Roadmap for Implementation of Water-Sensitive Urban Design and Planning (WSUDP) in Uttar Pradesh

Stormwater Harvesting in Parks and Open Spaces

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1 Introduction

Floods are quite common in South Asia, with India being the second-worst flood-affected country in the world.[1] Floods do not just occur due to overflowing rivers, they are also caused by the uninformed manner in which cities are interfering with the natural water cycle. Many factors such as low-lying landscape, unplanned urbanization that does not pay heed to natural topography and hydro-geomorphology, and overburdened drainage systems are responsible for creating floods that wreak havoc in urban areas.

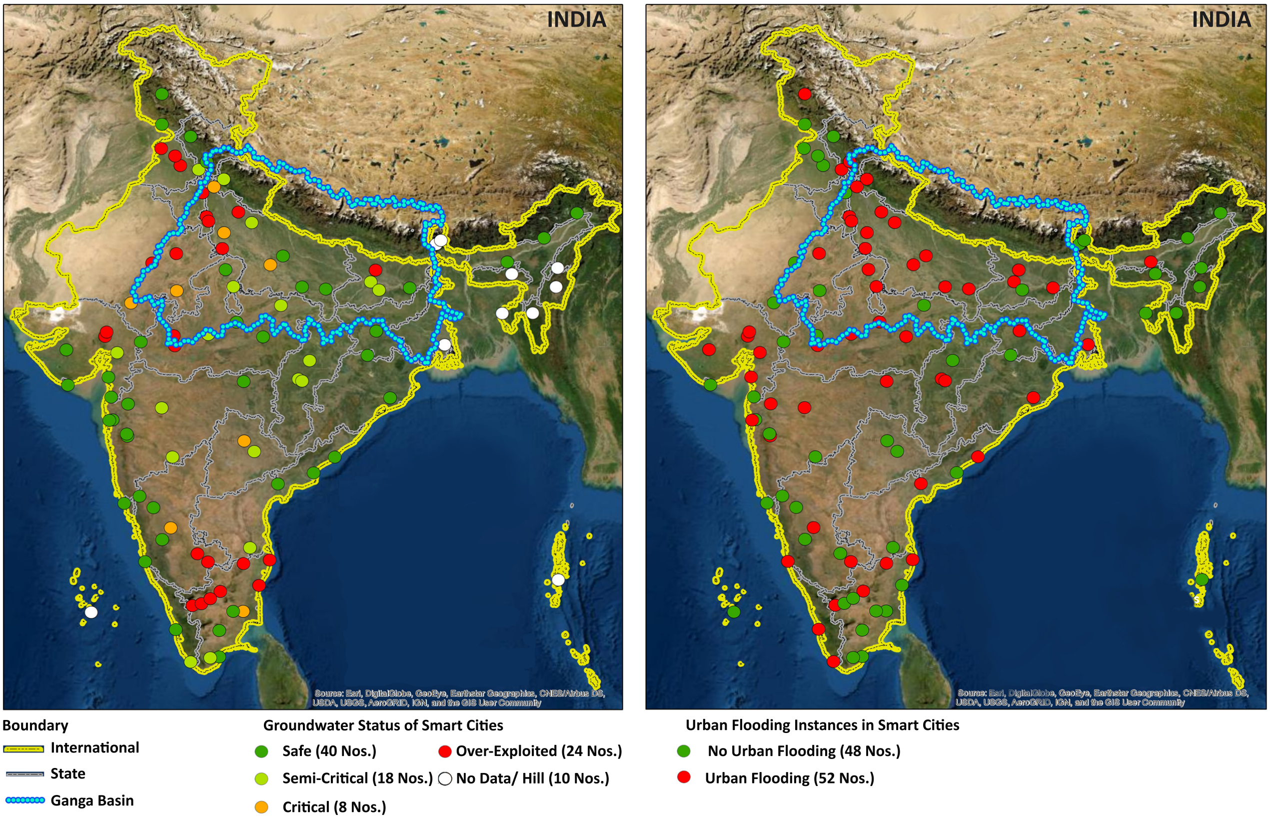
Today, urban water systems are confronted with significantly changing conditions. The impact of climate change, rapid urbanization, and deteriorating and outdated infrastructure are aggravating current water challenges of flooding, water scarcity and rehabilitation costs on a scale that will overwhelm the capacities of cities.[2] In this respect, stormwater management and water supply of cities serve as the vanguard and will take the brunt of the impact. This holds true for cities in the most populous river basin in the world: the Ganga river basin. Urban flooding during monsoons has become an annual affair for the towns and cities in the basin, posing steep social and economic constraints.

The Ganga basin has witnessed rapid urbanization over the past two decades. For instance, Uttar Pradesh has witnessed a 33 per cent increase in urban built-up area, 30.76 per cent from 3,122 sq. km in 2005–06 to 4,509 sq. km in 2015–16.[3] The basin is home to 25 of the 100 'Smart Cities' being developed in India, and Uttar Pradesh has been ranked number one in the implementation of projects under the Smart Cities Mission, AMRUT Mission and Pradhan Mantri Awas Yojna—Urban (PMAY-U).[4] However, of the 25 Smart Cities, 21 have reported repeated incidences of urban flooding, and only six have their groundwater regimes categorized as 'safe', while the groundwater regimes in as many as 11 cities are categorized as 'over-exploited' and in four cities they are categorized as 'critical' (see *Figure 1: Status of urban flooding and groundwater stage of development in Smart Cities*).

Centre for Science and Environment (CSE)'s research demonstrates the need for cities to adopt Water-Sensitive Urban Design and Planning (WSUDP) approach, including sustainable urban drainage interventions. WSUDP approach realigns urban water infrastructure towards a circular economy, aiming to mimic the natural water cycle in order to fix water systems in a city. Further, it integrates and optimizes the use of available water resources, and completes the urban water cycle through measures like protection of local water bodies, stormwater harvesting in public places, wastewater recycling and reuse, and improving water efficiency at the household, neighbourhood and city–regional scale.[5]

WSUDP in parks and open spaces has been successfully implemented in many parts of the world. It is seen as a critical component of efforts to mitigate urban flooding and managing high run-off volumes generated from urban catchments. Some of these approaches combine the best of traditional practices with the latest scientific insights. CSE has detailed some of them in *Dying Wisdom: Rise, Fall and Potential of India's Traditional Water Harvesting Systems*, considered a seminal work in the field and *Making Water Everybody's Business: Practice and Policy of Water Harvesting*, another essential read on the subject.[6]

Figure 1: Status of urban flooding and stage of groundwater development in Smart Cities of India



Source: CSE, 2020

CSE has documented the potential of stormwater harvesting in parks and open spaces for the National Capital Territory (NCT) of Delhi, and for the state of Odisha, focusing on Bhubaneswar, Cuttack, Rourkela and Berhampur under its series of publications on *Roadmap for Implementation of Water-Sensitive Urban Design and Planning: Stormwater Harvesting in Public Parks and Open Spaces*. The research has advocated the role of WSUDP in addressing issues related to pluvial flooding and groundwater recharge.

CSE has partnered with the National Mission for Clean Ganga (NMCG), Government of India for a three-year project on 'Developing Water-Sensitive Cities in the Ganga Basin', which focuses on research and capacity building of state officials to mainstream WSUDP in towns and cities in the Ganga basin. This report, prepared as part of the knowledge support under this initiative, will present WSUDP strategies for stormwater harvesting in parks and open spaces for five cities of Uttar Pradesh: Lucknow, Kanpur, Prayagraj, Varanasi and Moradadad, which face issues related to urban flooding and depletion of groundwater table.

1.1 Research aim, objectives and methodology

This report aims to assess the potential of stormwater harvesting in parks and open spaces in cities of Uttar Pradesh. The objectives are to:

- Assess the baseline information for Ganga basin in terms of natural resource profile and issues related to urban flooding and status of groundwater.
- Select priority cities in Uttar Pradesh, and assess the framework for urban planning, planning and management of parks and open spaces and park infrastructure of these towns.
- Estimate WSUDP potential for the same, supported by concept plans for stormwater harvesting structures aimed at recharging the depleting aquifers and improved urban flood management.

The report provides a brief overview on the Ganga basin, which is followed by a comprehensive review of the natural resource profile of Uttar Pradesh, land cover pattern, planning and management framework in the state and issues related to urban flooding and depleting groundwater table. The information presented in this section has been gathered from secondary sources and desk research. This section is concluded with the selection of priority towns based on the aforementioned criteria and their coverage under various urban development missions implemented by the Government of India.

The following section provides a general description of these cities, providing information on rainfall pattern and statistics, urban planning and provision of public parks and open spaces. For each city, potential sites for implementation are selected. Parks and open spaces of neighbourhood scale and zonal or city scale have been selected as pilot case studies, where WSUDP potential has been calculated, and certain preliminary design guidelines for each of these parks have been recommended.

The runoff generation calculations are carried via a rational formula. Since the structures involve catering to recharge and infiltration, storage calculations are not taken into consideration. Peak rainfall intensity for the cities is assumed to be within the range of 100–150 mm per hour.[7]

The rational formula used to predict the peak runoff generation is $Q = C \times I \times A$, where 'C' is the run-off coefficient, 'I' is the rainfall intensity, and 'A' is the catchment area. Preliminary data used is from Google Earth and open-source reports available on online (sourced from National Mission for Clean Ganga—NMCG—state government of Uttar Pradesh and other organizations). The report concludes with a section on potential of up-scaling of such interventions in cities of Uttar Pradesh, and across the Ganga basin cities.

2 WSUDP in parks and open spaces

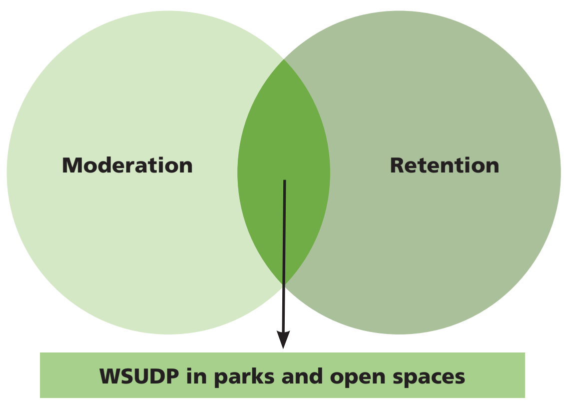
2.1 Principles for stormwater harvesting

WSUDP for urban green spaces is considered to be an effective approach to reduce the adverse impact of urbanization on the hydrological cycle. Green spaces improve the natural hydrological systems in urban areas and dampen peak flows from storms that can otherwise lead to flooding. These strategies augment the conventional drainage infrastructure by moderating run-off, so that the conventional systems are not overwhelmed in moderate and extreme flood events. Expansion of urban green spaces is not only an economical and environment-friendly approach to deal with stormwater run-off and urban flooding, but it can also improve the resilience and sustainability of cities.

WSUDP interventions in public parks and open spaces provides critical green infrastructure linkages, which address urban flooding and augment local groundwater resources. In addition to this, they also provide multi-dimensional benefits for the urban hydrological regime.

The process follows the principles of 'moderation' of run-off during rainfall, via 'retention' for a particular time, allowing water to infiltrate, and the drainage system to gain the capacity to accommodate the extreme run-off (see *Figure 2: Principles of WSUDP in parks and open spaces*).

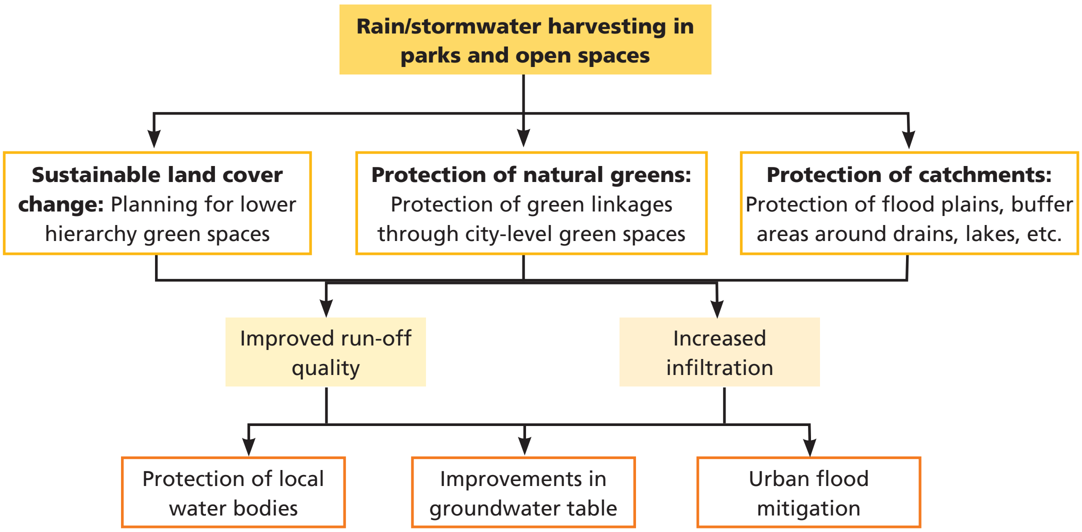
Figure 2: Principles of WSUDP in parks and open spaces



Source: CSE, 2020

WSUDP interventions in parks and open spaces at various scales leads to improved run-off quality and increased infiltration, which eventually leads to protection of local water bodies, groundwater recharge and urban flood mitigation (see *Figure 3: WSUDP approach—integrating the urban water cycle*). Additionally, these interventions also enhance the biodiversity of the area and improve the micro-climate.

Figure 3: WSUDP approach—integrating the urban water cycle



Source: CSE, 2020

Stormwater harvesting in parks and open spaces can be undertaken at different scales, depending on the hierarchy of the parks. Lower hierarchy interventions are localized and are successful in addressing local flooding, while higher hierarchy interventions provide a range of regional benefits. It must be noted that a majority of parks and open spaces in cities are planned at the neighbourhood level. WSUDP interventions in these areas can have a cumulative positive impact in addressing urban flooding in the city as a whole.

Interventions in parks and open spaces at various scales are illustrated in *Table 1: WSUDP options and benefits for parks and open spaces* along with their estimated benefits in terms of run-off volume reduction and peak flow reduction. The values are based on globally implemented solutions.

Interventions like rain-gardens, rainwater harvesting solutions and swales can be implemented in lower hierarchy parks and open spaces. These interventions can reduce run-off and peak flow, improve water quality and increase local biodiversity. Associated benefits include improved aesthetics and recreational benefits, which eventually lead to increased property values.

Detention ponds and bio-retention areas are more suitable for higher hierarchy parks and open spaces as they require more area and are able to handle higher volumes of run-off. These interventions have a higher percentage reduction in peak flows and run-off, and also augment the quality of water. In addition to this, protection (and creation) of local water bodies can also be done using these interventions. It is to be noted that various combinations of these interventions can be made in parks of various sizes. WSUDP interventions are most efficient if designed as a network of solutions within a particular park, and also as solutions in a network of parks of various scales.

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

Table 1: WSUDP options and benefits for parks and open spaces

Measure	City	Area (sq m) / Volume (cu m)	Reduction in		Co-benefits
			Per cent run-off	Per cent peak flow	
Rain-garden	Japan	Area: 1.862	36 to 100		• Increased biodiversity • Increased property value • Aesthetics
Vegetated swale	Beijing, China	Volume: 157	0.3 to 3	2.2	• Increased biodiversity • Reduced concentration of pollutants
	Hai He, China	Volume: 1,500	9.6	23.56	
Rainwater harvesting	Melbourne, Australia	Volume: 1 to 5	57.8 to 78.7		Improved water quality: • Total nitrogen reduced by 72–80 per cent
Dry-detention pond	Selangor, Malaysia	Area: 65,000		33–46	Recreational benefits
Detention pond	Texas, USA	Volume: 73,372		20	• Increased biodiversity • Recreational benefits
	Joinville, Brazil	Volume: 9,700	55.7	43.3	
Bio-retention	Beijing, China	Volume: 946	10.2 to 12.1		Improved water quality: • Reduced total suspended solids • Reduced total phosphorus
	Hai He, China	Volume: 1,708	9.10	41.65	
	Calgary, Canada	Volume: 48	90		
Infiltration trench	Hai He, China	Volume: 3,576	30.8	19.44	• Reduction in pollutants • Improved surface water quality
	Joinville, Brazil	Volume: 34,139	55.9	53.4	
Detention pond and rain-garden	Joinville, Brazil	Area: 18,327	70.8	60	Aesthetics
Detention pond and infiltration trench	Joinville, Brazil	Area: 18,327	75.1	67.8	Improved surfacewater quality

Source: L. Ruangpan et al.: Nature-based solutions for hydro-meteorological risk reduction

2.2 Indicators for WSUDP potential in parks and open spaces

Planning and designing WSUDP interventions in parks and open spaces is dependent on a variety of factors—natural resource profile, land cover and flood vulnerability. Different parts of a city have different potential for WSUDP accordingly. In order to analyse these parameters, indicators for assessment of WSUDP potential have been prepared and mentioned in *Table 2: Indicators for determining potential of WSUDP in parks and open spaces.*

Table 2: Indicators for determining potential of WSUDP in parks and open spaces

Indicator	Potential for WSUDP
Area under parks, open spaces and recreational zones	• Areas having higher number of parks provide more opportunities for implementing WSUDP. • Areas under regional-level parks have higher potential for large-scale interventions.
Post-monsoon groundwater level	• WSUDP designs for areas having shallow groundwater table are based on principles of retention and moderation of the excess run-off. • Areas with deep groundwater level are better suited for WSUDP interventions based on the principles of infiltration.
Geology and soil type	• WSUDP designs for areas having a rocky terrain are limited to small-scale retention interventions. • For areas having higher content of clayey soil, retention strategies are more suitable, whereas areas with sandy-loamy soil are better suited for infiltration-based WSUDP interventions.
Flood and water-logging hotspots	WSUDP interventions based on retention and moderation of run-off in parks and open spaces in the vicinity of flood and water-logging hotspots can address flooding issues.
Low-lying areas	WSUDP interventions in parks and open spaces in low-lying areas vulnerable to flooding are essential for flood mitigation.

