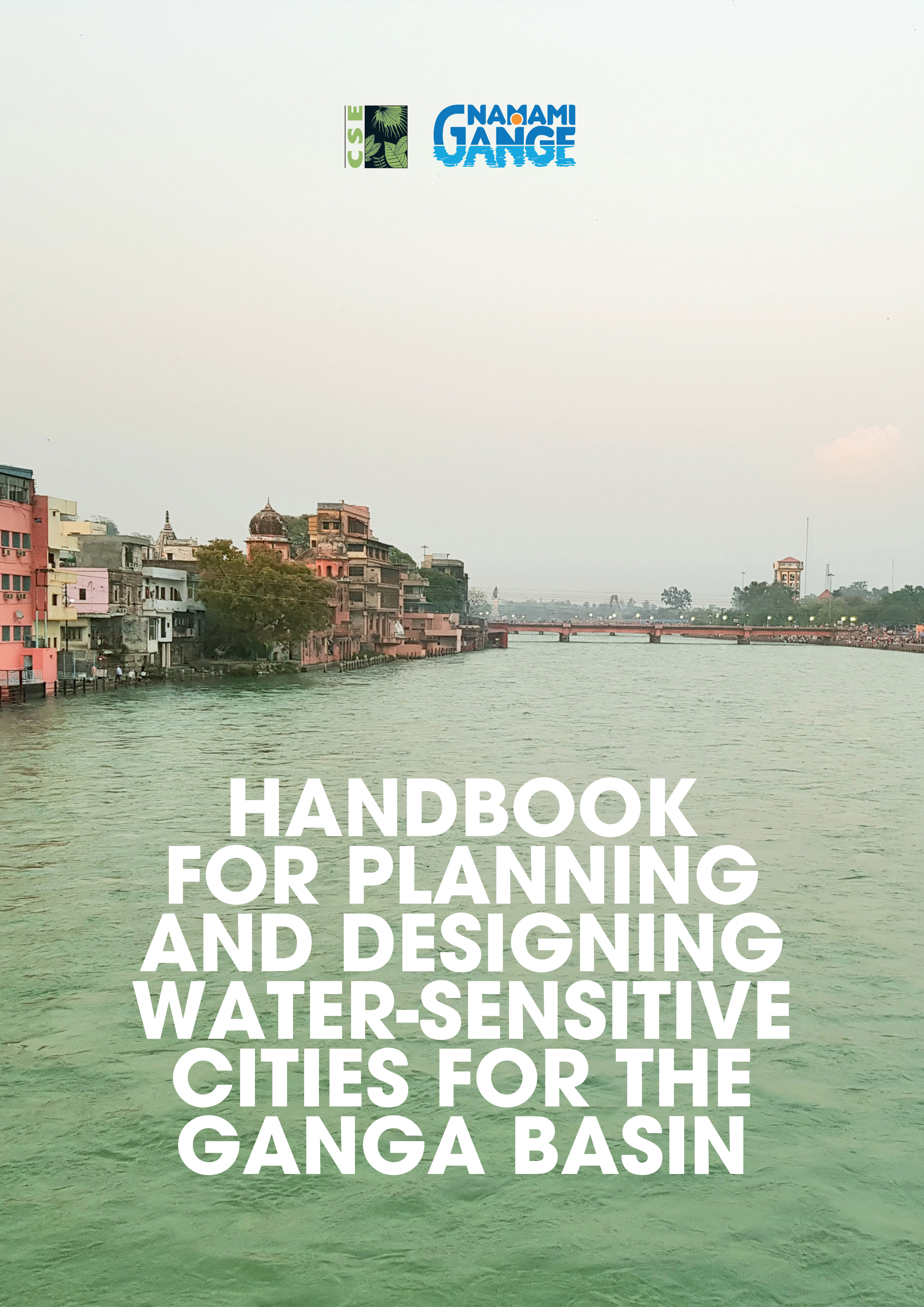

HANDBOOK FOR PLANNING AND DESIGNING WATER-SENSITIVE CITIES FOR THE GANGA BASIN

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Water-sensitive cities: Planning and design

For the majority of unplanned and congested Global South cities, green infrastructure alone cannot benefit urban habitations and populations that are without access to water supply, sewerage and drainage infrastructure and services. Massive investments of grey infrastructure of water pipelines, sewers and storm-water drains are required along with creating public spaces in congested settlements (roads and common areas for establishing sewerage and drainage systems).

> *The Global South water-sensitive cities framework is pivoted on principles of inclusion, equity and justice (water and wastewater in the context of the Global South context has both rural and urban contexts).*
>
> *The Global South water-sensitive cities framework must addresses creation of grey infrastructure and/or services (water supply, FSM/sewerage and storm-water drainage) for less privileged settlements, in addition to the green and blue infrastructure provisioning—unlike for cities in the Global North, with their already developed grey infrastructure (water pipelines, drainage and sewerage) .*

Planning considerations for water-sensitive cities

- **Water-sensitive urban planning and design**
  - o Statutory city development plans (Master Plans) need to have water sensitive city planning as part of its formal chapters on water and waste water. Mere usage of terminology of green and blue infrastructure, Integrated Urban Water Management, etc., without identifying concrete infrastructure options based on past Master Plan or elsewhere in the country, should be avoided.
  - o Regional scale(more than one city) planning for water and wastewater is important, given the trend of urban agglomeration and satellite cities and also rural areas. As Bengaluru has shown with its reuse of treated water for agriculture.
  - o Design solutions often implemented as projects of lakes and waterbodies rejuvenation and ground water recharge, without considerations of integrating the same in statutory urban planning will lead to at best, partial achievements in addressing existing challenges and may risk exacerbating existing inequities.

- **Fixing responsibility and accountability**
  - o State and city-level perspective and vision on long term water, wastewater and drainage will help in guiding policy and programs.
  - o Norms, roles and responsibilities for planning and implementation are needed.
  - o Water supply, storm-water and wastewater management (including septage management) cannot be entirely left to the market and outside the formal statutory urban planning ambit. Long-term city master planning and regional planning, regulation, monitoring and governance must precede the entry to market into basic services provisioning.

- **Both grey and green infrastructure provisioning is needed**
  - o Without grey infrastructure improving the living conditions, green infrastructure may have limited impact.
  - o Green infrastructure should be prioritized.

- **Adapting to climate change**
  - o Grey and green infrastructure for floods and droughts
  - o Mitigate the impact on informal settlements from any measures.

- **Look beyond urban "place making" and "beautification"**
  - o Rejuvenation of rivers, lakes and waterbodies should not be done simply with a "beautification" aim. Spending large sums of money on beautification if done wrongly may reduce the potential of lakes, rivers and waterbodies to provide the benefits that rejuvenation offers. Embankments and beautification can be done for very small stretches of rivers and lakes, not indiscriminately for large stretches.
  - o Dredging and deepening of rivers and lakes, creating concrete embankments can permanently destroy the aquifers and the water-harvesting potential.

- **Monitor city-level gains and distribute them fairly**
  - o All gains from interventions of any water-sensitive planning and design should be monitored.
  - o Electricity pumping cost of transporting water and wastewater over hundreds of kilometres to the cities and to treatment plants can be minimized in a water-sensitive cities approach. Benefits accruing from groundwater recharge and energy saving must be shared with the less privileged.

