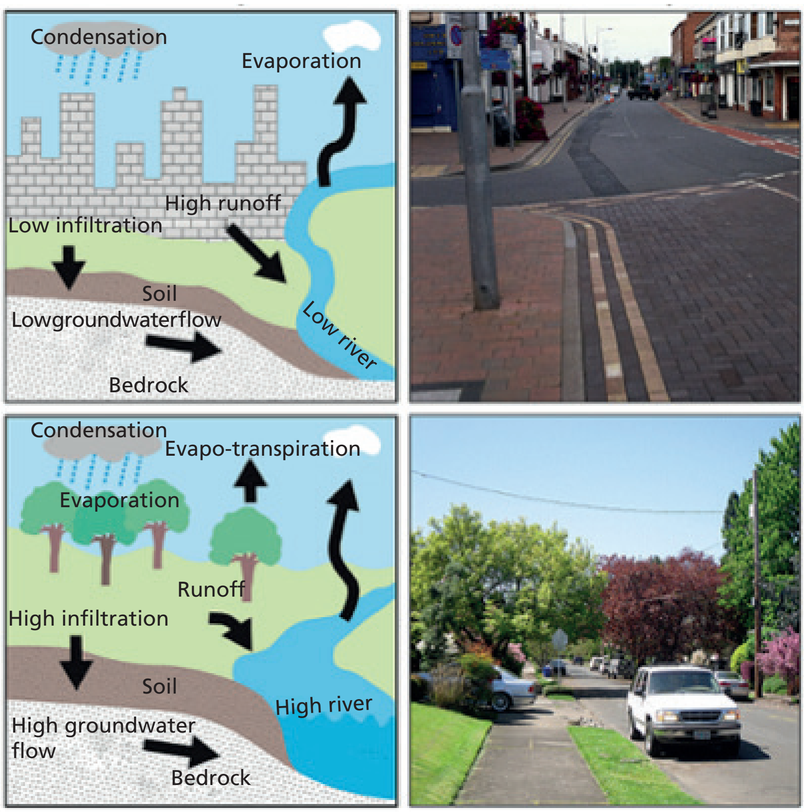
– Delaying the downstream passage of flood flows

Figure 2.2: Distinguishing between grey and green infrastructure



Adapted: Greening the Grey: An Institutional Analysis of Green Infrastructure for Sustainable Development in the US, 2013

Figure 2.3: Comparison of attributes of a conventional and green urban area



Source: Project website—www.bluegreencities.ac.uk

- Reducing the volume of rainwater runoff through interception
- Promoting rainfall infiltration into the soil

Riverine flood control

Floods are one of the most common and costly natural disasters. Traditional flood management infrastructure solutions rely on engineered solutions such as dams, levees and floodwalls. While these solutions are essential for safety in many areas, they can be expensive and can shift flood risk to other locations. Further, engineered solutions can contribute to a false sense of security and, when coupled with inappropriate land-use patterns such as dense housing within deep floodplains, can actually contribute to greater losses when they fail. Floodplains are among the most productive ecosystems. Hence, engineered solutions that focus on severing the connection between rivers and floodplains have contributed to a great loss of ecosystem services from river–floodplain systems, such as productive fisheries. A number of GI solutions can contribute to moderation of floods by increasing the ability of the landscape to store water or by increasing the ability of channels to convey floodwaters. On a watershed level, better forest and wetland management uses the natural ability of ecosystems to retain water, slowing down and absorbing some of the storm runoff. Forests also help to stabilize banks, reducing the impacts of flooding, land erosion and landslides. In urban areas, green roofs, permeable pavements and green spaces help to absorb water, facilitate infiltration and minimize storm water runoff. This, in turn, reduces or prevents sewer system overflows and flooding and relieves the load on existing flood management infrastructures.[12]

Coastal flood protection
Temporary extreme sea levels, and associated coastal storms and surges can result in coastal flooding and cause widespread damage to human construction, livelihoods and ecosystems. As a consequence of climate change, the projected sea rise may further expose coastal areas to damage by higher water tables and higher extreme water levels, shoreline erosion, inundation of low lying areas and saltwater intrusion. This calls for wider implementation of coastal protection measures, an area where GI can play a significant role. By functioning as buffer zones, coastal ecosystems such as mangrove forests, coastal marshes and barrier reefs can often provide the same benefits as conventional grey solutions in the form of dykes and levees and protect coastal areas from erosion and inundation (saltwater intrusion) during large storms.

GI can help:

- Reduce coastal (shoreline) erosion through creation of natural breakwaters that can absorb the energy of waves.
- Prevent saltwater intrusion by storing storm water and reducing inundation.

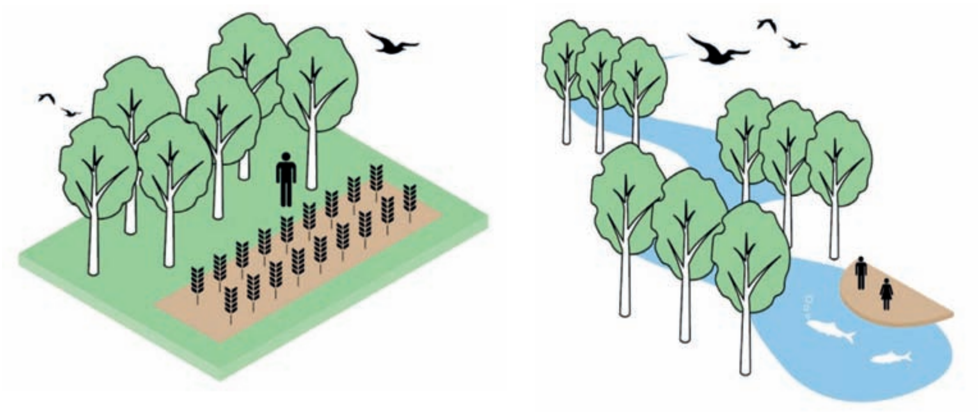
2.3 Potential of GI in India

In Indian cities, GI can be categorized into several systems with a set of functions under each of them.[13]

These systems operate at various hierarchies, from national- or regional-level to the household-level. However, they are broadly classified in two categories:
- Regional-scale
- City-scale

GI at different scales of urban areas
It is expected that most of the urban green resources in the future would be located outside the city or in the vicinity but not in central urban areas. GI requires working at various scales for its planning and designing. Its elements and functions should be incorporated at the regional-, city- and project-level.[14]
- *State- and regional-scale*: Encompassing statewide and national conservation and open space planning.
- *City- and community-scale*: Supporting local conservation and restoration efforts including parks, recreation and other open space projects.
- *Project scale*: Involving individual parcels of land within neighbourhood and private developments. This has already been included in the guide on WSUDP, which is further extended to cover the bigger scales through this guide.[15]

Figure 2.4: GI at different urban scales



Town, city and zone scale

District park
Neighbourhood park
Totlots
Playgrounds
Green belt (buffers)
Green strip
Plazas
Urban canals
Lakes and wetlands
Major recreational spaces
Rivers and floodplains

City-region, regional and national scale

Canals
Reserved forest
Protected forest
National park
Trails
Reservoirs
Road and railway networks
Designated greenbelt and strategic gaps
Regional parks
Rivers and floodplains
Shorelines

Source: CSE, 2017

Regional-scale greens

As per India's 2013 National Land Utilization Policy, the following 'land use management areas' are to be identified within existing 'land utilization zones' for proper management:

Protected areas

Areas protected from all human activity except those clearly specified under law. Such areas include environmentally sensitive and fragile ecosystems like national parks, forests, biosphere reserves; socially important areas like protected tribal settlements; and culturally important areas like historic sites and monuments. Any change in their status has to be mandated by an appropriate law or ruling.

Regulated areas

In regulated areas all human activities except those specifically prohibited under law can be carried out. Such areas may include prime agricultural lands, rural settlements, sensitive ecosystems, regions rich in natural resources (other than those covered under protected areas), regions demarcated for landscape conservation and tourism, cultural and heritage sites, and hazard prone zones. Land use of these areas should preferably not be altered. In case any alteration is necessitated, such changes should be governed by a set of rules, regulations and procedures. For example, construction activities should not be carried out in prime agriculture lands, unless backed by a new law or ruling.

Reserved areas
Human activity is permitted in the reserved areas, but should be carried out with caution and only when no other option is available. These are areas which should ideally be protected but are under pressure from the needs of development. Such areas may include regions close to human settlement like green belts and recreational areas.

City-scale greens
1. *City park and district park:* 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 level. 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 urbanizable limits of the urban centre.
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.

Area requirements for green spaces
Regional level green areas are protected areas the boundaries of which are based on natural links and settings (see *Table 2.1: Protected areas of India*). Hence, the area requirement norms are not prepared or standardized at this scale. For urban green spaces, the planned recreational areas are provided on the basis of planning norms. These norms are as per the Master Plan for Delhi, 2021 document 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 green
- Other common open spaces (such as vacant lands or open spaces including floodplains, forest cover etc.) in plain areas.

Considering overall open spaces in an urban area, the Guidelines suggests the norm of 10–12 sq m of open space per person. However, in hilly areas, the protected zones and ecological conservation areas shall be considered to be over and above this open space requirement. The hierarchy for organized greens such as parks, play fields and other open spaces are also included (see *Table 2.3: Hierarchy of organized greens in Indian cities*).

Protected areas are those in which human occupation or, at least, the exploitation of resources is limited. There are several kinds of protected areas, depending on the level of protection afforded by the laws of individual countries or the regulations of the international organizations involved. The term 'protected areas' also includes marine protected areas, the boundaries of which will

Table 2.1: Protected areas of India

	No.	Total area (km^2)	Percentage of total geographical area
National parks	103	40,500	1.23
Wildlife sanctuaries	543	118,918	3.62
Conservation reserves	73	2,547	0.08
Community reserves	45	59.66	0.002
Protected areas	764	162,024	4.93

Note: As in July 2017.
Source: WII-ENVIS Centre on Wildlife & Protected Areas, website (http://www.wiienvis.nic.in/)

Table 2.2: India's vital forest statistics

Geographical area of India	3,287,263 km^2
Forest cover of India	701,673 km^2
Percentage area under forest cover	21.34 per cent of geographical area

Source: WII-ENVIS Centre on Wildlife & Protected Areas, website (http://www.wiienvis.nic.in/)

Table 2.3: Hierarchy of organized greens in Indian cities

Hierarchy	Population	Green space	Area/unit		Units	Total area	
			(sq m)	ha		(sq m)	ha
Housing area	5,000	Totlots	125		20	2,500	0.25
		Housing area park	5,000	0.5	1	5,000	0.5
		Housing area play	5,000	0.5	1	5,000	0.5
		Total				12,500	1.2
Neighbourhood	10,000	Neighbourhood park	10,000	1.0	1	10,000	1.0
		Neighbourhood play	10,000	1.0	1	10,000	1.0
		Housing area green	12,500	12.5	2	25,000	2.5
		Total				45,000	4.5
Community	100,000	Community park	50,000	5.0	1	50,000	5
		Multi-purpose ground	20,000	2.0	1	20,000	2
		Neighbourhood green	45,000	4.5	10	450,000	45
		Total				520,000	52
District	500,000	District park	250,000	25.0	1	250,000	25
		Multi-purpose ground	40,000	4.0	1	40,000	4
		Community green	520,000	52.0	5	2,600,000	260
		Total				2,890,000	289
Zonal/sub-city	1,000,000	City park	1,000,000	100.0	1	1,000,000	100
		Multi-purpose ground	80,000	8.0	1	80,000	8
		District green	2,890,000	289.0	2	5,780,000	578
		Total				6,860,000	686

Source: Urban and regional development plans formulation & implementation (URDPFI) Guidelines 2014.

include some area of an ocean, and transboundary protected areas that overlap multiple countries that have made the borders inside the area irrelevant for conservation purposes.

It is also to be noted that area for buffers, green belts and green strips are not standardized as they vary on a case-to-case basis.

An area under planned green spaces for a city with a population of 10 lakh should be a minimum of 686 ha. This is over and above the national and regional parks, forests, buffer areas, green belts and green strips in the area.

In regional planning, existing protected areas can be part of holistic GI processes. These areas provide the unique benefit of serving various municipal needs in a region, while providing additional and emergency benefits like natural water supply regulation, water quality regulation, and moderation of regional flood events.

Tools to evaluate GI potential

A number of innovative models, tools, and technologies have been developed by United States Environmental Protection Agency (USEPA) for communities

Green Infrastructure Wizard (GIWiz)

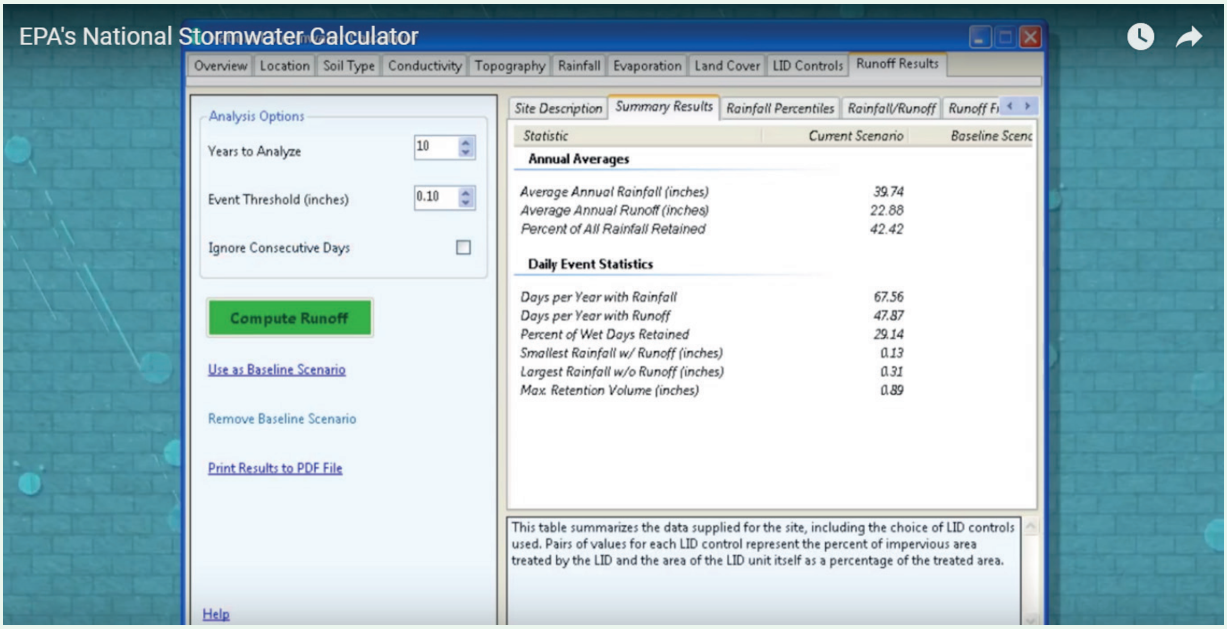
GIWiz is an interactive web application that connects communities to EPA GI tools and resources. GIWiz provides users with customized reports containing EPA tools and resources they select, direct links, and overview information.

Green Infrastructure Resources	More Info	Resource Type	Like
Do assessment or analysis to inform planning or policy decisions			
A Triple Bottom Line Assessment of Traditional and Green Infrastructure Options for Controlling CSO Events in Philadelphia's Watersheds			
Analytical Tools Interface for Landscape Assessments (ATtILA)			
BMP Siting Tool			
Better Assessment Science Integrating Point and Nonpoint Sources (BASINS)			
Community Based Public-Private Partnerships (CBP3s) and Alternative Market-Based Tools for Integrated Green Stormwater Infrastructure			
Controlling Stormwater Runoff with Tradable Credits for Impervious Spaces			
Costs of Best Management Practices and Associated Land for Urban Stormwater Control			
Data and Modeling Tools for Green Infrastructure			
Discharge Mapping Tool			

Source: www.epa.gov/sustainability/giwiz

United States Environmental Protection Agency (USEPA) National Storm Water Calculator

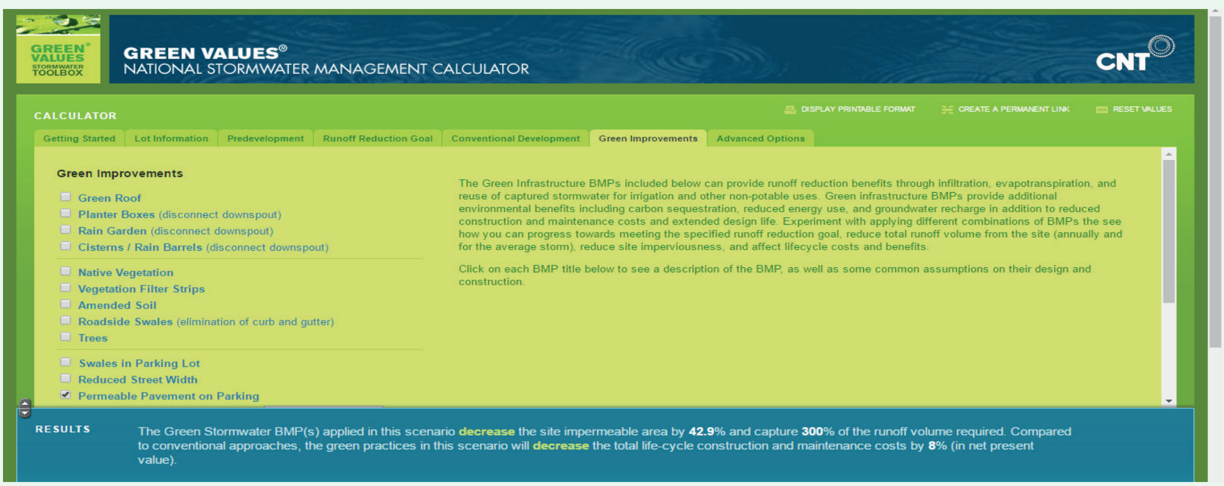
The National Storm Water Calculator (SWC) is a desktop application developed by USEPA that estimates the annual amount of rainwater and frequency of runoff from a specific site anywhere in the United States (including Puerto Rico). Estimates are based on local soil conditions, land cover, and historic rainfall records. SWC is a resource for all rainwater management credits in Leadership in Environment and Energy Design (LEED) by the US Green Building Council for all project types in all rating systems. The calculator accesses several national databases that provide soil, topography, rainfall, and evaporation information for the chosen site. The user supplies information about the site's land cover and selects the types of low impact development (LID) controls they would like to use.



Source: https://www.epa.gov/water-research/national-stormwater-calculator

Center for Neighbourhood Technology (CNT) Green Values Storm Water Calculator, USA

The National Green Values Calculator is a tool for comparing the performance, costs, and benefits of GI, or low impact development (LID), to conventional storm water practices. While the calculator is based upon the hydrology of the Great Lakes region, this calculator is highly refined and can be used to get a general sense of how GI might work in other areas.



Source: http://greenvalues.cnt.org/national/calculator.php to manage urban water runoff (see *Appendix 4: Tools on green infrastructure developed by USEPA*). The models and tools in this toolkit incorporate GI practices to help communities manage their water resources in a more sustainable way and increase resilience to future changes, such as climate and extreme events. Two major tools used to calculate GI potential for a city are enumerated in the boxes on the adjacent page. These tools can be used as an example by municipal officers to understand the GI potential in their respective contexts.

Key messages

- GI refers to natural or semi-natural ecosystems that provide water utility services by introducing the natural water cycle into urban environments. It provides effective measures to manage urban flooding, while following the concept of multi-functional greenspace and land use to generate multiple environmental benefits.
- Initially, with the Model Town and Country Planning Act, drafted in 1962 by TCPO, Indian cities and developing centres were designed to integrate distribution of open spaces. However, the link between green spaces and natural drainage patterns was subsequently broken or absent due to poor plan, implementation and lack of technical know-how.
- Metropolitan cities like Delhi, Hyderabad, Chennai, Mumbai, Kolkata and Bengaluru and large cities like Pune, Mysuru, Magarpatta, Auroville, NOIDA suffered from deviation from GI integration (as practiced in traditional settlements) during the time period of 1970s–90s. Presently, considering overall open spaces in an urban area, the URDPFI Guidelines, 2014, suggest the norm of 10–12 sq m of open space per person.
- GI requires working at various scales for its planning and designing. Its elements and functions should be incorporated at the regional-, city- and project-scale.
- The key water management issues that can be addressed by utilizing GI are water supply and quality regulation, and moderation of extreme events.

3. Green infrastructure approach

Spatially, GI strategies can help analyze the state of GI in relation to the urban sprawl. Further, these strategies can help formulate planning targets and measures for ecosystem functions. GI analyses for a particular city or region can be conducted by selecting GI options that together make up a strategy to provide the storage needed to meet the flood reduction target.

- The first step is to choose a quantifiable flood reduction target (i.e. what amount of flood reduction can be achieved). Associated target volume of runoff will need to be stored or reduced to meet the goal.
- The second step is to select GI options that will achieve the target.
- The third step is to assess where and how various strategies can be used to reach the flood reduction target.

The following can be examples of GI approach and strategies for an urban area:[1]

- **GI approaches**: Identification of vulnerable areas, living shorelines, floodplain restoration, riparian buffers, land preservation, land restoration, and wetlands and floodplain restoration and creation.
- **GI strategies**: The compilation of GI options (area-specific for particular watershed, including the constructed wetlands and green areas) that meet the flood reduction target for a watershed.

This chapter details out the potential of GI for various typologies prevailing in India. A brief outline of the focus areas is given as follows (see *Figure 3.1: Broad geographical zones of India*):

Inlands: In urban inlands, GI can be provided through 'water bodies' (lakes and wetlands) associated with 'public open spaces' (parks and green buffer) which help in decentralized ground water supply and quality regulation while moderating extreme floods.

Deserts: In desert areas, GI approaches focus on increasing the green cover and erosion control measures to ensure groundwater regulation.

Hills: GI practices in hilly areas focus on controlling the sediment yield and runoff volume. Some of these practices include mulching, grassland development, and creation of buffer zones with grass and trees moderating the flood events.

Floodplains: In floodplain areas, GI approaches focus on afforestation, riparian buffers, reconnecting rivers to floodplains, and wetlands restoration leading to riverine flood control.

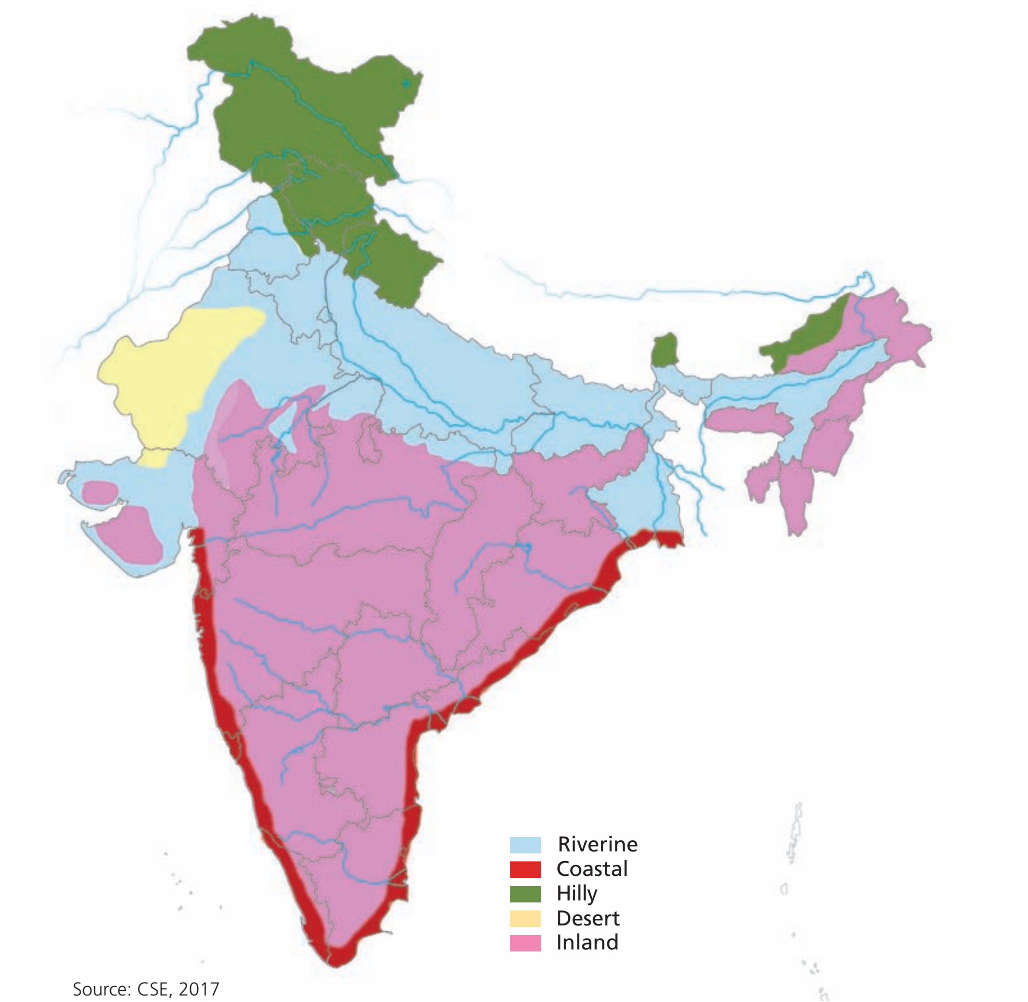
Coastal: In coastal areas, GI solutions focus on conservation of natural features like protecting or restoring mangroves, coastal marshes, dunes and reefs (coral or oyster) leading to coastal flood control.

3.1 Inlands and desert areas

In urban inlands, GI can be provided through water bodies (lakes and wetlands) associated with public open spaces (parks and green buffer).

Water pollutants due to urbanization: Urban runoff is often very contaminated

Figure 3.1: Broad geographical zones of India for GI



Source: CSE, 2017

and delivers excess sediment, phosphorous, nitrogen, heavy metals, and chemical pollutants into nearby aquatic ecosystems.[2] These pollutants can either be point source—from a specific location—or non-point source—from the accumulation of many sources that cannot be easily isolated and addressed.[3] Sedimentation in urban streams can be caused from exposed construction sites, in which the sediment is already loosened, or from bank erosion, due to a lack of vegetation to keep the soil in place.

While sediment can decrease primary production in aquatic systems, it has a greater potential to increase it, as nutrients, especially phosphorous, can bind to sediment and be transported into the watershed. Phosphorous and nitrogen, from lawn fertilizers, industrial waste, sewage treatment plants, pet waste, or poorly built and overflowing sewer systems, serve as fertilizers within aquatic ecosystems, causing eutrophication and large algal blooms.[4] When these algal blooms die, they create hypoxic conditions within the ecosystem, often causing large-scale death of fish and other aquatic life.