Source: CSE, 2020

3 Profile – Ganga basin and Uttar Pradesh

3.1 The Ganga river basin: An overview

The Ganga has the largest river basin in India, spread across an area of 861,404 sq. km in 11 states. It is one of the most populous river basins in the world, housing in excess of 655 million people, with an average density of 520 persons per sq. km.[8] The basin contains 2,009 statutory towns, with an urban population of 165.2 million as per the 2011 Census of India. This population is projected to increase by 68 per cent to 243 million by 2040.[9] The urban built-up area has increased approximately 44 per cent from 10,512 sq. km in 2005–06 to 15,138 sq. km in 2018.[10]

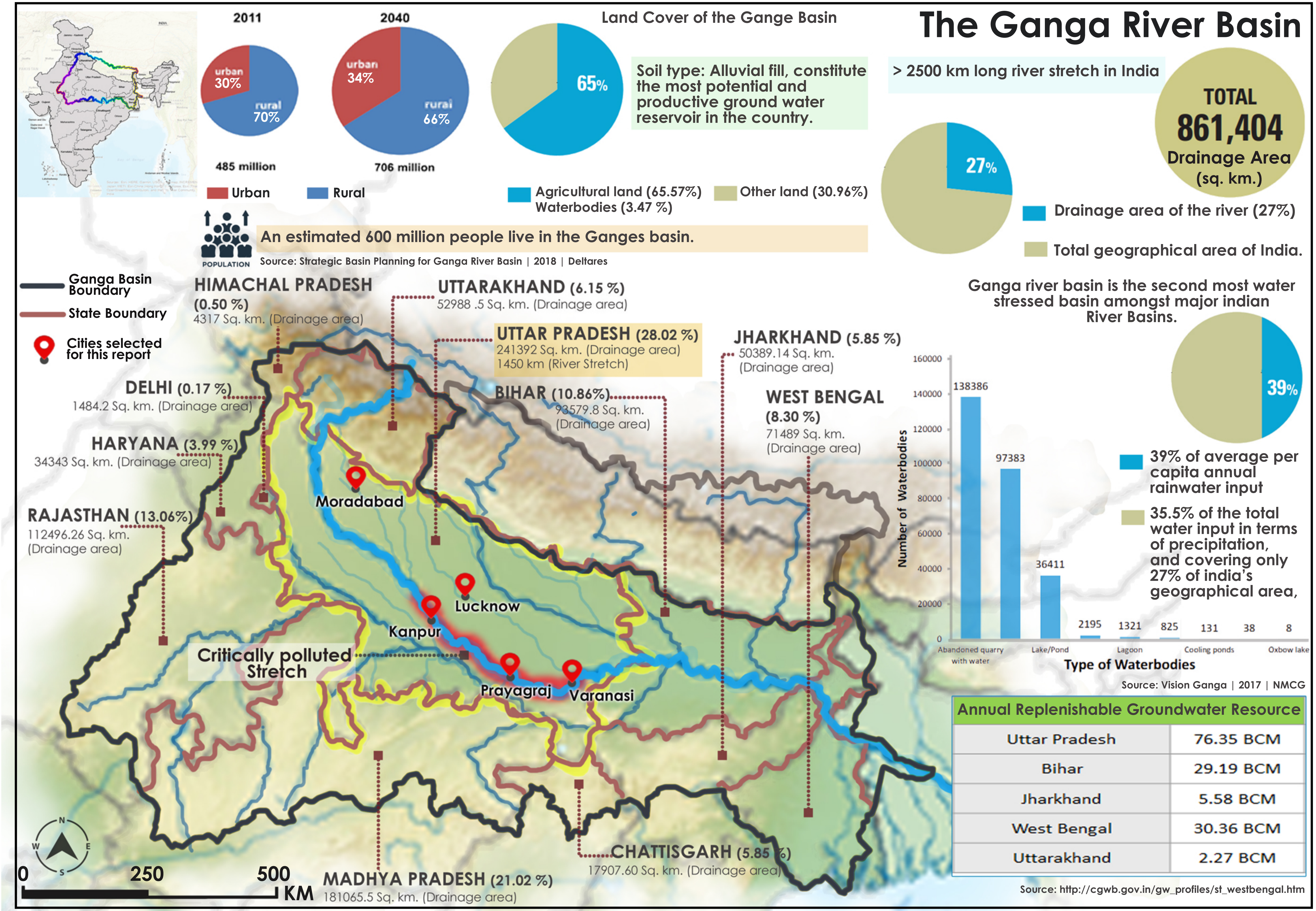
The basin is characterized by homogenous terrain in the plains leading to a flat depositional surface at an elevation below 300 m or a very gentle slope in general. Approximately 52 per cent of the basin is composed of alluvial soil. River Ganga and its tributaries forming a large flat and fertile plain with an abundance of water resources, fertile soil and suitable climate.[11] However, nowadays, the basin is experiencing high water stress, with most cities characterized as critical and over-exploited.

The climate in the basin varies from sub-humid to hot and humid monsoonal and rainfall mostly occurs in the monsoon period from June to September. The average annual rainfall for the Ganga basin varies between 500–2,500 mm. Due to high discharge into the Ganga river system and the seasonality of flow in rivers in the basin, the quantities of water pouring in are periodically so acute that they cause floods, particularly in many parts of Uttar Pradesh, Bihar and West Bengal. The frequency of floods was noted to be highest in the years 1987, 1998, 1999, 2001, 2003, 2013 and 2017.[12]

The surfacewater potential and groundwater potential of the Ganga basin is around 525.05 cu km and 170 cu km respectively.[13] Urban agglomerations are causing major depletion in groundwater table and degradation of groundwater. Water tables are declining at approximately an average of 0.20 m per year in many parts of the basin.A comparative view of the decadal fluctuation of post-monsoon groundwater levels from 2009–19 show that Uttarakhand, parts of Uttar Pradesh, Haryana and Rajasthan have witnessed groundwater levels dropping from 5–10 metres below ground level (m b.g.l.) in 2009 to 20–40 m b.g.l in 2019.[14] Urban water bodies (lakes and ponds) are also deteriorating and are being encroached upon at an alarming rate.

This loss is also reflected in the groundwater regime of urban and peri-urban areas, in the quality of water in drains and rivers, and in their failure to manage moderate and extreme rainfall events. Due to inadequately planned urbanization, the drainage of surfacewater within the basin has been disrupted as the small natural channels and low-lying areas have often been filled with municipal waste. The cities and towns running through the main-stem of Ganga generate some three billion litres of sewage every day, only a fraction of which is treated before being discharging into the river.[15] Since the 1980s, various governmental agencies, and multilateral and bilateral funding agencies have been investing resources and trying to improve the health of Ganga but despite many efforts, creation of pollution control infrastructure, policies and programmes, the health of the river has not improved significantly. An overview of the Ganga river basin is illustrated in *Figure 4: Ganga river basin at a glance*.

Figure 4: Ganga river basin at a glance



Source: Compiled by CSE, 2021

3.2 Profile—Uttar Pradesh in the Ganga basin

Uttar Pradesh is the largest state in the Ganga basin, occupying about 30 per cent of the basin area, i.e., 241,392 sq. km. Ganga transverses a distance of 1,450 km in the state. Uttar Pradesh is the most populous state in India (and the basin), with a total population of 44.5 million. It is home to 648 statutory towns, 267 census towns and 67 urban agglomerations.[16]

Uttar Pradesh is a critical state in the basin, infamous for large-scale withdrawal of water resources (both surface and groundwater) as well as the most polluted stretches of the Ganga river.

3.2.1 Climate and rainfall

Climate of Uttar Pradesh is predominantly sub-tropical monsoon, mild and dry winter and hot summer. Peak summer temperature can reach up to 48°C (May–June) while peak winter temperature can be as low as 0°C (December–January).

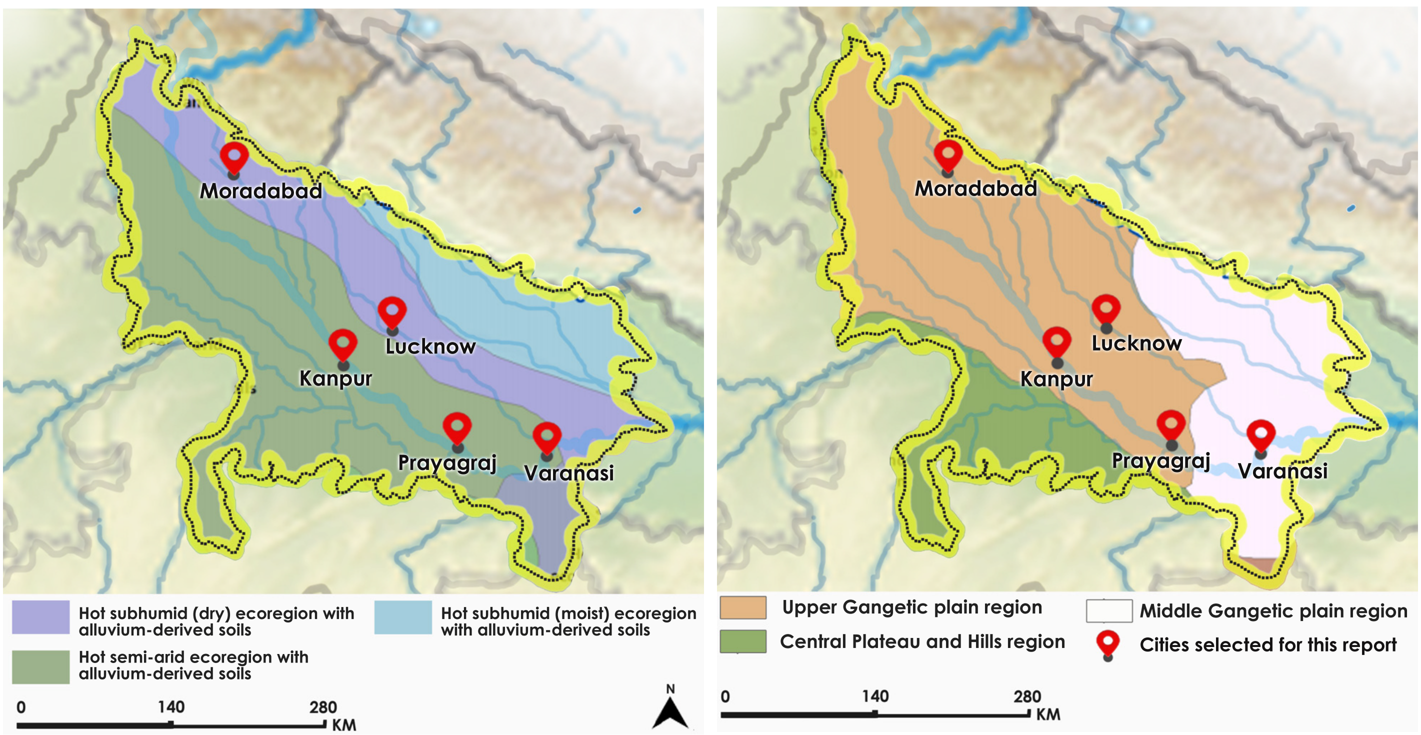
The average annual rainfall in Uttar Pradesh is 946.07 mm.[17] Around 84.4 per cent (799 mm) of it occurs in the southwest monsoon season (June–September). However, the southwest monsoon season rainfall has been showing a significant decreasing trend. The northern and eastern regions of the state receive the highest rainfall, which gradually decreases towards the southern and western regions. Non-uniform and unpredictable rainfall patterns cause recurrent droughts and floods in the eastern tracts of the state (see *Figure 5: Agro-ecological and agro-climatic zones of Uttar Pradesh*).

3.2.2 Land

Topography

The state has elevations ranging between 300–5,000 m above mean sea level

Figure 5: Agro-ecological and agro-climatic zones of Uttar Pradesh



Source: CSE, 2021, compiled from Ganga Basin Organization, retrieved from CWC: http://cwc.gov.in/lgbo/about-basins (m.s.l.). Geomorphologically, the state is divided into three major topographical regions as follows.

Siwalik foothills of Himalayas and the Terai region (border of Uttar Pradesh on the north)

The river streams tend to sink in the porous beds of sediments of the Siwalik range in Uttar Pradesh. The transition of the Bhabhar tract into the Terai region is marked by rich forests and various river streams.

Central Gangetic Plains (central portion of the state)

The Central Gangetic plain cover nearly 85 per cent area of the state and are characterized by a flat topography. Due to the flat topography, this region comprises various physical features like rivers, lakes and ponds, with elevation ranging from 60 m in the east to 300 m in the northwest and a gradient of 2 m per sq. km.

Vindhya Range and Bundelkhand Plateau Region (smaller part of southern Uttar Pradesh)

The Vindhyas are rendered by a discontinuous, hard range of hills, highlands and plateaus. With an average elevation of 300 m, the Vindhya range is a low-lying area that receives sparse rains and is devoid of adequate water resources.

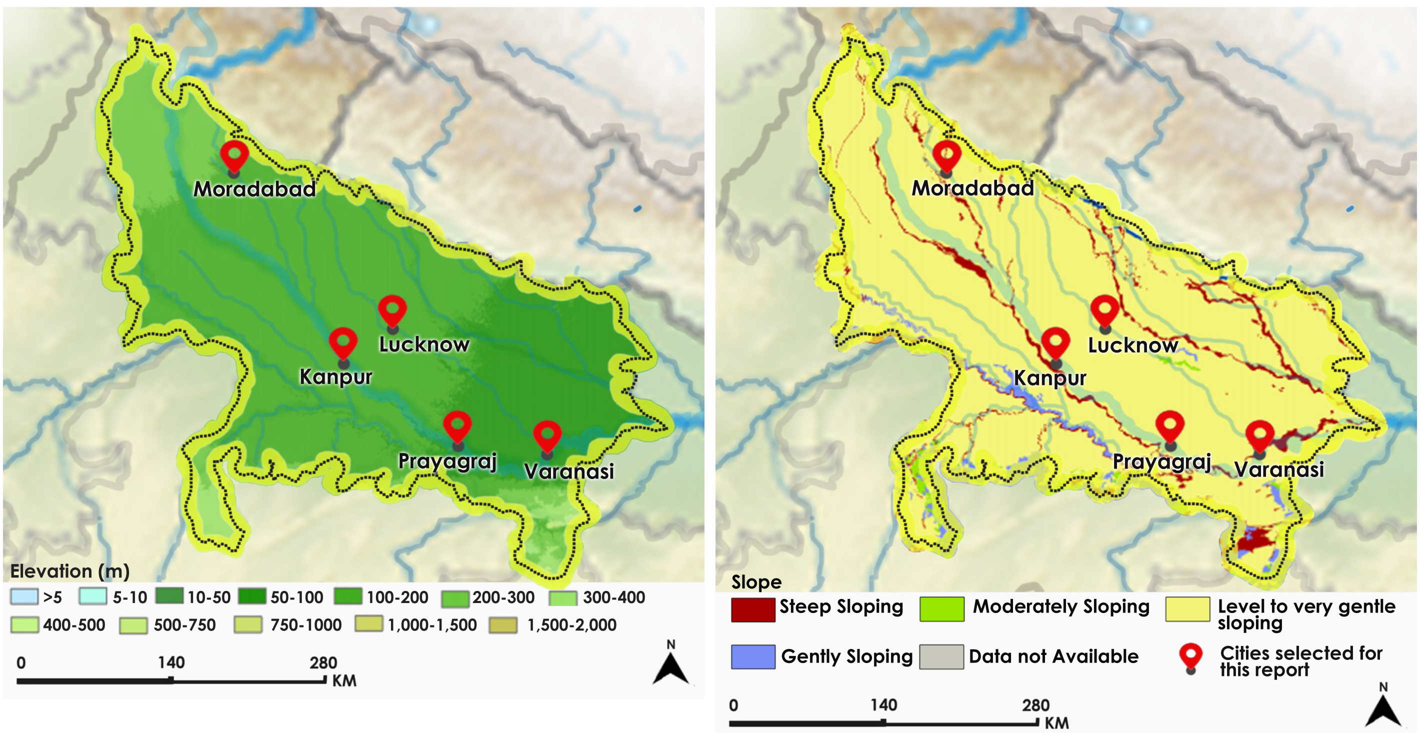
Slope

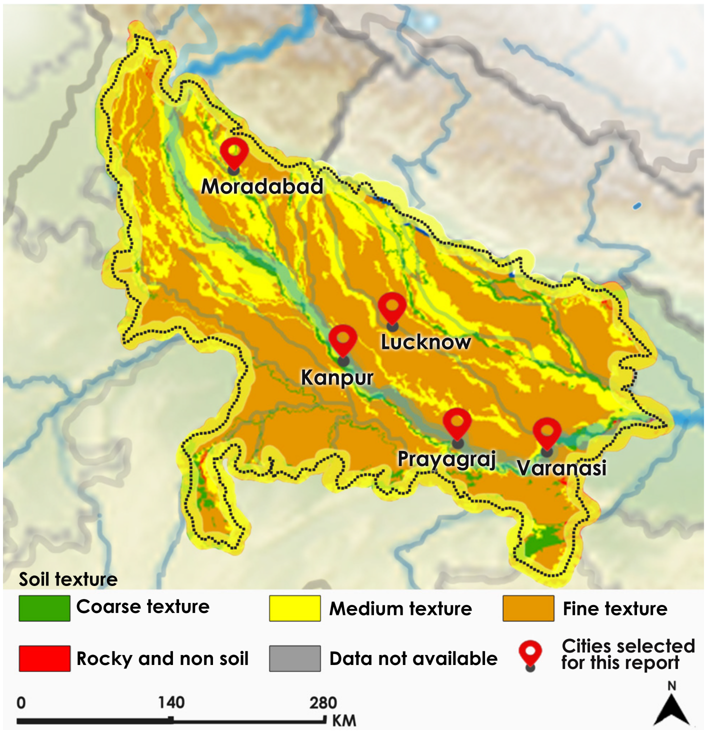
The state has mostly flat terrain that slopes gently in the southeast direction, with a steeper slope in the western part that flattens eastwards. As the river water flows down rapidly through the steeper slopes, sediments are deposited in shallow beds, and the sunken river streams re-emerge on the surface, causing massive floods in the relatively plain areas (see *Figure 6: Land profile of Uttar Pradesh*).