Planning process

- **Preparing a city water balance plan** not just as a numerical exercise of listing all the water flows of the hydrological cycle for a city. Doing assessment of wastewater, storm-water and sewerage generation on the one hand and water conservation and groundwater recharge potential on the other in different parts of the city, planned and unplanned settlements. Not merely aggregating city-level water balance.
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- **Identifying grey infrastructure priorities in unserved areas.** Identifying redevelopment of slums and congested settlements for enabling the reach of grey infrastructure—piped water supply, storm-water drains and sewerage systems.
- **Identifying water conservation, groundwater recharge and green infrastructure for water conservation in rest of the city,** where this is possible.
- **Groundwater recharge—mapping the urban aquifers, identifying the recharge and discharge potential of ground water.** Any intervention that recharges groundwater is a good intervention in most cases (except in heavy rainfall areas, in floodplains and pockets in cities with high groundwater tables).
- **Equity considerations in planning for groundwater recharge and green infrastructure.** Recharged groundwater may not be extractable or usable everywhere and by all. Hence benefits of water conservation and wastewater reuse should cross-subsidize residents who cannot afford high cost supply of water.
- **Governance and pricing.** Suitable pricing norms that forge complimentarities and convergent approach to subsidise the slums, informal settlements and congested unplanned settlements.
- **Emergency measures.** Define water supply rationing norms for emergency conditions of droughts and water supply shortages.

Design considerations for storm-water drainage management

What is meant by urban drainage?

Urban drainage comprises the removal of all unwanted water from urban areas depending on two factors: stormwater harvesting and flood mitigation. It includes stormwater and wastewater including sewerage and greywater. Greywater, also known as sullage, is domestic water predominately from baths, basins and washing machines. The unwanted water, may or may not, be used for other purposes with, or without treatment. According to Mc Donough & Braungart, 2002, it is a part of the philosophy of sustainability that there is, ultimately no waste; all "waste" from one process should be in input for another. Urban flooding occur because the flows into the city or town is faster than it could be drained or stored into natural depressions, lakes and reservoirs, or absorbed in ground, recharging the groundwater. The runoff doesn't get enough space and time to drain out. There are four different causes of urban flooding, giving it different characteristics. They are as follows:

- **Pluvial flooding:** The accumulation of local rainfall runoff due to insufficient drainage and buffer capacity.
- **River floods:** Overflowing rivers due to insufficient capacity of the rivers to discharge the rainfall or rapid snow melt in a catchment/ river basin, which can spread as wide as a whole region or even across borders.
- **Coastal flooding:** Storm surges induced by heavy storms, gale-force winds and hurricanes causing sea levels to rise and flood a city.
- **Groundwater:** Water that collects or flows beneath the surface of the ground, filling the porous spaces in soil, sediment and rocks originating from rain, melting snow and ice.

Urban drainage in India

Urban storm-water drainage systems in India have mostly been neglected or have been prioritized after water supply and sewerage projects. The megalopolises (megacities) in India have a long history of municipal drainage since the British era. These megacities usually have century-old antiquated brick masonry conduits within core clusters. The existing storm-water collection network in these megacities is designed to serve as a combined system for sewage as well as storm-water runoff. It eventually adds to the current situation's dynamics as it is required to have decentralized segregated systems to cater to city needs and invites high levels of challenges for planners, municipal engineers and financial resources. The conventional philosophy for flood mitigation in strongly urbanized areas of some ancient municipalities has been the construction of massive pipe network redesign campaigns improving the drainage capability of the existing older network system (building bigger pipes, improving surface collection system, etc.). For example, the oldest combined sewerage system in India is in the capital of the British Empire in India till 1911, the city of Kolkata (then Calcutta). In 1876, it was designed to cope with 6.35 mm/hour of rainfall with 100 per cent of runoff. Later in the 1970s, attempts were made to increase its capacity to 12.7 mm/hour of rainfall. However, in the same year, the city of Kolkata received rainfall of 54 mm in one hour, causing severe flooding. The Indian Roads Congress (IRC) guideline on urban drainage in 1999 (SP-50-1999, IRC) mentions that Mumbai drains are designed for 50 mm/hour and Chennai for 25mm/hour; yet these are the cities very often facing scenarios of annual urban flooding. Also, these guidelines do not provide protocols for future planning of urban drainage system for other small cities.

Another example can be Bengaluru, which receives an average annual rainfall of around 900 mm. The existing stormwater drains were constructed many years ago in the city, when the catchment area had more open spaces so that water could be absorbed in the soil and recharge groundwater. Recent urbanized growth of the city resulted in overflow of storm water in drains during rains and backflow into the roadside drains and flashfloods in low-lying areas adjacent to the drains due to backflow into the roadside drains.

Major cities like Bengaluru, Delhi, Chennai and Mumbai have initiated plans to divert runoff from one part of the system to another and rehabilitating or restoring the trunk sewers. Mumbai and Chennai also have demonstrated successful application of trenchless technologies for laying sewer pipes to avoid disrupting road and rail traffic. These are done in assistance by grants or loans from World Bank, Asian Development Bank or Urban Development Corporation etc. In Rajasthan, six major cities along with Jaipur are in the process of developing a drainage network plan with support from Asian Development Bank to improve sanitation. Smaller cities on the other hand are still struggling to provide basic drainage needs to implement these improvement plans as they do not have international funding assistance. For example, small cities like Puducherry have no implementation of an underground drainage system yet; septic tanks are still used. In the city of Ludhiana, Punjab, the large amount monsoon water falls into big potholes in the road due to lack of proper drainage system. As these potholes are 50 cm deep, this creates a situation of urban flooding and creates problems for vehicles.

The natural drainage systems which were made according to the topographical aspects of the city have now been completely destroyed in most Indian cities. This has worsened the problem of urban flooding over time due to non-availability of proper storm-water drainage infrastructure, rapid encroachment, rampant dumping of solid waste in drains and natural waterbodies, and lack of maintenance of the existing infrastructure. Urban drainage management in India usually focuses on supply-driven approaches by planning and constructing hard infrastructure based on practices of other developed countries rather than taking into account actual user needs, often resulting in bad investments, lack of cost recovery and lack of a holistic approach in most cases. According to a report on Indian Urban Infrastructure and Services (March 2011), published by the erstwhile Ministry of Urban Development (MoUD), the average coverage of storm-water drainage network is about 20 per cent of road network and its allied catchments. It is very inadequate to cater the storm-water disposal in the present scenario. As per Census 2011, there is no drainage facility in 48.9 per cent households, while 33 per cent households have only open drainage system at the country level.