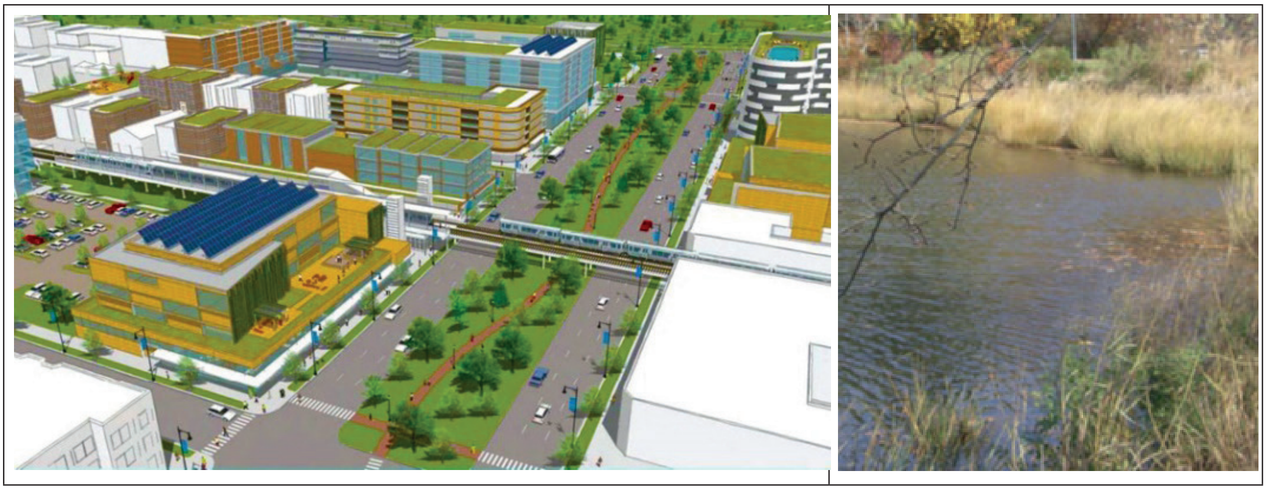
Water bodies: Big and small water bodies, in the form of lakes and reservoirs, dot the landscape of India. These ecosystems impound precious freshwater, and are most easily accessible source for human use. Unfortunately, these water resources face degradation due to multiple anthropogenic factors

Table 3.1: Legal provisions on GI for inland and desert urban areas

Description	Remarks
National Programme for Conservation of Aquatic Ecosystems, 2016	
All sites included under National Lake Conservation Plan (NLCP), National Wetland Conservation Programme (NWCP) and Ramsar Convention	• Lack of spatial attributes in the policy to define buffer areas and land use regulation. • Detail uses not mentioned in the Guidelines, except for recommendation for the preparation of detailed project report for protection. • Thirdpartyinspectionsandothertimelyinspections are conducted by MoEF&CC
Urban, peri-urban or semi-urban areas consisting perennial aquatic ecosystems having water throughout the year with peak inundation equivalent to or greater than 10 ha • Highly degraded due to pollution from domestic and industrial wastewater, municipal solid waste, or other non-point sources	
Representative, rare, and unique aquatic ecosystem	
Species and ecological communities • Supports vulnerable and endangered species • Supports population of species important for maintaining biodiversity • Supports species at critical stages of their life cycle (migratory path) • Supports a minimum of 20,000 water birds	
Hydrological services Source of water, regulates hydrological extremes, recharges groundwater, buffers floods and purifies water	
Livelihood and socio-cultural values	
High altitude aquatic ecosystem Located at a minimum altitude of 2,000 meter above mean sea level	
NGT Ruling on Bengaluru Lakes, 2016	
Buffer areas around lakes • 75 m from all lakes • 50 m, 35 m and 25 m from primary, secondary and tertiary of Raja Kaluve* respectively. *Raja Kaluve: Water channels connecting various lakes.	• No construction in these buffer zones • Existing construction to be demolished • Dredging activities to restore original capacity of water • Separate source of water for construction and O&M to be mentioned in ecological zone
NIDM Guidelines on Urban Flooding, 2010	
Guidelines recommend conservation of lakes and wetlands in coastal as well as inland cities to better manage urban flooding as these areas help in regulating excess surface runoff	State govt. and ULBs for actions and activities
Advisory on Conservation and Restoration of Water Bodies in Urban Areas by CPHEEO	Reflects the environmental and social impact of lake restoration with management steps in lake conservation.
EIA Guidelines, 2006	
Projects (as mentioned in the schedule) have to obtain an Environmental Clearance. Required documents at the first stage include Form 1, Form 1A (construction projects) and Pre-Feasibility Report (other than construction projects). Under Form 1, Environmental Sensitivity head	Mention all eco-sensitive areas under national, state, and local legislation, areas of ecological importance, areas prone to flooding, etc. within an aerial distance of 15 km. Buffer norms of these are to be followed based on appropriate laws.
Ministry of Environment & Forests Notification (1986) Restricting certain activities in specified area of Aravalli Range, which are causing Environmental Degradation in the Aravalli Region like: 1. Location of any new industry 2. Mining operations 3. Cutting of trees 4. Construction of any dwelling units 5. Laying of new transmission lines	The Aravalli hill region served its area and the people as a rich resource area providing forest products; fuel wood; fodder; timber; water through springs, streams and rivers; minerals, rich forest clad habitat; safe and secured locations to former rulers and their public and above all dependable and timely rainfall and healthy environment with more moisture and provide less temperature to the city in comparison to present higher radiation.

Source: Compiled by CSE, 2017

Figure 3.2: Green areas and buffers in the urban context



Source: 2009, St. Mary's College of Maryland, Buffer Management Strategy, Maryland

such as unprecedented population growth, and consequent urbanization, industrialization and chemical intensive agriculture. Among the first victims of this degradation process are the lakes and reservoirs in the vicinity of urban areas that underwent large-scale pollution due to sewage and industrial effluents and toxic chemicals. In most cases, nutrient enrichment leads to eutrophication of water bodies, exhibiting negative manifestations such as:

- Loss of water spread area because of siltation and construction activities.
- Continuous algal blooms.
- Excessive growth of macrophytes (e.g. water hyacinth) and loss of biodiversity.
- Water quality degradation.

However in desert urban areas, loss of vegetation due to deforestation, inadequate soil conservation measures, and excessive extraction are the major challenges in retaining the natural groundwater resource.

Government of India has taken a few initiatives to conserve and maintain lakes, however, there are no surrounding land use- or buffer area-specific guidelines provided, except recommendation for preparation of DPR for protection (see *Table 3.1: Legal provisions on GI for inland and desert urban areas*).

3.1.1 GI approach and strategies for inlands and desert areas

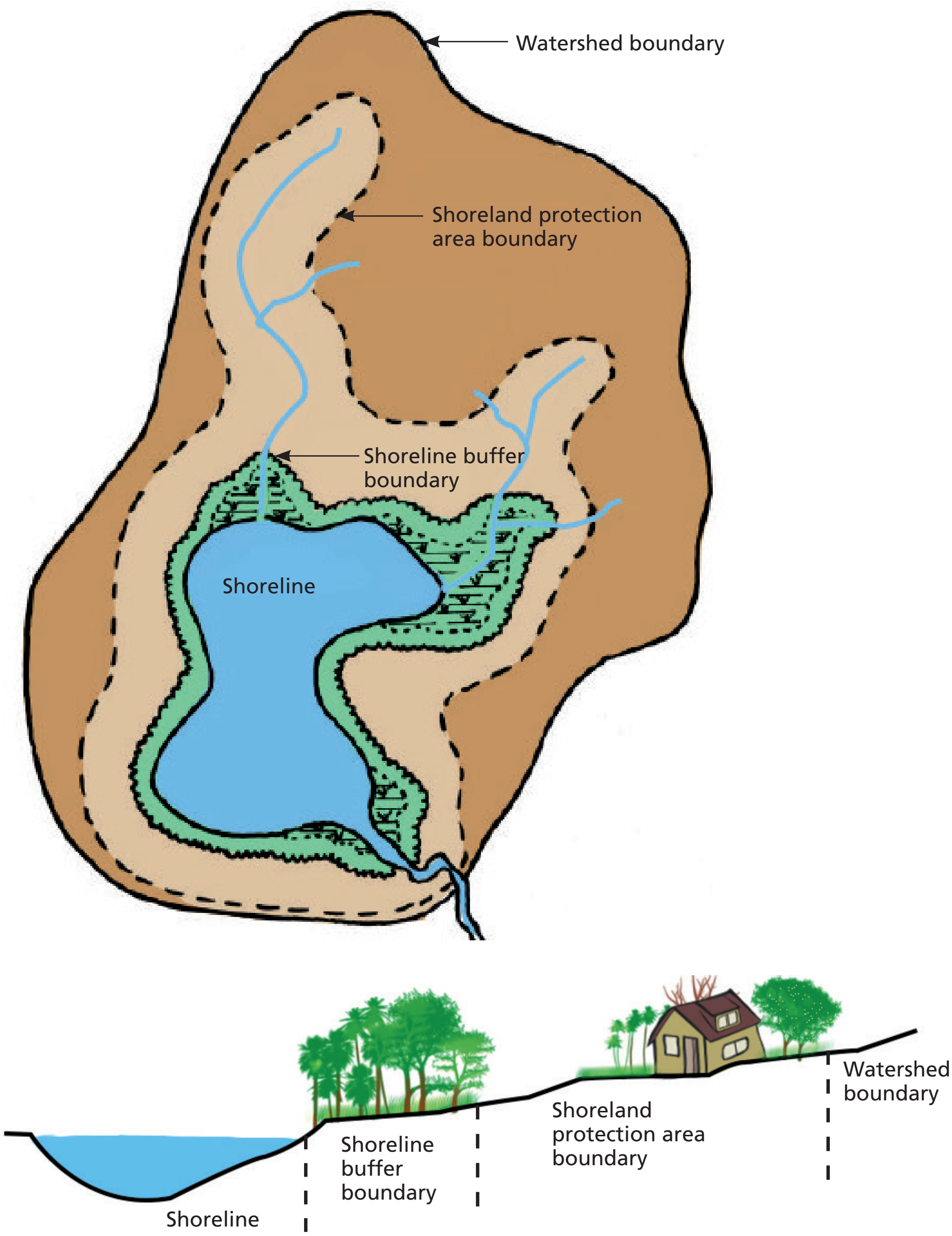
Within an urban context, buffers can be integrated into the city in a variety of forms that are different from traditional agricultural buffers—greenways and parks. These options are attractive for city planning because they offer services to humans as well; greenways are often accompanied by bicycle trails, providing a transportation corridor for human use, and parks offer aesthetic qualities as well as opportunities for activity and relaxation. Through the implementation of green buffers, urban environments can be in cohesion with natural environments, allowing for vibrant watersheds and cities[5] (see *Figure 3.2: Green areas and buffers in the urban context*).

In desert areas, GI helps in reducing erosion due to seasonal waterfall though use of native, drought-adapted plants. Use of mulch as GI helps in reducing evaporation of moisture from soil. Apart from the water retaining ability of native trees, they can withstand high winds as they develop deeper root systems, this preventing wind erosion as well.[6]

In desert urban areas, vegetation increases water infiltration, reduces soil erosion, moderates local climate, increase soil fertility, augments the habitat for flora and fauna, and allows cultures to flourish. Restorative action includes habitat protection, assisted regeneration, sand dune stabilization and tree planting.

Green areas and buffers: Fish and wildlife diversity, water quality, and recreational value are directly proportional to the health of a lake or pond. Vegetated shoreline buffers are an important feature of ponds and lakes that provide and enhance many functions essential to establish and maintain a healthy system. More diverse shorelines enhance ecological integrity, erosion

Figure 3.3: Four major zones surrounding a lake



Source: Crafting a lake protection ordinance. Watershed Protection Techniques, 3(4), 2001, p.751.

control, pollution filtration, and recreational and property values of ponds and lakes.[7]

An effective lake protection design extends over four major zones:[8] (see *Figure 3.3: Four major zones surrounding a lake*).

Zone 1: Shoreline: The point where the high water mark meets the land

- The littoral areas are an important habitat and vulnerable to alteration.
- There must be no disturbance in their natural state without permit. These areas have designated recreational spaces for boat houses and restricted access (in lakes which are not used as a source of water). Sometimes, the shorelines are constructed with retaining walls and bunds for better transportation and to avoid bank erosion.

Zone 2: Shoreline buffer: Extends landward from the high water mark (75–100 feet)

- Expanded to include steep slopes, wetlands and sensitive areas.
- The recommended minimum base width of the shoreline buffer is 75 feet and the maximum width is 300 feet (if the lake is a source of drinking water). Together with the shoreline vegetation, the aesthetic value and property value increases and the woody debris in the littoral zone provides habitat for wildlife and fish with reduction in erosion.

Zone 3: Shore land protection area

- Special overlay zone for residential development.
- Extends 250–1,000 feet from high water mark.
- Structural modification are often not feasible in these areas.

Zone 4: Contributing watershed

- The watershed, also called the drainage basin, is all of the land and water areas that drain toward a particular river or lake. Thus, a watershed is defined in terms of the selected lake (or river). There can be sub-watersheds within a watershed. For example, a tributary to a lake has its own watershed, which is part of the larger total drainage area to the lake.

Case study

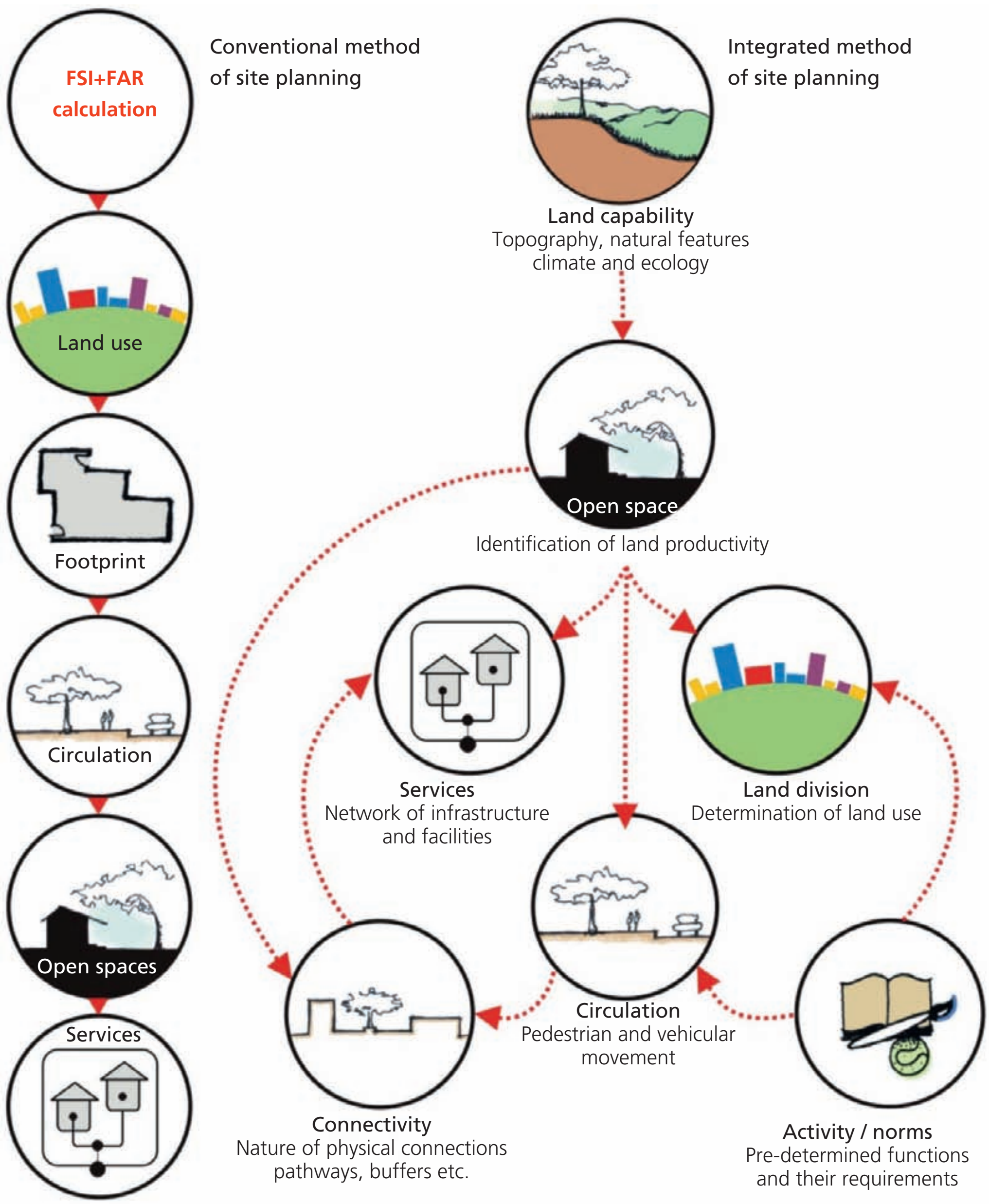
IIT campus Jodhpur—land capability-based master planning, Jodhpur, Rajasthan

Year of research: 2015

Background

The new permanent campus for IIT Jodhpur is proposed on 852 acres of land located approximately 24 km north–northeast of Jodhpur on NH-65 towards Nagaur. It presents an excellent example of GI in desert areas.

Figure 3.4: Comparison of conventional and integrated method of site planning



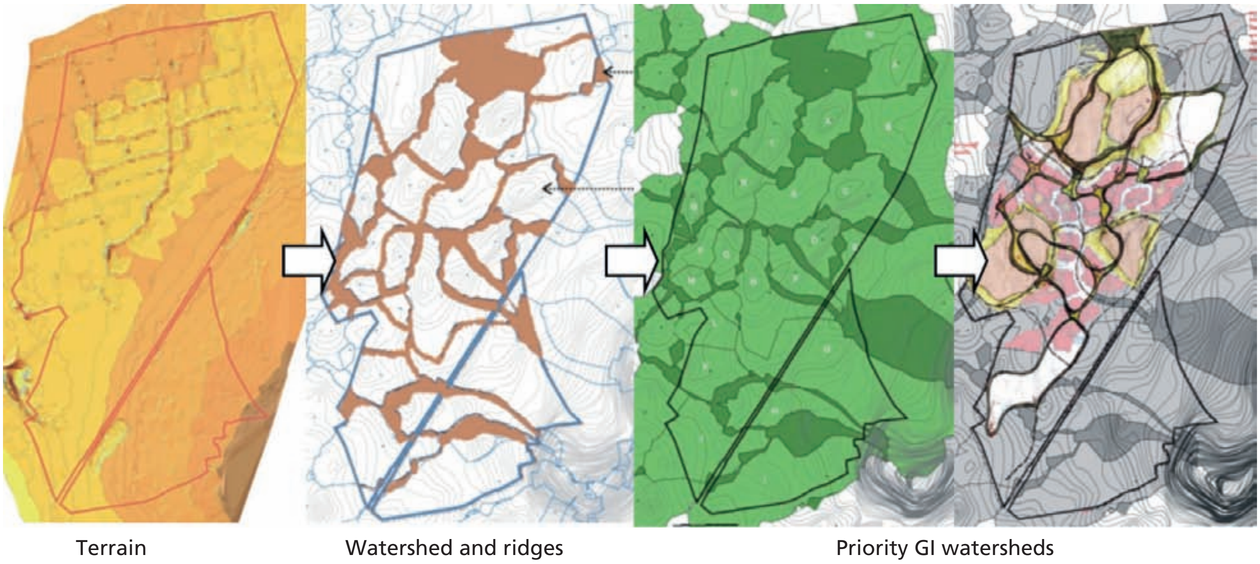
The campus planning exercise, instead of taking the conventional approach of floor space index/ floor-area ratio-based building footprint placement, took the approach of an integrated site planning method which was based on capability of the land, and this formed the basis of its GI.

Land divisions and services were placed in relation to this GI layout, the requirements of connectivity, and functional associations.

The circulation pattern which emerged were a well-integrated network of corridors linking land use activity, and ecological and infrastructure zones.

Source: Mohan S. Rao, Integrated Design, Bengaluru.

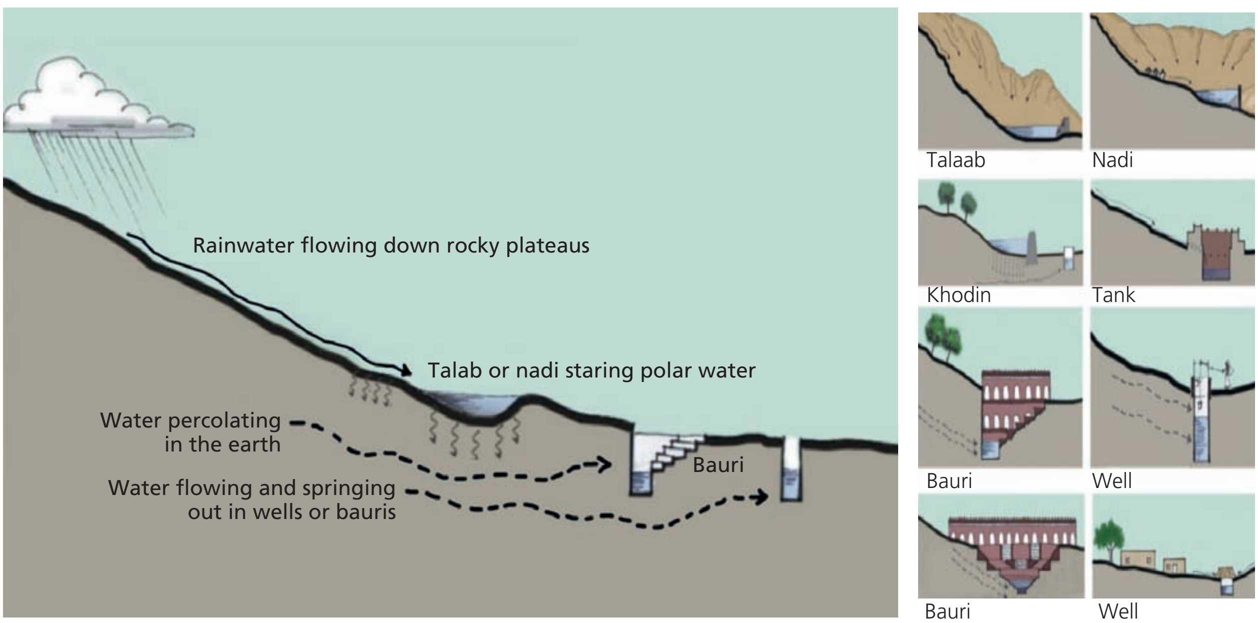
Figure 3.5: Overlay of maps for prioritizing GI



Source: Mohan S. Rao, Integrated Design, Bengaluru

A consortium of architects and planners was formed to work on the various aspects of designing the green campus. Landscape planning was executed by Integrated Design, a Bengaluru-based landscape architecture firm; the Campus master planning was implemented by SHiFt architects, New Delhi. CP Kukreja & Associates and Sikka Associates Architects, two Delhi-based architecture firms, were involved in designing the residential and academic buildings, while BDP India, a New-Delhi based landscape architecture firm, played a role in landscape and masterplanning of the campus.

Figure 3.6: Traditional water management in Jodhpur

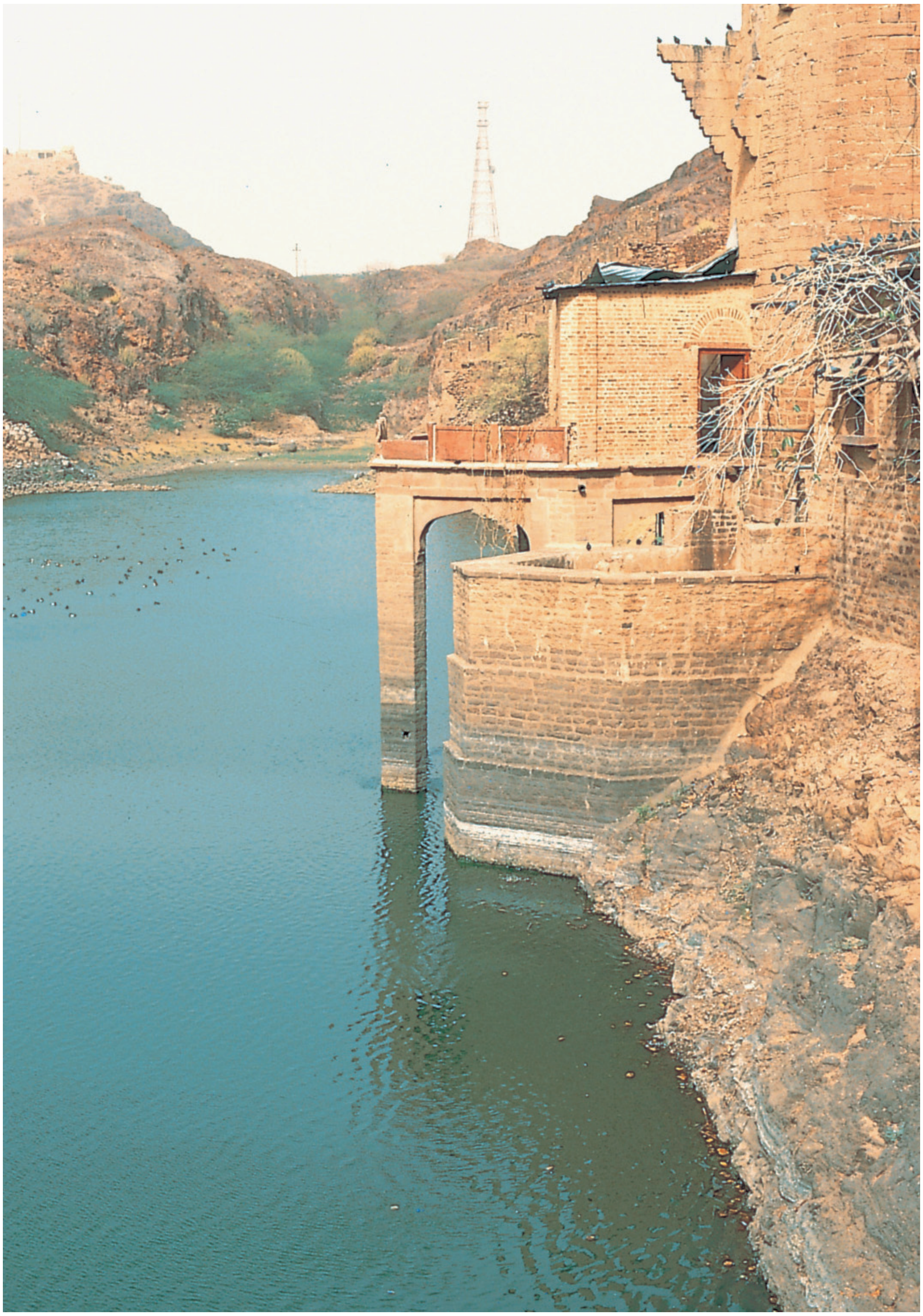


Source: Mohan S. Rao, Integrated Design, Bengaluru

Key learnings
The landscape and ecological conditions of a site are not isolated, they are an embedded extension of the larger regional systems. Terrain-landform is the fundamental feature which defines the water dynamics, which in turn determines the vegetation and soil conditions favourable for various ecological functions.

The proposed GI system focused on traditional practices as illustrated in *Figure 3.6: Traditional water management in Jodhpur*.

An excellent example of traditional rainwater harvesting, the water of Padamsar lake was used for drinking by the local populace. It was constructed by Baldia Seth in memory of his father Padma. The overflow from Ranisar lake flowed into the Padamsar



ANIL AGARWAL / CSE

Case study

Guideline for the determination of wetland buffer requirements, Perth, Australia

Year of notification: 2005

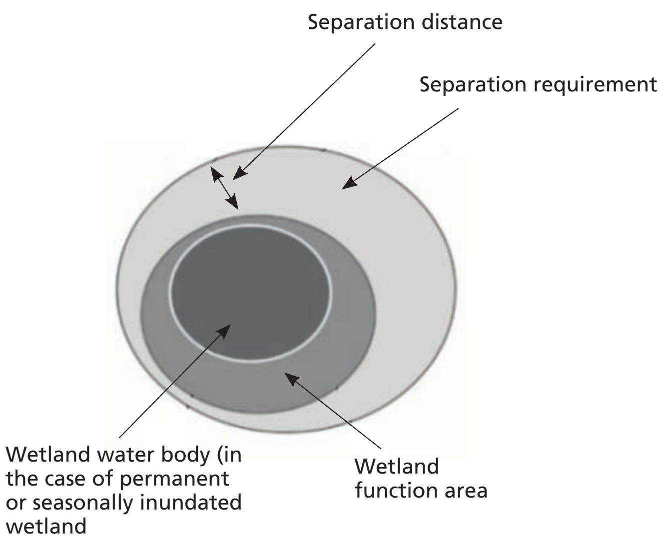
Background

This case study showcases the buffer management guidelines for the determination of wetland buffer requirements prepared by the department of planning and infrastructure, Western Australia. The guidelines have been prepared to assist landowners, developers, planners and architects to identify an appropriate buffer between wetlands and land uses that will enhance or maintain the significant attributes of a wetland. These guidelines are relevant in cases where development is proposed in the vicinity of a wetland. However, these guidelines do not apply to cases where landowners continue existing activities.

A wetland buffer has three areas (see *Figure 3.7: A generalized wetland buffer*).

1. Wetland water body—which has a water body permanently or seasonally inundated
2. Wetland function area—which normally includes the wetland, its vegetation, and any directly associated dependent terrestrial habitat.
3. Separation requirement—the input factors for the estimation which are values or attributes of the wetland and the threats associated with the surrounding land use.

Figure 3.7: A generalized wetland buffer



Source: Guideline for Determination of Wetland Buffer Requirement, 2005

Key learnings

Attributes for identification of wetland categories
This case study showcases that guidelines can be prepared on the basis of standard attributes identified for categorization of each wetland. These standard attributes can be derived from various anthropogenic threats to the existence of wetlands in reference to the given conditions in a particular location or region , including alteration to water regime, habitat modification—e.g. grazing in wetlands, invasion of exotic species, clearing, etc.—inappropriate recreational use, diminished water quality (nutrients, organic compounds, suspended solids, toxic compounds and salinity). The various attributes which are factored in order to assign a category to the wetland are mentioned in *Table 3.2: Attributes for categorization of wetlands*.

Table 3.2: Attributes for categorization of wetlands

Threats ↓	Separation requirement		
Category →	C	R	M
Alteration to water regime	Regulation of groundwater abstraction as catchment management resource		
Habitat modification	• 100 m weed infestation • Upto 100 m for bird habitat dependent on extent of use • 6–50 m firebreak • Fence for controlling exotic fauna access • ≥ 100 m to minimize edge effects	• 50 m weed infestation • 50 m avi-fauna habitat • 6 m firebreak	• 50 m weed infestation • 50 m avifauna habitat • 6 m firebreak
Inappropriate recreational use	• ≥ 50 m to improve aesthetics • ≥ 50 m for barrier • Fence, paths for controlling access	• 10 to 50 m for improving aesthetics • 10 to 50 m for barrier • Fence, paths for con-trolling access	• 10 to 50 m for improving aesthetics • 10 to 50 m for barrier
Diminished water quality	Drainage inflows eliminated or managed		

Note: C: Conservation wetland; R: Resource enhancement wetland; M: Multiple use wetland
Source: Guideline for Determination of Wetland Buffer Requirement, 2005

Case study

Lake buffer management strategy, Maryland, USA

Year of implementation: 2012

Background

Buffer management strategy for St. John's Pond, a tidal creek influenced by the tides of the St. Mary estuary in St. Mary's College Maryland (SMCM) campus, is taken as a 'best management practice' for zoning regulations in buffer areas. The pond is approximately 200 m on its axis and 60–90 m wide, and has a wetted area of approximately 4 acres (1.61 ha). A major concern is the poor water quality due to high sediment load from the land-based storm water runoff, diminished aquatic habitat, and limited wildlife terrestrial habitat.