Geology

The Bhabhar tract and Terai region is composed of fine alluvium, primarily sand, clay, silt and gravel with loamy texture. The Central Gangetic plains are blessed

Figure 6: Land profile of Uttar Pradesh





Source: CSE, 2021, compiled from Ganga Basin Organization, retrieved from CWC: http://cwc.gov.in/lgbo/about-basins

with highly fertile alluvial soil. These sediments consist of sands of different grades with clay, silt and occasional gravel and kankar with coarse loamy, fine loamy and fine silty texture. The southern range of the state comprises of hard rocks of Bijawar and Vindhyan. The soil type is fine loamy with stoniness and gravelliness (see *Figure 6: Land profile of Uttar Pradesh*).

3.2.3 Drainage and water resources

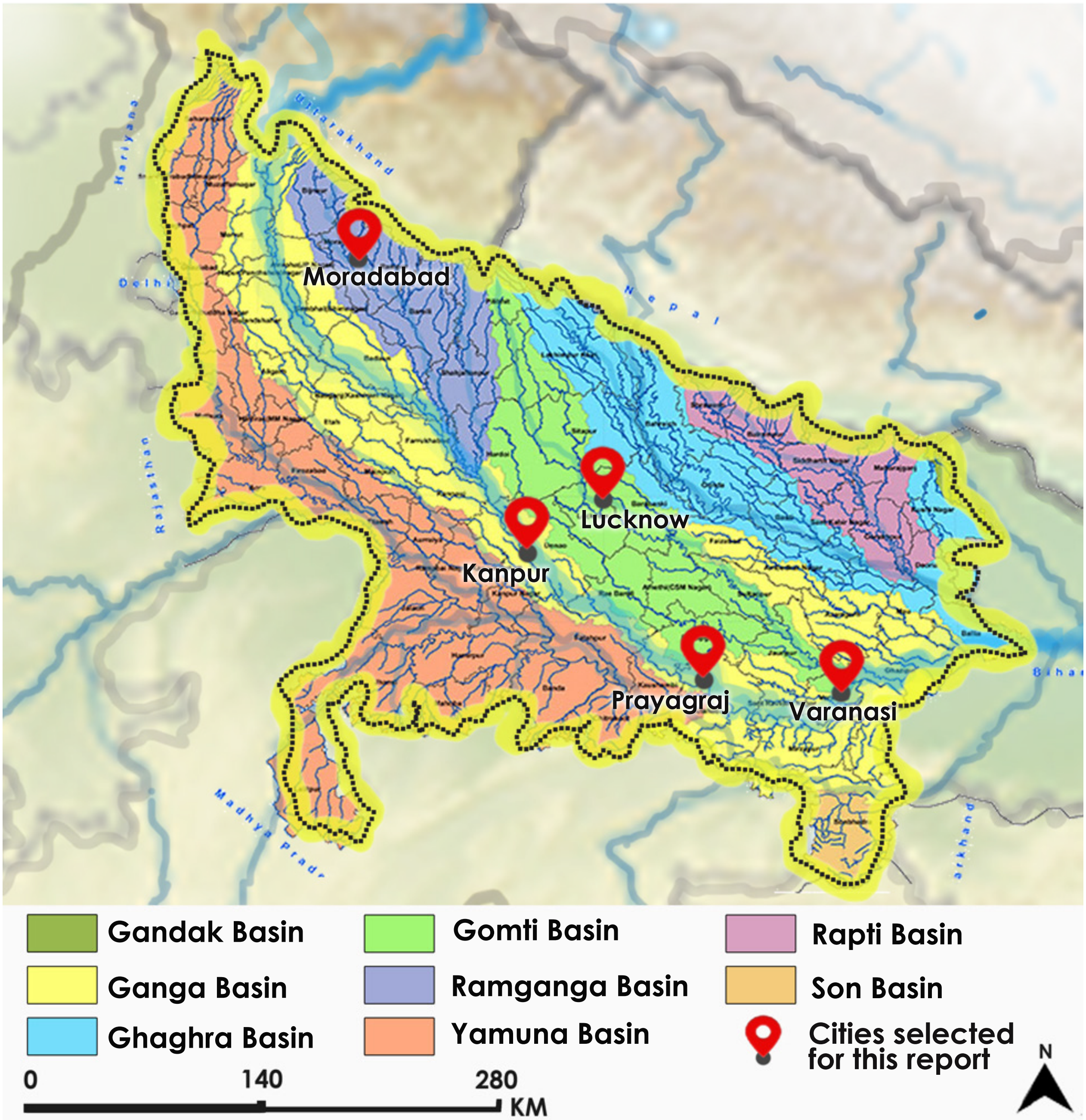
River Ganga and its major tributaries
River Ganga and its tributaries flow in the northwest—southeast direction. Other major rivers flowing through the state are Yamuna, Ghagra, Rapti, Gomti, Gandak, Son, Kosi, Sharda, etc. As per Land Use and Land Cover (LULC) 2015–16,[18] rivers, streams and canals account for 6,886.37 sq. km of the geographical surface area within the state (see *Figure 7: Drainage basins in Uttar Pradesh*).

Urban lakes and ponds
Due to the flat topography and meandering rivers, the central Gangetic plain region comprises of various physical features like lakes and ponds.

As per LULC 2015–16,[19] water bodies, river, stream or canals, wetlands, reservoirs, lakes and ponds cover 4.38 per cent (10,569.58 sq. km) of the geographical surface area within the state. The forest department of Uttar Pradesh is mainly responsible for maintenance of the lakes in the state.

Groundwater
The alluvium forms a very rich reservoir of groundwater in the state. The extent of groundwater utilization within the Ganga basin is the highest (45.36 billion cubic metre or BCM per annum) in Uttar Pradesh.[20] Almost all the prominent urban centres like Lucknow, Kanpur, Varanasi, Agra and Ghaziabad are severely affected by groundwater depletion. A comparison of the depth of water level

Figure 7: Drainage basins in Uttar Pradesh



Source: CSE, 2021, compiled from Ganga Basin Organization, retrieved from CWC: http://cwc.gov.in/lgbo/about-basins

with the decadal mean (2009–18) indicates that more than 67 per cent of the wells analyzed in the state have reported a decline in groundwater level within a range of 0–2 m. A decline of more than 4 m has also been observed in some pockets.[21] Before the 2019 monsoons, the groundwater level was in the range of 2–5 m b.g.l. in the northern parts of the state while in some regions it ranged from about 20 m b.g.l. to more than 40 m b.g.l. After the 2019 monsoons, the table only improved to a shallow water level of less than 2 m b.g.l. in some region while in some regions it was deeper, ranging from about 10-40 m b.g.l.

Annual groundwater recharge is significantly high in the region, varying from 0.25 m to more than 0.5 m. The total annual replenishable groundwater recharge is 69.92 BCM with provision of 4.6 BCM as natural discharges to contribute to base flow of the river (see *Table 3: Groundwater resources assessment for Uttar Pradesh, 2017*). Even though replenishable resources are abundant in the state, there has been indiscriminate withdrawal of groundwater leading to over-exploitation. Undifferentiated development of groundwater has resulted in depletion of groundwater storage and lowering of water levels in 70 per cent blocks in the districts of the state and in more than 80 per cent of the area under urban bodies.[22]

Table 3: Groundwater resources assessment for Uttar Pradesh, 2017

Groundwater recharge		
Monsoon season	Recharge from rainfall	37.73 BCM
	Recharge from other sources	11.67 BCM
Non-monsoon season	Recharge from rainfall	1.59 BCM
	Recharge from other sources	18.93 BCM
Total annual groundwater recharge		69.92 BCM
Total natural discharge		4.60 BCM
Groundwater extraction		
Annual extractable groundwater		65.32 BCM
Annual groundwater extraction		Irrigation: 40.89 BCM Domestic: 4.95 BCM
Total annual groundwater extraction		45.84 BCM
Net groundwater availability for future use		20.36 BCM
Stage of groundwater extraction		70.18 per cent

Source: R.S. Sinha (2021), State of Groundwater in Uttar Pradesh

The state is also facing an emerging crisis of groundwater pollution. The reported occurrence of arsenic in groundwater is turning out to be a major threat to safe drinking water supplies (see *Table 4: Groundwater quality in Uttar Pradesh*). In addition, salinity, fluoride and nitrate pollution, heavy metal toxicity, and bacteriological contamination in groundwater are also serious concerns in the state.[23]

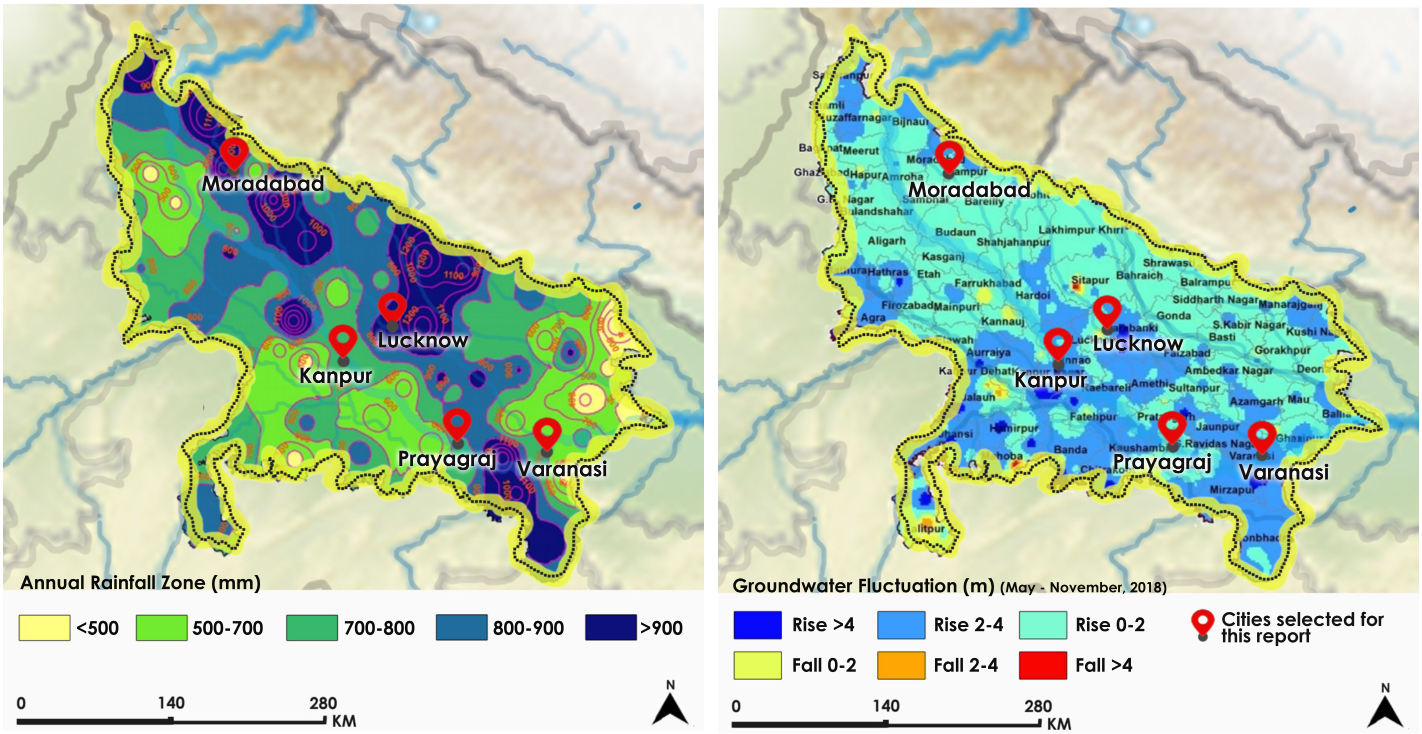
Table 4: Groundwater quality in Uttar Pradesh

Contaminant	CPCB standard	Affected regions*
Salinity	Electrical conductivity > 3,000 µS/cm at 25°C	Parts of Kanpur, Lucknow
Fluoride	> 1.5 mg/l	Parts of Lucknow, Prayagraj and Varanasi
Iron	>1 mg/l	Parts of Kanpur
Nitrates	> 45 mg/l	Parts of Moradabad, Prayagraj and Kanpur
Arsenic	> 0.05 mg/l	Parts of Moradabad, Kanpur and Lucknow
Lead	Above 0.01 mg/l	Parts of Moradabad, Prayagraj and Kanpur
Cadmium	Above 0.003 mg/l	Parts of Varanasi
Chromium	Above 0.05 mg/l	Parts of Kanpur and Varanasi
Manganese, zinc, nickel and copper	High level of these toxic metals are reported from various industrial and urban areas	

*Only regions affected in the cities selected for this report (discussed in detail in the next chapters) have been enlisted here.

Source: CGWB

Figure 8: Rainfall and groundwater profile of Uttar Pradesh



Source: CGWB. (2020) Ground Water Year Book, Uttar Pradesh (2018 –19)

3.2.4 Land cover pattern

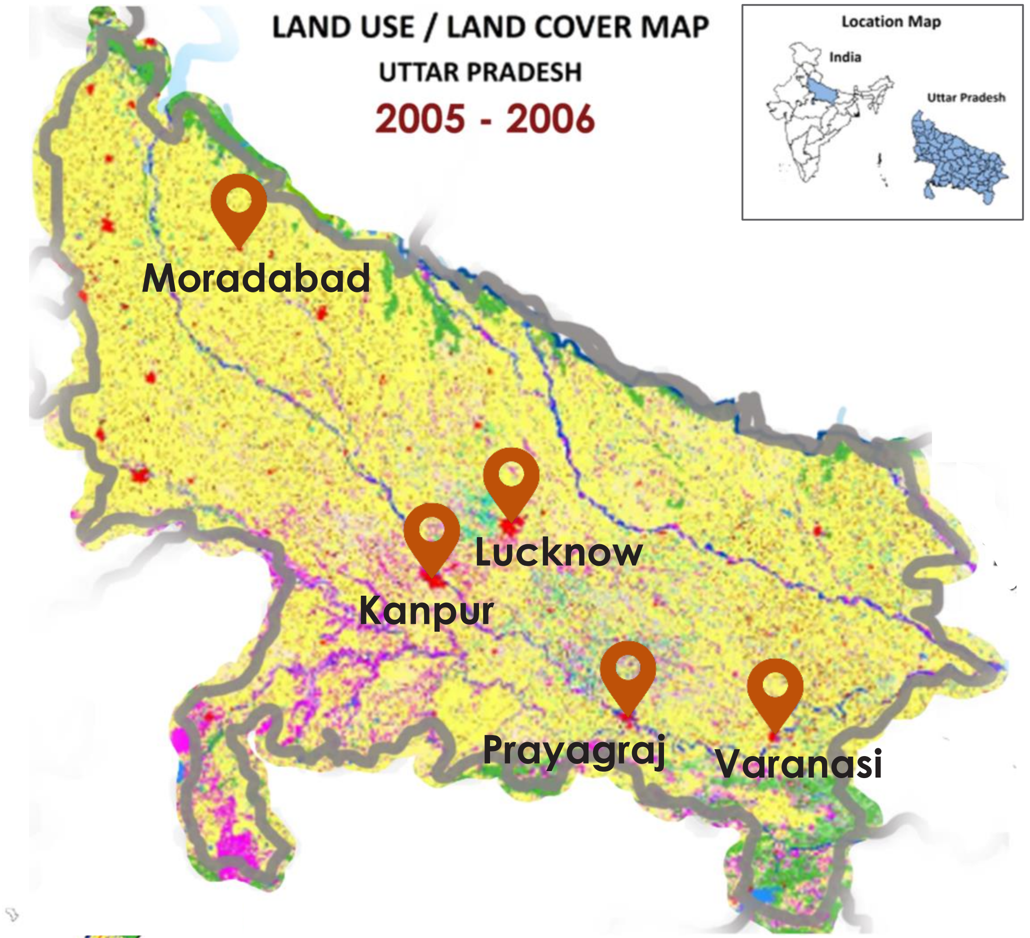
A decadal analysis (2005–06 to 2015–16) of the land cover pattern of Uttar Pradesh reveals that urban areas have increased dramatically. Urban built-up area has increased approximately 30.76 per cent from 3,122 sq. km in 2005–06 to 4,509 sq. km in 2015–16[24] (see *Figure 9: Land cover change in Uttar Pradesh, 2005–06 to 2015–16*). It should also be noted that significant changes have not been observed in land cover pattern for agriculture, forests and water resources in rural areas. Urban centres in the state have expanded spatially, at the expense of water bodies, open spaces and forests areas in urban and peri-urban areas.