Floods in relationship with Indian summer monsoon and geomorphological aspects

Major parts of India are situated in tropical or sub-tropical regions. Most of the rainfall is concentrated in about three months of the monsoon period, leading to urban flooding in major parts of the country. Most of the flooding occurs in two variations based on regional spatial aspects—from June to September due to the southwest monsoon in most of the India and from October to December in the Southern Peninsula due to the northeast monsoon. During the rest of the year, cities face flow due to discharge of treated, partially treated and untreated sewage through the outfalls meant for storm-water discharge. High-intensity rainfall in some cities is responsible for frequent flooding. Nearly 40 million hectare of area in India is flood-prone and nearly about 8 million hectare of land is flooded every year. For example, Mumbai receives an annual average rainfall of around 2,932 mm, causing urban flooding in the city during the monsoon period. One of the most notable floods in Mumbai was on July 26, 2005. Several other instances of urban flooding in Indian cities include floods in Hyderabad in 2000, Ahmedabad in 2001, Delhi in 2002 and 2003, Surat in 2006, Kolkata in 2007, Jamshedpur in 2008, again in Delhi in 2009 and 2010 along with Guwahati in 2010. In recent years, floods in Srinagar and Guwahati in 2014, Chennai in 2015, Hyderabad in 2016 and Ahmedabad in 2017 are instances of the extreme event of urban flooding. The most recent floods in the state of Kerala in 2018 submerged many cities in the state but most affected the city of Cochin.

Geomorphological settings along with extreme rainfall events leads to flooding in cities but the effect of flood varies with local topography/geomorphology and level of encroachment of natural landscapes. Considering example of bowl-shaped topography of Kashmir valley, which has a restricted natural outlet that makes it bound to suffer inundation in heightened rainfall events. This situation is accelerated by causes such as absence of efficient drainage network, reduced capacity of existing urban drainage channels, increases paved areas, loss of open spaces and waterbodies and replenished groundwater recharge due to rapid urbanization and loss of natural assets. Based on geomorphological settings, urban flooding is characterized by the following types (see *Table 1: Characteristics of urban floods in respect with different geomorphological settings*):

Configuration of urban drainage systems and its impacts

This section will highlight the structural configuration of drainage systems in India. Generally drainage systems are categorized in two types—major and minor drainage systems—according to NDMA guidelines.

- ***Major drainage systems:*** Comprise open nallahs and natural channels, surface drains or surface flow pathways, etc.
- ***Minor drainage systems:*** The network of underground pipes and channels. There are two types of minor storm-water drainage systems: "open" channels and "closed" pipes.

Table 1: Characteristics of urban floods in respect with different geomorphological settings

Coastal cities	Coastal cities or towns located on the coastline experience flooding due to localized rainfall and storm surges caused by cyclones. They also get affected by high tides, coinciding with localized rains.
Cities near dams/reservoirs	Cities or towns located along a river, either downstream or upstream of dams/reservoirs. Those located downstream of reservoirs can get flooded by release of water in excess quantities. Sometimes cities or towns located upstream of a dam or reservoir also get affected by rising levels of backwaters when release of water is sometimes withheld during the flood season.
Inland cities	Cities or towns located inland can experience floods largely because of localized heavy rainfall within the watershed due to overwhelming of the storm-water drainage system capacity.
Cities in hilly areas	Cities or towns located in the hilly areas experience flash floods due to localized heavy rainfall that can also result in landslides. Sometimes, habitations in hilly areas comprising a part of large cities or towns also get affected in a similar manner.

Source: Adapted and modified from Patil, A. (2015). Urban hydrology, need of India

Another important design consideration is whether the runoff is drained through a separate stormwater drainage system or it is combined along with the other systems, i.e. collection, drainage and disposal of other wastewater from domestic, industrial or commercial sources.

Minor systems can be categorized into two further types:

- ***Separate drainage system***: These systems comprise two conveyance drainage networks, one which drains the surface runoff (wet weather flows) and the other for dry weather flows of wastewater. Surface runoff is drained through a network of storm sewers and is discharged into the receiving waters generally without any treatment. Ideally, wastewater is drained through a separate network of sanitary sewers (usually underground pipes) conveying wastewater from homes, industries and businesses to treatment plant first so that treatment prior to discharge is done. However, the real situation in Indian cities is to the contrary.

- ***Combined drainage system***: These systems drain the combined form of domestic, commercial and industrial wastewater during dry weather, and during the monsoons they operate as flood-control drainage systems.

Generally, conventional design systems in Indian cities focus on minor drainage systems, which are easily recognizable and convenient. A conventional system comprises construction of drains and channels, roadside drains, channelization, rehabilitation, rectification, enlargement of existing storm-water drainage networks and provision of cross-drainage works. These systems may also collect wastewater derived from various domestic, commercial and industrial activities along with storm water.

Separate and combined drainage systems

The interaction between the major and minor drainage systems is essential in mitigation of flood conditions for a tropical and subtropical climate like India because the frequency of runoff is mostly greater than the capacity of the drainage system. Although the possibility to have such system is usually not the case in Indian cities, the approach towards major drainage systems managing storm water has not been adapted by Indian cities yet. Moreover, even in the minor drainage systems the reality about separate drainage systems is quite different in many Indian cities. In the majority of cases, separate systems rarely remain separated and combine with wastewater and effluents from septic tanks along with the storm water. Separate drainage systems demand spatial spaces in existing congested cities, which often becomes an excuse for the Indian management system to be hesitant about it; also these are more expensive to construct. Hence, a storm-water system is often constructed without provision for the drainage of wastewater or a combined drainage system is followed. For example, the core city of Kolkata has the oldest underground drainage system and combined sewerage system in India. Both the sewage and storm water flows through the same conduit. Besides, it does not have separate dry weather and wet storm-weather arrangement which results in bad siltation of all the major and minor underground trunk sewer lines. Lack of maintenance and regular cleaning makes the situation worse and has reduced the flowing capacity of storm weather flow to a considerable extent.

Roads as drains

An extremely common approach towards storm-water drainage and flood mitigation in India includes the use of roads as drains as part of the drainage system. To drain large flows of storm-water runoff, utilization of the road carriageway and road layout itself is a very common practice of urban Indian cities. In most cases and recent plans for stormwater drainage management, the major focus was given in 100 per cent coverage of roads as drain, which is an average of about 20 per cent of the catchment according to a 2011 Ministry of Urban Development (MoUD) report. This often leads to certain problems like urban flooding, paralysed vehicular movement and traffic jams during the monsoons as these drains are not efficient enough in terms of capacity, space and design aspects to cater to peak runoff. Taking the case of Ludhiana, Punjab: apart from the poor drainage system, the water accumulation during peak season rises above road levels because the drainage system beneath the road has ruptured. For example, earlier when the roads were constructed, the settlements on both sides of the road were 60 cm above the road level. However, due to frequent resurfacing the settlement is now about 50 cm below the level of the road. This is the case with many other Indian cities as well. Due to the unavailability of extra space for road widening, the drains are either undersized or non-existent as storm-water drainage doesn't get much priority. Difficulties also ascend in managing the cost of improvement of cross-drainage works in roads and railway lines intersecting the drainage lines.