Key learnings

Although the pond is surrounded by campus infrastructure in good shape and use, in order to link the water body to its natural hubs, buffer areas were proposed. The objective was to establish, augment and restore buffers around the pond to enhance water quality, wildlife habitat and aesthetics.

Figure 3.8: Proposed plan and the result after implementation (inset)

Buffer	Extent	Vegetation	Notes
Zone 1	Up to 15 m or the intersection with hard infrastructure from edge of pond	Native trees (space and limbed) low shrubs, and woodland ground cover	Trees are spaced to form an accessible corridor. Low coastal plain shrubs will protect banks and allow lower profile buffer areas
Zone 2	Up to 15 m or the intersection with hard infrastructure from outer edge of Zone 1	Native grass, wild flowers, and low shrubs and vines	Native landscaping is an important component in the form of planting beds, 'bayscape' or other thematic gardens

Source: SMCM, 2012. Buffer Management Strategy. SMCM: Maryland, USA.

Case study

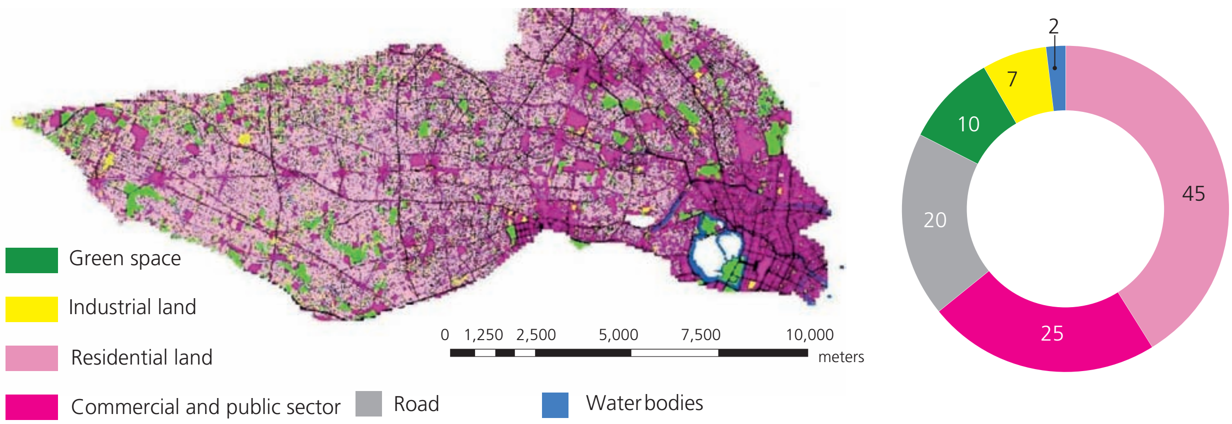
Policies for Green Tokyo, Tokyo, Japan

Year of Publication: 2007

Background
Tokyo is the largest city of Japan, having a population of 13.5 million, as of 2015. The population density of the city is 6,158 per sq km, which makes it the densest city in Japan and one of the densest cities in the developed world. The green cover in the city is considerably low at 2.9 sq m capita. Hence, the Tokyo Metropolitan Government initiated a 10-year policy called Green Tokyo. The green initiatives was also aimed at controlling urban flooding in the city and countering the heat island effect.

Key learnings
Land use of the city shows that a meagre 10 per cent of the area is under green spaces (*Figure 3.9: Land use plan of Tokyo*).

Figure 3.9: Land use plan of Tokyo

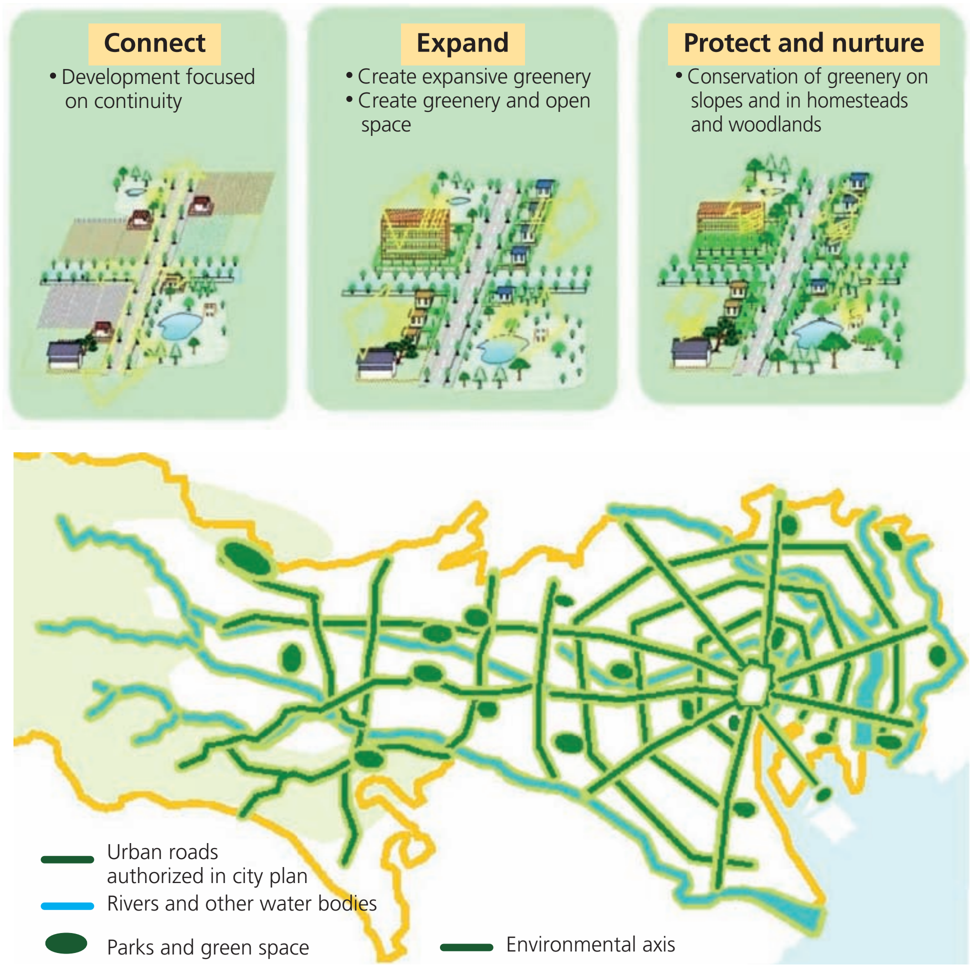


Source: Basic Policies for the 10-Year Project for Green Tokyo. 2007. Tokyo Metropolitan Government

Recommendations
The Tokyo Metropolitan Government aims to develop a green network based on the street network. The green vision includes:

- Formation of a 'green road network' connecting large-scale plots of greenery with roadside trees.
- Creation of a green island in Tokyo as large as the Imperial Palace's grounds.
- Creation of a green space with a size of 1,000 ha.
- To double roadside trees in Tokyo to 1 million.

Figure 3.10: Network plan under Green Tokyo



Source: Basic Policies for the 10-Year Project for Green Tokyo. 2007. Tokyo Metropolitan Government

Case study

Status of GI in Gauteng city-region, South Africa

Year of publication: 2013

Background

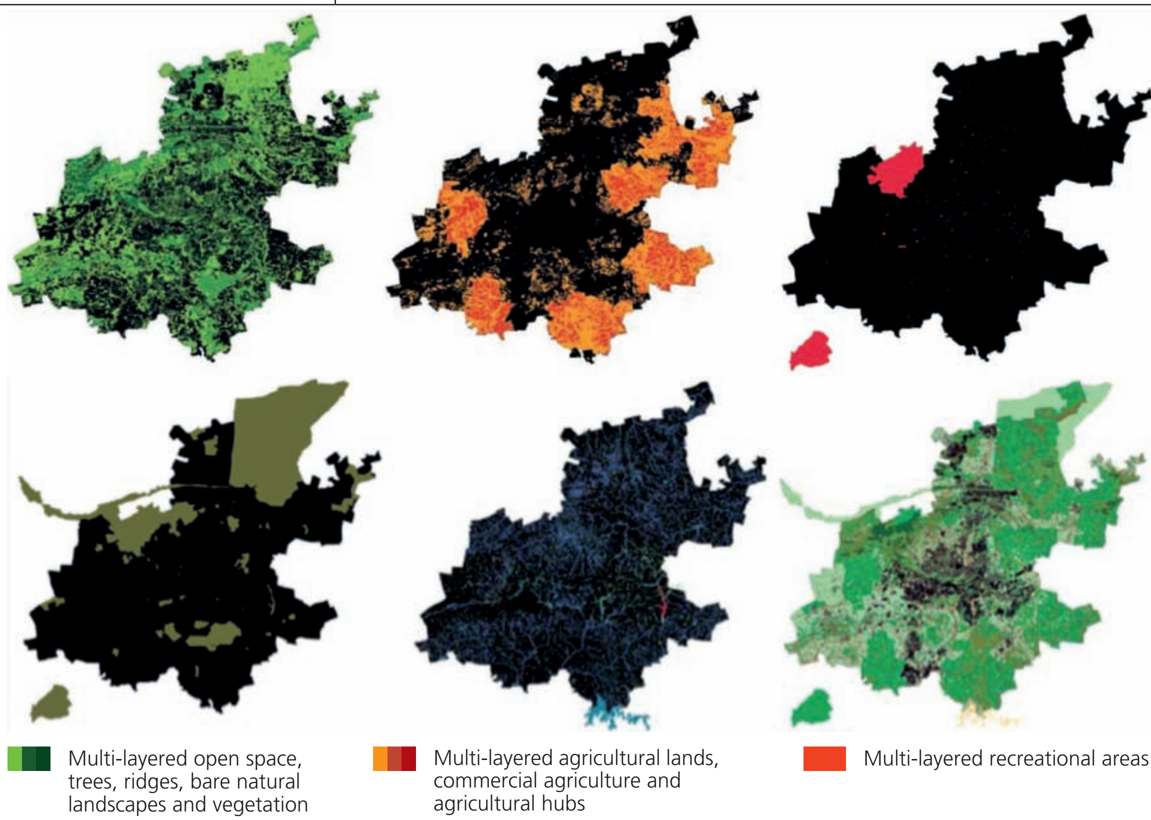
Gauteng city-region is located in northern South Africa. It has a population of 13 million and covers an area of 18,179 sq km. The region includes two of the largest cities in the country, Johannesburg and Pretoria, amongst other small urban and rural settlements. The Gauteng provincial government is focussing on new ideas to address the infrastructure issues in the region. Under various programmes like 2055 Process and Infrastructure Master Plan, it aims to establish GI as a way forward for regional scale infrastructure solutions.

Key learnings

In order to examine the status of GI, various data layers were retrieved and overlaid to establish a composite network of multi-layered GI, as mentioned in *Figure 3.11: Data layers for GI*.

Figure 3.11: Data layers for GI

Data head	Layers
Natural and planted vegetation	Indigenous forests, trees and their planting projects
Agriculture	Commercial agriculture and its hubs
Recreational green space	Single layer
Protected areas	Single layer
Hydrological networks	Perennial and non-perennial rivers or streams, Ramsar sites, wetlands, man-made water infrastructure, other natural water bodies (pools and lakes)



Source: State of Green Infrastructure in Gauteng City-Region, 2013

Case study

Water square Benthemplein, Rotterdam, The Netherlands

Year of Implementation: 2013

Background

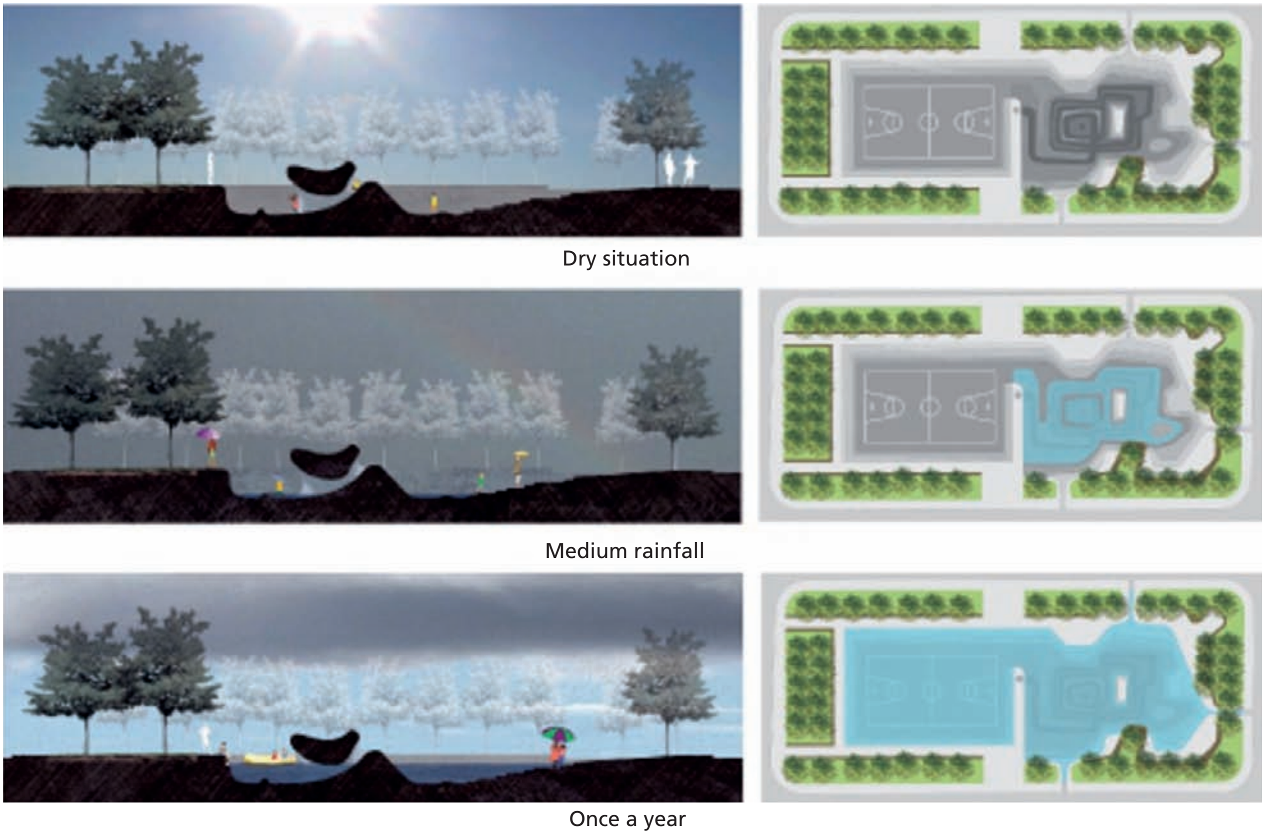
Rotterdam is a coastal city located in the South Holland province on the North Sea, within the delta of Rhine–Meuse–Scheldt River. It is the second largest city in the Netherlands, having a population of 623,953 (in 2015). It covers an area of 319 sq km, out of which 206.44 sq km is land area. It is the largest port city in Europe and is often known as 'gateway to Europe'. Rotterdam was voted as European City of the Year 2015 by the Academy of Urbanism. It is 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 regarding climate change, Rotterdam has been redesigning to manage floods due to extreme rainfall and rising sea levels. The various initiatives include roof gardens, green roofs, floating buildings and water plazas.

Key learnings

Water plazas (public open space) 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 captured by a green frame of grass and trees. When heavy rains occur, rainwater collected from the neighbourhood will flow visibly and audibly into the water square. Short cloudbursts will only fill parts of the square. When 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 the water can run off to the nearest open waterbody. 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 a buffering space, the water square is cleaned. It is designed to manage different levels of flooding based on different seasons and anticipated extreme events (*Figure 3.12: Seasonal flooding in water square—space capacity for different amounts of rainfall*).

Figure 3.12: Seasonal flooding in water square—space capacity for different amounts of rainfall



Source: Water square Benthemplein in Rotterdam, the Netherlands. Landscape Architecture Frontiers, 1(4), 2013, pp.136–143.

3.2 Urban areas with hills

Cities and towns located in hilly areas experience flash floods due to localized heavy rainfall which can also result in surface erosion and landslides.

Urbanization in hilly areas starts from a relatively flat area available along the ridge line and gradually expands towards the valley. Often during the process of expansion towards the prime valley line, encroachment occurs into the secondary transverse valley line blocking natural waterways.[9] These obstructions to natural drainage in urban areas may affect the slope stability adversely with varying severity, depending on the geology of the formation. Hence, inclusion of GI practices can keep these natural secondary valley lines clear so that natural drainage is not obstructed.

A few programmes and regulations In India contain provisions for city and regional level intervention of GI networks (see *Table 3.3: Legal provisions on GI for cities in hilly areas*).

3.2.1 GI approach and strategies for hilly areas

Various natural and traditional GI practices are available for controlling the sediment yield and runoff volume from hilly areas, like contour terracing, mulching, grassland development, creation of buffer zones with grass and trees, agroforestry, vegetated waterways and gully control measures.[10]

Grassy land: Grass reduces the velocity of surface runoff, minimizes the impact of rain on soil, and its root system helps in increasing infiltration. In urban areas, grassy land can also serve as open land needed to meet the requirements under municipal rules.

Forest land: Tree canopies reduce the direct impact of rain on soil. Besides, forest land, covered with falling leaves, also reduces the surface runoff velocity and increases infiltration. Falling leaves and decaying branches act as mulch and, thus, tree cover can control sediment yield and runoff volume.

Covering rain impacted areas with pebbles, vegetation or wood chips: The erosive power of rain drops depends on the size of the drop and the height from which it falls. Thus, the portion of ground lying below the line of a roof

Covering rain impacted areas with grass, pebbles, vegetation or wood chips
Source: Google images

Table 3.3: Legal provisions on GI for cities in hilly areas

Description	Remarks
Hill Area Development Programme (HADP), 2008	
HADP was initiated in 1965 and followed up by Western Ghats Development Programme (WGDP) in 1972	• Regional level GI networks can become part of this programme as per the strategies of HADP. • The activities under this programme by the respective forests departments include afforestation, forestry treatment, and maintenance of old plantations, village nurseries and parks.
Designated hill areas in India, under HADP: • Hill areas of the Great Himalayas covering the states of Jammu and Kashmir, Himachal Pradesh, Sikkim, Manipur, Mizoram, Arunachal Pradesh, Tripura, and Meghalaya. • Hill areas of the Great Himalayas in the following areas: Two hill districts of Assam, eight of Uttarakhand and major parts of Darjeeling District in West Bengal. • Hill areas of the Western Ghats covering the Nilgiri District (Tamil Nadu) and 163 Talukas comprising parts of Maharashtra, Karnataka. Kerala, Goa and Tamil Nadu.	
Approach and strategies: • Modernizing agriculture practices: Jhoom cultivation to be replaced by a more scientific method. • Development of small-scale industries at the household, cottage and village level. • Contain population growth to sustainable levels. • Afforestation programmes through village panchayats. • Generation of alternative means of livelihood. • Consolidation of small and scattered land holdings, thus helping in improving water and land management. • Improvement of the quality of livestock. • Fulfilment of requirements of food, fuel, timber and fodder through scientific utilization of scarce hill resources. • Development of non-conventional modes of energy. • Development of horticulture, serviculture and cash crops.	
MoEF&CC order regarding environmental clearance for Lavasa Corporation, 2011	
• The scale and intensity of development shall be as per hill station regulations • Clear demarcation of 'no development zone'	'No development areas' include: • All water bodies • Forest and forest-like lands • Areas steeper than 1:3
NGT Order Parwanoo-Shimla Highway, Decemeber 2016	
Construction of road was stayed	NGT banned felling of trees along national highways.

Source: Compiled by CSE, 2017

Detention drain and retention pond vegetated waterways

Source: Google images

edge is prone to more erosion as the accumulated rain over the roof falls with a higher velocity. Such drop line areas of water around the house can be covered with pebble or wood chips, or erosion resisting vegetation can be allowed to grow, which protects the soil from the direct impact of rain drops and allows more infiltration.

Detention drain and retention pond: To capture excess surface runoff, detention drains can be constructed across the slope and retention ponds can be constructed in a suitable location. This can minimize downstream erosion and flooding.

Vegetated waterways: Obstruction to flowing water is provided by covering paths (or channels) of accumulated surface runoff with vegetation. This reduces the velocity and, hence, the erosive power of the flowing water and prevents gully formation. The root systems of a vegetated waterway bind the soil, make it water resistant, and also promote infiltration. Depending on the status of the degradation of the waterway, different types of vegetation can be suggested.

Case study

Ecological and Energy Efficient Practices for Storm Water Management, Guwahati, Assam

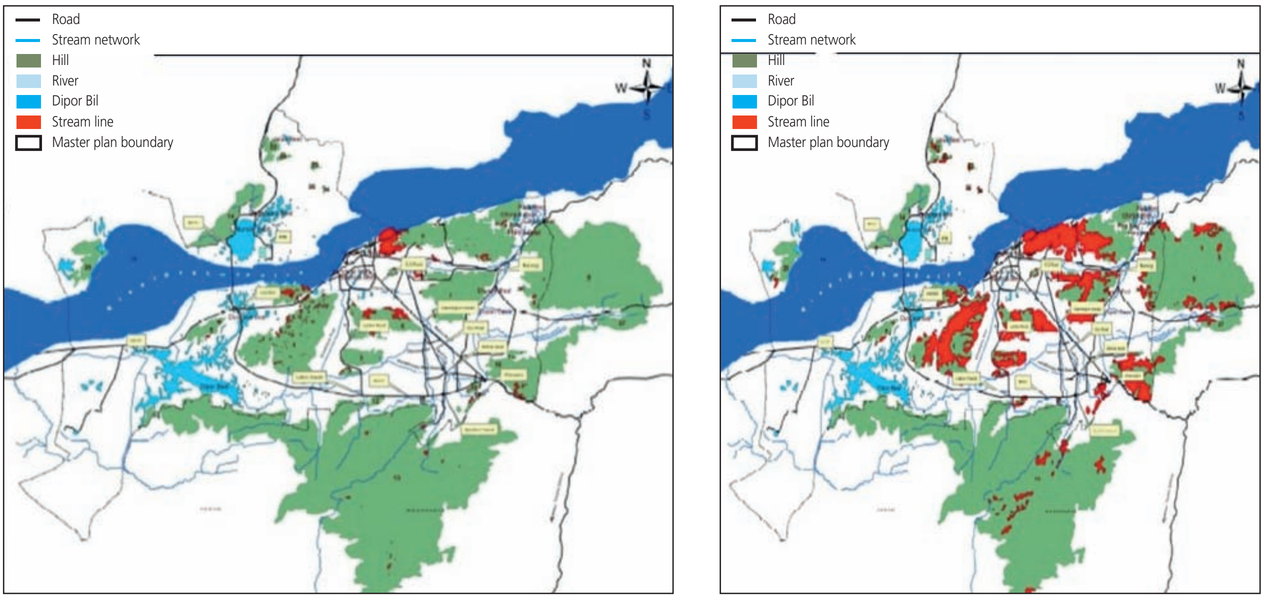
Year of research: 2010

Background

The research work focusses on addressing issues in urban water sector in hill areas of Guwahati, Assam. Recommendations include design strategies to control runoff and sediment deposition which, in the long run, are expected to address issues of urban flooding, drainage and water scarcity. Guwahati is a riverine port city, located in the hills of Assam, on the south bank of the river Brahmaputra. It is spread across 216 sq km. The change in land utilization from 1972 to 2000 shows a stark increase in the built-up area (see *Figure 3.13: Land utilization in Guwahati in1972 and 2000*).

The city receives an average rainfall of 35–40 mm per day during the monsoon seasons (1,740 mm average annually). A 20 per cent increase in precipitation is anticipated by 2050 (see *Figure 3.14:*

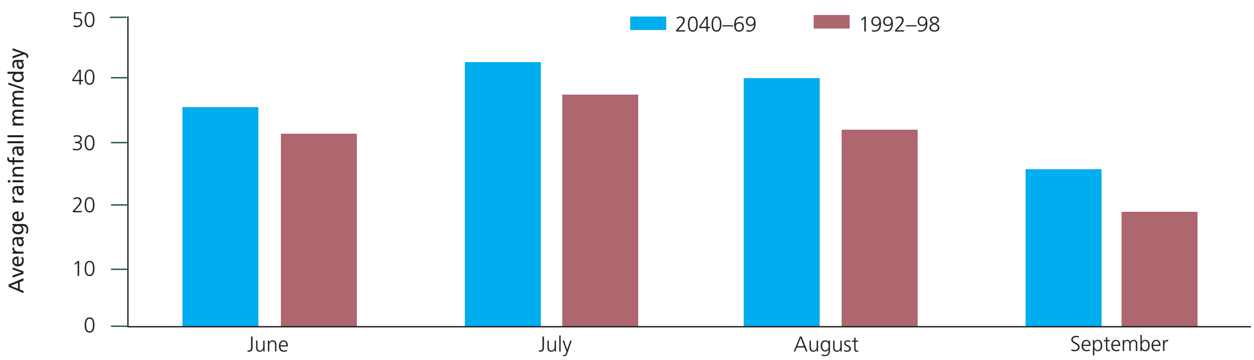
Figure 3.13: Land utilization in Guwahati in 1972 and 2000



1972 2000

Source: Planning and Design of Drainage in Hilly Area, IIT Guwahati, 2012

Figure 3.14: Projected average daily rainfall



Source: Planning and Design of Drainage in Hilly Area, IIT Guwahati, 2012

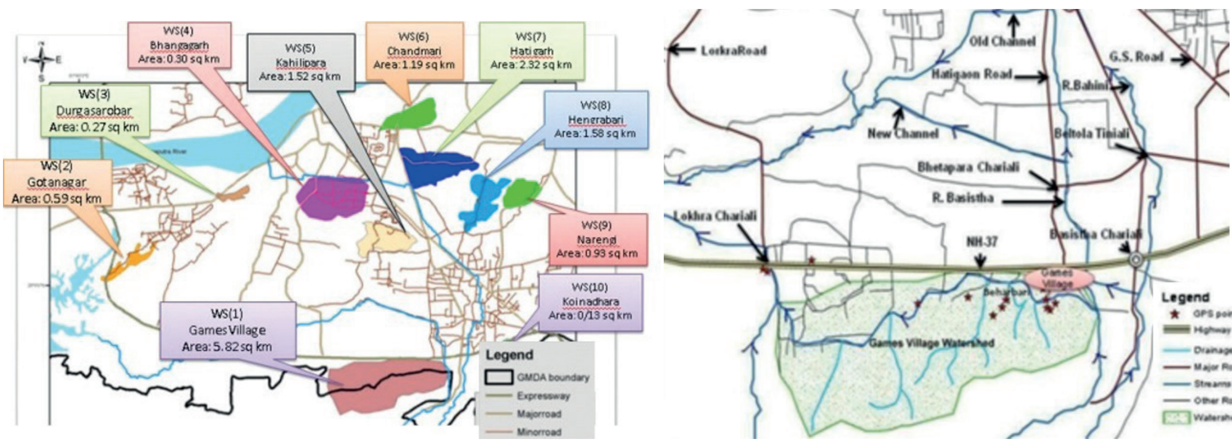
Projected average daily rainfall). It is estimated that such high intensity rainfall will result in high erosion in the hilly catchment area, high peak flow and longer dry spells.

Key learnings

The major issues faced by the city, particularly in the water sector are: • Flooding due to high water yield from the surrounding catchments because of conversion of forest land to urban areas. • Reduction in drainage capacity due to high sediment yield from the upper catchments and their deposition in the drains and river. • Water scarcity due to rapid depletion of ground water for reduced recharge and extensive pumping	To address these issues, more energy is required in terms of electricity, fuel, manpower for pumping out flood water, clearing waterways and drawing groundwater from deeper water tables.

Material and methods
A total of 10 experimental sub-watersheds were selected from the Guwahati Metropolitan Area (see *Figure 3.15: Experimental watersheds*) and the results regarding benefits were estimated. Optimal ecological management practices (EMPs) were modelled in order to assess results.

Figure 3.15: Experimental watersheds



Source: Planning and Design of Drainage in Hilly Area, IIT Guwahati, 2012

Results and recommendations
Disturbed watersheds, where unscientific practices of development are followed showed, the following characteristics on denudation:

• Increase in total sediment yield: 21-fold • Increase in total runoff volume: 54-fold • Change in chemical composition of water	Efficiency in sediment control, compared to barren land • Grassland cover: 65–100 per cent sedimentation control • Herb-land cover: 38–97 per cent sedimentation control

Figure 3.16: An example of planning and designing interventions in Guwahati

Source: Planning and Design of Drainage in Hilly Area, IIT Guwahati, 2012.

3.3 Urban areas with floodplains

Floodplains are among the most diverse, dynamic, productive and populated, but also the most threatened ecosystems on earth. Threats are mainly related to human activities that alter the landscape and disrupt fluvial processes to obtain benefits related to multiple ecosystem services.