3.2.5 Urban flooding

Flooding incidences at local and regional levels resulting in inundations in urban areas for a period extending from a few hours to several days in peak monsoon is a reoccurring phenomenon. The estimated annual losses in Uttar Pradesh due to floods are Rs 4.32 billion (US $70 million).[25] This flooding can be attributed to various anthropogenic causes such as rapid urbanization both planned and unplanned encroaching on floodplains, water courses and water bodies, resulting in impervious surfaces that reduce the percolation and increase surface run-off.[26] On the other hand, urban areas are over-extracting groundwater; extraction is estimated to increase from 49.48 BCM in 2017 to 72.06 BCM by 2025.[27]

According to state-wise flood frequency data examination for 1986-2003 and 2006–16, the eastern parts of Uttar Pradesh have a large flood inundation area (approximately 7.34 million hectare of land get affected annually) and are perhaps the worst flood-affected region in the state, leading to loss of lives, properties, communications and infrastructure facilities.

Figure 9: Land cover change in Uttar Pradesh, 2005–06 to 2015–16



LULC Class	Area (Sq.Km)	LULC Class	Area (Sq.Km)
Builtup,Urban	3087	Builtup,Rural	6767.7
Builtup,Mining	34.95	Agriculture,Crop land	166987.62
Agriculture,Plantation	4319.38	Agriculture,Fallow	14958.05
Forest,Deciduous	8613.77	Forest,Forest Plantation	59.07
Forest,Scrub Forest	2924.9	Forest,Swamp/ Mangroves	189.04
Grass/Grazing	706.27	Barren/unculturable/ Wastelands, Salt Affected land	4558.68
Barren/unculturable/ Wastelands, Gullied/Ravinous Land	3023.05	Barren/unculturable/ Wastelands, Scrub land	12172.68
Barren/unculturable/ Wastelands, Sandy area	249.73	Barren/unculturable/ Wastelands, Barren rocky	2124.52
Wetlands/Water Bodies, Inland Wetland	2713.96	Wetlands/Water Bodies, River/Stream/canals	6102.8
Wetlands/Water Bodies, Reservoir/Lakes/Ponds	1334.84		
Total			240928

LULC Class	Area (Sq.Km)	LULC Class	Area (Sq.Km)
Builtup,Urban	4101.9	Builtup,Rural	8289.32
Builtup,Mining	407.55	Agriculture,Crop land	182306.22
Agriculture,Plantation	4906.58	Agriculture,Fallow	7285.57
Forest,Evergreen/ Semi evergreen	230.97	Forest,Deciduous	12957.89
Forest,Forest Plantation	122.42	Forest,Scrub Forest	2091.16
Forest,Swamp/ Mangroves	67.41	Grass/Grazing	138.99
Barren/unculturable/ Wastelands, Salt Affected land	2573.72	Barren/unculturable/ Wastelands, Gullied/Ravinous Land	1278.4
Barren/unculturable/ Wastelands, Scrub land	3364.19	Barren/unculturable/ Wastelands, Sandy area	16.53
Barren/unculturable/ Wastelands, Barren rocky	219.6	Wetlands/Water Bodies, Inland Wetland	2224.89
Wetlands/Water Bodies, River/Stream/canals	6886.37	Wetlands/Water Bodies, Reservoir/Lakes/Ponds	1458.32

Source: National Natural Resources Management System, ISRO,2019

Source: CSE, 2021 (Compiled from Bhuvan Portal)

Maximum urban flooding events were recorded during the years 1987, 1998, 1999, 2001, 2003 and 2013.[28] In 2010, water levels at three gauge stations exceeded all previous high-flood records.[29]

As per the state government records, floods caused 380 deaths in 2013 and 93 deaths in 2017. Prayagraj received 102.22 mm of rain and Varanasi received 84.2 mm of rain on a single day.[30&31] In June 2021, the state received 158 per cent above normal rainfall. A total of 75 districts have received 'large excess' rainfall in the first three weeks of the southwest monsoon season. As against its normal 49.5 mm rainfall, the state has received 127.8 mm.[32]

It has been observed that various parts of Uttar Pradesh, including metropolitan and Class 1 towns are vulnerable to urban flooding. In addition to this, these cities have a poor groundwater regime with respect to depleting groundwater tables, poor recharge rates and deteriorating groundwater quality. Stormwater and floodwater harvesting can provide opportunities to capture this run-off through retention strategies, and allow aquifer recharge through infiltration; thereby capitalizing on floodwater as a potential resource.

Overall, it is imperative to understand that while floods can cause destruction of life and property, if harnessed properly, they can be a great source of quick replenishment of water resources.

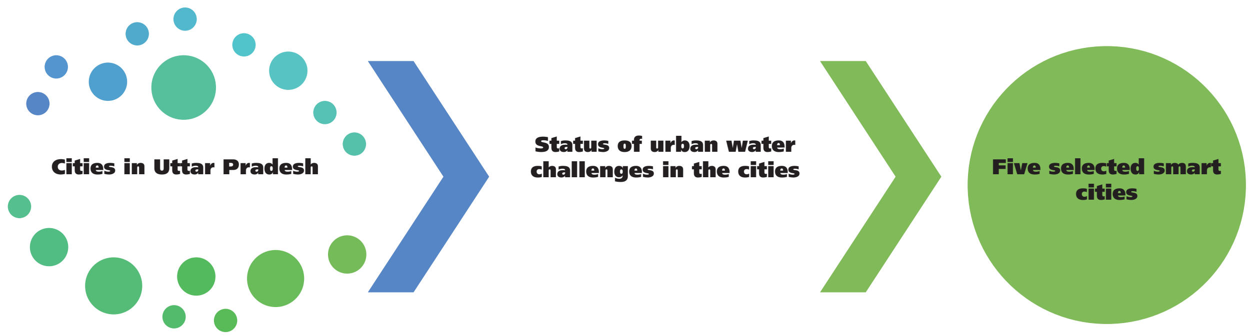
3.2.6 Selection of pilot cities

A few large metropolises and cities in the state accommodate about 30 per cent of the urban population of the state and are expanding rapidly into peri-urban areas. Five cities, namely Kanpur, Allahabad, Varanasi, Lucknow and Moradabad have been selected for this study. A baseline information for selected cities is based on secondary sources, *Excreta Matters* (2012) and *Why Urban India Floods* (2016) as well as other CSE publications and government publications and reports. The selection of cities has been done mainly considering the frequent urban flooding and rapidly depleting groundwater that is a major source of water supply and strengthening the ongoing efforts of government and other agencies.

These cities are also the priority cities under various national flagship programmes—namely the Smart Cities Mission, the Atal Mission for Rejuvenation and Urban Transformation and the Namami Gange Mission of the Government of India. All selected cities have Master Plans or City Development Plans. Several reports have shown rampant encroachment and loss of considerable number of water bodies in these cities that have been attributed to both planned and unplanned urban development. In this study, the effort is to identify and ensure convergence of these programmes at the city and local level.

The study focuses on select parks and open spaces in these cities with an aim to assess untapped rainwater or stormwater as well as demonstrate potential of capturing runoff by implementing suitable WSUDP interventions in these cities. The next section of the document provides a general description of these cities, providing information on rainfall patterns and statistics, urban planning

Figure 10: Methodology for selection of cities for pilot projects



- Smart cities in Uttar Pradesh
- NMCG priority Ganga cities and towns
- Population and pace of urbanization of cities
- Ganga cities in Uttar Pradesh with Master Plans and City Development Plans

- Status of groundwater exploitation
- Urban flooding issues
- Loss of water bodies
- Swachh Sarvekshan score, 2020

Different hierarchical parks and open spaces of neighbourhood scale and zonal- or city-scale have been selected as pilot case studies

Source: CSE, 2021

and provision of public parks and open spaces. For each city, potential sites for implementation have been selected. Different hierarchical parks and open spaces of neighbourhood scale and zonal or city scale have been selected as pilot case studies, where rainwater harvesting potential has been calculated and certain preliminary design guidelines for each of these parks have been recommended (see *Figure 10: Methodology for selection of cities for pilot projects*).

Based on the above indicators, Lucknow, Kanpur, Varanasi, Prayagraj and Moradabad have been selected for pilot research on WSUDP potential for stormwater harvesting in public parks and open spaces. Apart from Lucknow, all other selected cities are 'NMCG Priority Towns'. The details of the cities have been given in *Table 5: Key factors considered for selection of five smart cities*.

Table 5: Key factors considered for selection of five smart cities

City	Population 2011 (in lakhs)	Master Plan	Swachh Sarvekshan 2020 rank	Ground-water status (as per GEC–2015)	Urban flooding	Loss of water bodies
Lucknow	29.02	Yes	12	Over-exploited	Yes	Yes
Kanpur	28.76	Yes	25	Over-exploited	Yes	Yes
Varanasi	11.98	Yes	27	Over-exploited	Yes	Yes
Prayagraj	11.95	Yes	20	Over-exploited	Yes	Yes
Moradabad	8.78	Yes	117	Over-exploited	Yes	Not available

Source: CSE, 2021

4 WSUDP potential in select cities of Uttar Pradesh

4.1 Lucknow

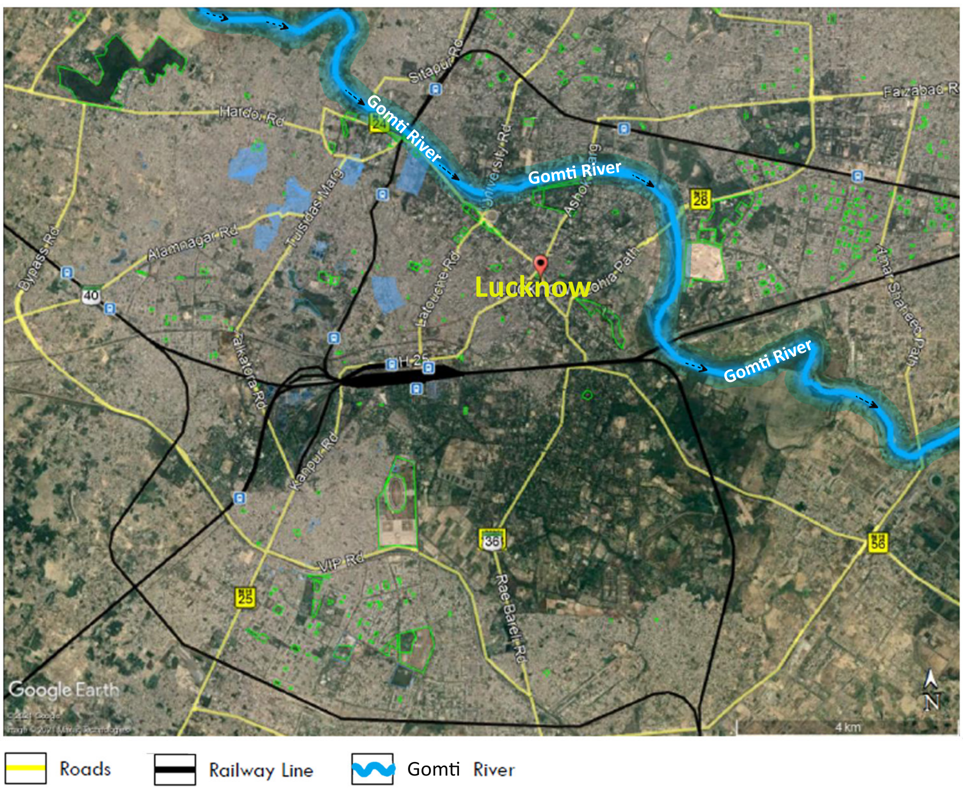
4.1.1 City profile

Lucknow, the 'City of Nawabs', is the capital of Uttar Pradesh. The city of 28,17,105 inhabitants (as per the 2011 Census), with a population density of 8,049 persons per sq. km, is divided into 110 wards.

The municipal area of the city (under the Lucknow Municipal Corporation or LMC) is spread over 349 sq. km and the larger Lucknow Development Planning area stretches over 980 sq. km.

The city is situated in the middle of the Gangetic plains and hugs the banks of the river Gomti, geographically bifurcating the city into two parts (see *Figure 11: Location-setting of Lucknow, Uttar Pradesh*). The city lies at an average altitude of 123 m above mean sea level and the general slope of the city is towards south and southeast. Lateral slopes are towards the river Gomti, which flows from northwest to southeast through the heart of the city.

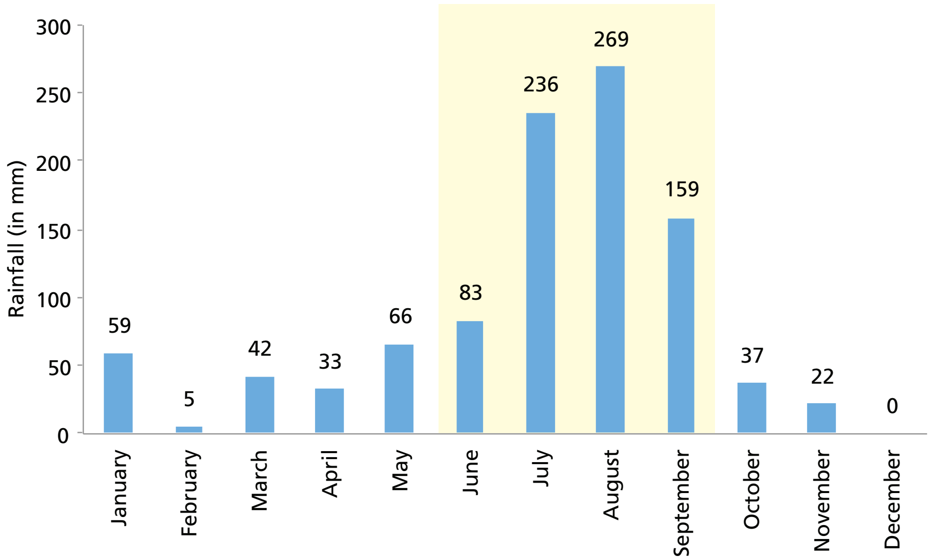
Figure 11: Location-setting of Lucknow, Uttar Pradesh



Source: CSE, 2021

The city has a warm humid subtropical climate, with the maximum temperature exceeding 45°C in the summer and the minimum temperature dropping to 3°C in the winter. The city receives an average of 1,010 mm annual rainfall, of which 75 per cent occurs mostly between July and September (i.e., the southwest monsoons) (see *Figure 12: Rainfall pattern of Lucknow*).

Figure 12: Rainfall pattern of Lucknow



Source: CSE (compiled from information retrieved from IMD, Government of India)

River Gomti stretches out over 20 km within the city and is its major water body. It also has some major canals, namely Haider canal, Kukrail drain and Sharda canal, etc. As per the records, the city has lost 11,000 ponds and other water bodies of the total 14,000 reported in the 1950s. Based on the Urban Groundwater Resource Estimation of 2017 (as per Groundwater Resource Estimation Committee or GEC, 2015), the annual decline in the groundwater table in the city is 0.44 m (pre-monsoon) and 0.54 m (post-monsoon). In the larger part of the city, groundwater levels are mostly declining at an average rate of 70 cm to 1 m per year. The annual extractable groundwater resource is 5,451 hectare metre (ha m) and the stage of groundwater extraction of the city is 177 per cent.

The geological profile exhibits flat alluvial terrain and is covered with thick pile of quaternary sediments classified into older and newer alluvium. The older alluvium comprises grey to brown coloured silt-clay and sand with or without kankar.

4.1.2 Urban planning in Lucknow

Historically, Lucknow has grown from a small Lakhanpur village to today's metropolis, with the area under LMC being 48 sq. km in 1951 and 250 sq. km at present. The central business district of Lucknow is a high density zone with major land uses being residential and commercial. The old city is congested, with narrow roads and lack of open spaces. The river divides the city into two parts, with urban development on both sides, radiating out in all the directions but significantly in the eastern and northern directions. At present, the total drainage length in Lucknow is 2,701 km, which is 80 per cent of the road network (against the standard of 130 per cent). The drainage system is a mix of open and closed drains.

The Master Plan for Lucknow, 2021 was prepared in 2004–05, covering an area of 413 sq. km. The area under the jurisdiction of the plan was increased to 980 sq. km by the Town and Country Planning Department of Uttar Pradesh in 2011. The City Development Plan (CDP) was prepared in 2006, which has been revised in 2016 to achieve a long-term vision by 2040. There has been lot of variations between the proposed land use and actual development taking place in the city. Only 3 per cent of the land area comes under recreational uses.

LMC is the major authority responsible for construction and maintenance of parks and gardens in Lucknow. Apart from LMC, Lucknow Development Authority, Awas Vikas Parishad and private developers construct parks and gardens in colonies which are later transferred to LMC for maintenance purposes. There are 1,684 parks and gardens under LMC's jurisdiction, with a total area of 259 hectares, unequally distributed in six zones of the city. Of these, 487 parks are in a developed stage, 825 parks are semi-developed, 344 are 'not developed' and the rest (28 parks) are open areas.

4.1.3 Rainwater harvesting in select public parks

Dr Ram Manohar Lohia Park
Coordinates: 26°51’19.47”N, 80°58’47.60”E | Area: 2,82,047 sq. m (approximated from Google Maps)

Figure 13: Dr Ram Manohar Lohia Park, Lucknow

Source: CSE, 2021

- Potential runoff generated: 32,760 kilo-litre (KL) annually with a rainfall of 1,010 mm
- Assuming peak rainfall to be within the range of 100–150 mm
- Depth of structure to be not more than 2–3 m
- Area required for infiltration structures will be within the range of 3,526–4,512.7 sq. m

Hence, the area required to be dedicated for the infiltration structure is in the range of 1.5–3 per cent of the total area of the park to cater to peak rainfall over 15 minutes.

Potential infiltration systems that can be proposed in the park area are:
- Trench with filter strips and swales along the footpath or desired path
- Bio-retention areas surrounded by vegetation at nodes or at the lowest point of the park
- Detention basins at the centre
- Infiltration basins in the relatively flat and pervious areas

Neighbourhood Park: LDA Colony
Coordinates: 26°47'33.29"N, 80°53'51.92"E | Area: 18,008 sq. m (approximated from Google Maps)

Figure 14: Neighbourhood Park, LDA Colony, Lucknow

Source: CSE, 2021

- Potential runoff generated: 2,092 KL annually with a rainfall of 1,010 mm
- Assuming peak rainfall to be within the range of 100–150 mm
- Depth of structure to be 2 m
- Area required for infiltration structures will be within the range of 225.1–288 sq. m

Hence, the area required to be dedicated for the infiltration structure is in the range of 1.5–3 per cent of the total area of the park to cater to peak rainfall over 15 minutes.