In the case of low-lying areas, roads must be constructed to be lower than surrounding areas to prevent water accumulation; the soil from excavation can be used to fill low-lying areas and reduce the ponding of surface water in these areas. Many Indian cities tend to do exactly the opposite. Taking example of Gorakhpur city, Uttar Pradesh, the southeast part of the city is low-lying and falls in the floodplains of river Rapti. Having a bowl-shaped topography makes it more vulnerable to urban flooding, but the road infrastructure and urbanization has accentuated the problem. The local roads in the part of city are on a much higher level than the surrounding settlements, giving multiple spaces for water to accumulate. Lack of efficient drainage infrastructure along with this road structure, and customization of natural topography results in waterlogging for almost six months in the southeast part of the city. Also, NH27 acting as a high embankment works as a barrier for rainwater to be drained out from the city. Another example is the informal settlement of Sangam Vihar in Delhi, As there are no adequate storm-water drains, the existing space of 3-metre-wide internal roads is not efficient enough to convey the storm water in high-peak runoff generation. Roadside drains in local streets have even less space and carry grey water from the households, effluent from household industries and storm water from streets and houses. It eventually results in flooded roads, with water sometimes about 3–4 feet deep.

Underground and surface drainage system

Underground drainage systems are preferable from a health and aesthetics perspective but due to difficulty in operation and maintenance, deterioration and accumulation of debris or sediment, difficulty in monitoring and controlling and importantly being expensive to maintain, it is not a common practice in India. Indian cities that have storm drainage network partly or completely are often a combination of both underground and surface drainage systems. Even a single street can have a part covered and partly open, which directs towards poor maintenance of the existing infrastructure. Many drains that are designed and constructed as open drains become covered later, and covered drains become partially open, are broken or removed. Surface or open drains are on the other hand are generally easier and cheaper to construct. Surface open drains often lead to more problems as they are open and act as recipients of solid waste, create a bad smell, are unsafe for children as they can fall into it, are a breeding ground for mosquitoes and create hygiene issues. Sewerage and raw sewage in open drains are a common sight in Indian cities. In many cities, the drainage plan has lagged behind water supply and sewerage system networks have never been fully implemented. For example, in Chennai, the existing sewerage network capacity is badly inadequate and open drains act as flood carriers in peak season. The capacity of these drains is also not efficient enough to carry the runoff and often end up overflowing, creating significant problems for storm-water drainage, flood protection systems and public health.

Wastewater management is a serious issue in major cities. A huge amount of solid waste is generated by Indian cities and it is estimated that only 60 per cent is collected (NIH, 2000). The uncollected waste fills open spaces, drains and roads and pollutes both surface and subsurface water resources. The encroachment of informal settlements on the banks of these open storm drains in megacities such as Delhi, Kolkata and Mumbai have aggravated this problem. There has been a gradual encroachment seen on the bank of these open storm drains; some have even had their width reduced to 20 per cent of their original width. The surface drainage system also includes natural storm-water drains and channels, which have been heavily encroached on and discharge solid waste and sewage from the whole catchment to natural surface waterbodies, polluting them eventually. In some extreme cases, multistorey buildings and government official buildings have been built on storm drains, which has reduced the capacity of these drains to carry storm water and increased incidences of urban flooding during the monsoon season.

Table 2: Storm-water drainage and sewage system impacts in reference with urban concentrations

System	Urban concentration	Sewage system	Storm drainage	Regions and cities	Main impacts
Separate	Small	Septic tank	Storm-water network	Small communities and in cities	Contamination of groundwater and surface water
			Street gutters	Small communities	Contamination of groundwater, surface water and streets. Potential disease proliferation.
	Medium to high	Sewage network and treatment plants;	Stormwater network	Megacities and other tier-2 cities	Contamination of groundwater and surface water
		Sewage overflow (local treatment, septic tank or unregulated storm-water network. In developing countries contamination of groundwater and surface waters linking to storm drainage system)	Street gutters	Poor neighbourhoods	Contamination of groundwater, surface water and streets. Potential disease proliferation.
Combined	Medium to high	Sewage pipe network and treatment plants	Overflow above the design discharge to storage system without treatment	Old drainage system in Megacities	High flood frequency in the street; high contamination during floods
		Sewage network without treatment or treatment without network	Overflow in the streets	Small cities	High urban flood frequency; contamination during floods
Without system	Small, medium and high	Without system	Streets	Poor neighbourhoods	Floods, contamination and diseases

Source: Adapted and Modified from, Tucci, C. E. (2001). Urban drainage issues in developing countries. *Urban Drainage in Humid Tropics, 40*, 23–40.

Flooding in low-lying areas

Habitations are coming up with construction in low-lying areas and floodplains, often encroaching on drainage channels, nallahs and natural drains as these areas have a cheaper land rate. What is surprising though is that not just private builders, the government too is building over such vulnerable areas. For example, overlooking environmental regulations in mega-projects is fairly common in the country. Back in the 2000s, Delhi's Akshardham Temple Complex and Commonwealth Games Village (CWG) were built right on the Yamuna's floodplain. Mostly these areas grow with absence of basic urban water services provided by the municipality. Most of the habitations discharge their sewerage into existing channels. Intensification of more impervious areas and encroachment of drains results in their reduced width, and significantly increases the rate of runoff. Eventually, the overall capacity to drain rainwater is decreased, and as a result even small amounts of rainfall cause urban flooding in these low-lying areas.

The preceding section reviews with case examples the urban drainage system in India while highlighting its main causes and impacts.

The causes of causes of frequent flooding in urban centres even with light rainfall can be summarised by the following:

Urban flooding occurs when runoff flows into a city faster than it can be drained, absorbed into the ground and stored in surface waterbodies. Increase in flood frequency due to basin urbanization leads to increase in impervious area and enhanced surface runoff, leading to frequent flooding. Urban drainage has been given low priority in India after water supply and sewerage so most of the plans were never implemented or completed. Most of the cities don't have adequate drainage infrastructure. Even some with existing drainage network, they were not designed properly considering the current rainfall intensity, due to lack of hydrological records, inadequate and insufficient assessment and measurement of flood risks. Therefore, "accommodation and transportation" capacities of such configured drainage facilities are easily overwhelmed in peak runoff generation. Rapid urbanization on floodplains, with low level of outfalls, dilapidated drains, obstructions of utilities, encroachment along nallahs, informal settlements along drains, loss of holding on to natural lakes and ponds, and garbage dumping or solid waste in storm-water drains are other factors that exacerbate the situation. The problem of wastewater management and solid waste management coupled with the existing drainage system often obstructs the storm-water runoff, causing local urban flooding. Indian cities lack the systematic approach to plan, formulate and implement storm-water drainage with a holistic approach.

Matrix of suggestions for configuration of urban drainage systems as per Indian ecological region characteristics

<table>
<tr><th>Ecological region</th><th>Rainfall pattern</th><th>Characteristics</th><th>Configuration of urban drainage systems storm-water management</th><th>Examples of cities that face frequent urban flooding in these regions</th><th>Remarks</th></tr>
<tr><td rowspan="2">Hilly and mountainous regions</td><td rowspan="2">Areas at elevations of 1,070–2,290 metres (3,510–7,510 ft) receive the heaviest rainfall, which decreases at elevations above 2,290 metres (7,513 ft). Elevations above 6,000 metres (19,685 ft) never experience rain; all precipitation falls as snow. Rainfall is seasonal in these region but heavy—typically above 2,000 mm (79 in) per year.</td><td rowspan="2">Hilly areas are characterized with high terrain slope. Different slope shapes give an indication of surface and subsurface water concentration or dispersion. For example, convex slopes (e.g, wide ridges) will tend to disperse water as it moves downhill. Straight slopes concentrate water on the lower slopes and contribute to the buildup of hydrostatic pressure.