Table 3.4: Benefits of floodplains in maintaining the natural hydrological cycle

Natural flood and erosion control	• Provide flood storage and conveyance • Reduce flood velocities • Reduce peak floods • Reduce sedimentation
Water quality maintenance	• Filter nutrients and impurities from runoff • Process organic wastes • Moderate temperature fluctuations
Groundwater recharge	• Improve infiltration and aquifer recharge • Reduce the frequency and duration of low surface flows

Floodplains of urban areas are prone to adverse changes due to development. Restoration of natural areas and the relocation of structures particularly threatened by flood hazards are included in the management options for these areas. Effective planning is of critical importance, and a special focus must be put on maintaining existing open areas along waterways and restoration of vegetation.[11]

In India, draft River Regulation Zone (RRZ) Guidelines are the only relevant document related to floodplain management. However, these guidelines have been in the pipeline since 2002 and no progress has been made to notify them (see *Table 3.5: Legal provisions on GI for cities with floodplains*).

3.3.1 GI approach and strategies for floodplains

A typical river corridor has several features carved by geological and hydrological processes effective on the landscapes (see *Figure 3.17: Major physiographic elements of a typical floodplain*). The river channel wanders through the landscape, carving through the terrain and depositing sediment on places where it goes. Sediment deposits and depressions on water banks might form wetlands, which are always or periodically flooded with water.[12]

Floodplains are areas bordering rivers and streams. These parts in river valleys are frequently defined as areas where the likelihood of flooding is high in a given year. Therefore, the term ‘100-year’ flood is used to define the flood with 1 per cent possibility of occurrence in any given year. As a river flows downward in an area, it may leave terraces, formed in time as the river flows at higher elevations. These landforms are part of a larger river corridor and play an extremely important role in the functioning of floodplain ecosystems.[13]

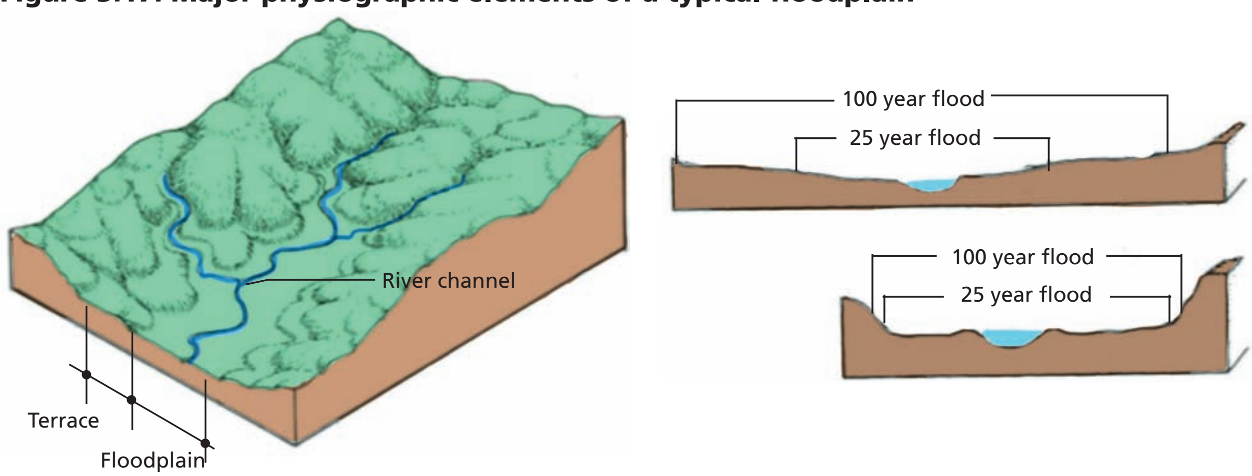
Watersheds are vital in understanding and managing the resources in floodplains. A watershed is an area drained by a river and its tributaries. Different watersheds are separated by ridges or divides. Like floodplains, they are formed in time due to the effects of various climatic, hydrological and geological processes. But watersheds are much bigger in size than floodplains, and more difficult to manage because larger areas are usually covered by

Table 3.5: Legal provisions on GI for cities with floodplains

Description	Remarks
Draft river regulation zone guidelines, 2017	
Prohibited zone: 500 m from 50-year flood line	RRZ Guidelines in the pipeline since 2002. However, no progress has been made to notify these Guidelines which regulate unplanned development in floodplains. Permissible activities and land uses not defined in the draft RRZ guidelines.
Restricted activities zone: 1 km from outer limit of the prohibited zone	
Regulated activities zone: 3 km from outer limit of the restricted zone	
River zone in Delhi: Zone 'O'	
Zonal Development Plan provides land use plan and permitted activities in the zone	Area proposed under recreation, agriculture and water bodies amounts to approximately 89 per cent of the total area (9,700 ha). These areas can have a maximum of 30 per cent built-up only.
NGT rulings for floodplain management	
Regarding construction on Yamuna floodplain in Agra, May 2017	Conditional clearance to construction projects: • A project will not be issued 'completed' certificate till the time it has constructed its own sewage treatment plant (STP). • Project proponents shall come up with composting unit to dispose compostable waste, to make arrangements for the disposal of solid municipal waste, and install their own rainwater harvesting system. • Regulating authorities shall ensure that the project is completed as per the order of the tribunal.
Regarding construction on Ganga floodplain in Uttarakhand, March 2016	Penalty of Rs 20 lakh imposed on Darrameks Hotels and Developers Pvt Ltd for flouting Uttarakhand High Court order prohibiting construction of commercial units within 200 m from the river.
Regarding camping on Ganga floodplain, December 2016	Ban on camping activity in the stretch between Kaudiyala and Rishikesh in Uttarakhand. A total of 33 camps banned. No activity in the 'eco-sensitive zone' upto 100 m from middle of the river. Conditional operation for 25 camp locations.
Namami Gange Programme, 2014	
Entry level projects	River surface cleaning, rural sanitation, crematoria modernization, and retrofitting of ghats
Medium-term	Municipal sewage management, industrial effluents management, biodiversity conservation, afforestation, and water quality management
Long-term	Ensuring adequate flow of water

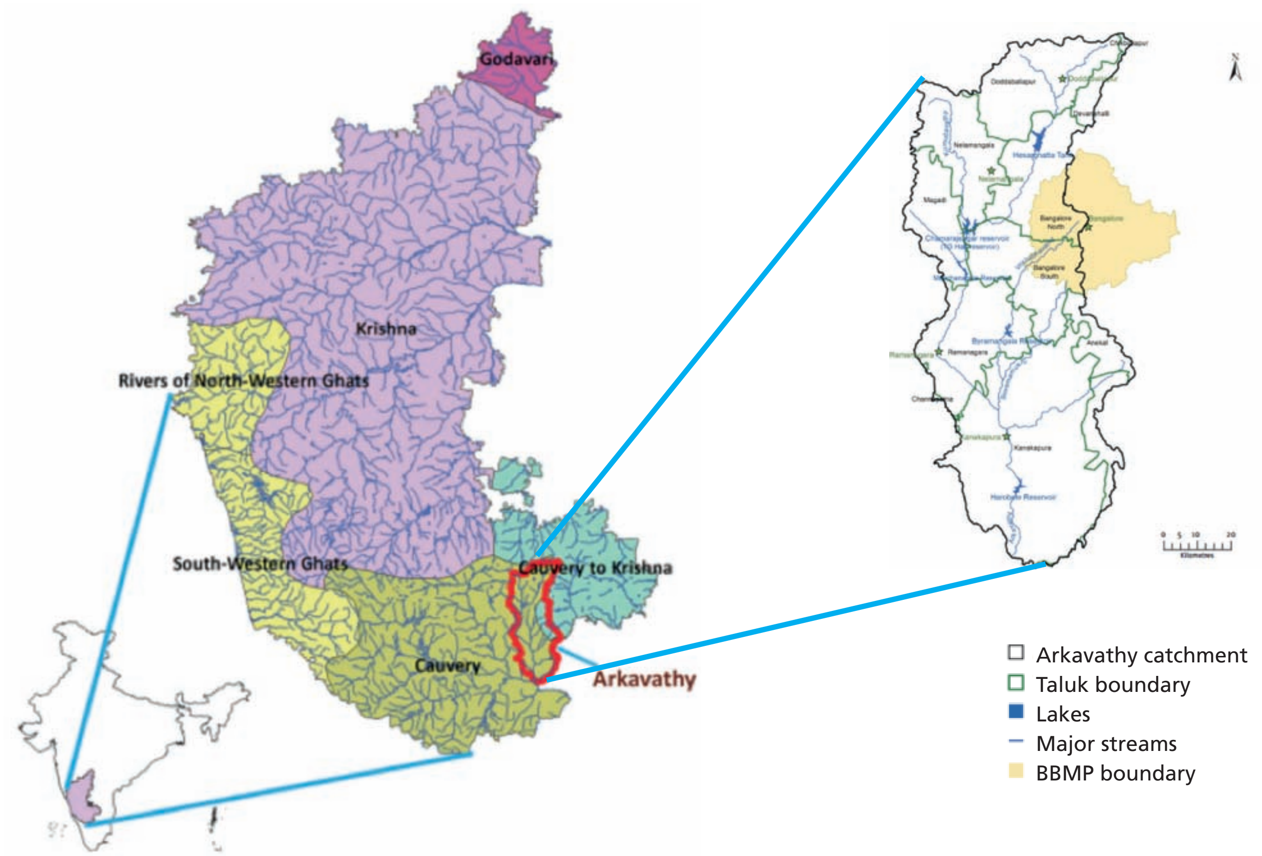
Source: Compiled by CSE, 2017

Figure 3.17: Major physiographic elements of a typical floodplain



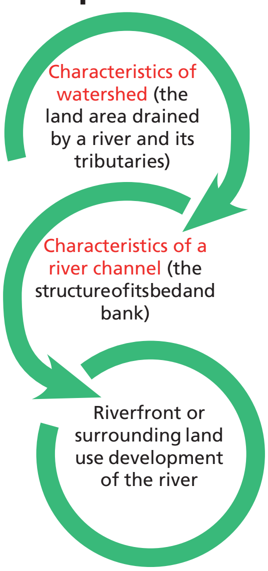
Source: Urban river landscapes. Advances in Landscape Architecture; 2013, Ozyavuz, M., Ed.; InTech: Rijeka, Croatia.

Figure 3.18: Example of a watershed—Arkavathy sub-basin within the river basins of Karnataka, India



Source: Water management in Arkavathy basin: A situation analysis. Environment and Development Discussion Paper No.1. Bengaluru: Ashoka Trust for Research in Ecology and the Environment, 2013

Figure 3.19: Green infrastructure approach for floodplains



Source: CSE,2017

various municipalities that have different governments and land-use strategies. However, it should be understood that upstream uses of land and water in a watershed have a negative impact on downstream areas and bring along the potential for increased flooding.

A developed landscape is confined to the river channel or wider flood-channel. Buildings and roads are flooded in the event of a 10-year or 100-year flood, which is not a pleasant situation for users and residents, but their inconvenience should be compared with other considerations. The preventive efforts for flood events are quite costly from both financial and environmental point of views, and it is also possible that these events will worsen the downstream flood problems.

GI in floodplains plays a more important role in ameliorating downstream flooding. In addition to the potential advantages of flood control and storage, it offers a wide range of other benefits, including improvement of water quality, conservation of nature, fisheries, recreation spaces and landscape. These areas are identified after considering watershed and river channel characteristics of the floodplain (see *Figure 3.19: Green infrastructure approach for floodplains*).

As a solution, management of flood events can be integrated into the land-use planning system. The present and recommended contours for each flood event can be drawn for every town:[14]

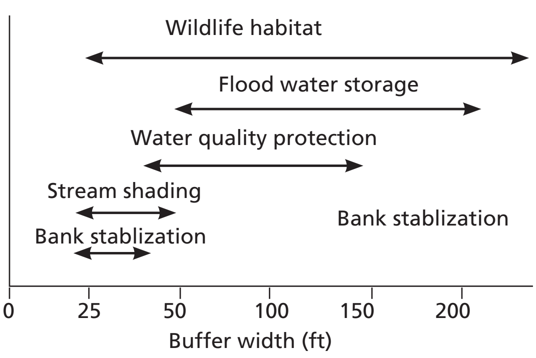
- Half-year: Natural reserves, playgrounds, and gardens.
- One-year: Needless car parks, light traffic roads, and flood-tolerant buildings.
- 25-year: Many roads and car parks, and the ground floors of needless buildings.
- 100-year: Large urban areas, excluding hospitals or other essential services. The effective areas of river form the overflow boundary.

The following are a few examples of the planning principles in floodplain urban areas:[15]

Stream buffers in urban areas: Buffer zones are areas situated next to a shoreline, wetland, or stream where development is restricted or prohibited. They facilitate the protection of ecological integrity of rivers, enhance connections between wildlife habitats, and allow rivers to function more naturally. A buffer network serves as 'right-of-way' for a river or stream and it is an indispensable part of the stream ecosystem. Buffers help protect the natural areas close to rivers and streams, and especially fragile zone like steep slopes and wetlands. They also reduce the impermeability of an area and filter sediments and storm-water pollutants like fertilizers and pesticides. They act like a filter and reduce the cost of water treatment systems by preventing pollutants from entering into the sources of potable water. Through the protection of open spaces along the river as buffer zones, storm water and flood control can be achieved in a natural way. Buffers also play an important role in reducing the risk of erosion caused by uncontrolled runoff and stabilize riverbanks with vegetation. A well-designed buffer zone helps protect the quality of water and habitat for plant and wildlife. As the water moves further through the wetland into the higher order streams and finally into the floodplain, it is essential to provide buffers at every stage.

Protect natural river features and functions: Protection of natural river features and functions necessitates avoiding the use of other engineering solutions, such as straightening, channelizing, or placing streams in underground pipes and culverts for flood control and management. There are rich and extensive predevelopment features in many urban rivers, including forested banks, fish and bird habitat, and wetlands.

Figure 3.20: Range of minimum riparian buffer widths for meeting specific buffer objectives



Source: USEPA, 3 August 2016

Figure 3.21: Stream orders with buffer areas and locations of associated riparian wetlands and floodplain

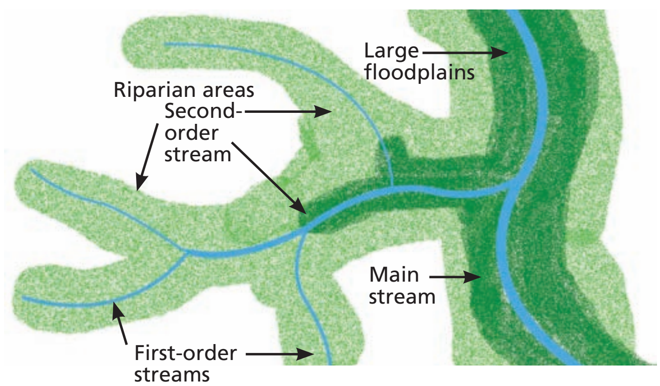
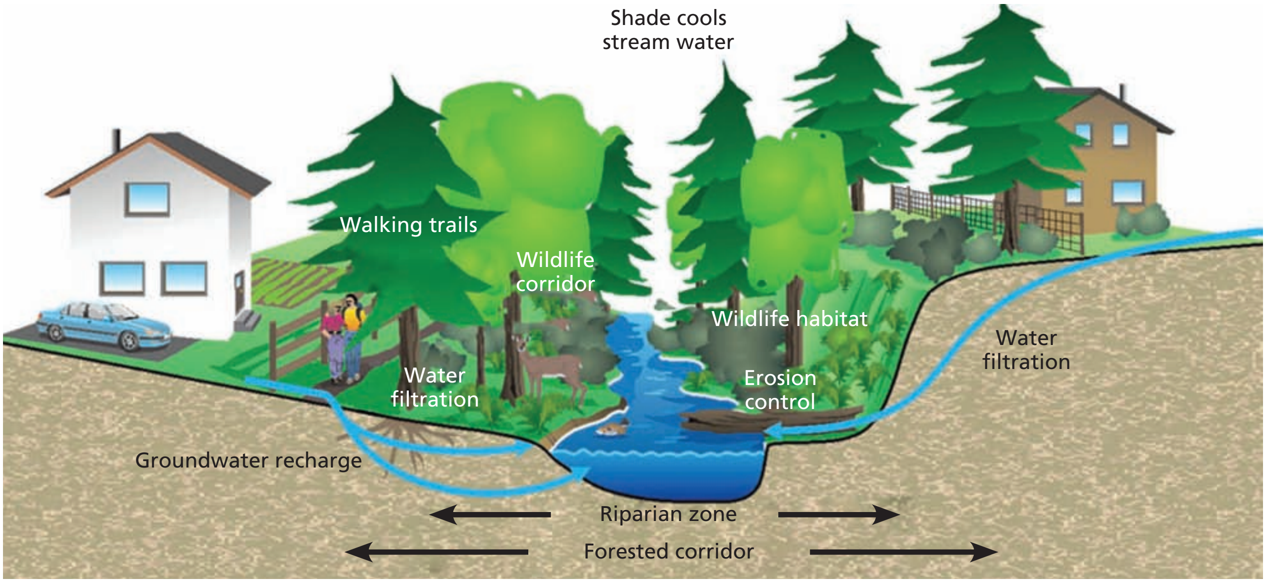


Figure 3.22: Stream buffers in urban areas



Source: http://www.cgenarchive.org/bowen-island-clean.html

Restore riparian and in-stream habitats: The restoration of riparian habitats requires taking other actions than simply replanting indigenous plants.

Reduce hardscapes: Hardscapes are structures like roads, parking lots, sidewalks, driveways, paved paths, rooftops, and other impermeable surfaces that prevent rainwater from filtering through soil and replenishing rivers and streams as groundwater. Nearly half of all stream flows are provided by groundwater. Through the reduction of hardscapes and installation of natural landscapes, it can be possible to restore natural watershed functions, filter pollutants, and prevent erosion of banks and channelization of streambeds.

The replacement of hardscape with soft, permeable surfaces, such as native grasses, shrubs, and trees in older, industrial or abandoned riverfront areas will improve environment from both aesthetic and ecological aspects.

Balance recreational and public access goals with river protection: Riverfront communities should be provided with facilities with as many recreational usages as possible; on the other hand, some conflicting usages should be balanced (e.g. between power boats and birdwatching platforms); and possible overuse of the river corridor should be managed.

Incorporate information about a river's natural resources and cultural history into the design of riverfront features, public art, and interpretive signs: Ecological interpretation and education is especially meaningful along urban rivers because most of the original forms of ecosystems have been damaged. The history and function of rivers may not be known well by the public. A conscious and well-informed society will understand the river ecology and regeneration potentials and know how to use their river safely; therefore, communities should be informed about water quality issues and hazards to swimming and boat navigation.[16]

Case study

River City Gothenburg, Sweden

Year of publication: 2011

Background

In 2010, the City Executive Board of Gothenburg decided to conduct an international workshop in order to prepare a vision for the future development of the city. 10 teams collaborated and prepared a vision and strategies for the city. This best management practice showcases the recommendations provided by the teams focusing on green areas. Gothenburg is situated on the Götaälv River, located on the west coast of Sweden. It is a collection of various small 'islands'. One of the major issues the city faces is urban flooding. Given the global climate change scenario, city officials expect the intensity and occurrence of flooding to increase. Recommendations made by the teams address various other initiatives, apart from green areas, like accessibility to services, mobility, inclusive planning, urban design, green economy, etc.

Key learnings

Strategies for urban flood control:	Steps:
• **Mitigation**: Make city car-parks porous and develop a green public space network	1. Study topography of the city to identify areas vulnerable to flooding.
• **Adaptation**: Creating space for water to enter the city, to be stored and released slowly back into the river	2. Prepare green and water network: Skeleton of green spaces, avenues and water bodies
• **Protection**: Protective landscape around the city	3. Overlay public uses on the skeleton for conceptual land use (*Figure 3.23: Conceptual land use plan*)

Figure 3.23: Overlay of maps for GI in Gothenburg

Topography map | Proposed green and water work | Proposed public spaces

Source: River City Gothenburg, 2011. Outcome of the International Workshop. Gothenburg City Executive Board: Gothenburg

Table 3.6: Recommendations

Vision		
Connect the city	**Embrace the water**	**Reinforce the centre**
Connect the city through social and physical links: Emphasis on green neighbourhoods and streets: Potential for green hubs	Active riverside space with connected green spaces	Concept of 'compact city' for diversified, robust and sustainable economy and environment

Proposed projects: • Backaplan: Change from large paved trading floor to green urban environment • Central region: Transformation to green spaces • Gullbergsvass: Heritage area • Lindholmen: Shipyard • Ringon and South River Bank	**Implemented projects till now:** Freeport neighbourhood: High density development in the inner core with park on the water. It connects the city across the river.

Source: RiverCity Gothenburg, 2011. Outcome of the International Workshop. Gothenburg City Executive Board: Gothenburg

Case study

Kahn Riverfront Development Project, Indore, India

Year of Implementation: 2017

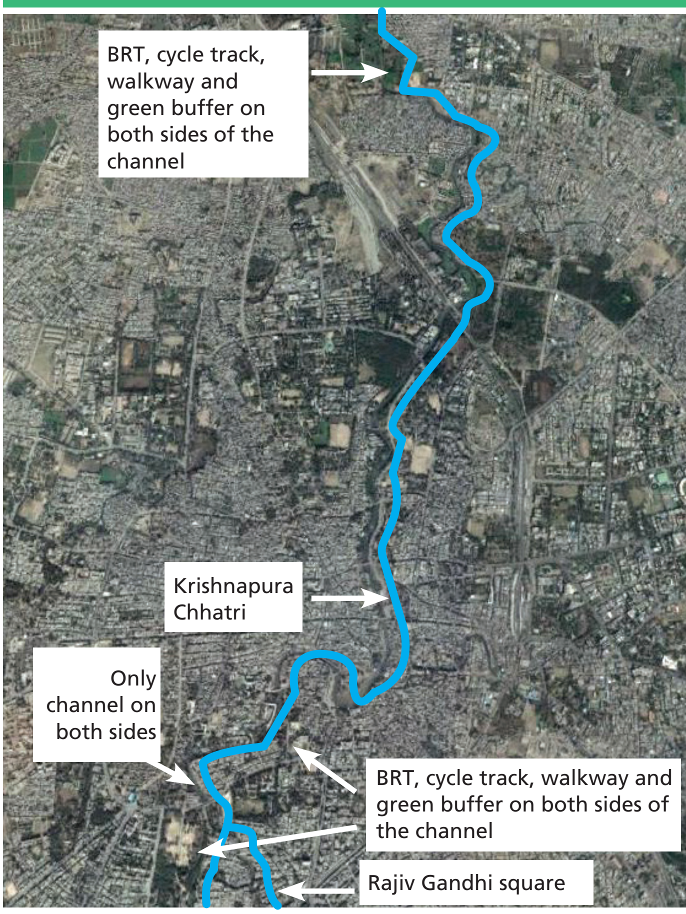
Background

The riverfront development for Kahn River is one of the projects envisaged by the Indore Municipal Corporation (IMC) under government of India's SMART Cities Mission.

River Kahn has a total length of 21 km in the city of Indore, out of which 3.9 km abuts the Rajwada. This stretch has been taken up for rejuvenation under the area-based development of the Rajwada. The river, once an urban heritage, has now been transformed into channels which carry sewage, becoming a dumping site for municipal solid waste and construction waste; has been encroached upon by unauthorized development; and has also become a source of groundwater contamination. A total of 33 slums exist along the river, a total of around 12,000 households.

Figure 3.24: Riverfront development project—Kahn river

Kahn river in Rajwada ABD



Key learnings

Key project features:

- Provisionofwaterretentionprojectsbymeansofcheck damsandrainwaterharvestingtoensureavailabilityof water for longer periods.
- Development of landscaping and open spaces for city-level recreational space.
- Interlinking public and religious places along the river for effective use as recreational space.
- Development of a fruit and vegetable market to accommodate shops and hawkers in the area.
- Treatment of wastewater and diversion of sewer network away from the river to uplift water quality.
- Improvement of bridges, footpaths and hawkers zone.

Expected benefits:

- Visual improvement of surrounding areas and clearance of encroachment.
- Urban rejuvenation and environmental improvement of the city.
- Groundwater recharge and improvement of water quality in wells/pumps.
- Cleaning of water and riverbed promotes aquatic life.
- Creation of a city-level recreation space making the riverfront accessible or all people
- Enhanced opportunities for tourism purposes.

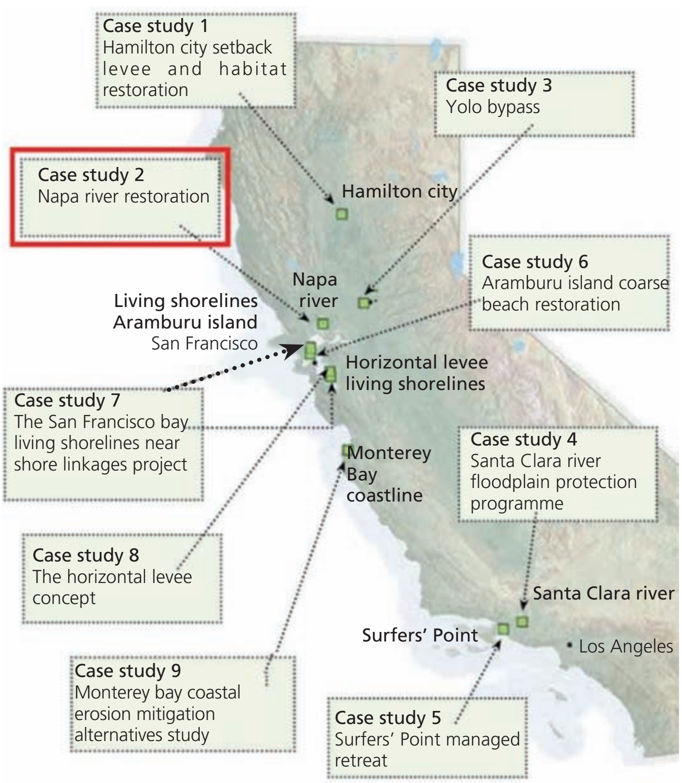
Source: IMC, 2016. SMART City Proposal for Indore,Indore: IMC

Case study

Reducing climate risks with natural infrastructure, California, USA

Year of implementation: 2013

Figure 3.25: Location of case studies



Source: Reducing Climate Risks with Natural Infrastructure, 2013

River Napa Restoration:
- Restoration, structure + nature, structure
- Around 900 acres of tidal wetlands and 135 acres of flood-plains and associated habitat restored

Background

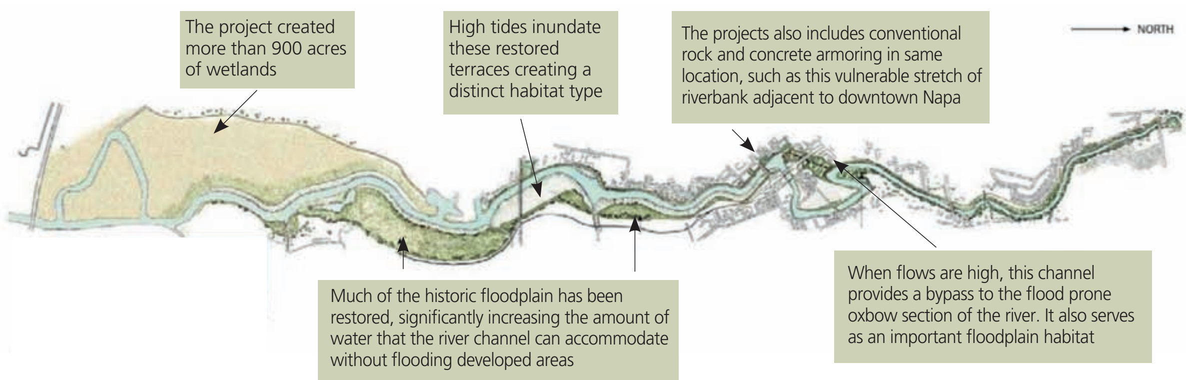
Nature Conservancy argues the case for GI as the way forward to tackle impacts of climate change on California, USA. It emphasises that GI can reduce risk to human life, property and businesses and build resilience. In *Figure 3.25: Location of case studies*, nine cases located in California which address sea-level rise, flood mitigation, etc. are showcased. Also see *Figure 3.26: River Napa restoration*.

Key learning:

Napa River restoration*:* As a short-term measure, 1 mile of the river was restored, from Trancas Road to Napa Creek, and from the confluence to one mile upstream. The project, 'Living River' plan for restoration and flood protection provides 100-year flood protection for the city of Napa.

Principles followed:
- **Preservation:** Protection of existing ecology and river and coastal processes
- **Restoration:** Restores natural ecology and river and coastal processes
- **Structure and nature:** Combination of engineered solutions and restored natural systems
- **Structure:** Build defences with a neutral or negative impact on natural systems

Figure 3.26: River Napa restoration



Source: Reducing Climate Risks with Natural Infrastructure. The Nature Conservancy, USA, 2013

3.4 Coastal cities

The coastal zone is a zone of transition where terrestrial and marine environments meet and interact to form distinctive environmental conditions. It is an area that has particular human, biological and physical features. Human activity and land use patterns in the coastal zone are shaped by a moderated climate and unique resources. Conversely, there are also the dangers of natural disaster and unrelenting erosion by the sea. Ecologically, habitats and species in the coastal zone are specially adapted to these environmental conditions.