Potential infiltration systems that can be proposed in the park area are:
- Trench with filter strips and swales can be located along the footpath
- Bio-retention areas can be located after identifying low-lying areas within the park
- Infiltration basins in relatively flat and pervious areas can be proposed

Indira Park
Coordinates: 26°53'4.10"N, 80°56'30.21"E | Area: 5, 227 sq. m (approximated from Google Maps)

Figure 15: Indira Park, Lucknow

Source: CSE, 2021

- Potential runoff generated: 607 KL annually with a rainfall of 1,010 mm
- Assuming peak rainfall to be within the range of 100–150 mm
- Depth of structure to be 2 m
- Area required for infiltration structures will be within the range of 65.3–83.6 sq. m

Hence, the area required to be dedicated for the infiltration structure is in the range of 1.5–3 per cent of the total area of the park to cater to peak rainfall of over 15 minutes.

Potential infiltration systems that can be proposed in the park area are:
- Trench with filter strips and swales can be located along the footpath or desired path
- A small rain-garden can be proposed with provisions for overflow

- From these three parks, a total of 35.45 million litres of rainwater can be harvested annually.
- Even if 15 neighbourhood-level parks implement RWH in Lucknow, an additional 31.38 million litres of rainwater can be harvested.
- Therefore, a total of 66.83 million litres of rainwater can be harvested in Lucknow annually from only 15–20 parks.

As per the CDP, 2041, Lucknow has 1,684 parks and gardens, spread across an area of 259 hectares. All these parks have stormwater harvesting potential. Therefore, a total of 309 million litres of rainwater can be harvested in Lucknow annually.

4.2 Kanpur

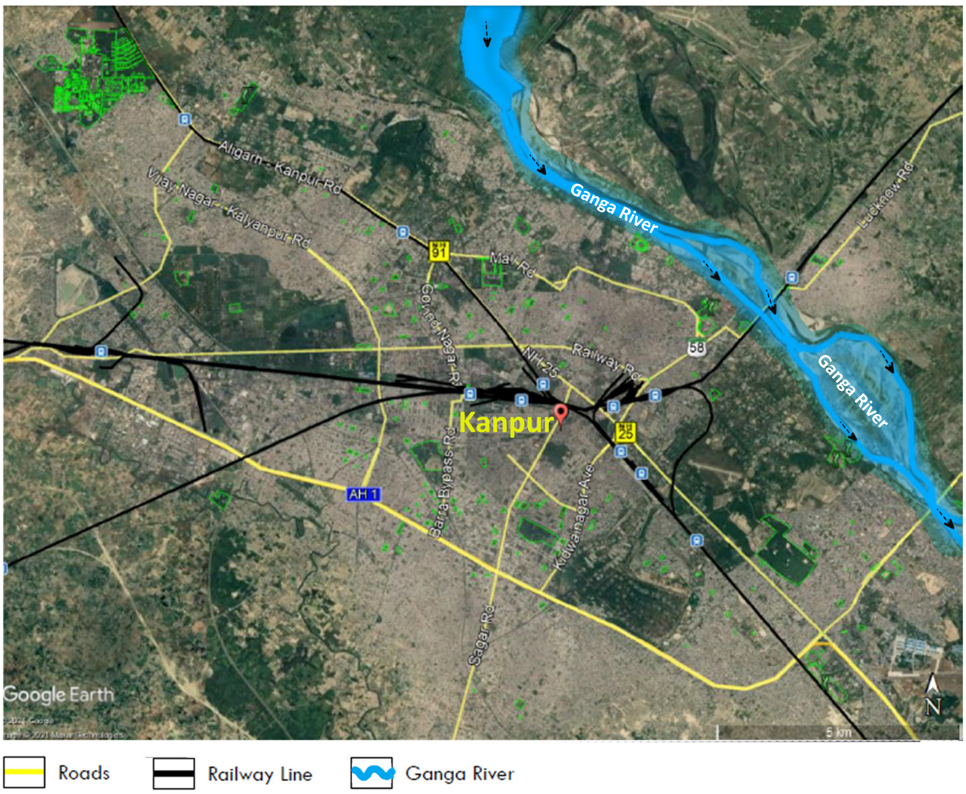
4.2.1 City profile

Kanpur is the second largest city and the largest urban agglomeration in Uttar Pradesh. It is one of the largest industrial towns in northern India.

The municipal area of the city is spread across 260.89 sq. km. towards north, west and south directions. The total urban agglomeration area of the city is 563 sq. km. The city holds a population of 27,65,348 (as per the 2011 Census), with an average density of 9,756 persons per sq. km.

The city is situated on the southern bank of Ganga and is located at an average altitude of 126 m above the sea level (see *Figure 16: Location-setting of Kanpur, Uttar Pradesh*). The level rises sharply from river bed to the high cliff where the main city is situated and then slopes gently towards the central and southeastern part of the area. The city is divided into two broad topographical units, the upland (older settlements) and lowland (new development). The city typically exhibits alluvial and sandy soil, owing to it being in the Indo-Gangetic plains.

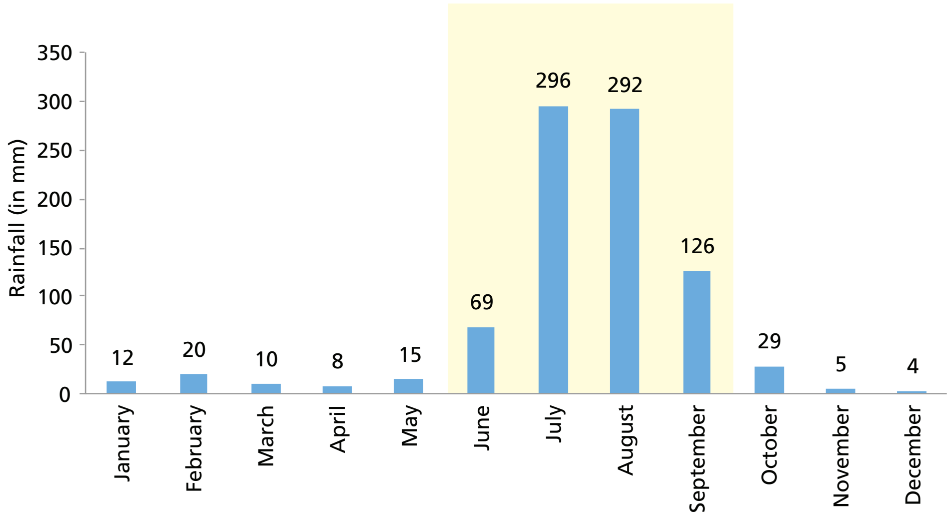
Figure 16: Location-setting of Kanpur, Uttar Pradesh



Source: CSE, 2021

The city's climate is characterized by tropical hot summer and dryness, with the maximum temperature exceeding 48°C in the summer and the minimum temperature dropping to 2°C in the winter. The city receives an average annual rainfall of 885 mm, of which 89 per cent is received during the southwest monsoon (see *Figure 17: Rainfall pattern of Kanpur*).

Figure 17: Rainfall pattern of Kanpur



Source: CSE (compiled from information retrieved from IMD, Government of India)

Rivers Ganga and Pandu are the major water bodies in the city. The city is dotted with water bodies like Jhakarkati lake, Diggi Talab, etc., located near the GT Road. The two tanks at Motijheel were used as freshwater reservoirs for water supply for the city, but have been abandoned due to excess silting. The Upper Ganga Canal network flows to the south of the city. Based on the Urban Groundwater Resource Estimation 2017 (as per GEC, 2015), the annual decline in groundwater table in the city is 0.51 m (pre-monsoon) and 0.47 m (post-monsoon). The annual extractable groundwater resource is 2,445 ham and the stage of groundwater extraction of the city is 201 per cent.

4.2.2 Urban planning in Kanpur

Kanpur city started growing southwards from the banks of river Ganga in the early 18th century, as industrial estates, mills and defence establishments sprang up. This has resulted in the linear growth of the city ever since. At present, the total coverage of stormwater drainage network in Kanpur is 63.66 per cent of its road network.

The first Kanpur Master Plan, 1991 was notified in 1970 and revised as Master Plan, 2021 by the state's Town and Country Planning Department to promote systematic and planned development of the city and to correct the imbalances of past development. Even the land use proposed in the Master Plan, 2021 doesn't reflect adequacy of many activities when compared to Urban and Regional Development Plans Formulation and Implementation (URDPFI) guidelines proposed by the Ministry of Urban Development, Government of India for cities with million-plus populations. In almost all sectors, the proposed land use component has been less than the minimum required under norms. For example, only 9.56 per cent of the area has been demarcated for recreational activities, when it should be 16–20 per cent.

Kanpur Municipal Corporation (KMC) is the major authority for construction and maintenance of parks and gardens. Apart from it, Kanpur

Development Authority and Awas Vikas Parishad also construct parks and gardens in colonies which are later transferred to KMC for maintenance. There are 844 hierarchal parks and gardens with a total area of 260 hectares under the jurisdiction of KMC.

4.2.3 Rainwater harvesting in select public parks

Eco Park

Coordinates: 26°29'8.43"N, 80°15'13.33"E | Area: 67,396 sq. m (approximated from Google Maps)

Figure 18: Eco Park, Kanpur

Source: CSE, 2021

- Potential runoff generated: 7,903 KL annually with a rainfall of 885 mm
- Assuming peak rainfall to be within the range of 100–150 mm
- Depth of structure to be not more than 2–3 m
- Area required for infiltration structures will be within the range of 842.4–1213.12 sq. m.

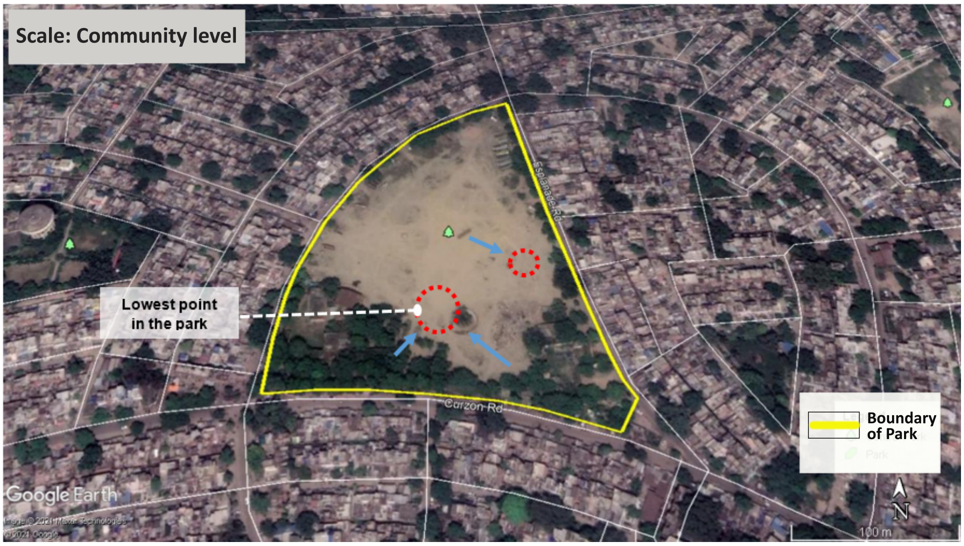
Hence, the area required to be dedicated for the infiltration structure is in the range 1.5–3 per cent of the total area of the park to cater to peak rainfall over 15 minutes.

Potential infiltration systems that can be proposed in the park area are:

- Bio-retention areas surrounded by vegetation at nodes or at the lowest point of the park
- Detention basins at the centre to detain with provision of metered discharge that reduces peak flow rates
- Trench with filter strips and swales along the footpath or desired path

Central Park
Coordinates: 26°28’8.48”N, 80°17’45.55”E | Area: 33,135 sq. m (approximated from Google Maps)

Figure 19: Central Park, Kanpur



Source: CSE, 2021

- Potential runoff generated: 3,885 KL annually with a rainfall of 885 mm
- Assuming peak rainfall to be within the range of 100–150 mm
- Depth of structure to be 2 m
- Area required for infiltration structures will be within the range of 414.1–596.4 sq. m.

Hence, the area required to be dedicated for the infiltration structure is in the range 1.5–3 per cent of the total area of the park to cater to peak rainfall over 15 minutes.

Potential infiltration systems that can be proposed in the park area are:
- Bio-retention areas surrounded by vegetation at nodes
- Trench with filter strips and swales can be located along the footpath

Kamla Nehru Park
Coordinates: 26°28'9.97"N, 80°19'16.66"E | Area: 11,694 sq. m (approximated from Google Maps)

Figure 20: Kamla Nehru Park, Kanpur

Source: CSE, 2021

- Potential runoff generated: 1,550 KL annually with a rainfall of 885 mm
- Assuming peak rainfall to be within a range of 100–150 mm
- Depth of structure to be 2 m
- Area required for infiltration structures will be within the range of 146.1–210.5 sq. m.

Hence, the area required to be dedicated for the infiltration structure is in the range 1.5–3 per cent of the total area of the park to cater to peak rainfall over 15 minutes.

Potential infiltration systems that can be proposed in the park area are:
- A small rain-garden with provisions of overflow
- Trench with filter strips and swales can be located along the footpath or nodes

- From these three parks, a total of 13.33 million litres of rainwater can be harvested annually.
- Even if only 15 neighbourhood-level parks implement RWH in Kanpur, an additional 23.25 million litres of rainwater can be harvested.
- Therefore, a total of 36.55 million litres of rainwater can be harvested in Kanpur annually from only 15–20 parks.

As per the CDP, Kanpur has 844 parks and gardens, spread across an area of 260 hectares, where stormwater harvesting can be implemented. Therefore, a total of 305 million litres of rainwater can be harvested in Kanpur annually.

4.3 Varanasi

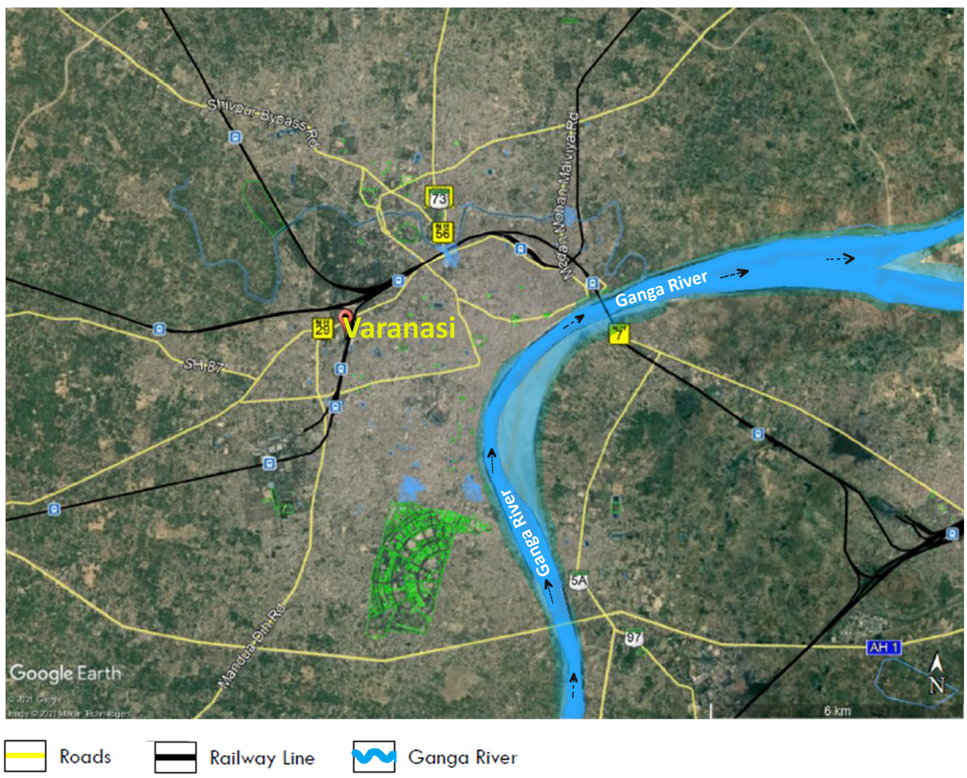
4.3.1 City profile

Varanasi, also known as Banaras or Kashi, is one of the world's oldest living cities and is heterogeneous with multiple layers of religion, culture, art forms and profiles. According to the 2011 Census, the city has a population of 11.98 lakh, with a population density of 14,598 persons per sq. km.

The municipal area of the city (under Varanasi Municipal Corporation or VMC) is spread across 82.1 sq. km. and the larger Varanasi Development Region area stretches across 793 sq. km.[33]

The city is located in the middle-Ganga valley, along the left crescent-shaped bank of the river Ganga. Most of the city area exhibits a more or less flat topography with a gentle slope towards the southeast (see *Figure 21: Location-setting of Varanasi, Uttar Pradesh*). The city slopes gently (at between 15–21 m) towards the river.