Water in these areas is concentrated at the lowest point on the slope and therefore represent the least desirable location for a road.
In case of a storm, the runoff gushes down the hill at very high velocities causing erosion of soil along drains/slopes.

The amount and size of soil particles transported, increase the volume and velocity of runoff and are subsequently carried along drainage system of the basin to the receiving bodies e.g., river and stream.</td><td colspan="3">• In a conventional stormwater management in Indian cities, the minor drainage system is usually an underground, open or closed pipeline system with sufficient capacity to contain the nuisance flows and the major drainage system comprises of open nallahs and natural channels, surface drains along road or surface flow pathways, etc. The pipelines don't always follow the natural drainage path and are usually aligned along property boundaries and the roadway kerb (based on CPHEEO and IRC recommendations) and channels irrespective of the natural terrain.
• Most of the underground drainage facilities within core clusters of these megacities are usually century-old antiquated brick masonry conduits.
• The coverage of storm water drainage network in cities/ towns stands about 20 per cent of road network and its allied catchments as per the report on Indian Urban Infrastructure and Services (March 2011) which is inadequate to cater to the storm-water disposal in the present city scenario.</td></tr>
<tr><td>In hilly or mountainous region, the conventional drainage systems are road side drains.

Outsloping is done toward downhill side of the road.

Insloping is done where a more reliable drainage system is required such as on permanent roads, roads with high anticipated traffic volumes and/or loads, or in areas with sensitive soils or severe climatic conditions.</td><td>The city of Guwahati has significantly undulating topography with a plain area in the middle making it inherent to flooding and water-logging problems. The natural drainage channels have been made ineffective today by unscientific developmental process and subsequent encroachment along its banks.

The small drains alongside the roads in the city cannot provide relief to the localities. Due to their inadequate depth and width, these drains are not capable of carrying storm water.</td><td>Design of an urban drainage system requires knowledge of the catchment area and topography, urbanization details, rainfall intensity, hydrology, hydraulics, etc.

Watershed/catchment as basis of urban drainage design.

Contours are necessary for determining the boundaries of a watershed/catchment and for computing directions of flow.</td></tr>
</table>

Ecological region	Rainfall pattern	Characteristics	Configuration of urban drainage systems storm-water management	Examples of cities that face frequent urban flooding in these regions	Remarks
		Cities/towns in hilly areas experience flash floods due to localized heavy rainfall which can also result in landslides.	This may be desirable in steep terrain in order to reduce excavation.	Insufficient coverage with storm water drains lacks proper connectivity linkage to major canals and waterways.	Hillslope geomorphology and hydrologic factors are important considerations in the location, design, and construction of a road. Natural drainage characteristics of a hillslope, as a rule, should not be changed. Slope morphology impacts road drainage and ultimately road stability. Design considerations for hilly terrain in Manual on Stormwater Drainage Systems (2019) by CPHEEO.
Arid and semi-arid regions	Includes Karnataka, inland Tamil Nadu, western Andhra Pradesh, and central Maharashtra, which receive 400–750 mm (15.7–29.5 in) annually. Most of western Rajasthan experiences an arid climatic regime (hot desert climate) with rainfall totals less than 300 millimetres (11.8 in)	In this region, urban drainage deals generally with short duration processes, the evaporation process is normally neglected in the traditional procedure of design. This may result in considerable over-estimation of runoff. The high temperature and low humidity and their large daily variations destruct the soils from pervious surfaces and provide loose materials to be carried with flash storm water to the drainage system. In addition, dust, dirt, sediments carried with sandstorms and pollutants of various kinds, settled from the atmosphere and generated by urban activities, accumulate on the impervious surfaces during the long rainless period and are eventually washed off by the flash runoff during the rainstorms. Climate in arid areas affect the concentration of sediments in runoff.	In arid and semi-arid regions open drain channels along the roadside is a common practice. Normal practice in arid climates include: • Embankment and slopes protection against sliding may be by placing granular materials. • instalment of concrete sediment racks in the detention basin to avoid the transport of debris and boulders. • instalment of trash racks to hold rubbish, papers, leaves, etc.	Hyderabad is divided into 16 stormwater/ catchment zones by GHMC. Among the storm-water zones, zone 12 Kukatpally and zone 13 Alwal and Begumpet area are major flood-prone areas.	In semi-arid and arid areas, urban storm water can be detained in detention ponds. This can reduce the capacity requirements of storm-water drainage systems, and. Identify potential rainwater harvesting sites of semi-arid region. Most green infrastructure practices were first developed in temperate climates, but most also are applicable to arid and semi-arid regions, although they may require modification. Green infrastructure can be a cost-effective approach to stormwater management and water conservation in arid and semi-arid regions, reducing runoff, conserving water, recharging ground water, conserving energy and improving air quality (USEPA 2010b).

Ecological region	Rainfall pattern	Characteristics	Configuration of urban drainage systems storm-water management	Examples of cities that face frequent urban flooding in these regions	Remarks
Plains and floodplains	This region receives between 1,500–2,000 mm (59–79 in) of rainfall each year in the western part, and 2,000–3,000 mm (79–118 in) in the eastern part.	In plains, the accumulation of local rainfall runoff is due to insufficient drainage/ overwhelming of existing and buffer capacity within the watershed where topographical differences are relatively small. Water that collects or flows beneath the surface of the ground, filling the porous spaces in soil, sediment and rocks originating from rain. Cities/towns in upstream of a river gets affected by rising level of back waters when release of water is sometimes withheld during the flood season. Cities in downstream of rivers can get flooded by release of water in excess quantities. In floodplains and low-lying areas, non-existence of natural drainage to the sea because most of the lands are either below the sea level or at the same level. It has a restricted natural outlet which makes it bound to suffer inundation in heightened rainfall events.	In a conventional network, a storm water system with open channels for the discharge of rainwater exists in most urbanized areas. The channels usually drain off rainwater into rivers or sometimes into agricultural irrigation canals. The existing storm-water collection network in these cities is mainly designed to serve as a combined system for sewage as well as storm water runoff. Minor system—network of underground pipes and channels. Minor system categorized into two types: separate and combined. Major drainage systems comprise open nallahs and natural surface drains, etc. Drains in various points.	Surat is highly vulnerable to flooding because much of the city is in the low-lying areas. Most of the floods in the city were caused by heavy rainfall in the catchment area of Tapi River, 6 per cent of which lies in Gujarat. The catchment area receives 90 per cent of the annual rainfall between June and October, and most floods occur in August. Heavy rainfall in the catchment area results in heavy inflow of water into the dam's reservoir, which gets filled up often leading to heavy discharges from the reservoir, creating flood-like situation in the city. The secondary runway of Chennai International Airport was also built right over the Adyar River. Most of the airport was constructed on the riverine floodplains, leading to massive flooding during the 2015 Chennai floods. The case in Delhi's Yamuna Pushta area—the floodplain region where Akshardham and CWG Village have been built— where slum areas flood almost each year. Even recent developments such as Andhra Pradesh's Amaravati Capital City Project had major areas proposed to be built on the floodplains of Krishna River.	Low-lying areas should be reserved for parks and other low -impact human activities. Wherever unavoidable, buildings in low lying areas should be constructed on stilts above the high flood level (HFL)/full tank level (FTL) For chronic flooding spots, alternative locations may be explored to accommodate people staying there. For larger drainage areas, though it is desirable that the sewer capacities be designed for the total tributary area. To prevent water accumulation in low-lying areas, the roads should be constructed to be lower than the surrounding area and the soil from the excavation was used to fill up low-lying areas and reduce the ponding of surface water in these areas.