Managed coastal realignment is the most common form of natural flood and erosion risk management in coastal areas. It has the potential to reduce the risk of flooding (or coastal erosion) and, at the same time, create connected habitats for wildlife. Natural coastal habitats provide a significant range of wider 'ecosystems services', including nutrient cycling, wave energy dissipation, provision of fish spawning areas, and carbon sinks.[17]

In order to protect coastal areas from adverse impacts of human settlements, the government of India, in 1991, issued the Coastal Regulation Zone (CRZ) Notification under the Environment Protection Act, 1986. The objective of the Notification was to regulate activities in the coastal areas. Amendments made to the CRZ Notification were notified in 2011. Coastal land up to 500 m from high tide line and 100 m from the banks of creeks, estuaries, backwaters and rivers, subject to tidal fluctuations, is CRZ. A comprehensive list of restricted, regulated and permissible activities in CRZ is available in the Notification. A provision for the preparation of a coastal zone management plan with the participation of local communities is also associated with it (see *Table 3.7: Coastal area regulations in India*).

3.4.1 GI approach and strategies for coastal areas

In coastal areas, natural features are created and evolved over time through the actions of physical, biological, geologic, and chemical processes. Nature-based features are those that may mimic characteristics of natural features but are created by humans to provide specific services such as coastal risk reduction. Nature-based features are acted upon by the same physical, biological, geologic, and chemical processes operating in nature, and as a result, they must be maintained in order to reliably provide the intended level of services.

Natural and nature-based features can enhance the resilience of coastal areas challenged by sea-level rise and coastal storms. For example, beaches are natural features that can provide coastal storm risk reduction and resilience. The sloping near shore bottom causes waves to break, dissipating wave energy over the surf zone. Dunes that may back a beach can act as a physical barrier that reduces inundation and wave attack on the coast landward of the dune (see: *Figure 3.27: Factors involved in reduction of coastal flooding*).[18]

One of the first widely used wetland classifications systems (devised by Cowardin *et al.* in 1979) categorized wetlands into marine (coastal wetlands), estuarine (including deltas, tidal marshes, and mangrove swamps), lacustarine (lakes), riverine (along rivers and streams), and palustarine ('marshy'—marshes, swamps and bogs) based on their hydrological, ecological and geological characteristics.

Lagoons and backwater plays a very important role in stabilizing coastal borders. Mangroves are mostly found in such eco-systems, not only protecting

Table 3.7: Coastal area regulations in India

CRZ-1: Ecologically sensitive zones which play an important role in maintaining the ecological integrity of the coastal area, e.g., mangroves, coral reefs, mud-flats, sand dunes, national parks, marine parks, sanctuaries, reserved forests, wildlife habitats, salt marshes, nesting grounds of birds and turtles, structures of archaeological importance, and inter-tidal areas.
CRZ-2: Areas that have been developed up to or close to the shoreline, including roads, infrastructure lines and developed areas.
CRZ-3: Areas that are relatively undisturbed and don't belong to CRZ-1 or CRZ-2. This may include a coastal zone of rural areas, areas in the municipal limits or any other designated urban area which is not substantially built-up.
CRZ-4: Water area from the low tide line (LTL) upto 12 nautical miles into the sea. It also includes water areas of tidal induced water bodies, from the mouth of the water body to the point of influence of the tide.
CRZ-5: Areas requiring special considerations for the purpose of protecting the critical coastal environment and difficulties faced by the local communities. It has two categories: • Category 'A': CRZ areas under ULB of Greater Mumbai, Goa and Kerala, including backwaters. • Category 'B': Critically vulnerable coastal areas, e.g., sundarbans in West Bengal and other ecologically sensitive area.

Source: Compiled by CSE, 2017

the land from speedy waves but from cyclones as well. During a tsunami, coasts with abundant mangrove vegetation are least affected.

Coastal wetlands may contribute to coastal storm protection through wave attenuation and sediment stabilization. Dense vegetation and shallow water in wetlands can somewhat slow the advance of storm surges and slightly reduce the surge landward of the wetland or slow its arrival time. Wetlands can also dissipate waves, potentially reducing the amount of destructive energy propagating on top of the surge, though evidence suggests that slow-moving storms and those with long periods of high winds that produce marsh flooding can reduce this benefit.[19]

Apart from coastal wetlands, vegetated tidal shoreline buffers can protect coastal waters from these influences as well as provide treatment of non-point source pollution through active filtration and uptake of excess nutrients, sediments, and other pollutants. A tidal shoreline is a strip of land at the edge of an estuarine water body. Tidal shorelines occur along bays, rivers, creeks and ponds and are influenced by the force of ocean tides into an estuary. The natural functions of a shoreline buffer is to protect coastal water quality and provide an area of transition for upland and aquatic habitats. Tidal shorelines are subject to tidal pulses and currents, storm surges, wind, waves and boat wakes as well as runoff and disturbance from up-gradient and overland sources. Plant and wildlife communities flourish in the undisturbed environment of a shoreline buffer, providing greater ecological value.

Example of coastal shoreline buffers

Intertidal and muddy coast: This type of coast is characterized by fine-grained sedimentary deposits, predominantly silt and clay that come from rivers; it can be classified as a 'soft' coast. It has a broad gentle seaward slope, known as an intertidal mudflat, where mangrove forest, saltmarshes, shrubs and other trees are found. Most erosion is generated by river damming that reduces sediment supply, diminishes the cover of vegetation (usually mangroves and saltmarshes) and exposes roots of the vegetation by lowering the mudflat, which leads to their final collapse. During storms, healthy and dense vegetation or coastal forests and trees can serve as barriers and reduce storm wave height, as well as afford some protection to the area behind them. In the case of a tsunami, coastal forests and trees can decrease wave height and tsunami flow speed to some

Figure 3.27: Factors involved in reduction of coastal flooding

Vegetated features

Benefits/processes
- Breaking of offshore waves
- Attenuation of wave energy
- Slow inland water transfer
- Increased in filtration

Performance factors
- Marsh, wetland, or SAV elevation and continuity
- Vegetation type and density

Oyster and coral reefs

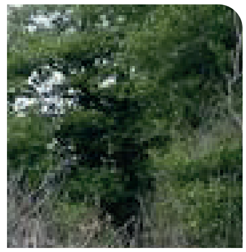
Benefits/processes
- Breaking of offshore waves
- Attenuation of wave energy
- Slow inland water transfer

Performance factors
- Reef width, elevation and roughness

Barrier islands

Benefits/processes
- Wave attenuation and/or dissipation
- Sediment stabilization

Performance factors
- Island elevation, length, and width
- Land cover
- Breach susceptibility
- Proximity to mainland shore



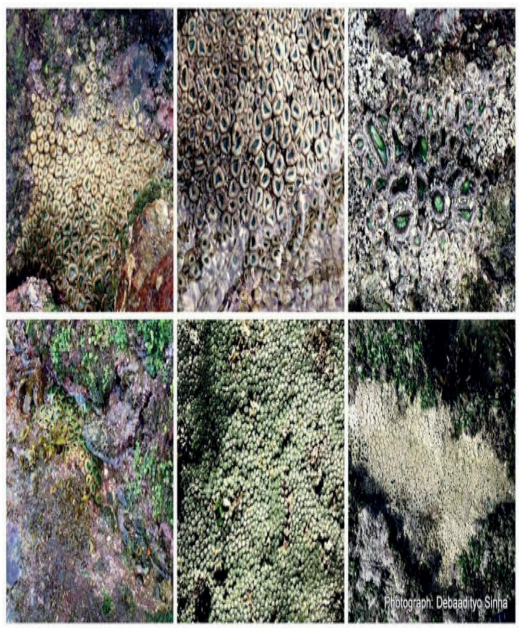
Maritime forests/shrub communities

Benefits/processes
- Wave attenuation and/or dissipation
- Shoreline erosion stabilization
- Soil retention

Performance factors
- Vegetation height and density
- Forest dimension
- Sediment composition
- Platform elevation

Source: USACE (U.S. Army Corps of Engineers). 2013 (September). Coastal Risk Reduction and Resilience: Using the Full Array of Measures.

Mangrove along Kerala coast. Mangroves are habitats for numerous aquatic species and protect coastal lands from erosion.



Corals at Kanyakumari, India.

Source: Google image

extent if the forest is dense and wide enough. Both extreme events can cause severe erosion and scouring on the coast and at the river mouth. Sundarbans of West Bengal are an excellent example of this type of coast.

Sandy coast: This type of coast consists of unconsolidated material—mainly sand from rivers and eroded headlands, broken coral branches (coralline sand) and shells from the fringing reefs. It can be classified as a soft coast with reef protection offshore. The beach slope varies from gentle to steep slopes depending on the intensity of natural forces (mainly waves) acting on them. Coconut trees, waru (Hibiscus tiliaceus), casuarina catappa, pandanus, pine trees and other beach woodland trees are common here. Most erosion is caused by loss of the protective function of the coastal habitat, especially coral reefs (where they are found) that protect the coast from wave action; and coastal trees that protect the coast from strong winds. During extreme events, healthy coral reefs and trees protect coasts to some extent by reducing wave height and energy as well as severe coastal erosion. Some of the stretches along Western Ghats are examples of this type of coastal area.

Figure 3.28: Muddy coastal shoreline buffer

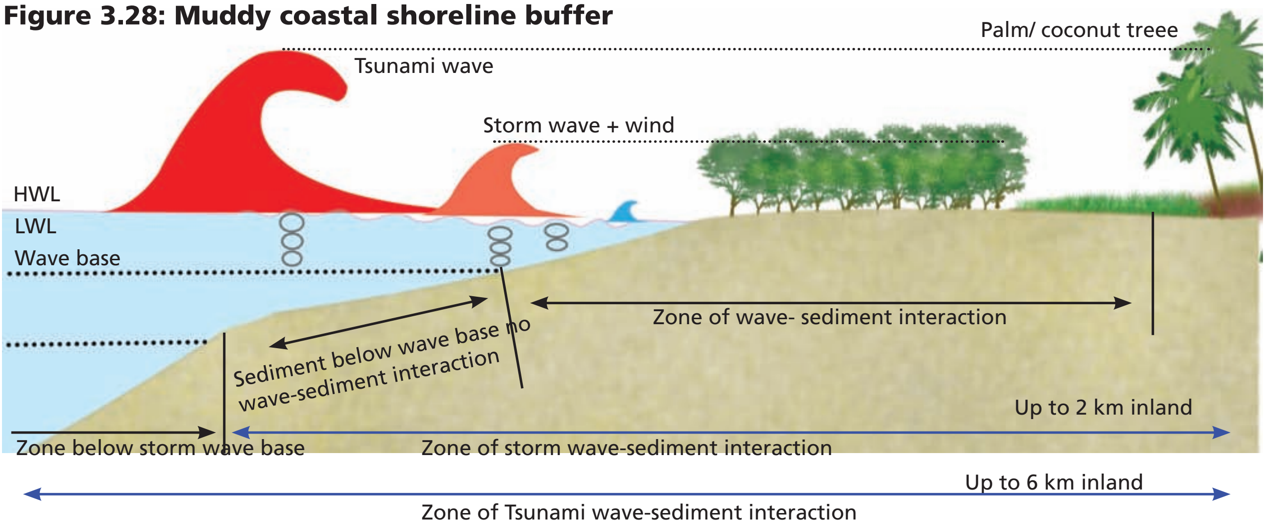
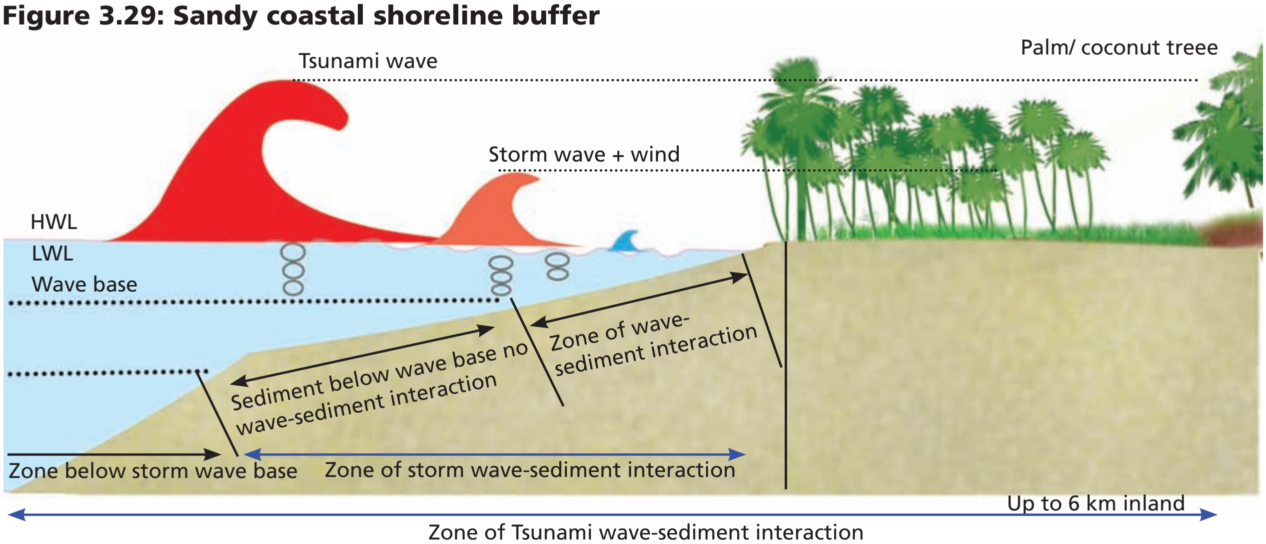


Figure 3.29: Sandy coastal shoreline buffer



Source: Coastal protection in the aftermath of the Indian Ocean tsunami: What role for forests and trees? Rap publication, p 7, 2007

Case study

Coastal zone protection and conservation in spatial planning for Laane-Viru, Estonia

Year of publication: 2011

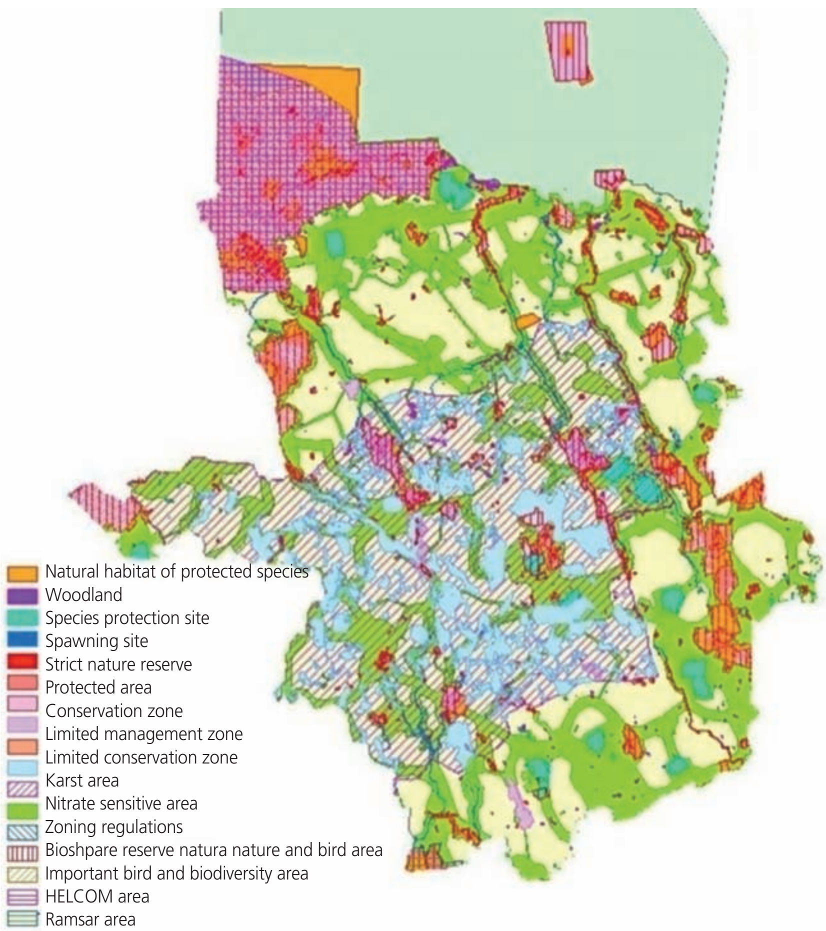
Background

Several measures have been undertaken for the protection and management of coastal areas in Europe. Coastal zoning regulations have been discussed in various conventions under European Integrated Coastal Zone Management. Regarding the spatial planning in the Baltic Sea region, zoning regulations are discussed under Vision and Strategies around the Baltic Sea, 2010 and Helsinki Convention: Convention on the Protection of the Marine Environment in the Baltic Sea Area (HELCOM). As a BMP, the main features of the county plan for Laane-Viru, Estonia are discussed here.

Key learnings

County plan for Laane-Viru: The purpose of preparing the plan is to define the key areas and conditions for developing the coastal area of the county over the next ten years, determine the feasibility to locate GI, and establish the general terms for vulnerable land use areas considering natural water regulation, controlling flood events and maintaining water quality.

Figure 3.30: Zoning of Laane-Viru, Estonia



Plan features:

- Zoningforbothsea-wardandland-ward side

  Land-ward side: 3 km from shore-line; sea-ward side: Up to the imaginarylinejoiningthepeninsulas

- **Shore zone:** Up to the first national road
- **Hinterland zone:** Land-ward from the national road to coastal zone boundary (3 km)
- Near-shore zone and coastal sea zonearesea-wardsideoftheshore line

Source: The best practices of coastal zone protection and conservation in spatial planning. Report.Estonian University of Life Sciences, 2011

Case study

A guide to assess green infrastructure cost and benefits for flood reduction, Ohio, USA

Year of notification: 2015

Background

A BMP of Silver Creek Watershed, Toledo, Ohio, USA is discussed as an application to assess the potential of GI in flood mitigation. The study is part of a guide, 'Assessing Green Infrastructure Cost and Benefits for Flood Reduction' which was prepared by NOAA (2015). The guide was prepared with the purpose of outlining a process to assess the cost and benefits of GI to reduce flooding.

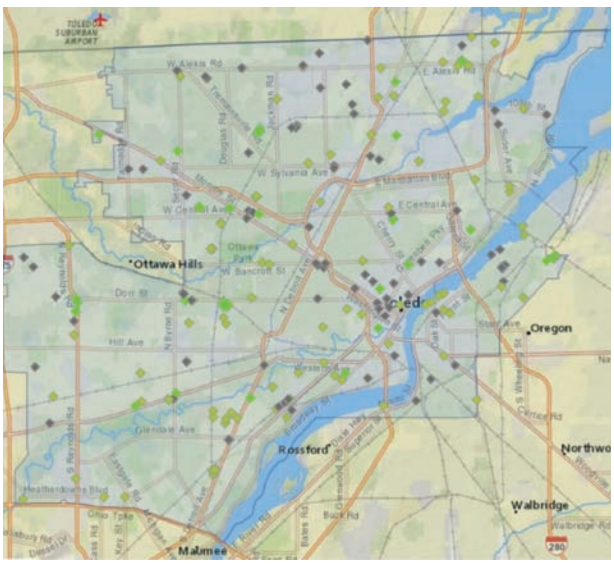
Key learnings

Silver Creek Watershed: The Silver Creek Watershed in Toledo, Ohio covers an area of 4,746 acres. It was selected because future land use was anticipated to change and there was information available from a previous study that could be used to conduct assessment. Precipitation data till 2035 was anticipated and this was selected as a horizon year. Damages due to flood were estimated to be $7,38,300 for the current scenario and $980,800 for the future scenario. Characteristics of the project are mentioned in T*able 3.8: Characteristics of Silver Creek Watershed, Toldedo.*

Table 3.8: Characteristics of Silver Creek Watershed, Toledo

Flooding characteristics	GI options	Costs and benefits
• Flat terrain • High built-up • Frequent street and basement flooding • Mostly building and infrastructure damage	Bio-swales; acquisition of tax-forfeited land for flood storage; green roofs; permeable pavements; retention ponds, widen storm water drain.	• 20-year-horizon: Damages reduced by $7,00,000 ($38,000/year) • 50-year-horizon: Benefits exceeded costs by $70,000

Figure 3.31: Spatial representation of benefits of GI



GI: Multiple cost benefits from flood mitigation
Infiltration: Retention and detention benefits; groundwater recharge benefits
No cost benefits but water quality improved   Toledo city

GI benefits include groundwater recharge, conservation of habitat, increasing aesthetic value, improved water quality, reduced runoff, reduced peak discharges and reliance on (and costs associated with) grey infrastructure.

He'eia watershed priority GI: Reinstating traditional taro patches to provide flood storage along with cultural value and ecosystem services.

Flood storage volume required to reduce peak discharge of 100-year-storm for Silver Creek, Toledo: 31 acre-feet over 3 hours (38, 238 cub. m.)

The various benefits of GI in the Silver Creek Watershed are spatially presented in Figure 3.31: Spatial representation of benefits of GI.

Source: NOAA, 2015. A Guide to Assessing Green Infrastructure Costs and Benefits for Flood Reduction. NOAA, US

Case study

Coastal storm-water management through green infrastructure: A handbook for municipalities, USA

Year of publication: 2014

Background

The handbook *Coastal Storm-water Management through Green Infrastructure* was designed by USEPA in 2014, primarily to assist the coastal municipalities within the Massachusetts Bays Programme Area to incorporate GI into their stormwater management planning and address stormwater runoff. However, the principles outlined in this handbook can also be applied more broadly by municipal infrastructure and resource managers of other states and regions.

GI concepts

GI planning practices:	Attributes addressed through GI:
• Reducing impervious surfaces • Disconnecting impervious areas • Using cluster or consolidated development • Using xeriscaping and water conservation practices	• Maximum allowable contributing drainage area • Soil infiltration • Pollutant removal: Sediments, nutrients, trash, metals, bacteria, oil, organics, pesticides • Runoff volume reduction and peak flow control • Groundwater recharge

GI design and planning process

The approach to designing and planning GI as per the handbook is illustrated in *Figure 3.32: Design and planning process of GI.*

Figure 3.32: Design and planning process for GI

ASSESS WATERSHED

Provide background on regulatory requirements related to stormwater management and geography of the site

- Indentify stakeholders and roles
- Identify watershed/sub-watershed
- Identify existing hydrologic and hydraulic date
- Characterise known pollutant loading
- Identify additional data needs

IDENTIFY GI OPPORTUNITIES

To evaluate and prioritize each potential parcel and street segment for the potential implementation of GI concepts and practices

- Indentify target sub-watershed(s)
- Complete primary screening of potential BMP
- Complete secondary screeding and prioritization

SITE ASSESSMENT, PLANNING AND DESIGN

To apply GI concepts and practices for a retrofit, redevelopment or new development site

- Review site planning and design principles
- Incorporate GI principles and concepts in a site design
- Prepare conceptual site design plans

GI PRACTICES

To provide an overview of GI practices with guidance on selecting the appropriate practices(s) for the selected site design

- Use 'BMP selection matrix' to select BMPs
- Review common GI practices and utilize resources to develop full design
- Consider potential BMP construction and post-construction issues

GI REVIEW PROCESS

To achieve effective implementation

- Incorporate a process of reviewing and approving GI plans
- Provide incentives to encourage GI

Source: US EPA, 2014. Coastal Storm-water Management through Green Infrastructure: A Handbook for Municipalities. US EPA: US

Key messages

- Flooding can be classified as localized, riverine, and coastal. GI solutions are highlighted in alignment with different typologies of urban areas, e.g., inlands, hilly areas, coastal areas and floodplains.
- In urban inlands, GI can be provided through 'water bodies' (lakes and wetlands) associated with 'public open spaces' (parks and green buffer).
- Various natural and traditional GI practices (like contour terracing, mulching, grassland development, creation of buffer zones with grass and vegetated waterways) are available for controlling the sediment yield and runoff volume from hilly areas.
- GI (like stream buffers and reducing hardscapes) in floodplain plays an important role in ameliorating downstream flooding. In addition to the potential advantages of flood control and storage, it offers a wide range of other benefits, including improvements in water quality, nature conservation, fisheries, recreation and landscape.
- GI practices (natural and nature-based features like coastal wetlands and coastal shoreline buffers) can enhance the resilience of coastal areas challenged by rising sea levels and coastal storms.

4. Value of green infrastructure

This chapter addresses the value of and benefits attached to GI. The illustrative case studies in this chapter provide examples of GI options that address water management challenges with possible GI solution, while delivering a number of significant co-benefits. *Table 4.1: GI solutions for water resources management* provides an overview of GI solutions that are relevant for water resources management and are discussed in this guide. Furthermore, these GI solutions are compared with grey water infrastructure solutions (such as water-treatment plants, dams and levees, and the expansion of sewage networks) which are attractive as they can offer immediate and high visibility impacts. The solutions marked with an asterisk consist of built or grey elements that interact with natural features and seek to enhance their water-related ecosystem services.[1]

4.1 Benefits of GI

The benefits of GI can be classified into: hydrological, ecological, social, environmental, and land regeneration (see *Figure 4.1: Benefits of green infrastructure*; also see *Appendix 5: Benefits provided by Green Infrastructure recognized across the globe*).[2]

Hydrological: In urban areas, alterations of the natural environment affects the movement of water through the hydrological cycle and changes its composition. By replacing vegetation with more impermeable material, urban development has had a significant impact on the hydrology, freshwater ecology and terrestrial ecosystems that river systems support.

GI can provide hydrological benefits in areas of flood alleviation and water quality (improvement and protection). Trees (in the riparian zone and floodplains) can contribute to flood alleviation by delaying the downstream passage of strong water flows, reducing the volume of runoff, and promoting rainfall infiltration into the soil, thereby reducing the rate of runoff. Flood alleviation using trees may be restricted to small-scale floods. However, this is significant as trees store more water during lower intensity rainfall events over longer time periods than intense events over short periods. Moreover, small storm events are responsible for most of the annual pollutant load into receiving waters so there is considerable scope for water quality improvements through GI solutions. Wetlands and retention or detention basins also offer hydrological benefits through reduced runoff, increased storage, and improved water quality.

Ecological: Ecological benefits of urban GI are largely related to the provision of habitat. Species from the very common to the very rare make use of all types of GI, from large sites to tiny patches on roundabouts and road islands. Provision of GI in urban areas can help create effective networks to provide opportunities for species to move, spread and colonize new habitats.

Social: There are many potential social benefits that good quality, accessible green spaces and infrastructure can provide. The most significant of these can be grouped into three broad categories of improvements in levels of physical activity and health, promotion of psychological health and mental well-being, and facilitation of social interaction, inclusion and community cohesion. At

Table 4.1: GI solutions for water resources management

Water management issue (Primary service to be provided)		GI solution	Location				Corresponding grey infrastructure solution
			Watershed	Floodplains	Urban	Coastal	
Water supply regulation (including drought mitigation)		(Re-)afforestation and forest conservation	■				Dams and groundwater pumping water distribution systems
		Reconnecting rivers to floodplains	■				
		Wetlands restoration and conservation	■	■			
		Constructing wetlands	■	■			
		Water harvesting*	■	■			
		Green spaces		■			
		Permeable pavements*		■			
Water quality regulation	Water purification	(Re-)afforestation and forest conservation	■				Water treatment plant
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Green spaces			■		
		Permeable pavements*			■		
	Erosion control	(Re-)afforestation and forest conservation	■				Reinforcement of slopes
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
	Biological control	(Re-)afforestation and forest conservation	■				Water treatment plan
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration and conservation	■	■	■		
		Constructing wetlands	■	■	■		
	Water temperature control	(Re-)afforestation and forest conservation	■				Dams
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration and conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Green spaces (shading of water ways)			■		
Moderation of extreme events (floods)	Riverine flood control	(Re-)afforestation and forest conservation	■				Dams and levees
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration and conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Establishing flood bypasses		■			
	Urban storm water runoff	Green roofs			■		Urban storm water infrastructure
		Green spaces			■		
		Water harvesting*	■	■	■		
		Permeable pavements*			■		
	Coastal flood (storm) control	Protecting mangroves, coastal marshes				■	Sea walls
		Protecting and restoring reefs (coral or oyster)				■	

Source: 2014. Green Infrastructure: guide for water management, United Nations Environment Programme their best, green spaces can also help facilitate social interaction, integration and the development of community cohesion.