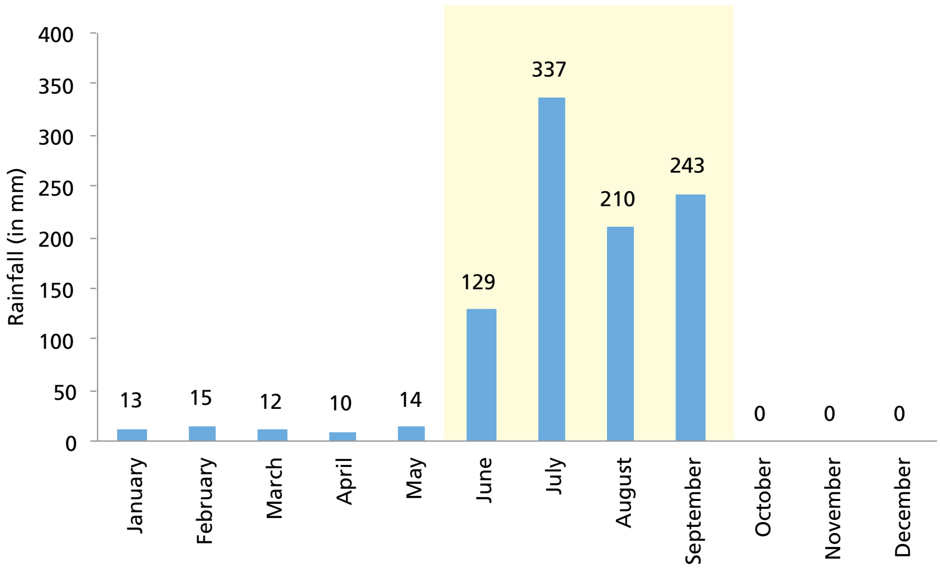
Figure 21: Location-setting of Varanasi, Uttar Pradesh



Source: CSE, 2021

The city has a humid subtropical climate, with the maximum temperature exceeding 46°C in the summer and the minimum temperature dropping to 5°C in the winter. The city receives an average of 982 mm annual rainfall, of which a large portion occurs between July and September (see *Figure 22: Rainfall pattern of Varanasi*).

Figure 22: Rainfall pattern of Varanasi



Source: CSE (compiled from information retrieved from IMD, Government of India)

The river system consists of river Ganga and Gomti. In addition, the Assi and Varuna rivers pass through the city and merge into Ganga. There are about 88 kunds (ponds) in Varanasi which are an effective means of drainage because they can store excess run-off generated due to extreme weather events. Based on the Urban Groundwater Resource Estimation, 2017 (as per GEC, 2015), the annual decline of groundwater table in the city is 0.15 m (pre-monsoon) and 0.47 m (post-monsoon). The zone of groundwater level between >15 m to 25 m increased from 36.84 sq. km. in the post-monsoon 2006 to 87.95 sq. km in post-monsoon in 2015. The annual extractable groundwater resource is 2,445 ham and the stage of groundwater extraction of the city is 201 per cent.

The geological profile exhibits fertile alluvial Gangetic plain characteristics and is underlaid with sediments deposited in successive stages. Layers of clay, fine sand and clay mixed with kankar and stone bazari can be encountered during drilling operations.

4.3.2 Urban planning in Varanasi

The city of Varanasi has grown along the arc of the River Ganga in a semi-circular direction. The city has a radial development pattern and has grown in the north and northwest direction. The city can be divided into three settlement typologies, the old city area, the central area and the new area.

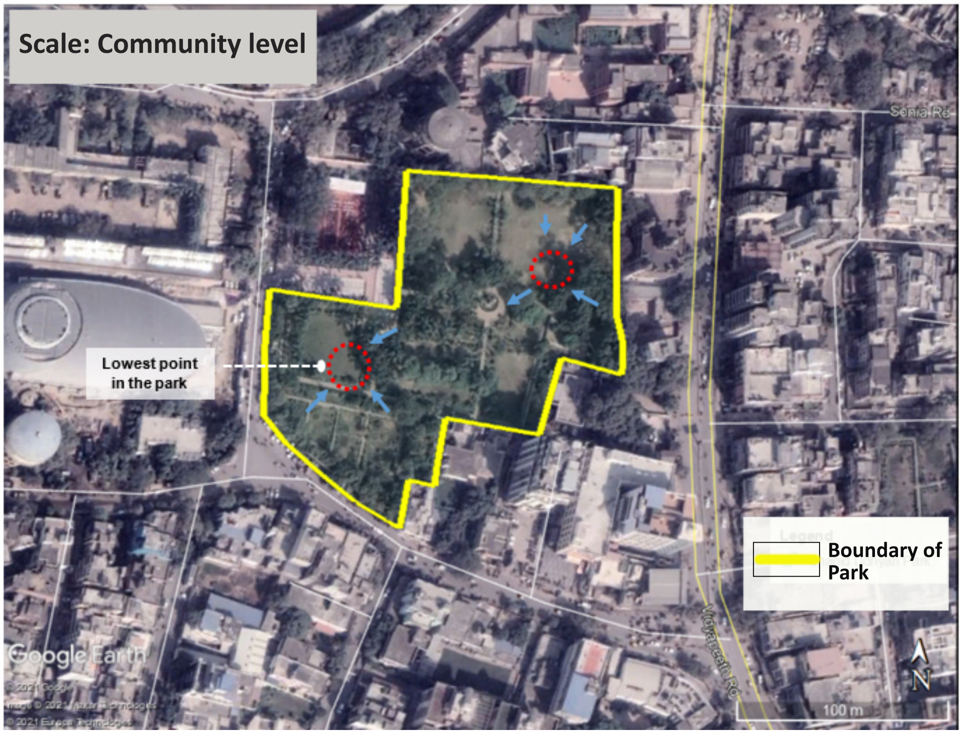
The city has observed a significant increase in the area under transportation and recreation. Most of the proposed land uses are in line with the URDPFI guidelines. Of the total developed area, recreational land use, including parks and playgrounds, constitutes 8 per cent (i.e., 775.54 ha), as recorded in 2011. At present, the city does not have a separate stormwater drainage network. Stormwater is drained off through a very old and incomplete underground and *kachcha* open drainage system, which is only 117 km long.

The draft Master Plan, 2031 proposes that 18.87 per cent of the total area be under open spaces and gardens. VMC is responsible for construction and maintenance of parks and gardens. Apart from this, 7.59 per cent of the entire development area has been proposed for a green belt of 100 m on each side of the river Yamuna, 50 m on each side of NH-2 bye-pass and 25 m on each side of the Assi nalla.

4.3.3 Rainwater harvesting in select public parks

Shahid Udhyan Park
Coordinates: 25°18'46.63"N, 82°59'15.90"E | Area: 17,475 sq. m (approximated from Google Maps)

Figure 23: Shahid Udhyan Park, Varanasi



Source: CSE, 2021

- Potential runoff generated: 2,188 KL annually with rainfall of 982 mm
- Assuming peak rainfall to be within a range of 100–150 mm
- Depth of structure to be not more than 2–3 m
- Area required for infiltration structures will be within the range of 218.43–279.6 sq. m.

Hence, the area required to be dedicated for the infiltration structure is in the range of 1.5–3 per cent of the total area of the park to cater to peak rainfall over 15 minutes.

Potential infiltration systems that can be proposed in the park area are:
- Trench with filter strips and swales can be located along the footpath
- Bio-retention areas can be located after identifying low-lying areas within park
- Infiltration basins in relatively flat and pervious areas

Nehru Park
Coordinates: 25°20’4.77”N, 82°58’37.62”E | Area: 9, 638 sq. m (approximated from Google Maps)

Figure 24: Nehru Park, Varanasi

Source: CSE, 2021

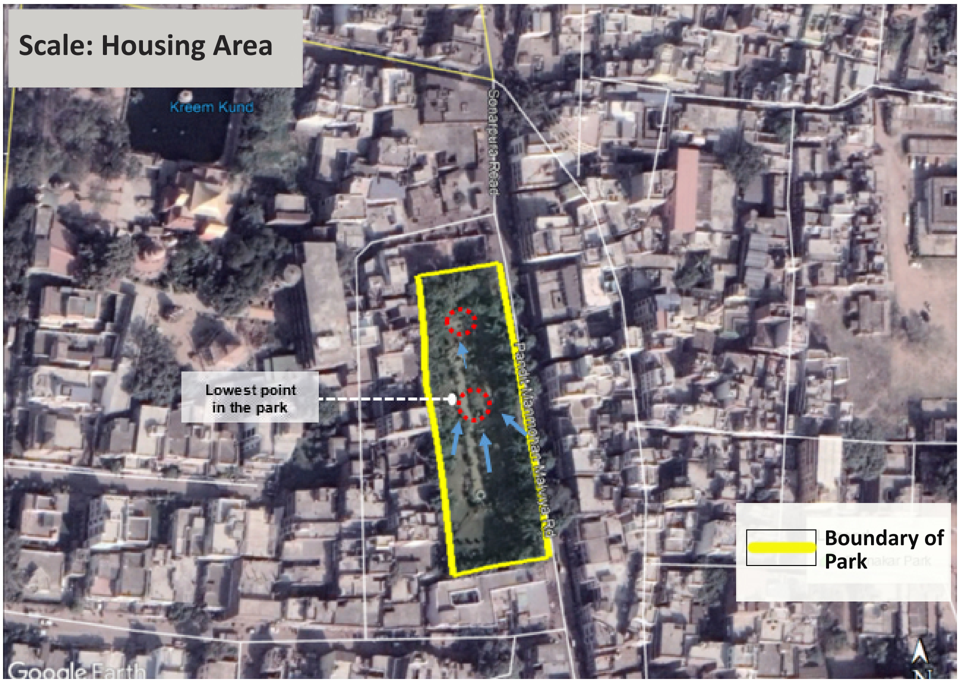
- Potential runoff generated: 1, 207 KL annually with a rainfall of 982 mm
- Assuming peak rainfall to be within the range of 100–150 mm
- Depth of structure to be 2 m
- Area required for infiltration structures will be within the range of 120.47–154.20 sq. m

Hence, the area required to be dedicated for the infiltration structure is in the range of 1.5–3 per cent of the total area of the park to cater to peak rainfall over 15 minutes.

Potential infiltration systems that can be proposed in the park area are:
- Infiltration trench with filter strips and swales along the footpath
- Bio-retention areas surrounded by vegetation at nodes

Ratnakar Park
Coordinates: 25°17’43.59”N, 83° 0’15.57”E; | Area: 4,561 sq. m (approximated from Google Maps)

Figure 25: Ratnakar Park, Varanasi



Source: CSE, 2021

- Potential runoff generated: 571 KL annually with a rainfall of 982 mm
- Assuming peak rainfall to be within the range of 100–150 mm
- Depth of structure to be 2 m
- Area required for infiltration structures will be within the range of 57.01–72.97 sq. m

Hence, the percentage required to be dedicated for the infiltration structure is in the range of 1.5–3 per cent of the total area of the park to cater to peak rainfall over 15 minutes.

Potential infiltration systems that can be proposed in the park area are:
- A small rain-garden with provisions of overflow
- Infiltration trench with filter strips and swales along the footpath

- From these three parks, a total of 4 million litres of rainwater can be harvested annually.
- Even if just 15 neighbourhood-level parks implement RWH in Varanasi, an additional 18.10 million litres of rainwater can be harvested.
- Therefore, a total of 22.10 million litres of rainwater can be harvested in Varanasi annually from only 15–20 parks.

As per CDP plan, 2041, Varanasi has parks and gardens spread across an area of 775.54 hectares in which stormwater harvesting can be implemented. Therefore, a total of 971 million litres of rainwater can be harvested in Varanasi annually.

4.4 Prayagraj

4.4.1 City profile

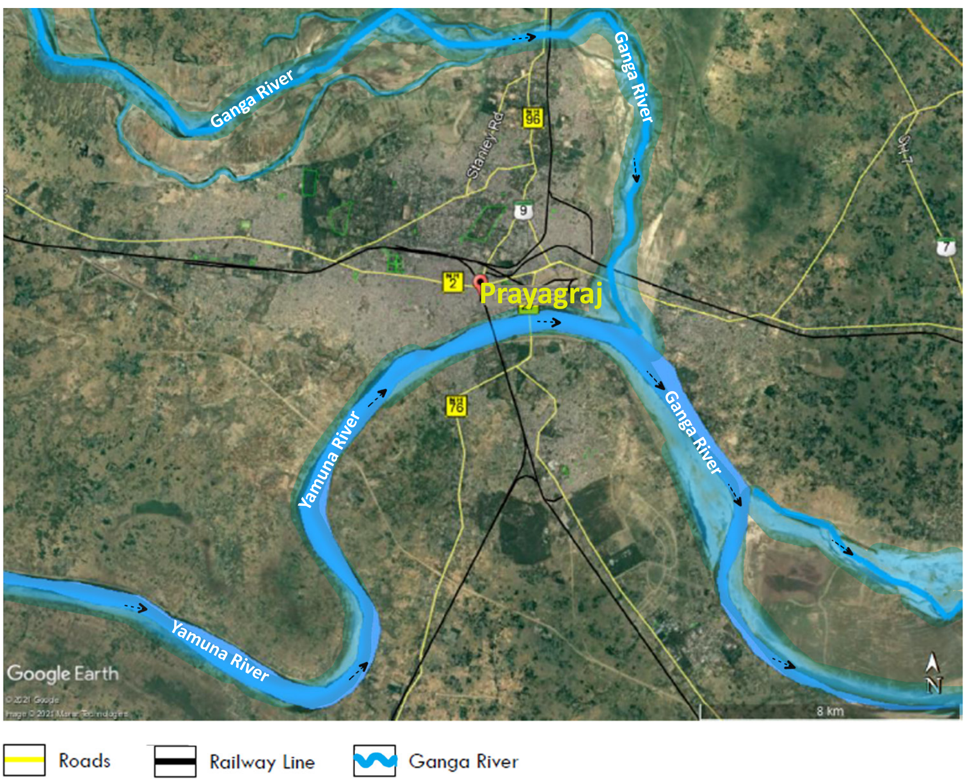
Prayagraj, formerly known as Allahabad, is one of the largest commercial centers in Uttar Pradesh with an administrative and educational profile. The population of the city is 11.12 lakh (as per the 2011 Census), with a population density of 159 persons per hectare.

The municipal area of the city (under Allahabad Municipal Corporation or AMC) is spread over 70.05 sq. km and the larger Allahabad planning area stretches across 309 sq. km.

The city is located in the southern part of Uttar Pradesh at an elevation of 98 m and stands at the confluence of the Ganga and Yamuna. There are three distinct physical parts of the city; Trans-Ganga or the Gangapar Plain, the Ganga–Yamuna Doab and Trans-Yamuna. Because of this topography, the city has grown across all the three sides. The inclination of the area is generally towards east or southeast (see *Figure 26: Location-setting of Prayagraj, Uttar Pradesh*).

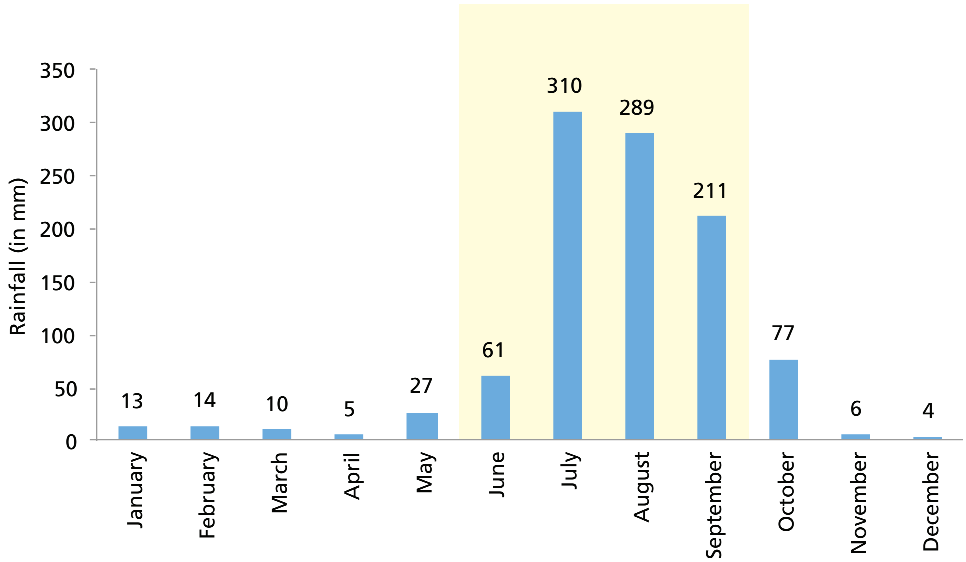
The city has a warm humid subtropical climate, with the maximum temperature exceeding 43°C in the summer and the minimum temperature dropping to 5°C in the winter. The city receives an average of 1,027 mm rainfall annually, with the highest monthly rainfall in August (see *Figure 27: Rainfall pattern of Prayagraj*).

Figure 26: Location-setting of Prayagraj, Uttar Pradesh



Source: CSE, 2021

Figure 27: Rainfall pattern of Prayagraj



Source: CSE (compiled from information retrieved from IMD, Government of India)

Ganga flows on the north of the city and Yamuna flows on the south, and the rivers converge on the east flank of the city. Apart from the two rivers, the city also has various natural ponds and other water bodies. As per the *Groundwater Year Book of Uttar Pradesh (2020)*, the average depth of the groundwater table in the city is in the range of 3–15 m pre-monsoon, while in the Trans-Ganga area the average water level is 6–7 m. Post-monsoon, the water level varies between 1.45 – 13 m in the Trans-Ganga area and between 5–6 m in the Trans-Yamuna area. The groundwater level in the city is rising instead of declining in both pre- and post-monsoon seasons. Annual extractable groundwater resource is 2,562 ham and the stage of groundwater extraction of the city is 149 per cent.

The geological profile exhibits terrace alluvium and Varanasi alluvium. The area is characterized by a thick pile of quaternary alluvium consisting of sand, gravel and clay with occasional presence of thin to thick kankar intercalation.

4.4.2 Urban planning in Prayagraj

A marked increase has been observed in the growth of urban settlements in the city between the years 1994 and 2000, though the core city has not grown as it is bound by rivers on three sides. The existing urban setting of the city can be classified into three categories, the old city, the new city and the out-grown areas. At present, total stormwater drainage length in Prayagraj is 585 km, which is 26 per cent of the road network. However, the total existing drainage system covers only 40 per cent of the city.