Ecological region	Rainfall pattern	Characteristics	Configuration of urban drainage systems storm-water management	Examples of cities that face frequent urban flooding in these regions	Remarks
Tropical wet	In this region, the rainy season lasts from June to September; annual rainfall averages between 750–1,500 mm (30–59 in) across the region. Once the dry northeast monsoon begins in September, most precipitation in India falls on Tamil Nadu, leaving other states comparatively dry.	In tropical climates, where runoff is frequently greater than the capacity of the drainage infrastructure, a significant proportion of runoff occurs as overland flow. In this region drainage systems are often constructed below ground in closed pipes, because they are preferable from a health and aesthetic perspective. So, deterioration and accumulation of debris or sediment are more difficult to monitor/control, also closed drains are more expensive to maintain.	The storm water of the city from minor drains, drains into major drain. Three types of sub-drainage systems are commonly used: (1) Pipe underdrains. This system consists of perforated pipe placed at the bottom of a narrow trench and backfilled with a filter material such as coarse sand. (2) Drilled drains. This system consists of perforated metal pipes placed in holes drilled into cut or fill slopes after construction. (3) French drains. This system consists of trenches backfilled with porous material, such as very coarse sand or gravel.	The oldest combined sewerage system in India is in the capital of the British Empire in India till 1911, the city of Kolkata (Calcutta, back then). In 1876, it was designed to cope with 6.35 mm/h of rainfall with 100 per cent of runoff. Later in 1970's, attempts were made to increase its capacity to 12.7 mm/ hr rainfall. However, in the same year the city of Kolkata received rainfall of 54 mm in one hour and caused severe flooding. Sometimes these measures surcharge the existing network by storm water and even frequent rainfall leads to flooding. These orthodox approaches often cause flooding problems in the downstream along with pollution and erosion of natural water bodies that are receiving the runoff.	A road drainage system must satisfy two main criteria if it is to be effective throughout its design life: 1. It must allow for a minimum of disturbance of the natural drainage pattern. 2. It must drain surface and subsurface water away from the roadway and dissipate it in a way that prevents excessive collection of water in unstable areas and subsequent downstream erosion.

Ecological region	Rainfall pattern	Characteristics	Configuration of urban drainage systems storm-water management	Examples of cities that face frequent urban flooding in these regions	Remarks
Coastal regions	The coastal zone receives the heaviest rainfall with an average rainfall of about 3,638.5 mm per annum, far in excess of the state average of 1,139 mm (45 in).	The coastal areas present a unique challenge to the design of storm water drainage systems, owing to tides, high groundwater tables, and relatively flat terrain. During high tides, low lying areas along the coast are prone to flooding/ inundation and disposal of storm water becomes a problem. Backflow of seawater further exasperates the problem. During severe storms or cyclones, the discharge of stormwater through drains is often not effective and results in water logging and flooding. The following section mentions the special design considerations in storm drainage outfalls in coastal areas.	Generally open channels with free board of 0.3 m are provided based on CPHEEO and IRC recommendation.	Mumbai has legacy storm-water drainage system in the core cluster: gravity system without pumping arrangement Number of catchments:121 System more than 100 years old. Designed for 25 mm rainfall and Rrun-off coefficient of 0.5. Chennai: The topography of the island city is relatively flat with some reclaimed areas between the islands precariously close to the mean sea level (MSL). The city is saucer shaped with some areas in the middle being lower than the High Tide Line (HTL). Thus, when water accumulates at these points during monsoons, it is difficult to drain it by water pumps as the level of water elsewhere is higher. Being a coastal city, Chennai faces flood threats often both through cyclonic activities and monsoon rains.	Stormwater drainage systems for coastal cities have to be designed taking into account the tidal variations. Design considerations for Coastal Regions in Manual on Stormwater Drainage Systems (2019) by CPHEEO.

Source: Compiled by CSE, 2023

Planning and designing considerations for urban storm-water drainage management

- Conduct scientific analysis of the storm-water drainage system; catchment delineation and drain analysis—terrain analysis to determine dominant areas contributing the storm runoff for each drain, local rainfall analysis—return period of extreme rainfall (15 min.), preparation of soil type and landuse data to be adopted in the study,
- Deploy models to stimulate the floods: Capture the drainage infrastructure, validate the model by mapping flooding hotspots, storm drain carrying sewage/ solid waste/ C & D waste, encroachment, analyse to check technical aspects of drains and its performance for conveyance, effectiveness of desilting of storm drains, no construction should be allowed inside any storm drains (pillars of elevated roads etc.).
- Hydrologic and hydrodynamic modelling to derive runoff hydrographs, surface water profiles and extent of backwater effects within the storm drainage network under various envisaged scenarios
- Vulnerability assessment: to cater equity in distribution of infrastructure
- Design of new storm drains should not be done in isolation; retention cum harvesting corridors can be laid along the road to capture the runoff and recharge

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

- Major and/or minor approach: Combination of conventional systems and SUDS
- Attenuate and infiltrate first: Control volume and peak run-off from site by retention and detention, and preserve natural streams and waterbodies
- Interventions at all scales: Follow the SUDS train at individual, neighbourhood and zonal and/or city scale
- Context-based interventions: Locating interventions as per city's dense urban fabric, topography and along physical features.
- Stormwater harvesting: Alternatives for sustainable stormwater management and suitability in Indian context: Harvesting at the site scale may prove to be more beneficial as the collected stormwater can be either used for multiple purposes or infiltrated into ground. Retrofitting of site-scale watersheds with SUDS measures: micro scale, infiltration-based SUDS/LID techniques applied in decentralized way.