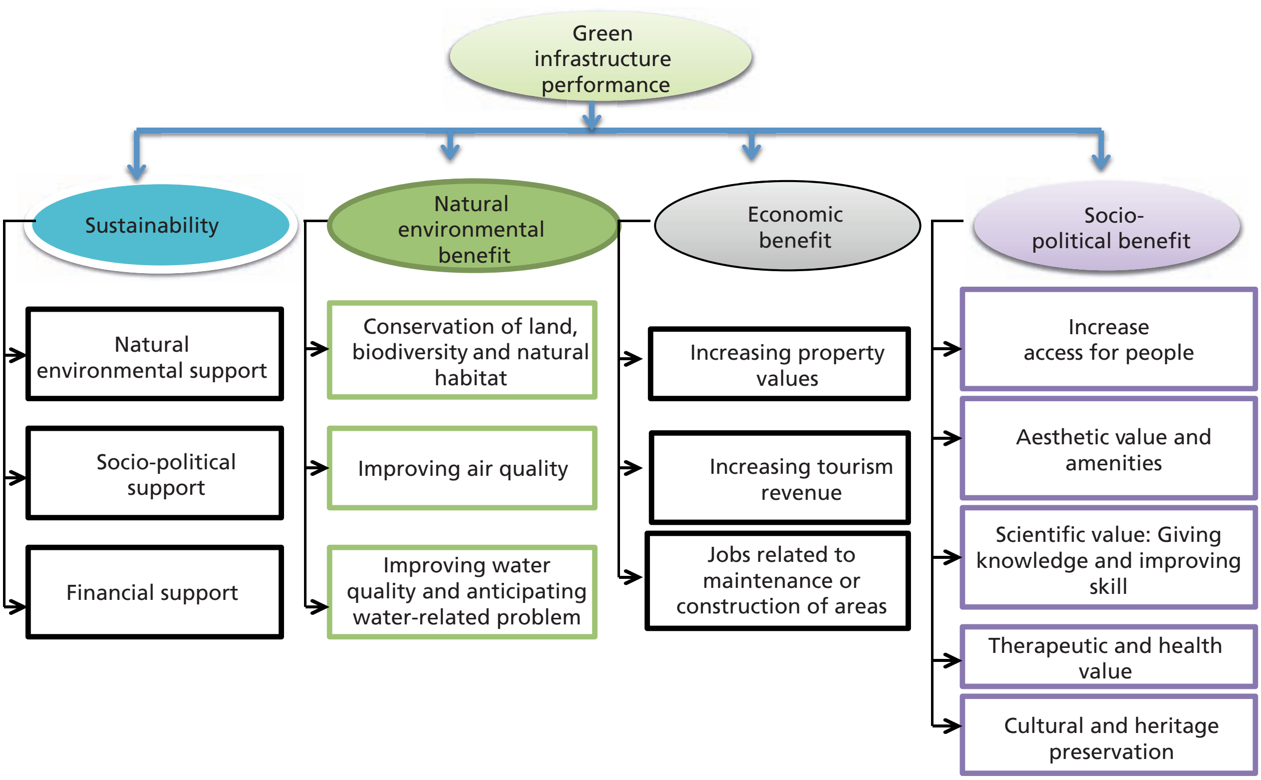
Environmental: Urban GI can deliver a wide range of environmental benefits, particularly:

- Reduction in air pollution.
- Reduction in flood risk as part of sustainable urban drainage systems.
- Improvement of the perceptions of an urban area as aesthetically pleasing.
- Amelioration of high summer temperatures caused by the urban heat island effect and climate change.

Land regeneration: Previously developed under-used and neglected land in and around urban centres can provide real opportunities to deliver social, environmental and economic benefits via conversion to GI. In particular, by delivering improved environmental health, quality of place and subsequently increased land value and regional investment, the conversion of barren land to GI can be very cost-effective. Nevertheless, land regeneration requires both project resources and revenue funds for long-term management and maintenance. These can be substantial. The regeneration of land presents a prime opportunity to make the connections between existing green spaces and facilitate their functioning at a larger scale.

Ecosystem services: GI provides a number of ecosystem services that contribute to making human life possible and worth living. There is a wide range of goods and services that different land-use sectors, including GI, can provide. These

Figure 4.1: Benefits of green infrastructure



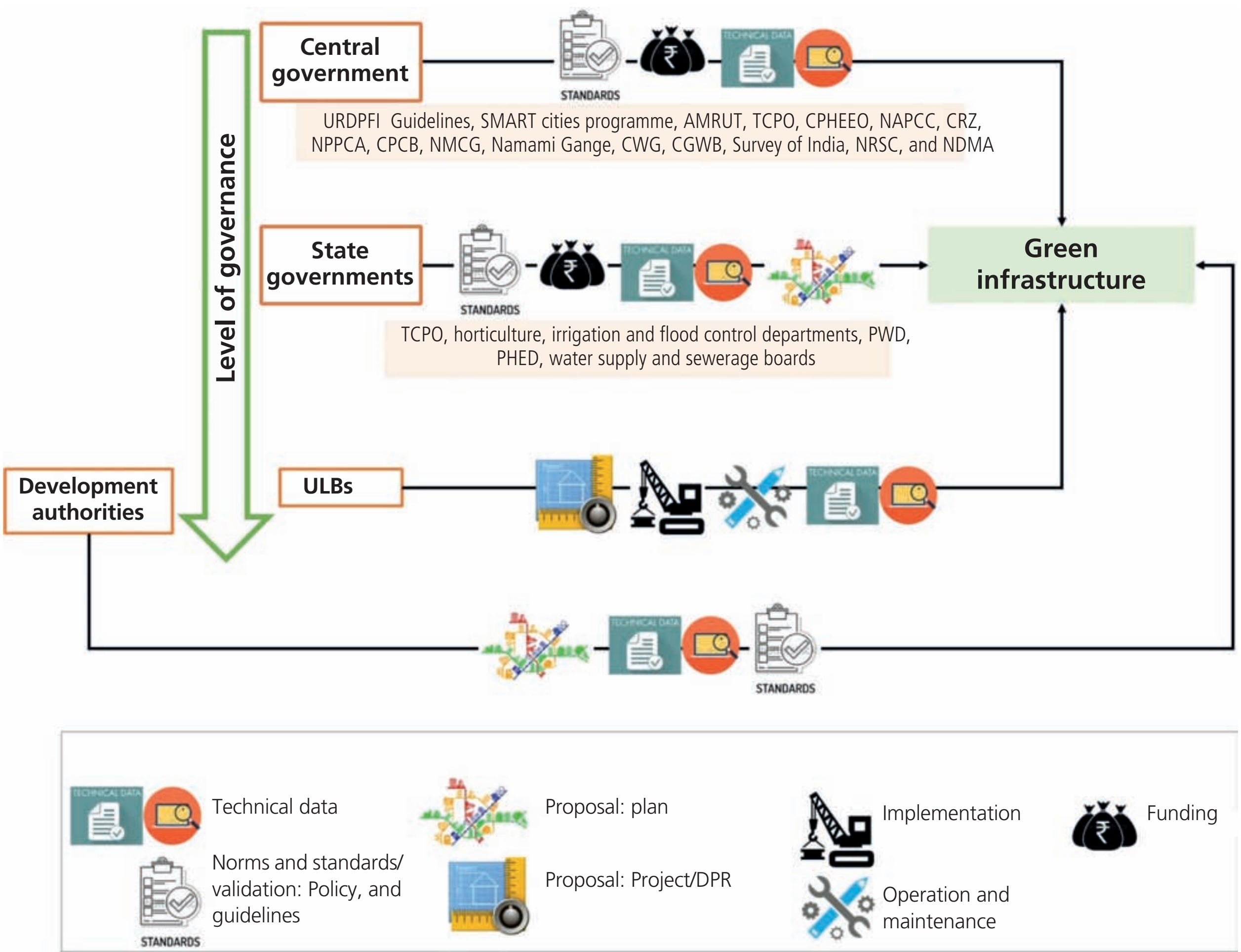
Source: Multi-stakeholder involvement and urban green space performance.Journal of Environmental Planning and Management, 54(6), pp.785-811, 2011 can be classified as supporting, provisioning, cultural and regulating services. Since the benefits are multi-functional, a common understanding needs to be developed among planners, ecologists, economists, sociologists and other disciplines within public administration, and stakeholder groups for their designing and implementation.

4.2 Stakeholder involvement

Multi-stakeholder participation is an essential component of GI planning and implementation. It is required for a more efficient interaction and better accepted projects. A holistic planning approach on GI should involve a strategy to combine the knowledge of planners with that of the local stakeholders.[3]

Government bodies are the main stakeholders in the implementation of effective GI solutions. The major components of a project, i.e., collection of data and other relevant norms and standards, proposal and the preparation of the detailed project report, implementation of funding, and operation and maintenance, can only be effectively carried out in line with different government departments (see *Figure 4.2: Role of government bodies in GI implementation*).

Figure 4.2: Role of government bodies in GI implementation



Source: CSE, 2017

Table 4.2: Multi-stakeholder involvement in designing and implementing GI

Stakeholder type	Roles in green infrastructure implementation
NGOs	• Conduct information and background surveys to identify project need • Communication campaigns and advocacy • Development of educational materials • Capacity building for stakeholders
Scientific and technical experts or expert groups	• Advisor and consultative role during planning and implementation stages • Serve as specialist for specific theme or area of the project, supporting decision-making processes
Research institutes (e.g. universities, think tanks, scientific foundations)	• Evaluation of project (including costs and benefit analysis) • Monitoring activities • Scoping studies
Private companies	• Provision of funds (potentially as 'Corporate Social Responsibility' or as part of mandatory compensation/mitigation measures) - donations, sponsorships

Source: CSE, 2017

GI design and planning can be associated with inclusive processes of increasing awareness and understanding of issues and challenges, generating more data, helping determine priorities, increasing support for analyses to identify GI solutions, and enhancing existing green spaces in urban area (see *Table 4.2: Multi-stakeholder involvement in designing and implementing GI*). Stakeholder processes often provide a reality check for technical efforts—they seek to synthesize ecological, technical, social, cultural, political and economic concerns through a process that helps to define feasibility.[4]

Combining spatial planning tools and approaches with interactive participation at an early stage can result in a high level of involvement. The participatory process must be continuous (see *Figure 4.3: How to improve participation in GI*). Furthermore, in GI, maintenance is also crucial for long-term management and holds potential to save financial resources while improving the ownership and acceptance of a project.[5]

Figure 4.3: How to improve participation in GI

Combination of different, tailored approaches to stakeholder engagement to involve all relevant stakeholder groups

Continuity of participation to ensure the process remains on track

Openness about new tools: Implementation of e-participation tools such as social media, GIS, 3D visualizations etc.

Implementation of performative participation as a chance to activate the public and especially hard-to-reach groups through a physically active participation approach

A high degree of involvement that allows stakeholders to feel responsible for the project and increases acceptance

Early involvement of stakeholders and clear rules of participation including information and publicity regarding the employed participation methods

Source: Fitschen.CR, Rusche.K and Wilker.J. 2015. Strategy for Smart Green Growth - Participation in Green Infrastructure Planning, ILS, Research institute for regional and urban development

4.3 BMPs and research work in the Indian context

Table 4.3: BMPs on GI in the Indian context highlights the case studies included in this section according to the water resource services provided.

Table 4.3: BMPs on GI in the Indian context

Moderation of extreme flood events	Water supply regulation	Other ecological benefits including water quality regulation
• Surat safe habitat—spatial planning of a low-lying areas with high flood risk, Surat, Gujarat • Gorakhpur city resilience strategy, Gorukhpur, U.P. • Zonal Development Plan for Yamuna River and River Front: Zone 'O', New Delhi	• Bellandur and Varthur Lakes rejuvenation blueprint (ENVIS Technical Report), Bengaluru, Karnataka • Implications of built up areas surrounding wetlands– Case of East Kolkata Wetlands, West Bengal	• An ecological approach to planning: Case Study of Mt Abu eco-sensitive area, Rajasthan • SMART City proposals for green areas of New Delhi (NDMC Area)

Source: Compiled by CSE, 2017

Case study

Surat safe habitat—spatial planning of a low-lying area with high flood risk, Surat, Gujarat

Year of research: 2010

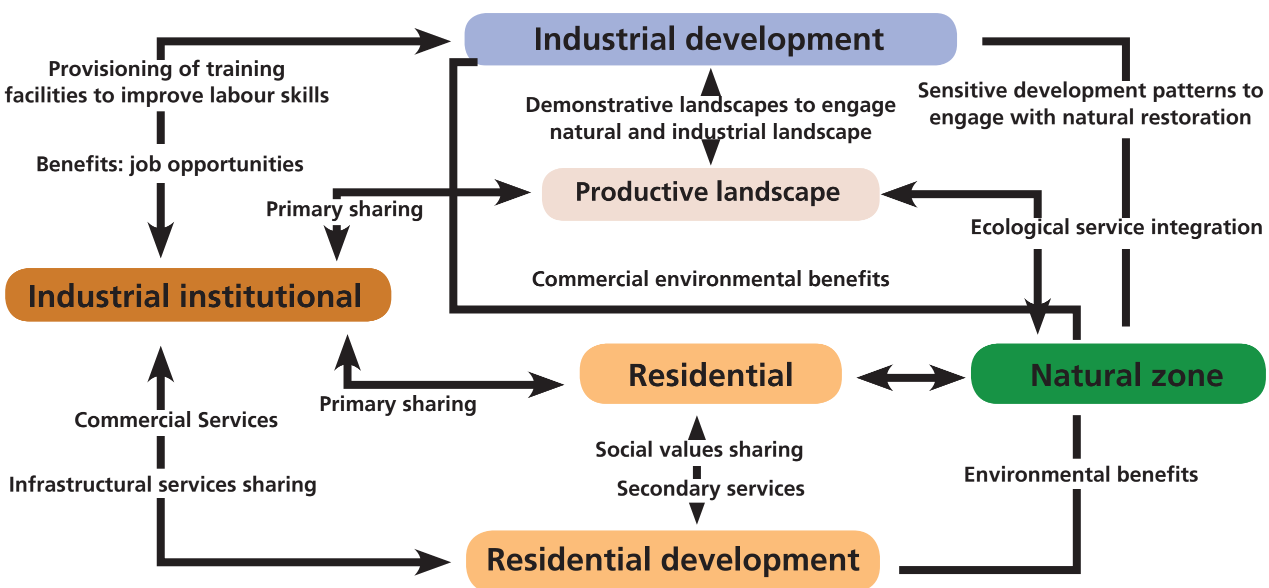
Background

The spatial planning exercise demonstrates an alternative to conventional micro-planning and local area planning by re-casting the approach to land valuation-based town planning scheme of Gujarat. By embedding the productive value of unbuildable lands into development rights and land valuation, ecosystem services provided by the landscapes is recognized. The competition named 'Surat Safe Habitat', organized in partnership between the Surat Municipal Corporation (SMC), Gujarat State Disaster Management Authority (GSDMA) and the Asian Cities Climate Change Resilience Network (ACCCRN), is an initiative that aims at stimulating debate and research, encouraging design and planning innovations, addressing the challenges of urbanization for natural and industrial risk-prone areas, and creating awareness among governments and professionals on development planning in areas prone to flood. For the purpose of the competition, Ichhapore low-lying area of 145 hectares, which is at risk from natural and industrial hazards, has been identified in the vicinity of the Surat municipality.

Key learnings

- As a low-lying area, the assessment of the regional flooding patterns and flood mitigation measures should be the primary driver of the land readjustment mechanism. The allocation of appropriate land use, compatible with safe development ensuring social and physical cohesion, while being economically productive, became the vision for the Ichhapore site.
- To respond to the increasing challenges of climate change, the approach undertaken was based primarily on two parallel yet interrelated strategies of 'land value economics' and 'landscape infrastructure' that seek to inform a multi-disciplinary proposal to reinvent a strategy reconciling the inherent conflicts between urbanization and ecology.
- In relation to the natural and industrial risk parameters of the Ichhapore site and its regional location, the development strategy is grounded on the potentials and limitations of the existing

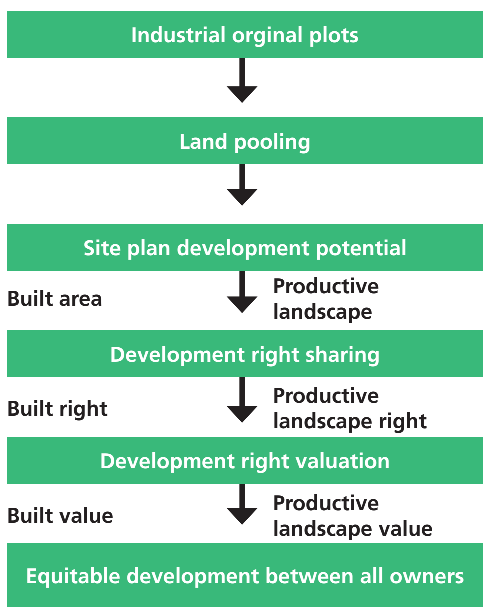
Figure 4.4: Comprehensive land valuation process



Source: Source: Mohan S. Rao, Integrated Design, Bengaluru, 2015 micro-planning tool (the town planning scheme), and its necessary re-modelling to provide a more equitable and balanced form of development and social structure.

- Within such a strategy, the introduction of 'ecological infrastructure' as a design tool not only allowed reworking land dynamics and economics by equating non-built components in tandem with built fractions (as opposed to conventional notions) but also helped derive malleable urban relations by negotiating natural (flood mitigation) and social (urban spaces) for the low-lying flood prone site. A comprehensive evaluation matrix was also developed to comparatively analyze the 'sustainability index' of GI and conventional infrastructure interventions, which clearly demonstrated that GI-based interventions are much more beneficial economically, socially, culturally and ecologically.

Figure 4.5: Development potential process



GI forms the anchoring landscape structure for the master plan as it encompasses landscapes which otherwise would have fallen under risk areas. Given the location and nature of the site, the vulnerable landscapes form a critical determinant in landscape and land use planning. Recovering the productive potential of vulnerable landscapes helps add value to these lands through direct benefit of food production as well as indirect benefit of flood mitigation and other ecsystem services to the larger landscape of Ichhapore.

To balance the inequitable potential for development, individual land owners should associate through mutual consensus so as to successfully satisfy their economic, social and cultural needs and aspirations through jointly owned and democratically controlled urban development. A planned development project is operated by a group of owners for their mutual benefit. This benefit is then equitably shared between all the owners. The approach aims to balance the potential for development between all the owners in an equitable manner, reduce disparity between land value at the site level, ensure equitable development between all the owners, and promote cohesion. To meet this objective, all individual parcels are unified to form a single site treated as an alternative physical and financial entity (land pooling mechanism).

Development right concept and its sharing permissible built up area		Built right	Unbuilt right	Total development right
		Productive landscape		
Step 1	Global development right at site level	(Area under residential) * FSI	Area under landscape	Buildable land + productive landscape
Step 2	Individual sharing of development right	Proportional sharing of permissible built up as per initial land holding	Proportional sharing of productive land as per initial land holding	Sum of individual sharing

Source: Mohan S. Rao, Integrated Design, Bengaluru, 2015

Case study

Gorakhpur City Resilience Strategy, Gorakhpur, Uttar Pradesh

Year of research: 2010

Background

Gorakhpur City Resilience Strategy (CRS) was formulated under the ACCCRN programme of 100 resilient cities. Gorakhpur is located on the banks of river Rapti in the north-eastern part of Uttar Pradesh. It has a population of 673,446 and covers an area of 147.2 sq km, as per the Census of India. It is one of the most flood-prone cities in India, with an extreme event occurring every three–four years. The city has many water bodies, the largest of which is the Ramgarh Tal Lake, spread over 678 ha in the south of the city.

Key learnings

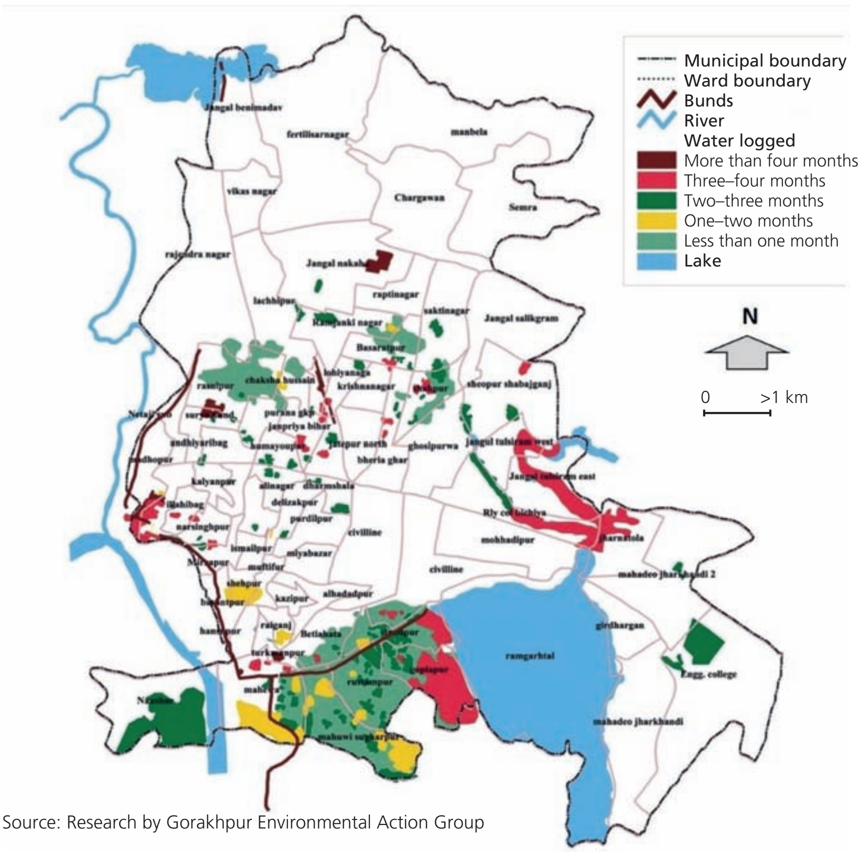
Conservation of water bodies is an integral component of flood mitigation. The Ramgarh Tal Lake plays an important role in the natural drainage pattern of the city. However, due to construction activities in the catchment area and sewage inflow, the lake's health has deteriorated.

The citizens of Gorakhpur took ownership to clean and manage the water body.

Strategies for conservation of the lake are incorporated in the drainage master plan.

The waterlogged areas (see *Figure 4.6: Waterlogged areas of Gorakhpur, 2008*) were converted into green spaces for better management of urban runoff.

Figure 4.6: Waterlogged areas of Gorakhpur, 2008



Source: Research by Gorakhpur Environmental Action Group

Case study

Zonal development plan for Yamuna River and River Front: Zone 'O', New Delhi

Year of notification: 2010

Background

The zonal development plan (ZDP) for Zone 'O' has been prepared under special circumstances to address the ecological needs of the River Yamuna and its floodplain in the context of Delhi. The ZDP aims to rejuvenate the river by regulating land use in the floodplain. The major proposals include the restriction of land use for recreational activities and agriculture. The proposed area under recreation is 2,045 ha (21.1 per cent), and the area under the water body and agriculture is 6,591 ha (67.8 per cent). Delhi is divided into 15 planning zones, out of which eight are in urban Delhi ('A' to 'H'), six in urban extensions ('J' to 'N' and 'P') and one is the river zone ('O'). Zone O is spread across an area of 9,700 ha. The zone is further divided into eight sub-zones.

The river enters Delhi at Palla (north) and leaves at Jaitpur (south), traversing a total of 48 km. The average slope from north to south is 9 m (208 msl at Palla, 199 msl at Jaipur).Yamuna is the major source of water supply for the city of Delhi, and is also one of the most polluted rivers in the country. As per a CPCB estimates, Delhi contributes approximately 78 per cent of the total pollution load of the river.

Key learnings

In order to finalize the ZDP, provisions of previous master plans for the city, and studies on Yamuna conducted by institutes like CWPRS, IWAI, SPA and NEERI were consulted. These studies provided adequate information regarding river flow and channelization, potential for waterways, different planning approaches, and floodplain management. Other information used for the preparation of the ZDP is the existing land use of the zone (see *Table 4.5: Land use for Zone 'O' prior to notification*).

Recommendations

The ZDP aims to achieve the objectives of water supply augmentation, pollution abatement, land utilization or management and eco-friendly development. Other areas of concern are flood vulnerability and encroachments, etc. The proposed land use is mentioned in *Table 4.6: Proposed land use distribution for Zone 'O'*.

- No additional areas other than existing and earmarked ones have been proposed under residential, commercial, industrial, government and public and semi-public use zones. Commercial zone includes an existing IT park (6.0 ha) and bottling plant (28.0 ha) at Madanpur Khadar, and a commercial site in the form a hotel (5.5 ha) site at the commonwealth games village.
- Proposed recreational uses will be as a green use zone in which green stretches, bio-diversity park, forest, botanical and herbal park, science park, theme park, etc. will be permitted without any pucca or permanent construction.
- The area of 'river and water body' may decrease by about 980 ha after the regularization and subsequent change of land use of unauthorized colonies falling in Zone 'O' as per government guidelines.

Table 4.4: Studies conducted on Zone O development plan

SPA study	NEERI study
Different planning approaches: • Ecosystem based approach—focus on environment • Integrated development scenario—multiple use with proximity to water for citizens • Post-channelization development scenario (extension of integrated development scenario with partial channelization as a precondition)	Environmental management plan for rejuvenation of river Yamuna in NCT. • Recommendations for permissible activities based on type and intensity at sub-zone level • Proposed land use at sub-zone level • Proposals based on area under 10, 50, 100-year flood and safe area

Source: CSE

The zone has an assortment of activities like Delhi Secretariat, Samadhi complex, cremation grounds, Sports complexes, and thermal and gas power stations, bathing ghats, sewerage treatment plants, and fly ash ponds and brick plants etc.

Some of the pockets are under thick plantation and most of the river basin area in Zone O is being used for agriculture and horticulture, and has a wealth of flora and fauna. The encroachments in the riverbed area aggravate the pollution in the river. In some parts, land from the river basin has been reclaimed for unauthorized constructions.

Strategies in ZDP:

- Water supply augmentation
- Rejuvenating the riverfront
- Riverfront development
- Infrastructure improvement
- Cleaner, quieter and multiple use
- Availability of sufficient quantity of water
- Capacity augmentation of existing barrages
- Pollution abatement

The proposed land use and modified river typology for Zone O (Wazirabad Barrage to Okhla Barrage) is shown in *Table 4.7: Proposed land use—Wazirabad Barrage to Okhla Barrage*. The figure also mentions the area under flood vulnerable category. The proposed uses in each sub-zone is mentioned in *Table 4.8: Proposed activities in sub-zones*.

For sub-zones 2–7, area under safe return of flood is mentioned at the right, along with recommended built-up areas.

Table 4.5: Land use for Zone 'O' prior to notification

Land use	Area (ha)	Per cent
Planned residential (Madanpur Khadar and CWG village)	62.21	0.64
Unauthorized colonies	980.00	10.1
Commercial	39.50	0.41
Industrial	34.04	0.35
Recreational	528.40	5.45
Transportation (DMRC depot, stations, and circulation)	345.65	3.56
Utilities	166.00	1.71
Government	1.80	0.02
Public and semi-public	179.84	1.85
River and water body (including agriculture)	7,362.56	75.9
Total	9,700.00	100

Source: Zonal Development Plan for river Yamuna Zone O, Delhi Development Authority, 2010.

Table 4.6: Proposed land use distribution for Zone 'O'

Land use	Area (ha)	Per cent
Residential	62.21	0.64
Commercial	39.50	0.41
Industrial (fly ash brick plant)	34.04	0.35
Recreational (green)	2,045.00	21.08
Transportation	582.93	6.01
Utilities	172.66	1.78
Government	1.80	0.02
P/SP	181.74	1.87
River and water Body (including Agriculture)	6,591.12	67.84
Total	9,700.00	100.00

Source: Zonal Development Plan for river Yamuna Zone O, Delhi Development Authority, 2010.