In the land use comparison between Master Plans of 1991 and 2021, only 3 per cent of the land use for recreational purpose has been developed. As per the Master Plan 2021, 140.14 ha of parks and open areas existed within the development area in 2002.

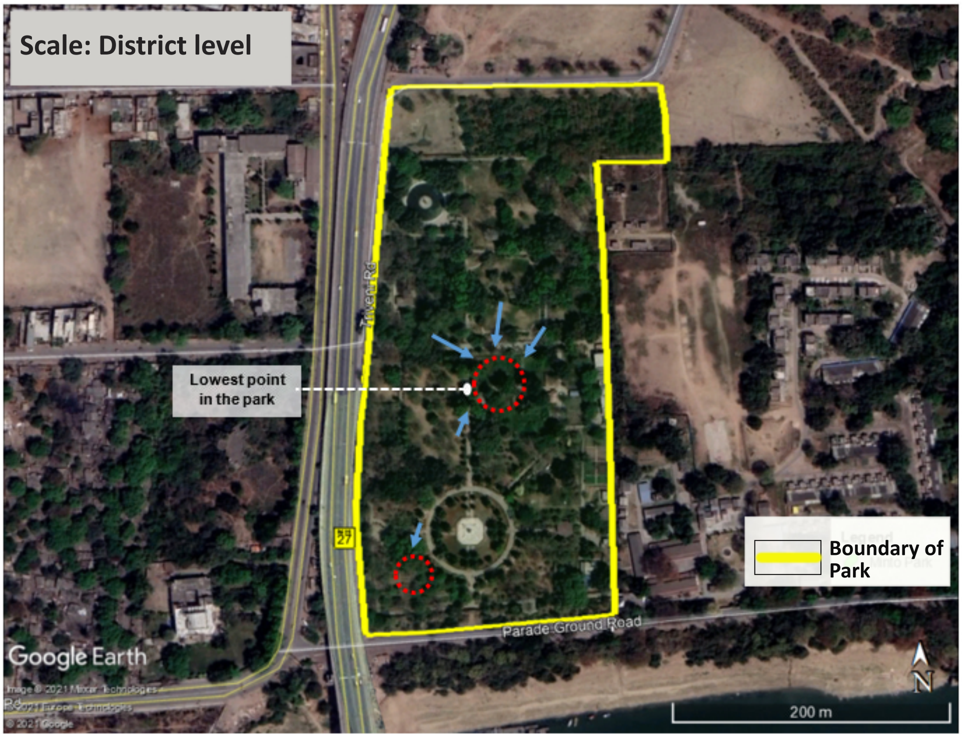
The Master Plan, 2021 proposes development of 1,730.45 ha of parks and open spaces in the main city area till the horizon year. The old or core city is overcrowded and lacks open spaces. Land use proposed for recreation in the

Master Plan, 2021 is 16 per cent (a big chunk of which is the Kumb Mela area). There are 150 parks in the city, which are owned and maintained by AMC. Some parks are maintained by Allahabad Development Authority (ADA).

4.4.3 Rainwater harvesting in select public parks

Minto Park
Coordinates: 25°25'55.38"N, 81°51'45.72"E | Area: 66, 347 sq. m (approximated from Google Maps)

Figure 28: Minto Park, Prayagraj



Source: CSE, 2021

- Potential runoff generated: 7,836 KL annually with a rainfall of 1,027 mm
- Assuming peak rainfall to be within the range of 100–150 mm
- Depth of structure to be not more than 2–3 m
- Area required for infiltration structures will be within the range of 829.33–1194.24 sq. m

Hence, the area required to be dedicated for the infiltration structure is in the range of 1.5–3 per cent of the total area of the park to cater to peak rainfall over 15 minutes.

Potential infiltration systems that can be proposed in the park area are:
- Trench with filter strips and swales along the footpath or desired path
- Bio-retention areas surrounded by vegetation at nodes or at the lowest point of the park
- Detention basins at the centre
- Infiltration basins in relatively flat and pervious areas

Bharadwaj Park
Coordinates: 25°27'26.63"N, 81°51'30.49"E | Area: 17,202 sq. m (approximated from Google Maps)

Figure 29: Bharadwaj Park, Prayagraj

Source: CSE, 2021

- Potential runoff generated: 2,031 KL annually with a rainfall of 1,027 mm
- Assuming peak rainfall to be within the range of 100–150 mm
- Depth of structure to be 2 m
- Area required for infiltration structures will be within the range of 215.02–309.63 sq. m

Hence, the area required to be dedicated for the infiltration structure is in the range of 1.5–3 per cent of the total area of the park to cater to peak rainfall over 15 minutes.

Potential infiltration systems that can be proposed in the park area are:
- Trench with filter strips and swales can be located along the footpath
- Bio-retention areas can be located after identifying low-lying areas within park
- Infiltration basins in relatively flat and pervious areas

Kalyani Devi Park
Coordinates: 25°25’53.23”N, 81°49’59.81”E | Area: 4, 224 sq. m (approximated from Google Maps)

Figure 30: Kalyani Devi Park, Prayagraj

Source: CSE, 2021

- Potential runoff generated: 499 KL annually with a rainfall of 1,027 mm
- Assuming peak rainfall to be within the range of 100–150 mm
- Depth of structure to be 2 m
- Area required for infiltration structures will be within the range of 52.8–76.032 sq. m

Hence, the area required to be dedicated for the infiltration structure is in the range of 1.5–3 per cent of the total area of the park to cater to peak rainfall over 15 minutes.

Potential infiltration systems that can be proposed in the park area are:
- Trench with filter strips and swales can be located along the footpath or desired path
- A small rain-garden can be proposed with provisions for overflow

- From these three parks, a total of 10.36 million litres of rainwater can be harvested annually.
- Even if just 15 neighbourhood-level parks implement RWH in Prayagraj, an additional 7.48 million litres of rainwater can be harvested.
- Therefore, a total of 18 million litres of rainwater can be harvested in Prayagraj annually from only 15–20 parks.

As per the CDP, 2041, Prayagraj has 150 parks and gardens, spread across an area of 140.04 hectares, in which stormwater harvesting can be implemented. Therefore, a total of 166 million litres of rainwater can be harvested in Prayagraj annually.

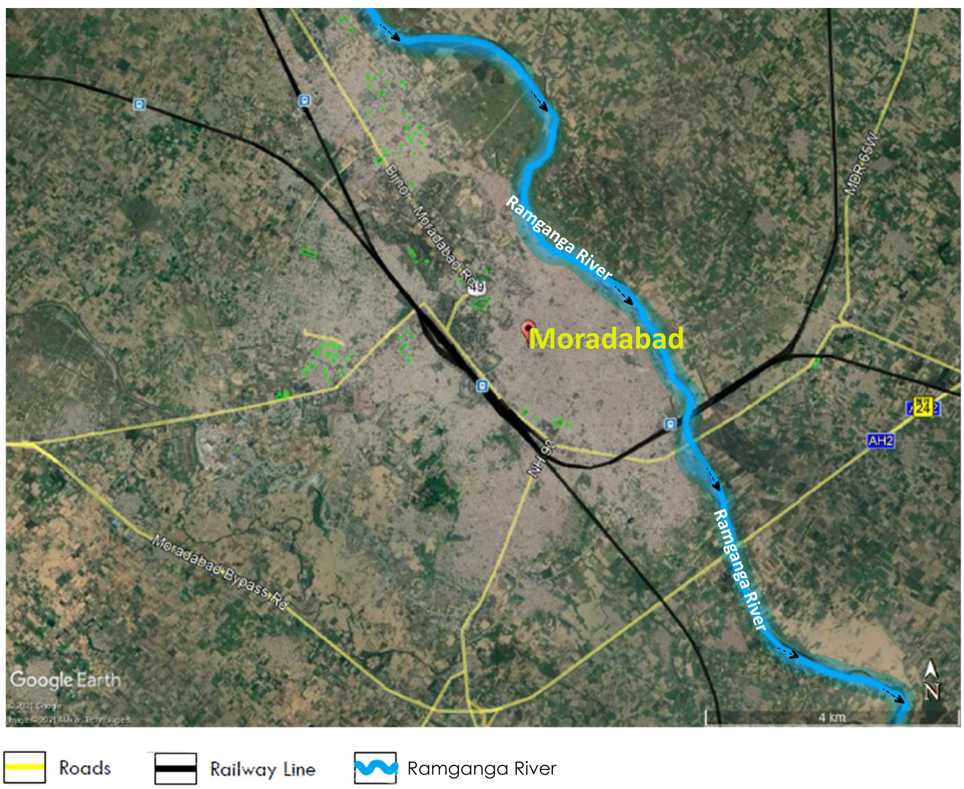
4.5 Moradabad

4.5.1 City profile

Moradabad, also known as 'Brass City', has a population of 887,8718 with a population density of 116.63 persons per hectare. The municipal area of the city (under Varanasi Municipal Corporation or VMC) is spread over 75 sq. km and the larger planning region area stretches across 390 sq. km.[34]

Moradabad, primarily a fort town, is situated on a ride of hard ground on the right banks of the Ramganga river at an elevation of 198 m (see *Figure 31: Location-setting of Moradaba*d). The town lies within the Gangetic plain and there is a distinct slope from north to south.

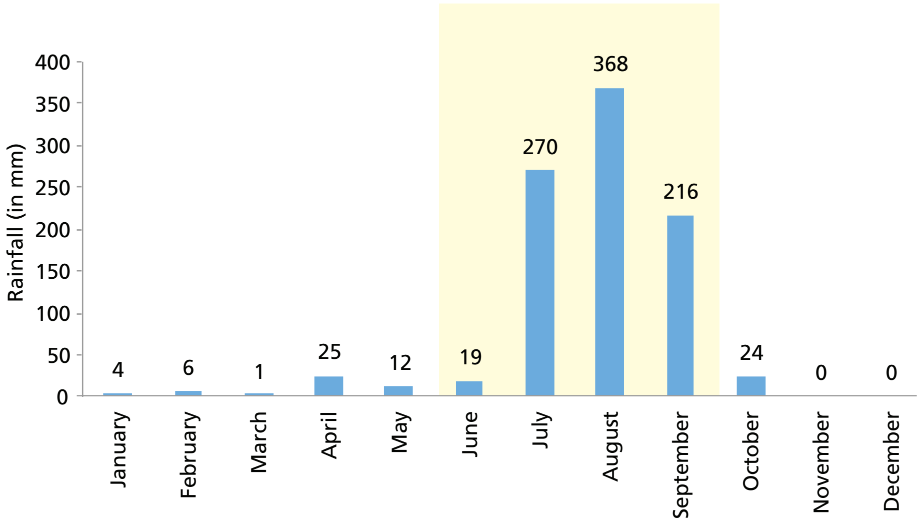
Figure 31: Location-setting of Moradabad, Uttar Pradesh



Source: CSE, 2021

The city has a warm and temperate climate, with the maximum temperature exceeding 43°C in the summer and the minimum temperature dropping to 5°C in the winter. The city receives an average of 944.3 mm rainfall annually, of which 86 per cent occurs from June to September (see *Figure 32: Rainfall pattern of Moradabad*).

Figure 32: Rainfall pattern of Moradabad



Source: CSE (compiled from information retrieved from IMD, Government of India)

River Ramganga on the east, and the Karula drain and Ganga river on the west support the natural drainage in Moradabad. The city has a very gentle slope from northeast to southwest. The large drain Karula emanates in the northwest of the city from the Puraina Tal, one of the major water bodies in the city. Based on the Urban Groundwater Resource Estimation, 2017 (as per GEC, 2015), the annual decline of groundwater table in the city is 0.27 m (pre-monsoon) and 0.34 m (post-monsoon). The annual extractable groundwater resource is 1,759 ham and the stage of groundwater extraction of the city is 308 per cent.

The geological profile exhibits characteristics of the very fertile Indo-Gangetic alluvium which consists of alluvial sand, clay and loam.

4.5.2 Urban planning in Moradabad

The town of Moradabad presents a combination of heterogeneous pockets of different functions. Developed municipal area is 41.15 sq. km. The city can be divided into three settlement typologies, the 'core' or old area with unplanned spread of working-class settlements with the lleast municipal facilities and the 'new' area with affluent-to-comfortable residential quarters and new production units. No vacant land is available within the core city except a few parks.

As per the Moradabad Mahayojna (Master Plan), 2021, the existing area under developed parks and open spaces is approximately 724.77 ha (2009) and area under undeveloped parks is 264.80 ha.

4.5.3 Rainwater harvesting in select public parks

Company Bagh
Coordinates: 28°50'35.74"N, 78°45'55.89"E; | Area: 30,147 sq. m (approximated from Google Maps)

Figure 33: Company Bagh, Moradabad

Source: CSE, 2021

- Potential runoff generated: 3,630 KL annually with a rainfall of 944 mm
- Assuming peak rainfall to be within the range of 100–150 mm
- Depth of structure to be not more than 2–3 m
- Area required for infiltration structures will be within the range of 376.8–482.35 sq. m

Hence, the area required to be dedicated for the infiltration structure is in the range of 1.5–3 per cent of the total area of the park to cater to peak rainfall over 15 minutes.

Potential infiltration systems that can be proposed in the park area are:
- Bio-retention areas surrounded by vegetation at nodes or at the lowest point in the park
- Detention basins at the centre to detain with provision of metered discharge that reduce peak flow rates
- Trench with filter strips and swales along the footpath or desired path

Gandhi Nagar Park
Coordinates: 28°49'39.39"N, 78°46'22.52"E | Area: 5,173 sq. m (approximated from Google Maps)

Figure 34: Gandhi Nagar Park, Moradabad

Source: CSE, 2021

- Potential runoff generated: 623 KL annually with a rainfall of 944 mm
- Assuming peak rainfall to be within the range of 100–150 mm
- Depth of structure to be 2 m
- Area required for infiltration structures will be within the range of 64.6–82.76 sq. m

Hence, the area required to be dedicated for the infiltration structure is in the range of 1.5–3 per cent of the total area of the park to cater to peak rainfall over 15 minutes.

Potential infiltration systems that can be proposed in the park area are:
- Swale along the footpath or desired path
- Bio-retention areas surrounded by vegetation at nodes

Chatrapati Shivaji Park
Coordinates: 28°50’3.07”N, 78°44’16.69”E; | Area: 3,202 sq. m (approximated from Google Maps)

Figure 35: Chatrapati Shivaji Park, Moradabad

Source: CSE, 2021

- Potential runoff generated: 386 KL annually with a rainfall of 944 mm
- Assuming peak rainfall to be within the range of 100–150 mm
- Depth of structure to be 2 m
- Area required for infiltration structures will be within the range of 40.02–51.23 sq. m

Hence, the area required to be dedicated for the infiltration structure is in the range of 1.5–3 per cent of the total area of the park to cater to peak rainfall over 15 minutes.

Potential infiltration systems that can be proposed in the park area are:
- A small rain-garden with provisions of overflow
- Trench with filter strips and swales can be located along the footpath or nodes

- From these three parks, a total of 4.63 million litres of rainwater can be harvested annually.
- Even if just 15 neighbourhood-level parks implement RWH in Moradabad, an additional 9.34 million litres of rainwater can be harvested.
- Therefore, a total of 13.97 million litres of rainwater can be harvested in Moradabad annually from only 15–20 parks.

As per Moradabad Mahayojna, 2021, the existing area under parks and open spaces is approximately 724.77 ha, in which stormwater harvesting can be implemented. Therefore, a total of 873 million litres of rainwater can be harvested in Kanpur annually.

5 The way forward

The cities of Lucknow, Kanpur, Varanasi, Prayagraj and Moradabad together contain more than 2,000 ha of planned open spaces, which provide an opportunity to harvest more than 2,600 million litres of stormwater annually (refer *Table 6: WSUDP potential in select cities of Uttar Pradesh*). This opportunity must not be missed any more. If not harnessed, it may lead to incidences of localized urban flooding. This potential can be realized by allocating only 1–3 per cent of the area of these parks to stormwater harvesting structures based on WSUDP principles.

Table 6: WSUDP potential in select cities of Uttar Pradesh

City	Area under parks (ha)	WSUDP potential (million litres)
Lucknow	259	309
Kanpur	260	305
Varanasi	776	971
Prayagraj	140	166
Moradabad	725	873
Total	2,160	2,624
A run-off quantity of 2,624 million litres is the missed potential which sometimes becomes a liability in these cities. If managed efficiently, the run-off can be stored, recharged and moderated during peak rainfall		

Source: CSE, 2021

Uttar Pradesh receives more than 1,000 mm average rainfall every year. Instead of allowing the excess run-off in urban areas to flood cities and wreak havoc, it is important that we create mechanisms to harvest this run-off by implementing green infrastructure solutions. Stormwater harvesting in public parks and open spaces provides a unique opportunity to utilize the excess urban run-off for groundwater recharge, at the same time providing space and time for flood waters in case of moderate and extreme rainfall events, thereby allowing the drainage system to cope with the excess run-off.

This would eventually help in transforming the cities of Uttar Pradesh into water-sensitive cities. Parks provide ideal opportunities for stormwater harvesting as they are often highly visible, multifunctional public spaces. Parks are a common land use feature in the cities of Uttar Pradesh and can be used to their maximum capacity to recharge groundwater.

As per the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC), extreme climate events are occurring frequently, and these are projected to become more frequent due to changing climate. In future, high intensity rain over fewer rain days is expected to become normal, especially in cities in the Ganga Basin, thereby generating high volumes of run-off in a short time-period, which will increase vulnerability towards urban flooding. In addition to the various ecological, hydrological and drainage benefits, stormwater harvesting in parks and open spaces will also strengthen the resilience of cities to tackle moderate and extreme precipitation events due to climate change.