Alternative storm-water management measures and their suitability in the Indian context

Storm-water management alternative	Advantages	Disadvantages	Suitability in Indian conditions
Bioretention (rain gardens and bioswales)	• Reduction in runoff volumes and peak flows (Davis, 2008; Hunt et al., 2008) • Generally, requires less space and is more economical • Requires less maintenance • Removes pollutants (Carpenter and Hallam, 2010; Kim et al., 2012) • Has aesthetic value • Offers good retrofit opportunities for existing urban landscapes	• High sediment may cause premature failure • Cannot be provided for large drainage areas	• May not be suitable as a centralized means for management of stormwater due to high sediment load. • Can be utilized in a decentralized way for small drainage areas (Luellet al., 2011)
Grass swales	• Reduces runoff volume, peak flow and pollutants (Parker et al.., 2009) • Application is primarily along residential streets and highways • Adaptable to a variety of site conditions • Flexible in design and layout • Less costly than conventional storm drain pipe system	• Open channels may be potential nuisance problems • Moderate or high maintenance cost	• May lead to favorable conditions for proliferation of vectors or carriers of tropical disease (Silveira, 2002) • Maintenance issues may further complicate adoption of this measure
Green roofs/vegetated roof covers	• Reduces percentage of impervious spaces in urban areas • Reduction in runoff volume (Fioretti et al., 2010; Simmons et al., 2008) • Reduce peak discharge rates (Alfredo et al., 2010; Fioretti et al.., 2010; Getter et al.., 2007; Stovin et a.l., 2012; Teemusk and Mander, 2007) • Provides aesthetic benefits (Banting et al., 2005) • Better thermal performance (Simmons et al., 2008) • Decrease in total energy consumption of buildings (Banting et al., 2005; Castleton et al.,2010	• High initial cost • Moderate maintenance cost • Climatic condition	• May not be suitable for old, small residential buildings due to structural considerations • May be adopted for large roofs in commercial zone where open space is limited

Storm-water management alternative	Advantages	Disadvantages	Suitability in Indian conditions
Permeable or porous pavements	• Effective in reducing imperviousness in a drainage basin • Recharges the groundwater • Improves the quality by arresting the pollutants (Collins et al., 2010)	• Costlier than conventional pavements (USEPA, 2000) • Suitable for low traffic areas such as parking lots and sidewalks (Fletcher et al., 2008; Scholz and Grabowiecki, 2007) • Clogging problems may arise due to high sediment load (Chopra et al., 2009; Fassman and Blackbourn, 2010) • Maintenance is costly (Ahmed et al., 2011	• May not be suitable due to high sediment load in stormwater
Infiltration devices (leaky wells, retention trenches, infiltration basins)	• Reduces peak flow (Holman-dodds et al., 2003) • Recharges the groundwater (Moura et al., 2011) • Improves the groundwater quality • Reduces runoff volume (Ahammed et al., 2012a)	• Require pre-treatment to remove sediment • Unsuitable for soils with very low hydraulic conductivity • Cannot be installed on steep slopes • Not suitable in areas with rising water table or where salinity of groundwater is increasing	• Can be provided for small drainage areas in a decentralized manner (Ahammed et al., 2012a) • Can be connected to any conventional RWH system which has a filter to trap the debris
Detention basins (dry ponds, extended detention basins, detention ponds, extended detention ponds)	• Attenuates peak flow • Simple to design and construct • Easy to maintain • Can also function as a recreational facility • Can be used with lining where groundwater is vulnerable	• Little reduction in runoff volume • Has large space requirement hence may not be suitable in ultra-urban areas • Provides moderate removal of pollutants (Yangand Cui, 2012).[4] May turn into mosquito breeding sites if improperly managed • Normally provided towards the end of sustainable urban drainage management train	• Unsuitable due to large space requirement and highly polluted nature of stormwater (Silveira, 2002)2. • Regular maintenance is required to prevent unhygienic condition
Retention Ponds (stormwater ponds, wet retention ponds, wet extended detention ponds)	• Reduces peak flow • Provides good stormwater treatment • Provides high amenity and aesthetic benefits • Adds value to local properties	• Land requirement may limit use in dense urbanized landscapes • Pose health and safety risks (Goldenfum et al., 2007)	• Not suitable due to scarcity of space and safety hazards. • May lead to favorable conditions for proliferation of vectors or carriers of tropical disease

Source: Compiled by CSE. (2023) Adapted from: Gogate, N. G., Kalbar, P. P., and Raval, P. M. (2017). Assessment of stormwater management options in urban contexts using Multiple Attribute Decision-Making.

Table 4: A compilation of the high-intensity rainfall (greater than 50 mm day−1) and subsequent flooding incidents during 2018–19 in the capital cities of the 28 Indian states and the 9 Union Territories

s.no.	State Capital	no of times exceeded 50 mm day^{-1}	no of times exceeded 100 mm day^{-1}	remarks
1	Agartala (Tripura)	7	—	90 mm on 04-06-18
2	Aizawl (Mizoram)	5	1	150 mm on 11-06-18
3	Bengaluru (Karnataka)	1	—	50 mm on 16-09-18
4	Bhopal (Madhya Pradesh)	2	—	150 mm on 20-08-18
5	Bhubaneshwar (Orissa)	11	6	190 mm on 20-08-18
6	Chandigarh (Haryana, Punjab)	4	—	—
7	Chennai (Tamil Nadu)	5	—	—
8	Dehradun (Uttarakhand)	12	3	130 mm on 05-08-18
9	Guwahati (Assam)	—	—	—
10	Gandhinagar (Gujarat)	1	—	—
11	Gangtok (Sikkim)	15	—	—
12	Hyderabad (Telangana)	2	—	—
13	Imphal (Manipur)	2	1	200 mm on 22-06-18
14	Itanagar (Arunachal Pradesh)	13	2	100 mm on 13-06-18
15	Jaipur (Rajasthan)	4	—	—
16	Kohima (Nagaland)	5	—	—
17	Kolkata (West Bengal)	10	3	160 mm on 25-6-18
18	Lucknow (Uttar Pradesh)	7	1	110 mm on 02-08-1008
19	Mumbai (Santacruz) (Maharashtra)	12	9	230 mm on 24-06-18
20	Panaji (Goa)	1	1	110 mm on 09-06-18
21	Patna (Bihar)	1	1	130 mm on 28-07-18
22	Raipur (Chhattisgarh)	3	1	100 mm on 28-08-18
23	Ranchi (Jharkhand)	5	1	100 mm on 25-08-18
24	Shillong (Meghalaya)	6	1	130 mm on 04-05-19
25	Shimla (Himachal Pradesh)	5	1	170 mm on 12-08-18
26	Thiruvananthapuram (Kerala)	8	2	120 mm on 4-08-18
27	Jammu (Winter Capital) (Jammu & Kashmir)	13	1	110 mm on 01-09-18
28	Kavaratti (Lakshadweep)	—	—	—
29	Leh (Ladakh)	—	—	—
30	Delhi (Safdarjung)	2	—	—
31	Port Blair (Andaman and Nicobar)	13	2	130 mm on 07-10-18
32	Puducherry/Pondicherry (Puducherry)	—	—	—
33	Srinagar (Summer Capital) (Jammu & Kashmir)	1	—	—

Source: Gupta, K. (2020). Challenges in developing urban flood resilience in India.

Design considerations for rainwater harvesting and groundwater recharge

The technology of rainwater harvesting has been used since ancient times and is ignored today in favour of modern systems. If only we can revive this traditional wisdom of catching rainwater and reinforce it with modern science and technological inputs, the modern-day water crisis can be addressed. Rainwater can be collected from rooftops of buildings, playgrounds and parks, roads and flyovers and urban forested areas. The diverse forms of harvesting rainwater have multi-functional and serve different purposes ranging from drinking, non-potable uses, groundwater recharge, mitigation of urban flooding and improving the quality of groundwater. Rainwater and run-off can be harvested, collected and stored, or conveyed to the aquifer to recharge groundwater. For any urbanizing city facing huge water-stress issues, leading to over-extraction of groundwater in the area, there is an urgent need to consider rainfall as an important and manageable resource in water management plans. A fresh multi-prolonged impetus is necessary to take rainwater harvesting forward; pricing incentives for rainwater harvesting, disincentives to discourage water wastage, regeneration of waterbodies, rainwater harvesting in public buildings, colonies and green open areas, but to be done mindfully where it is feasible and has the potential.