Table 4.7: Proposed land use—Wazirabad Barrage to Okhla Barrage

Sub-zone	Safe return of floods for			Safe
	10-yr	50-yr	100-yr	
2	475	342	180	39
3	82	25	-	-
4	192	78	19	-
5	179	106	50	-
6	206	104	60	-
7	1,063	474	236	78
Total	2,197	1,129	545	117
Per cent built up area	0	30	60	100

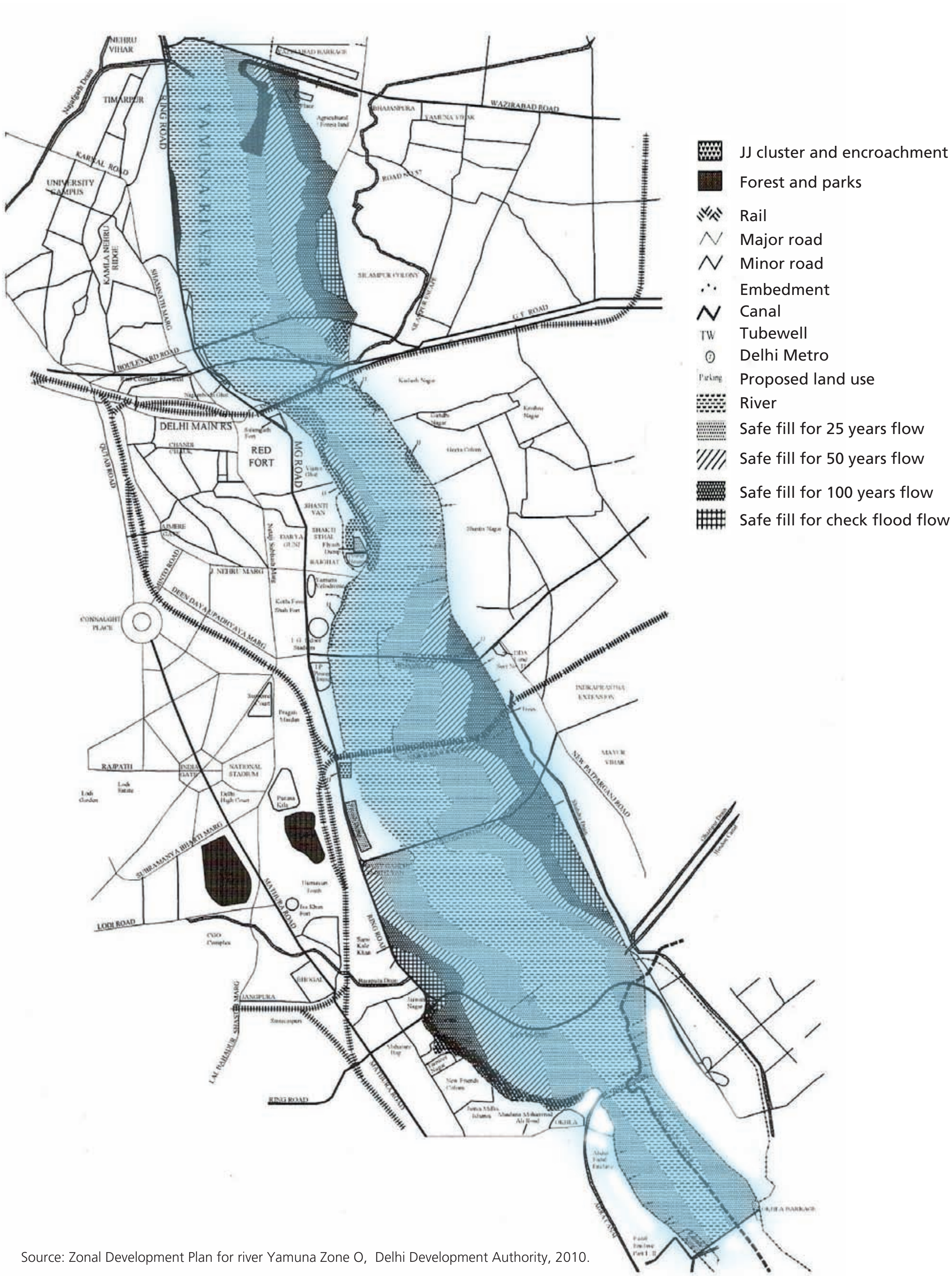
Source: Zonal Development Plan for river Yamuna Zone O, Delhi Development Authority, 2010.

Table 4.8: Proposed activities in sub-zones

Sub-Zone	Reach	Segment	Area (Ha)	Proposed use
01	UP border– Wazirbad barrage	East	3,620	Recreation, pondage (water harvesting) and ghats
		West		Recreation, pondage (water harvesting), ghats and PSP
02	Wazirbad barrage–ISBT bridge	East	1,100	Recreation, pondage (water harvesting) and ghats
		West		Recreation and ghats
03	ISBT bridge–old railway bridge	East	225	Recreation, pondage (water harvesting) and ghats
		West		Recreation and ghats
04	Old railway bridge–IP barrage	East	800	Recreation, pondage (water harvesting) and ghats
		West		Recreation
05	IP barrage–new railway bridge	East	365	Recreation and metro depot
		West		Recreation and ghats
06	New railway bridge–NH-24 bridge	East	390	Recreation
		West		Recreation
07	NH–24 bridge– Okhla barrage	East	1,300	Recreation
		West		Recreation and utilities
08	Okhla barrage–Haryana border	West	1,900	Recreation
		Zone 'O'	9,700	

Source: Zonal Development Plan for river Yamuna Zone O, Delhi Development Authority, 2010.

Figure 4.7: Proposed land use—Wazirabad Barrage to Okhla Barrage



Source: Zonal Development Plan for river Yamuna Zone O, Delhi Development Authority, 2010.

Case study

Bellandur and Varthurlakes rejuvenation blueprint, Bengaluru, Karnataka

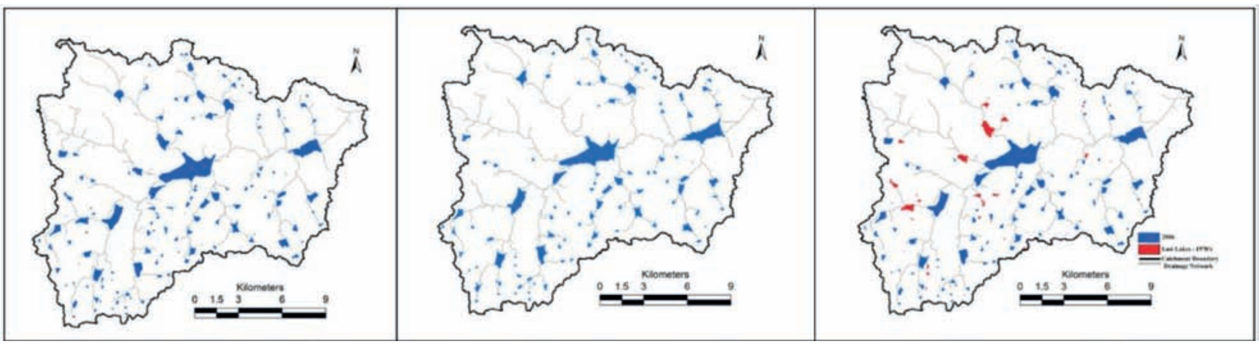
Year of research: 2017

Background

This study discusses the major issues regarding the status of the Bellandur and Varthur lakes in Bengaluru. It has been observed that both water bodies are severely polluted, which is evident from their physical and chemical analysis. Rejuvenation strategies include water quality management through setting up of STPs and constructed wetlands, restoring land use in buffer areas by clearing encroachments and strengthening public organizations responsible for management and conservation of these water bodies. Bengaluru has experienced unprecedented levels of rapid urbanization and sprawl in recent times due to concentrated developmental activities with impetus on industrialization for the economic development of the region. This has resulted in stark changes in the land use land cover (LULC) of the city. Using satellite images, the LULC map of the city shows an 88 per cent decline in area under vegetation and 79 per cent decline in area under wetlands and water bodies. Using the multi-criteria decision analysis and analytical hierarchical process, it is estimated that 93 per cent of Bengaluru's surfaces will be paved by 2020.

The Koramangala Challaghatta valley is located in the south-eastern part of Bengaluru. It has a catchment area of 290.44 sq km and drains into the Dakshina Pinakini River. As per the 2011 Census, the area has a population of 39.6 lakh. Using Survey of India's topographical sheets from Bhuvan Portal, it has been estimated that 37.5 per cent of lakes disappeared from 1970–2016, as their number dropped from 132 interconnected lakes to 96 (see *Figure 4.8: Change in water bodies in KC Valley, 1970–2016*).

Figure 4.8: Change in water bodies in KC Valley, 1970–2016

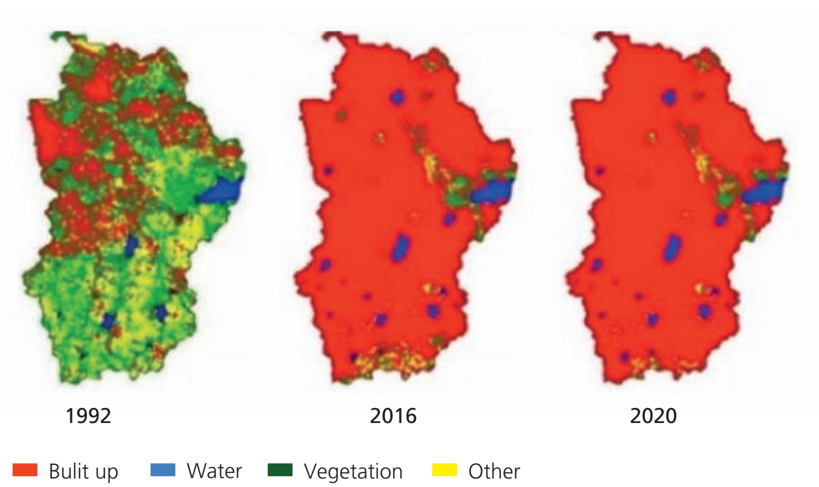


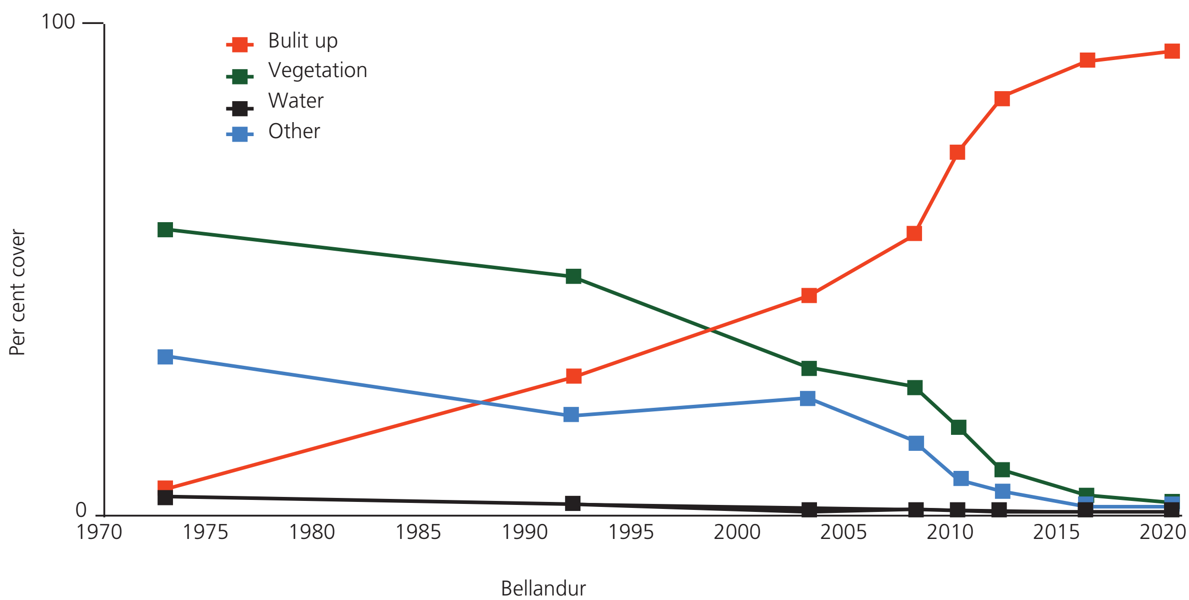
1970's (SOI Toposheet) 2016 Lost lake 1970's to 2016

Source: Bellandur and Varthurlakes rejuvenation blueprint, ENVIS technical report, , IISc, Bengaluru, 2017

The changes in LULC of the catchment areas of both lakes show a stark decline in the area under vegetation from 1970–2016. As per MCDA and AHP, the area under built-up in these catchment areas is set to cross 95 per cent by 2020 (see *Figure 4.9: LULC change in KC Valley, 1992–2020*). Moreover, the decline in area under vegetation has a direct correlation with the decline in the number of water bodies and area under the water bodies.

Figure 4.9: LULC change in KC Valley, 1992 to 2020 (top), built-up area has dramatically expanded over the years (bottom)





Source: Bellandur and Varthurlakes rejuvenation blueprint, ENVIS technical report, , IISc, Bengaluru, 2017

Key learnings

Apart from the spatial issues regarding LULC and diminishing water bodies, the water quality of the two lakes is also an area of concern. Both Bellandur and Varthur lakes fall under the Catergory 'E' of best designated use for inland surface water as per CPCB guidelines. It is evident from the data that the two lakes are severely polluted and have been in this condition over the past several years. Traces of heavy metals are also found, indicating discharge of industrial effluents. However, the quantity is within critical limits. The major sources of pollution in the lakes is identified as untreated domestic sewage, which is evident from the high levels of BOD and COD.

The recommended action is provided in *Table 4.9: Short- and long-term measures suggested to save Bengaluru's lakes*.

Table 4.9: Short- and long-term measures suggested to save Bengaluru's lakes

Short-term measures	Long-term measures
Enhance water quality through: • Regular harvesting of macrophytes. • Improve aeration. • Prohibit dumping of municipal solid waste. • Evict all waste processing units from the lake bed. • Prohibit dumping of C&D waste. • Allow discharge of only treated wastewater. • Strengthen legal and governance dimensions of lake management. Physical integrity of lakes and stormwater drains: • Surveying and mapping of water bodies and buffer zones (75 m as per NGT), valley zones (eco-sensitive zones as per RMP 2015) and green belts (as per CDP 2005). • Remove all encroachments. • Recover areas identified for STP (40 acres). • Identify areas to set up STPs and constructed wetlands (CWs). Improved lake management through strengthening of KLDCA.	Domestic sewage: • No more untreated sewage diversions in the city. • Decentralized treatment of sewage. • Sewage treatment model to be a combination of conventional and non-conventional methods of treatment. • STP with CW to be designed and constructed in the vicinity of the lake. • Area considerations for CW based on thumb rule of 1.7 ha for treating 1 MLD, where influent BOD is 40–80 mg/l and effluent BOD is 10 mg/l. • This will also help recharge of groundwater without any contamination. Regarding industries, 'Polluter pay' principle and ZLD from industries to be followed. De-silting through wet dredging and excavation. Evict all encroachments. Harvesting of macrophytes at regular intervals

Source: Bellandur and Varthurlakes rejuvenation blueprint, ENVIS technical report, , IISc, Bengaluru, 2017

Case study

Blueprint for water augmentation in Delhi

Year of proposal: 1999

Background

The 'Blueprint for Water Augmentation in Delhi' was completed in January 1999. This was the first document which pointed out a comprehensive way for NCT Delhi to achieve water security by increasing reliance on its internal resource endowments. While there has been a broad-based agreement upon its premises and proposals, the implementation has been tardy owing to an over-emphasis on capital- and engineering-intensive approach by officialdom.

Key learnings

The NCT of Delhi, owing to its administratively confined landmass of some 1,485 sq km, half of which is urbanized, presents a complex challenge to concept operationalization. The annual precipitation over NCT Delhi in volumetric terms comes to 900 million cubic metres (MCM) as against the projected annual requirement of 1,800 MCM, and it is a challenging objective to store the highest possible fraction of this precipitation in the limited and densely built-up land mass available. Satellite imagery, field surveys, historical data, old Survey of India maps, as well as hydro-geological mapping carried out by the Central Groundwater Board were employed at several sites of water harvesting in Delhi. It has been proposed that water be harvested under the following generic components:

a) *On-channel storage and recharge of storm water channels:* Several seasonal streams become activated during the monsoons, providing the outlet to floodwaters as well as local area runoff. A few major drains are those in Najafgarh, Mungeshpur, Bawana (all rural), and Kushak–Barapullah (which is an urban stormwater channel).

b) *Off-channel storage for floodwaters:* On-channel storage can only hold around 20 per cent of stormwater. Therefore, Delhi requires additional storage space in the form of off-channel reservoirs. Sites for twelve such reservoirs have been identified.

c) *Storage in lakes and depressions:* In urban areas, lakes have often been misused for dumping of solid waste and sewage disposal. Eighteen small and large lakes and depressions have been identified for development and enhancement of storage capacities.

d) *Floodplain reservoirs for conjuctive extraction:* Very often the most copious freshwater aquifers underlie the floodplains. In urban areas, there is no place to store monsoon discharge of rivers. To overcome this difficulty partially, it is proposed that reservoirs be created on the floodplains by scooping out earth at appropriate locations and letting these reservoirs to be filled up by the expansive monsoon flows of the river. Thereafter, the waters can be extracted from the aquifer by a battery of shallow tubewells for a long duration in the lean season. Six sites covering 760 ha have been identified on the floodplains for this purpose.

e*)* *Quarries:* Often, abandoned quarries are available in the vicinity of urban areas. With some shaping of their catchment area and linkage with some nearby channels, these can be used to store rain or floodwaters. Twelve major pits have been identified in Bhatti, Tajpur, Rajokri etc.

f) *Historical waterbodies:* In many urban areas, large historical reservoirs have fallen into disuse either by change of catchment characteristics or by destruction of the feeding channel in view of water scarcity, these reservoirs have a fresh relevance and need to be accordingly restored. Hauz Khas, Satpula, Mughal Tank (Narela) and several baolis have been identified under this component.

g) *Checkdams:* Wherever checkdams are possible according to local relief and regional topography, they should be built, taking caution not to use them for surface withdrawal but, instead, for recharging the falling water table.

h) *Paleo-channels:* These are abandoned course of rivers or streams. Located through satellite imagery, paleo-channels serve as excellent groundwater recharge locations, and diversions of some of the monsoon flows into these channels greatly replenishes the declining water table for subsequent use. While a major paleo-channel has been located in west and north-west Delhi, coinciding with the main Mungeshpur drain, several paleo-channels have been located in and adjacent to the Yamuna floodplains.

i) *Village ponds*: These are another endangered category owing to misuse and reclamation for 'development purposes'. In general, as villages are absorbed into urban areas and with increasing reliance on tubewells, the ponds are becoming cesspools. It is recommended that suitable ponds be preserved, desilted and their water quality improved. The main purpose of ponds is to function as dispersed recharge structures. Field surveys have established the existence of 355 ponds in NCT Delhi and the creation of 15 additional ponds has been suggested—one in each rural growth centre.

j) *Rooftop water harvesting*: At the level of campus or institutional establishments, rainwater falling on rooftops may be let to infiltrate into the ground through injection wells so as to impart a measure of sustainability to groundwater extraction. Several hundred institutions and other major built-up complexes have been identified for rooftop water harvesting.

k) *Ecoparks:* Using aquatic root zone systems in combination with conventional treatment to treat sewage up to tertiary levels for recycling to the irrigation and horticultural sector, and possibly to the industrial sector, it is proposed that ecoparking techiques be employed in the existing and proposed 17 sewage treatment plants in the form of wetlands, and the recycled water be used in the proximity or even to recharge some confined aquifers.

The estimated quantity of increased water available in NCT Delhi at a level of 75% per cent dependability on rainfall have been tabulated in *Table 4.10: Volume of water harvested and recharged and the capital cost per MCM.*

Table 4.10: Volume of water harvested and recharged and capital cost per MCM

Water harvesting component	Volume of water harvested (MCM)	Estimated annual recharge (MCM)	Cost incurred (Rs crore)	Cost incurred per MCM (Rs crore)
Drainage channels	107.77	29.67*	1092.04	7.94
Quarry reservoirs	8.87	-	4.5	0.50
Historical water bodies	0.35	-	2.026	5.78
Lakes and depressions	39.59	7	72.50	1.55
Checkdams	0.183	-	2.0	10.92
Village ponds	7.659	4.51	39.53	5.16
Floodplain reservoirs	11.14	30.4*	38.2	0.92
Rooftop harvesting	1.89	-	18.92	10.0
Total	177.45	60.07*	1,183.7	4.98
Ecoparks (recycling)	803	-	175	0.22
Grand total	980	71.58	1,358.7	1.30

*Recharge additional to storage

Source: INTACH, blueprint for water augmentation in Delhi for Irrigation and flood control department.

The estimated cost of the engineering work and land acquisition is Rs 1,360 crore, which works to Rs 1.30 crore per MCM, as compared to an average of Rs 4 crore per MCM for water obtained from upstream Himalayan reservoirs.

Through water harvesting, 50 per cent (150 million gallons per day) of the projected domestic demand supply gap of 300 MGD can be met. In addition, the entire irrigation and horticultural demand can be met through recycled water, thus releasing groundwater for use in the domestic sector. Water harvesting, combined with higher treatment of recycled water and plugging of line losses, would eliminate in toto the demand–supply gap by the year 2021.

The headway achieved so far is as follows:

1. In 1999, the stretch of outfall drain no. 8 (upstream of Najafgarh Jheel) from Dhansa Regulator to Jhatikra, a stretch of 5 km was desilted to hold stormwaters. This resulted in perennial submergence of this reach with the freshwater recharge diluting the brackish groundwater of the area and enabling resumption of farming operations.
2. In 2002, rainwater harvesting by-laws were passed, making rainwater harvesting mandatory for institutions and plotted houses over 500 sq m in area. This trend has continued ever since with flyovers and metro stations being brought under the ambit of the by-laws.
3. The revival of the Hauz Khas lake was an exemplary project which not only revived the dry 16 acre lake but demonstrated the efficacy of large-scale rainwater harvesting through waterbodies and also the possibility of recycling treated wastewaters through groundwater recharge from the bed of the lake. The treated wastewaters were sourced from Vasant Kunj STP and treated with aquatic plants (duckweed blanket) in check dams in the Sanjay Van. In 12 years, approximately 1,200 million litres of groundwater recharge has been achieved, raising the local water table.
4. The INTACH report also brought a focus on ponds and waterbodies in Delhi. Many exercises were undertaken to establish the numbers, locations, and sizes of the waterbodies and the last one carried out by INTACH in 2015 shows that 450 waterbodies are still feasible in Delhi. The model of Hauz Khas lake is now sought to be implemented by the authorities in several waterbodies across Delhi.
5. The INTACH report also identified the role of exhausted quarries in the Bhatti mines area in storing rainwater as well as highly treated (tertiary level) domestic effluents from nearby STPs for groundwater recharge as well as decentralized supply in south Delhi. A feasibility report has been recently completed by Water and Power Consultancy Services Limited.
6. The use of the stormwater network for groundwater recharge is also under consideration and a feasibility report has been commissioned for the north-western recharge network by Delhi Jal Board.
7. Work is on-going for the revival of Sanjay lake (East Delhi), using bio-remediated secondary level effluents from Kondli STP. The bio-remediation aspect would use a baffle reactor (already built) and a linear constructed wetland (3 m x 500 m). On similar lines, a management plan for Bhalaswa lake has also been drawn up.
8. The proposals and sites for water bodies identified in the INTACH blueprint were also marked in Master Plan 2001 and zonal plans (as well as NCR Regional Plan 2011) as areas of conservation important for groundwater recharge.
9. A floodplain reservoir north of Wazirabad has been taken up and implemented by Delhi Jal Board after consulting Central Groundwater Board regarding its potential and the battery of tubewells installed for extraction to augment water supply in the capital.
10. The influence of this project can be gauged from the fact that the Master Plan of Delhi 2001 clearly states that waterbodies above 1 ha area and drainage channels are to be preserved. Nodding to the report, the Plan also emphasizes recycling of water resources.
11. NCR Regional Plan 2021 also incorporates the need to preserve paleo-channels, oxbow lakes, waterbodies, and drainage channels.
12. Several cases have come up in courts to preserve individual waterbodies across the NCR and it has become much more difficult to eliminate waterbodies and reclaim them compared to the pre-2000 situation.

Source: INTACH, Blueprint for Water Augmentation in Delhi for irrigation and flood control department.

Case study

An ecological approach to planning: Mount Abu eco-sensitive area, Rajasthan

Year of research: 2012–15

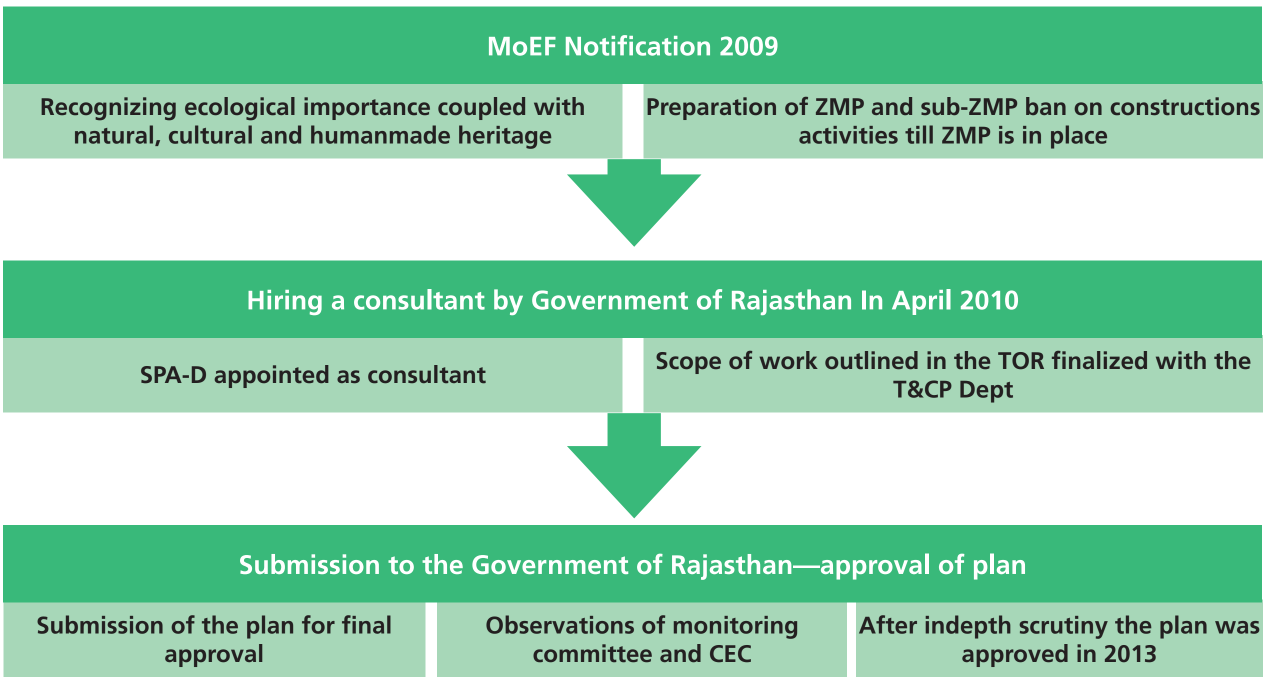
Background
Acknowledging the ecological significance of the heritage, and the threat environmental degradation poses to Mount Abu, the Ministry of Environment and Forests (MoEF), notified Abu and its surroundings villages as an ecologically sensitive area (ESA) in 2009 under the Environment (Protection) Act, 1986.

Key learnings
The landscape planning approach was used for the preparation of a Zonal Master Plan for Mount Abu ESA. Geomorphology, drainage, vegetation, land cover, water, soils, and wildlife were evaluated to assess their vulnerabilities to change. All resources were combined to prepare a composite vulnerability map. This formed the basis for land use planning. The process demonstrates how an ecological approach can guide the development of sensitive landscapes while preserving their resource base and unique sense-of-place.

Mount Abu (Sirohi district) is a semi-arid region in the southern Aravalli ranges marked by isolated hillocks and a chains of hills. The native vegetation consists of thorny forests characterized by a discontinuous vegetative cover with open areas of bare soil, and soil-water deficit throughout the year. Sitting on a raised forested plateau enveloped by a wildlife sanctuary, Abu is the only hill-town in Rajasthan.

Natural resource assessment methodology
Extensive data was collected through on-site reconnaissance and from secondary sources. This data was mapped and assessed using the overlay method. Each resource was mapped and evaluated for its

Figure 4.10: Planning process for Mount Abu



Source: http://spa.ac.in/writereaddata/Day3SPA.pdf (Zonal master plan for Mount Abu eco-sensitive zone) intrinsic sensitivity to change against established parameters. These maps were overlaid to prepare a composite vulnerability map to evaluate inherent development suitability of a given parcel of land. Natural thresholds were established for low and high impact land uses.

Geomorphology and drainage

Mount Abu municipal area is spread over 21.41 sq km and has a population of 22,943. according to the 2011 Census. The town is an irregular plateau surrounded by several projecting peaks and ridges. Most of the town accommodates itself between 1,120 m to 1,200 m height above mean sea level (see *Figure 4.11: Elevation of Mt Abu*). All lakes and water bodies found in the region have been created by impounding streams and drainage channels. Based on the correlation between land use and slope classes (see *Figure 4.12: Slope of Mt Abu*), a slope sensitivity map indicating least sensitive, moderately sensitive, and highly sensitive slopes was prepared (see *Figure 4.13: Slope Sensitivity of Mt Abu*). Relatively flat areas were classified as least sensitive for their intrinsic suitability to higher-intensity development or active recreation, while moderate slopes were classified as more suitable for low-impact development or passive recreation. Slopes above 35 per cent were deemed unsuitable for any development activity.