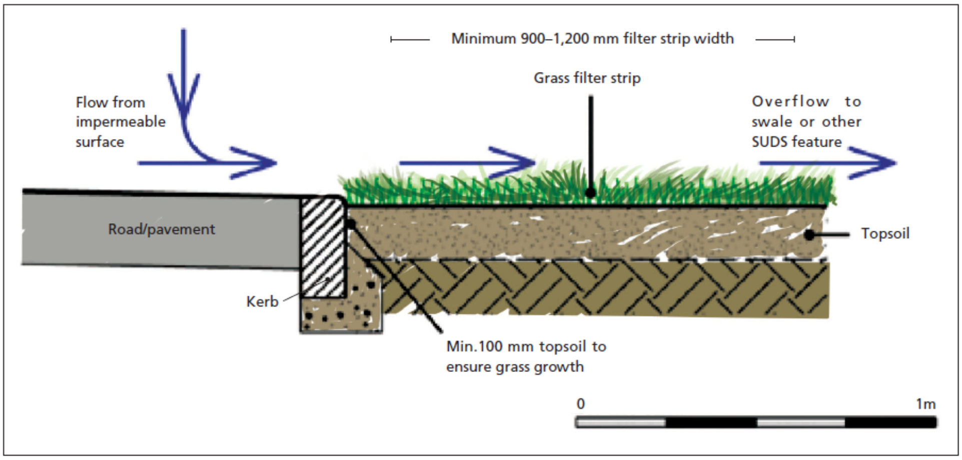
As this report amply demonstrates, rainfall can be converted into an important and manageable resource by contributing only 2–3 per cent of open public space for harvesting infrastructure. Implementation of WSUDP systems focusing on stormwater harvesting in cities of Uttar Pradesh can contribute significantly to addressing the water demand–supply gap, dealing with water logging and flooding and recharging depleted aquifers and groundwater.

6 Annexure

6.1 Options and techniques of stormwater management in public open spaces

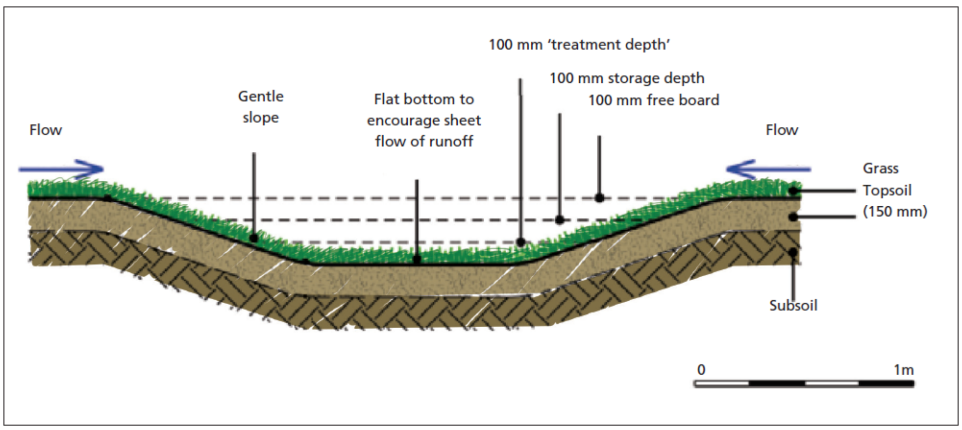
The following are sustainable urban drainage system (SUDS) measures for public open spaces:

Filter strips: Filter strips are grassy or other densely vegetated strips of land that collect surface water run-off as sheet flow from impermeable surfaces.



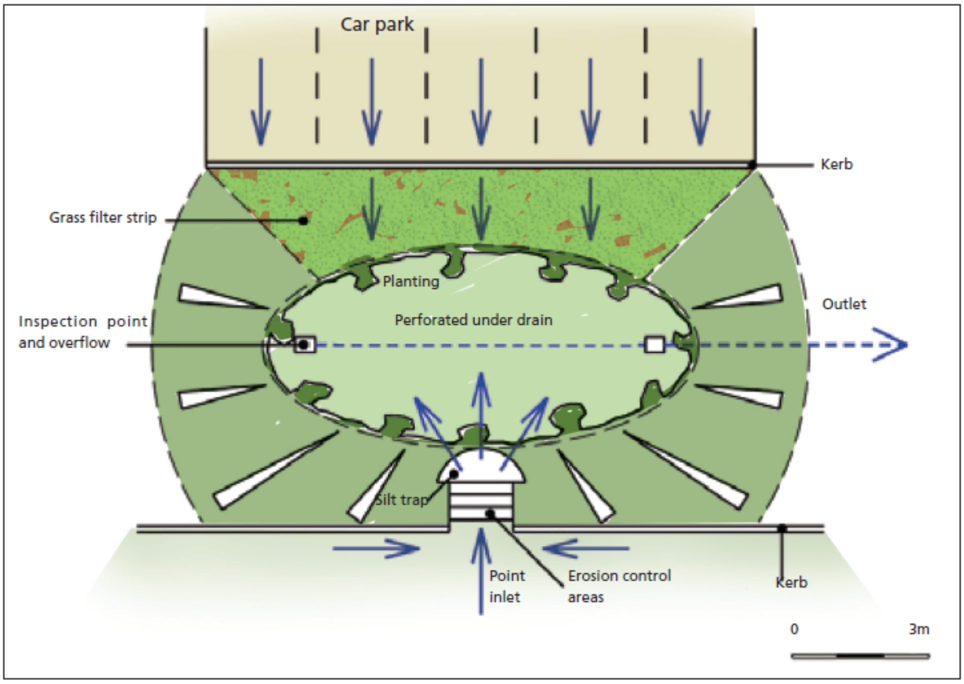
Source: CSE, 2017

Swales: Swales are linear vegetated channels with a flat base that encourage sheet flow of water through grass or other robust vegetation. They collect, convey and sometimes store surface water run-off allowing water to soak into the ground where soil conditions are suitable.



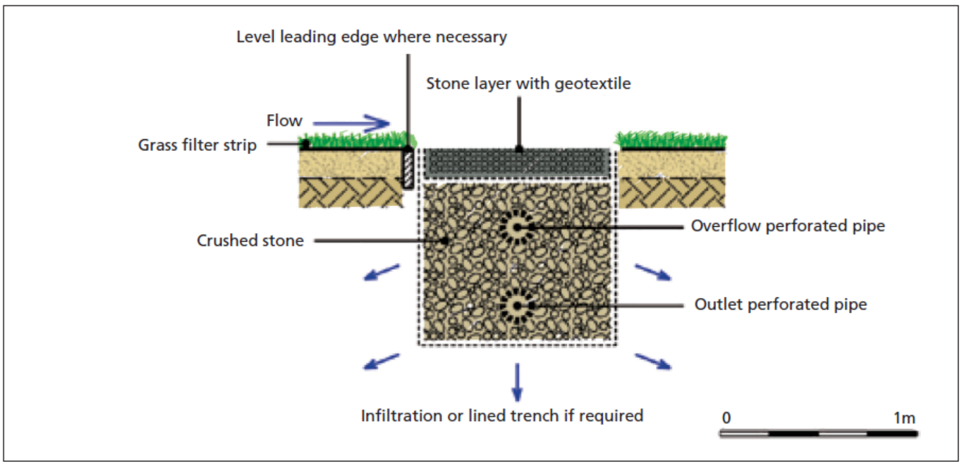
Source: CSE, 2017

Bio-retention areas and rain gardens: Bio-retention areas and rain gardens are planted areas designed to provide a drainage function as well as contribute to the soft landscape.



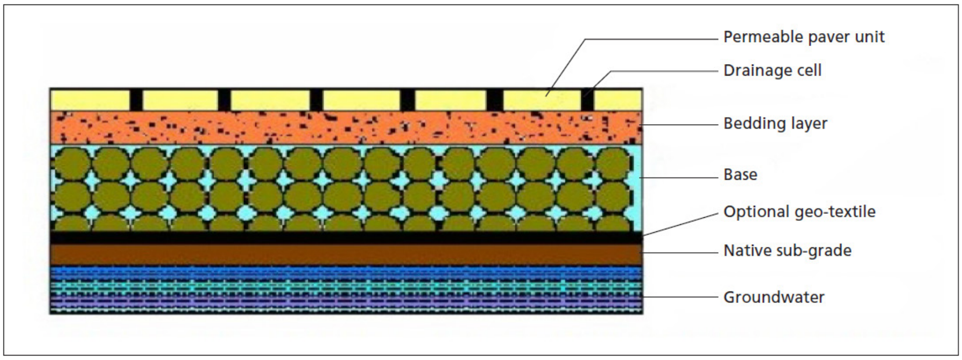
Source: CSE, 2017

Filter drains and trenches: Filter drains and trenches are linear excavations filled with stone that ideally collect surface water run-off laterally as sheet flow from impermeable surfaces. They filter surface water run-off as it passes through stone, allowing water to infiltrate into soil or flow.



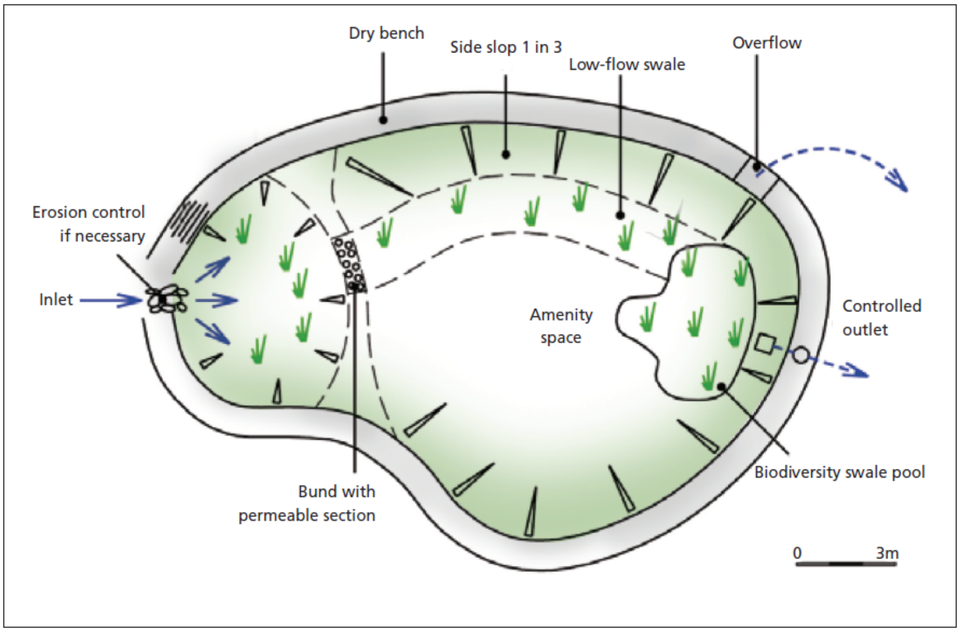
Source: CSE, 2017

Permeable pavements: Permeable pavements provide a surface that is suitable for pedestrian or vehicle traffic while allowing surface water run-off to percolate directly through the surface into underlying open stone construction.



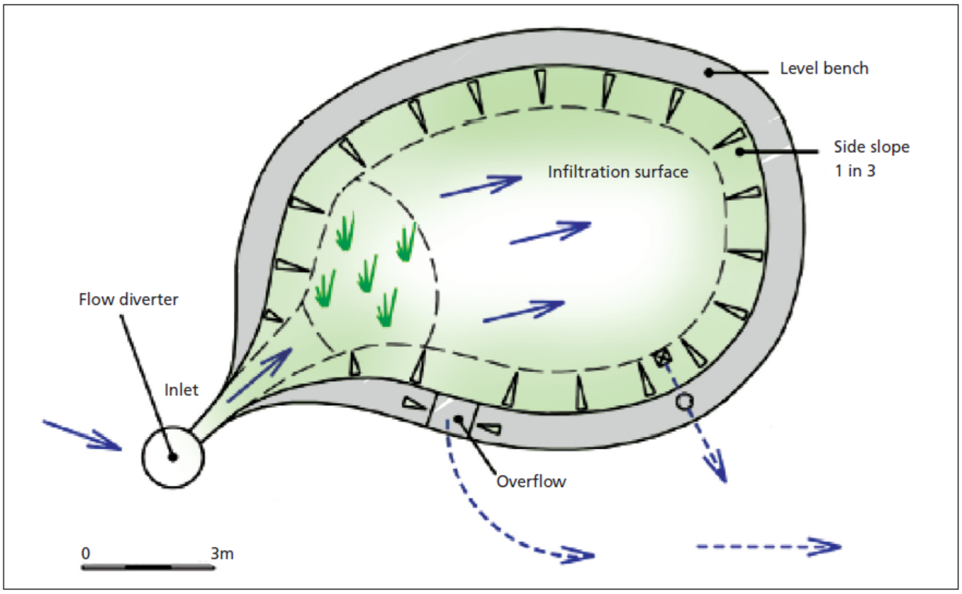
Source: CSE, 2017

Detention basins: Detention basins are vegetated depressions in the ground designed to store surface-water run-off and either allow it to soak into the ground or flow out at a controlled rate. Within developments, these basins are usually small grassed areas, sometimes with a micro-pool or planted area at a low point where some standing water can accumulate.



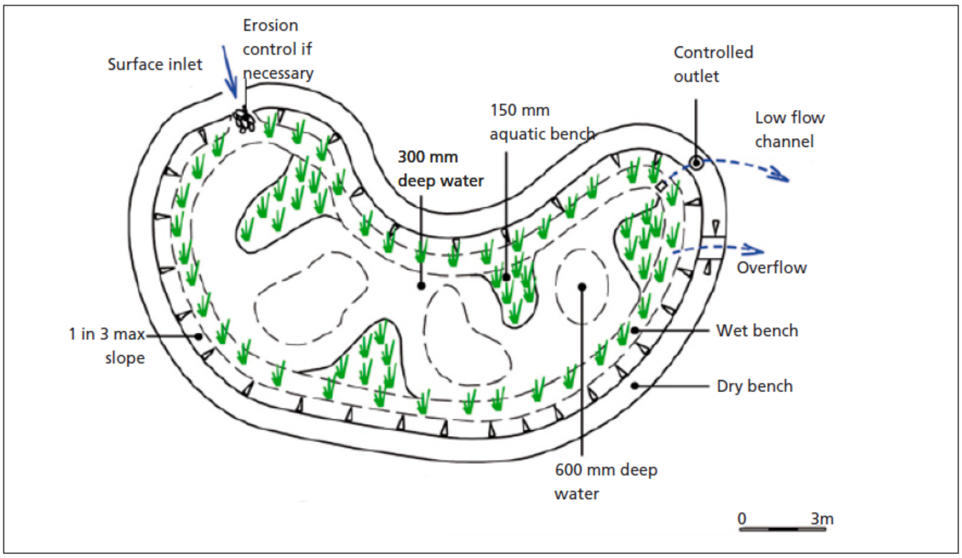
Source: CSE, 2017

Infiltration basins: The basins collect surface water run-off from small areas and are usually off-line to prevent siltation.



Source: CSE, 2017

Ponds: Ponds are depressions in the ground that contain a permanent or semi-permanent volume of water.



Source: CSE, 2017

6.2 Template for data requirement for Preliminary Action Plan (PAP)

CITY-LEVEL INFORMATION

General information	
Name of the city	
Population (with year)	
Municipal area	
No. of wards	
City-level task force (CLTF) (Yes/No)	Attach a list of CLTF members as annexure
Name of organization preparing PAP	
Rainfall data	
Average annual rainfall (mm/year)	
Peak-hour intensity rainfall (mm/hr)	
Monsoon months	
Average number of rain days	
Groundwater (GW) data	
GW table fluctuation map	
GW quality map	
Total number of GW monitoring structures	
Geological profile	

Information on GW monitoring structures

Type	Coordinates	Pre-monsoon level	Date	Post-monsoon level	Date
Dug-well					
Borewell					
Piezometer					

Information on public parks

Data on parks and open spaces	
Total number of parks	
Number of neighbourhood-level parks	
Number of city-level parks	
Number of parks with RWH structures installed	
Number of parks with functional RWH structures	

INFORMATION ON PARKS

(For parks selected for implementation of stormwater harvesting under PAP)

Area (sq. m)	Latitude and longitude	Nature of use	Soil type	Existing RWH structures (Y/N)		Horticulture		Borewell/ dug-well	Depth (m b.g.l.)	
				Type(s)	Operational (Y/N)	Demand (KL)	Source		Pre-monsoon	Post-monsoon

For each park, provide a layout plan or schematic drawing containing the following information:

- Park dimensions and geometry
- Location and dimensions of walkways, park furniture, etc.
- Contour levels and gradient with direction
- Landscape profile: Nature of green cover, location of trees and type of species
- Existing stormwater drains in and around the park
- Utilities commissioned inside the park: Electrical, telecommunication, solid waste, water supply, wastewater and sanitation (mention source of water)
- Water bodies in the park (if any): Source of water, depth and size, and use of water
- Location of existing RWH structures (if any) and borewell/dug-wells (if any)
- Surrounding land use: Roads, residential area, etc.

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This report has been prepared by the Centre for Science and Environment (CSE) as part of its knowledge support for the National Mission for Clean Ganga (NMCG) to develop water-sensitive cities in the Ganga basin.

This report showcases the potential of run-off infiltration in stormwater harvesting systems in parks and green open spaces in five cities—Lucknow, Kanpur, Varanasi, Prayagraj and Moradabad—in Uttar Pradesh, India's largest and most populous state, which falls in the Ganga basin.

The report also presents city profiles, pilot case studies of select parks for implementation of stormwater harvesting strategies, and templates for data collection and implementation of stormwater harvesting.

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