Figure 4.11: Elevation of Mt Abu

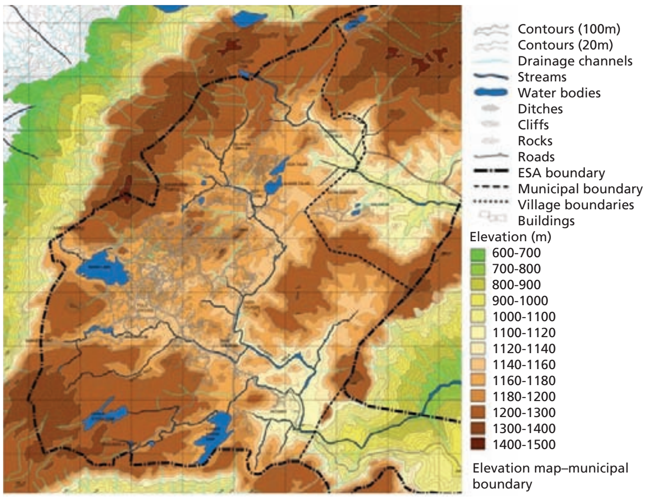


Figure 4.12: Slope of Mt Abu

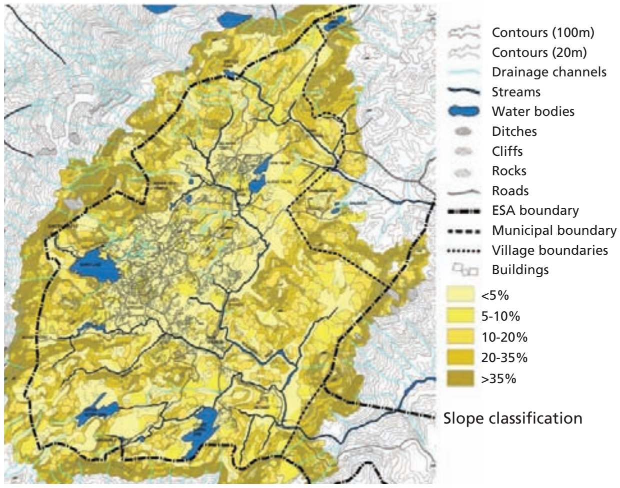


Figure 4.13: Slope sensitivity of Mt Abu

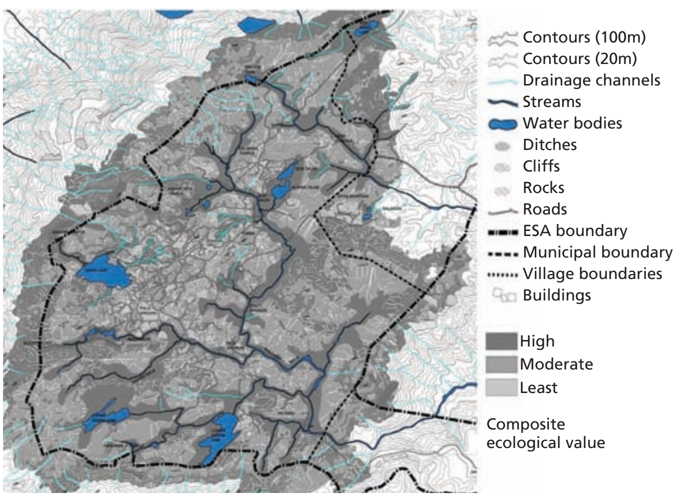
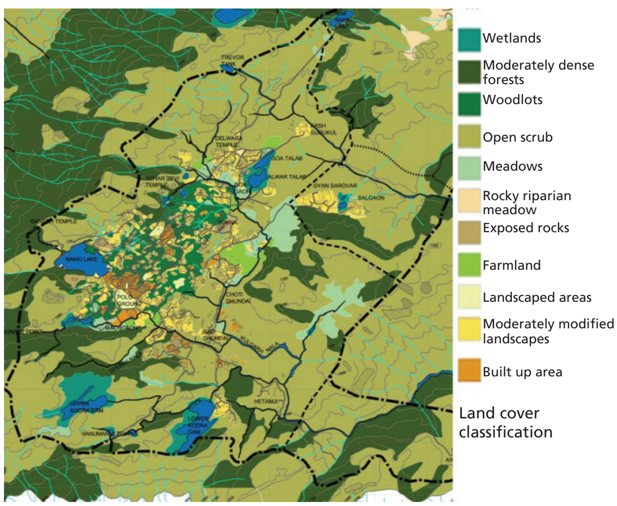


Figure 4.14: Land cover of Mt Abu



Source: https://studiovinyas.wordpress.com/ecology-and-planning/zonal-master-plan-mount-abu/, per Anita Tikoo Matange

Land cover and vegetation

The vegetation is predominantly tropical dry deciduous forest type with relict patches of dry tropical riverine forests along the water courses and valleys at higher altitudes. Scrub is the other major vegetation type. The land cover classification map (see *Figure 4.14: Land cover of Mt Abu*) illustrates the distinctive landscape typologies found here. The vegetative associations were scored against three criteria—rarity, refurbishment period, and species richness. The cumulative scores are presented in the land cover sensitivity map. Most of the town area fall in the moderately sensitive category.

Surfacewater

Steep slopes, exposed rocks, and shallow soils contribute more to runoff than to recharge. The streams and surface water bodies support rich biodiversity and contribute to improved water quality. Depending on land availability, a buffer of 100–200 m was proposed along the water bodies and marked as a zone of high sensitivity. Given the criticality of the resource in this arid region, it was accorded additional weight.

Soil and wildlife

Existing vegetation was used as an indicator of soil productivity with denser vegetation signifying more productive soils. Dense vegetation was found on northwestern slopes and within stream channels. These, as well as the farmlands, woodlots, and wetlands constitute areas with high productive potential. A large variety of mammals, birds, reptiles and fish are found in this area. The numbers of big game animals have dwindled over time, except in the core sanctuary areas. Birds are more abundant near lakes and tanks. Despite addition of new species to the list of local birds, a decline in the overall bird population has been observed. This may be attributed to habitat degradation and reduction of key habitat areas such as open scrub and grasslands.

Composite vulnerability map

Individual resources were mapped based on their inherent value in shades of grey, light to dark, signifying successively higher sensitivities. In order to identify potential areas for development, these maps were overlaid to produce a composite vulnerability map illustrating areas with high, moderate and low ecological values for all the resources combined. Highly sensitive slopes (slope greater than 35 per cent) and high value wetland–riparian buffer zone classes emerged as areas of the highest ecological value. The composite sensitivity map became the base for land use zoning. The development potential of the land under consideration was based on its level of sensitivity. This revealed that there was little scope for expansion within Abu's municipal limits. A similar method was then applied to the entire ESA, and an appropriate area to accommodate future growth was identified.

Natural resources are not equally incompatible for all activities. Each parcel of land was studied with respect to its composite ecological value, in addition to the resource-specific ecological sensitivity before land use allocation. To accommodate certain objectives of the development plan, the buffer zone was reduced to 50 m at some locations, with overrides for site characteristics and potential uses requirements.

Conclusion

The master plan for Mount Abu municipal area was arrived at through an ecological planning process. Assessment of natural resources and the underlying ecological processes following a scientific and objective approach presents the pros and cons of a given development scenario in an irrefutable manner, removing subjective opinions. The master plan demonstrates how a simplified overlay method can be an optimum tool to capture comprehensive ecological values of any region to guide sustainable development.

Case study

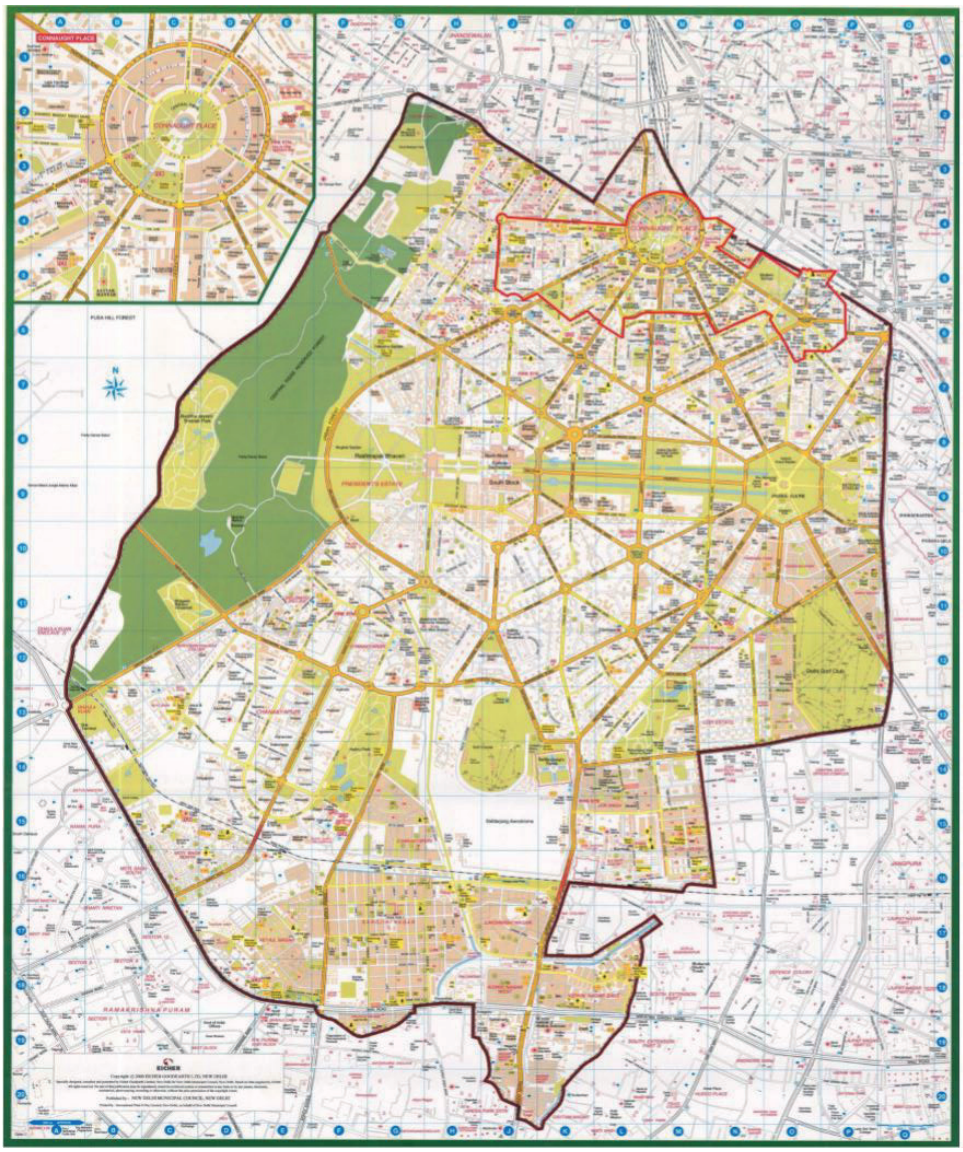
SMART city proposals for green areas of New Delhi (NDMC area)

Year of implementation: 2017

Background

New Delhi was designed by Edward Lutyens and Herbert Baker in 1913 as the new capital of British India. Post-independence, the city of Delhi grew around Lutyens' Delhi (known as New Delhi). New Delhi is governed by the New Delhi Municipal Council (NDMC) and has an area of 43.7 sq km (see *Figure 4.15: New Delhi Municipal Corporation area*). The city is selected for the government of India SMART city mission under which various parameters are unto be achieved by 2025.

Figure 4.15: New Delhi Municipal Corporation area



Source: NDMC, 2015. SMART city proposal for NDMC, New Delhi

Key learnings

Under the first phase, the New Delhi City Center (NDCC) will be taken up for redevelopment as an area-based project. As a pan-city initiative, green areas are earmarked as happiness areas, along with other community spaces. Pan-city: • Recommended public outdoor recreation space per capita: 20 sq m. • Recommended green area per 100,000 population: 190 ha	Initiatives: • Developing open gyms in 59 parks in the NDMC area: Completed • BRICS rose garden and Indo-African rose garden: Completed • Plaza at Connaught Place: In-progress

Source: NDMC, 2015. SMART city proposal for NDMC, New Delhi

Key messages

- The benefits of GI can be classified into hydrological, ecological, social, environmental and land regeneration.
- Since the benefits are multifunctional, a common understanding needs to be developed among planners, ecologists, economists, sociologists and other people working in other disciplines within public administration, and stakeholder groups, for designing and implementation of GI. Multi-stakeholder participation is an essential component in GI planning and implementation.
- Various research work and case studies from India show that GI solutions can be planned based on generic and GI potential analysis of urban areas.

5. Conclusion

The practitioner's guide provides an overview of GI solutions for water management, along with their direct and auxiliary benefits. It is designed for practitioners in both governmental and non-governmental institutions to help them raise awareness about GI. It also promotes inclusion of GI solutions within the urban fabric in the form of water management infrastructure. Research work and case studies from India show that GI solutions can be planned based on analysis of urban area and how GI potential within the existing developed urban areas can be identified.

The guide also aims to assist decision-makers in evaluating options and deciding where, when and to what extent GI practices should become part of future planning and development (and redevelopment) within communities. Recognizing GI's benefits will help municipalities make choices that not only provide solutions to urban storm water management issues but also result in a number of additional benefits to the communities.

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Appendix 1: Impact of flooding in urban areas

HYDERABAD
About the City
Hyderabad is the state capital of Telangana and de jure capital city of Andhra Pradesh. The city's population is 6.7 million and metropolitan population of 7.7 million (2011 Census). The city is located on the banks of river Musi and is an established IT and knowledge hub of India.

Flooding Events
- August 1954
- 1970
- August 2000 (240mm in one day and 469mm total rainfall) major flood
- August 2001
- August 2002
- 2006
- August 2008 (220.7mm in 36 hours)

Losses
In 2000 floods damaged 35,693 homes worth Rs.135 lakhs and affected 2 lakh people.
In year 2008, floods affected 1.5 lakh people

DELHI
About the City
Delhi, is the capital of India, and with a population of 22 million in 2011 (area 33578km^2 as per NCRPB), it is the world's second most populous urban agglomeration. Delhi's population is 16.8 million and it has an area of 1483 km^2.River Yamuna is major water body in the city.

Flooding Events
- 1977, 1978, 1988, 1995, 1998
- 2010 (water level in Yamuna had crossed the 207 m mark), 2011
- 2013 (117.8 mm in four and half hours)
- 31st July 2016 (62mm rain in 3 hours)

Losses
In 1978, total damage to crops, houses and public utilities was estimated at Rs.176.1 million;
In 1988, floods affected approximately 8,000 families;
In 1995, floods rendered approximately 15,000 families homeless
In 2016, extreme heavy spell of rainfall created city wide traffic jam at morning office hours.

CHENNAI
About the City
At 7.6 % decadal growth of population, Chennai is one of the fastest growing metropolitan cities in India. The metropolitan area has a population of 8.6 million as per Census 2011 (7.08 million in city). The geographical area of Chennai metropolitan area is 1189 km^2, while the city area is 426 km^2. Adyar and Cooum Rivers are the main river of the city.

Events
- 2004
- 2015 (Mega Floods in November and December)

Losses
New developments in southern and western Chennai flooded. Rail and Air services disrupted. Floods claimed 280+ lives in Chennai and more than 1,27,580 people rescued. All schools, colleges, offices, AUTO and IT companies were closed. Assocham reported a loss of Rs. 15,000 crore (CNBC)

MUMBAI
About the City
Mumbai is the financial capital of India. The metropolitan population is 20.7 million (12.4 million population of Mumbai city). The decadal growth rate (2001-11) of Mumbai city was 4.2%. The metropolitan region of Mumbai is 4355 km^2, while the city covers an area of 603 km^2. Meethi river, Powai lake, Vihar lake, Tulsi lake are main water bodies within the city.

Flooding Events
- July 2005 (944mm of rain in 24 hours)-Mega Floods
- 2007
- 2015 (300mm rainfall in 24 hours)

Losses
In 2005 floods, 1094 lives lost, all major suburbs affected, train services, buses, airport operations suspended (for about 30 hours);
Loss of Rs. 550 crores in two days.

BANGALURU
About the City
It is the 'IT city' or 'silicon valley' of India due to the presence of several software companies. Bangaluru is the 5th largest metropolitan region of India with population of about 8.52 million. Bangalore's population registered a decadal growth of 46% between 2001-11. Bangalore's city population is 8.4 million and it covers an area of 741 km².

Flooding Events
- October 2005 (525 mm in 24hours)
- 2009, 2013
- July 2016 (38 mm rain in 24 hours, 96 mm rain in 72 hours)

Losses
In 2005, 100 homes were damaged and 54 collapsed, 10 persons died. Schools and colleges were closed. WIPRO and Hinduja TMT offices were flooded.
In July 2016, 38 mm rainfall in just 24 hours on 28th July led to over flowing of lakes which flooded the city, particularly IT hub in south-east Bangaluru. The rainfall inundated all arterial roads upto 3 feet, cars submerged, trees uprooted, and traffic snarls reported.

SRINAGAR
About the City
Srinagar is the summer capital of Jammu and Kashmir and is also the largest city in the state. It is a popular tourism destination in Kashmir valley. Population of Srinagar urban agglomeration was 12,73,312 (as per census 2011). Jhelum river, Dal lake and Wular lake are main water bodies in the city.

Flooding Events
- 1950, 1957, 1959
- September 1992 (151 mm rainfall in 24 hours)
- 2-6 September 2014 (breach in the levee of river Jhelum)

Losses
In 1992 floods, 200 people lost their lives, 60,000 marooned
In 2014, floods affected entire Kashmir valley (including the city of Srinagar). Srinagar inundated as river Jhelum crossed danger mark. Water was as high as 12 feet in many neighbourhoods of Srinagar. Preliminary estimate of damage was Rs. 5000-6000 crores. City administration, transport, telecommunication and hospitals operations were affected.

Source:National Institute of Urban Affair (NIUA). 2016.India – Urban Climate Change Fact Sheets.Urban Flooding. Asian Cities Climate Change Resilience Network (ACCCRN)

Impact of flooding in urban areas of India

The 2015 mega floods in Chennai left new developments in southern and western Chennai flooded. Rail and air services were disrupted. Floods claimed more than 280 lives in Chennai and more than 127,580 people had to be rescued. All schools, colleges, offices, automobile and IT companies were closed. Assocham reported a loss of Rs 15,000 crore. The map shows flooded streets (pink) in Chennai, as of 22 November 2017.

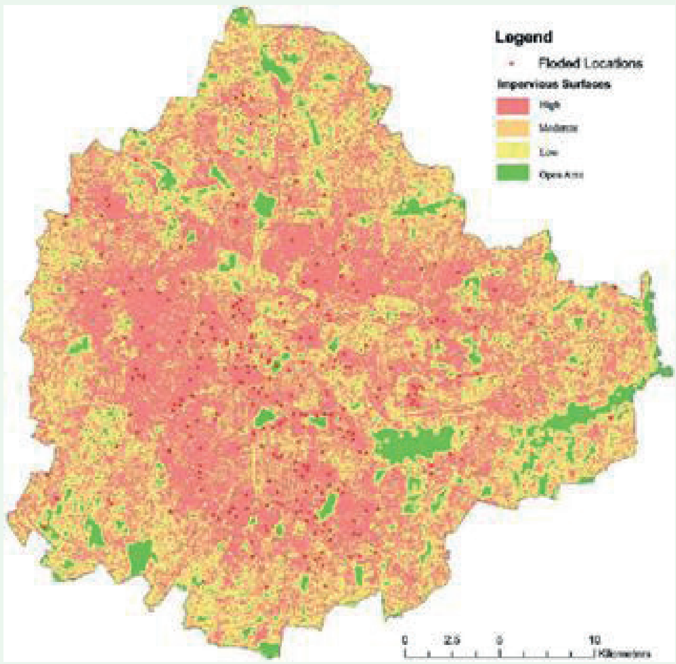
The marshland in Chennai, spread around 5,000 ha at the end of the British-era, got reduced to almost 600 ha around 2010–11 due to rapid urbanization. This reduction has greatly reduced the capacity of water infiltration of the city landscape.

This map of Chennai is a crowd sourced effort to mark inundated roads. All data is open sourced from public websites.

Source: https://osm-in.github.io/flood-map/chennai.html#11/13.0000/80.2000

Major flooding events in Bengaluru city include 2005 (525 mm in 24 hours), 2009, 2013, July 2016 (38 mm rain in 24 hours, 96 mm rain in 72 hours). In October 2005, 100 homes were damaged and 54 collapsed and 10 persons died. Schools and colleges were closed. In July 2016, 38 mm rainfall in just 24 hours led to overflowing of lakes, which flooded the city, particularly the IT hub in south-east Bengaluru. The rainfall inundated all arterial roads up to three feet, submerged cars, uprooted trees, and log-jammed traffic.

In 1960, Bengaluru had 262 lakes, but today not even 10 lakes are in a healthy state. This reduction in the number of water bodies has resulted in higher runoff, which is beyond the capacity of the existing drainage infrastructure. An Indian Institute of Science study estimates that 30 mm rainfall for 30 minutes will result in flooding in the city.



Flood area locations in Bengaluru

Source:https://www.researchgate.net/profile/Priya_Priya_Narayanan/publication/295255556/figure/fig6/AS:391383765536773@1470324570139/Figure-8-Map-showing-flood-affected-points-with-the-impervious-surfaces.png

Appendix 2: Definitions of green infrastructure across the world

Definition	Reference
An interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife.	Benedict, M. and McMahon. E., 2006, *Green infrastructure. Linking Landscapes and Communities*
GI is the network of natural places and systems in, around and beyond urban areas. It includes trees, parks, gardens, allotments, cemeteries, woodlands, green corridors, rivers and wetlands.	*Commission for Architecture and Built Environment*, 2011
GI is an approach to land use, underpinned by the concept of ecosystem services. Green assets such as parks, coastlines or embankments have generally been thought of in terms of their single functions—the approach that recognizes their vast range of functions and their interconnectivity is called GI.	Landscape Institute, 2009. *Green Infrastructure Position Statement*
GI is a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services.	European Commission, 2011
GI maintains and improves ecological functions in combination with multifunctional land uses. Natural and 'man-made' structures or a territory devoid of permanent man-made structures that provide—directly or indirectly, partly or totally—through the vegetation it supports, a series of services to society.	Marco Fritz, European Commission, Environment DG
GI is an approach to wet weather management that uses soils and vegetation to utilize, enhance and mimic the natural hydrologic cycle processes of infiltration, evapotranspiration and reuse.	US Environmental Protection Agency, 2008, *Managing Wet Weather with Green Infrastructure: Action Strategy*
GI is the actions to build nature protection networks as well as the actions to incorporate multifunctional green spaces in urban environment.	EEAC, 2009, *Green Infrastructure and Ecological Connectivity*
GI is a concept that is principally structured by a hybrid hydrological and drainage network, complementing and linking relict green areas with built infrastructure that provides ecological functions. It is the principle of landscape ecology applied to urban environments.	Ahern, J., 2007, *Green infrastructure for cities: The spatial dimension*
GI is a strategically planned and delivered network of high-quality green spaces and other environmental features. It should be designed and managed as a multi-functional resource capable of delivering a wide range of environmental and quality-of-life benefits for local communities. GI includes parks, open spaces, playing fields, woodlands, allotments and private gardens.	Natural England, 2010

Source: Compiled by CSE, 2017

Appendix 3: A few practitioner's guides on green infrastructure developed by other countries

Year	Country, city, and organization	Title of the GI guide
2008	USA, North West think tank	North West Green Infrastructure Guide
2009	UK, Natural England	Green Infrastructure Guidance
2010	European Commission	Green Infrastructures
2012	Australia	Green Infrastructure Guidelines
2012	UK, Town & Country Planning Association, London, UK	*Planning for a healthy environment—good practice guidance for green infrastructure and biodiversity*
2013	USA, The Green Infrastructure Center Inc, for Arkansas, New York, North Carolina, South Carolina and Virginia	*Evaluating and conserving green infrastructure across the landscape: A Practitioner's Guide*
2013	USA, City of Freeport, Illinois, USA	*Green Infrastructure Guide Book City of Freeport, Illinois | Managing Stormwater with Green Infrastructure*
2014	Program, Caribbean Islands NOAA Coral Reef Conservation Program, Caribbean Islands	*Stormwater Management in Pacific and Caribbean Islands: A Practitioner's Guide to Implementing LID*
2014	United Nations Environment Programme (UNEP)	*Green Ecosystem-based management approaches for water-related infrastructure projects* *Guide for water management*
2015	Australia, Australian Institute of Landscape Architects	15 Year Infrastructure plan for Australia
2016	USA, Esri	Green Infrastructure for the U.S

Appendix 4: Tools on green infrastructure developed by USEPA

Watershed Management Optimization Support Tool (WMOST)

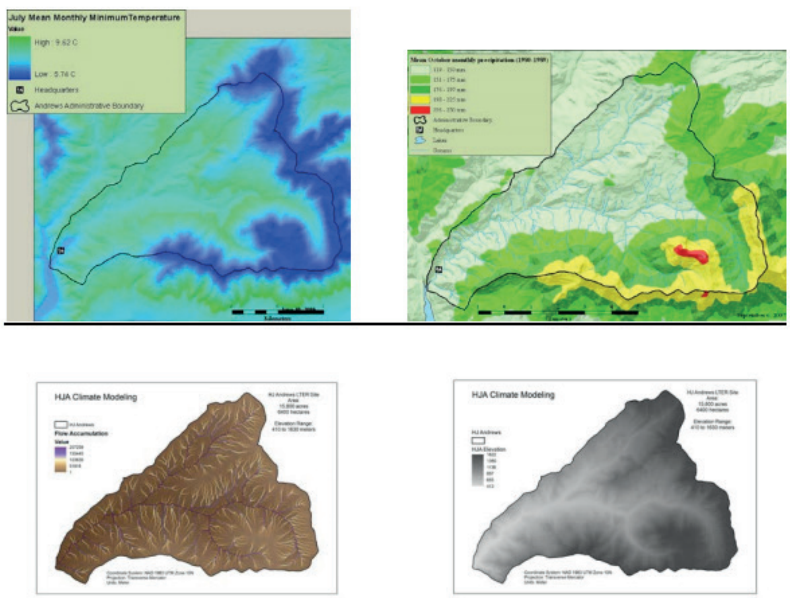
WMOST is a software application designed to facilitate integrated water resource management across wet and dry climates. The tool allows water-resource managers and planners to screen a wide range of practices, including low impact development or GI across a watershed for cost-effectiveness as well as environmental and economic sustainability.

WMOST modelling process from user inputs through to results used to derive optimal solutions.

Visit: www.epa.gov/exposure-assessment-models/wmost

WVisualizing Ecosystems for Land Management Assessment (VELMA)

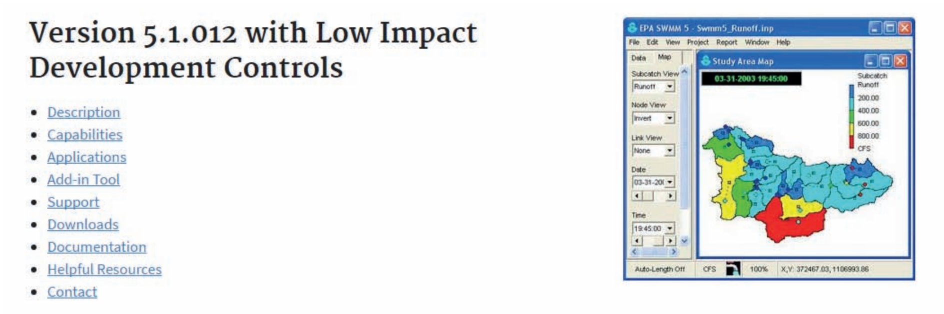
VELMA is a computer software eco-hydrological model used to quantify the effectiveness of natural and engineered GI management practices for reducing non-point sources of nutrients and contaminants in streams, estuaries, and groundwater.



Visit: https://www.epa.gov/water-research/visualizing-ecosystem-land-management-assessments-velma-model-20

Storm Water Management Model (SWMM)

SWMM models hydrology and hydraulics to simulate the movement of water through the landscape and into and through sewer systems. A GI module was added to SWMM in 2010 to simulate the integration of GI practices, ranging from green roofs to permeable parking lots, into a community's stormwater management plan. SWMM is widely used throughout the world and considered the 'gold standard' in the design of urban wet-weather flow pollution abatement approaches, and allows users to include any combination of low impact development and GI controls to determine their effectiveness in managing stormwater and sewer overflows.



Visit: https://www.epa.gov/water-research/storm-water-management-model-swmm

Appendix 5: Benefits provided by green infrastructure recognized across the globe

Topic area	Benefits	Reference: Environment DG (2010)	US EPA (2009)	Landscape irstitute (2009)	Natural England (2010)	Ahern (2007)	Benedict & McMahon (2006)
Biodiversity/ species protection	Habitats for species			●	●	●	
	Permeability for migrating species	●		●		●	●
	Connecting habitats	●				●	●
Climate change adaptation	Mitigating urban heat island effect with evapotranspiration, shading and keeping free corridors for cold air movement			●	●	●	
	Strengthening ecosystems' resilience to climate change	●		●			
	Storing flood water and ameliorating surface water run-off to reduce the risk of flooding	●	●	●	●	●	●
Climate change mitigation	Carbon sequestration	●		●		●	
	Encouraging sustainable travel			●			
	Reducing energy use for heating and cooling buildings			●			
	Providing space for renewable energy like ground source heating, hydroelectric power, biomass and wind power			●		●	
Water management	Sustainable drainage systems — attenuating surface water run-off		●	●		●	●
	Groundwater infiltration		●			●	●
	Removal of pollutants from water (e.g. reed beds)		●	●			●
Food production and security	Direct food and fibre production on agricultural land, gardens and allotments			●			
	Keeping potential for agricultural land — food security (safeguarding of soil)						
	Soil development and nutrient cycle					●	●
	Preventing soil erosion	●		●			
Recreation, well-being and health	Recreation			●	●	●	●
	Sense of space and nature				●	●	●
	Cleaner air						●
Land values	Positive impact on land and property			●		●	●
Culture and communities	Local distinctiveness			●			
	Opportunities for education, training and social interactions			●	●	●	
	Tourism opportunities			●			

Source: Green Infrastructure and Territorial Cohesion` European Environment Agency Technical Report – 2011- ISSN 1725-2237

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