Planning considerations	Design (technology) consideration	Financing (cost optimization)	Operation and maintenance consideration
The **planning and designing of an RWH system is a step-by-step process**. A checklist: • **Step 1:** Collection of information on the catchment, rainfall, physiography, soil and rock, aquifer, water demand, objectives and uses, laws and incentives. • **Step 2:** Studying the site plan to understand the slope, the location of the catchments, space available and other details. • **Step 3:** Estimating the amount of water that can be collected (water harvesting potential) and matching this with the water demand. • **Step 4:** Deciding the number, type, capacity and location of structures—whether to harvest water for direct use from storage containers or to recharge the aquifer. • **Step 5:** Allocating funds—the budget is one of the most important determinants of rainwater harvesting work.	A few, basic elements are common to all RWH systems: ***The catchment area*** where the rain falls; • Paved area catchments—High runoff (smooth catchments) • Unpaved area catchments—low runoff, high permeability, keeping in mind the contaminants **The conveyance** or ***conduit system*** that channels the flow of water in a given direction; • The diameter of the down take pipe will be directly proportionate to the roof area and inversely proportionate to the rainfall intensity. • In flat catchments velocity of flow towards the collecting inlets shall be limited • Gutters should be sized to direct the flow during the highest intensity rain without loss of water ***The first flush*** (a valve that ensures that run-off from the first spell of rain is flushed out and does not enter the system) and ***the filter system***; and, • It is necessary to install filters both for storage and recharge systems. There are several ways of filtering contaminants. There are simple systems that keep out leaves and debris and remove the first flush of rainwater. • More complex systems filter out bacteriological and other dissolved contaminants.	• Soil type—Excavation costs are higher on rocky soils • Groundwater vulnerability—In vulnerable areas some RWH measures will need impermeable liners to prevent infiltration which will increase costs • Design criteria—More stringent requirements for run-off control will lead to larger and more WSUDP measures in the system • Access issues and space requirements—Some measures take up land that would otherwise be used for development • Location—Regional variations in labour and material costs, topography and soil conditions, including permeability and local rainfall characteristics, affect design criteria • System size—Larger schemes offer the opportunity for economies of scale to be realized • New build or retrofit—The cost of installing a WSUDP solution in an existing development is different from the cost of installing it as part of a new development. • Maintaining Community RWH	• Proactive maintenance in the ***first two years*** after the establishment period (construction and planting phases) are the ***most intensive and important to the long-term success of the treatment system*** • Before an arrival of monsoon, the ***rooftop/catchment area must be cleaned to avoid pollutants*** (dust, toxic elements, chemical, bird dropping etc.) to enter into either aquifer or storage reservoir. • The ***inlet at roof on the terrace should be covered with a mesh*** to prevent entry of leaves or other solid waste into the system • The diversion valve (first flush) must be opened for the first 10–15 minutes of rain to dispose of pollutants from the first rain spell • The ***filter media should be replaced or cleaned thoroughly*** with new season • Storage tanks should be checked for ***cracks, leakages and cleanliness*** for optimum storage levels • Water quality must be checked regularly. It should meet the quality criteria as per the purpose and as decided by the government organizations. • Once you have installed a RWH system, also set a system for monitoring. This will help you to provide concrete evidence of the **impact of rainwater harvesting**

Planning considerations	Design (technology) consideration	Financing (cost optimization)	Operation and maintenance consideration
• **Mapping the aquifers in the city:** Aquifers can be artificially recharged but only after studied extensively for geological, hydrogeological, geomorphological and climatological conditions. Three methods, namely surface spreading, watershed management (water harvesting) and recharge wells. • **Defining the purpose of final use of harvested rainwater** is most important. 1) Through storage in receptacles and reuse 2) By recharging the aquifer that depends on: Quantum of surface runoff available, Rainfall pattern, Land use and land cover, Topography and terrain profile, Soil type and soil depth, Hydrological and hydrogeological characteristics 3) Both storage and recharge • **Stormwater harvesting schemes** are best incorporated within new projects, as the costs are substantially lower than retrofitting them into existing systems. Good stormwater management will play an important part in controlling urban floods during monsoons. It is also a good means to dilute pollution of rivers. • **Planning for RWH in open green areas/ public spaces**—Cognizant that rooftop RWH has had limited success and needs incentivization and other measures, it is imperative to undertake radical changes in the RWH strategies for cities. Noting that there lies immense potential of rain storm-water harvesting via public parks, roads and flyovers etc. • The equity argument for urban groundwater doesn't have to do with whether it's there or not, but whether the poor have access to it. • **Policy steps**—Construction and improvement of drains/storm-water drains • Preservation of waterbodies,	***The storage area***, consisting of tanks/receptacles. • Storage tanks are available in diverse materials ranging from cast iron sheets and PVC to RCC structures. • Storage tanks can also be made of ferrocement, an inexpensive material, essentially a thin cement mortar reinforced with wire mesh. Overground tanks are less expensive than underground tanks, as excavation and costs of stronger reinforcing can be avoided. • One can also have more than one storage tank, depending on the site conditions. • Ensure that the tank is properly covered and all lights excluded to prevent growth of algae and bacteria. • Harvested rainwater can be further purified by boiling, chlorination, direct solar radiation and ultra-violet rays ***The recharge area***, where the harvested rainwater is used to replenish the groundwater. • Rainwater may be charged into the aquifers through recharge pits, recharge wells, recharge trenches, and dry dugwells/borewells. • Quality of runoff, getting recharged through the shaft/ pipe can be further ensured by passing the rainwater through a filter bed comprising of coarse sand, gravel and pebble. • The recharge shaft/borehole pipe should be kept some distance above (min. 5 ft) the water table level to avoid contamination and enhance natural filtration through soil. ***The storm-water drains*** • Harvesting water from stormwater drains is receiving more attention in India today since it can control the annual flooding in cities; at the same time, it can supplement the rainwater collected from rooftops		• Positive results will encourage other people to opt for the RWH option • Repair cracks in ferro-cement tanks immediately • ***Private consultants***: Technology providers, costs investments, O&M contracts • ***Local community***: Key role in planning and O&M. Awareness for local community is key in successful implementation of RWH projects • ***Research organizations/NGOs:*** Create awareness, advocacy, and bring issues to the forefront

Planning considerations	Design (technology) consideration	Financing (cost optimization)	Operation and maintenance consideration
• Revision of bylaws that make RWH mandatory in all buildings and adoption of water conservation measures, • Institution of bylaws for reuse of recycled water. • Degraded lakes need to be regenerated on a priority basis; • Costs of sourcing, conveyance, treatment and collection and treatment of wastewater should be incorporated in the price of water supplied; • Sewage could be recycled and reused for horticulture or industrial purposes; • Laws or financial disincentives need to be put in place to discourage wastage of water	• The run-off from the city roads, drains, creeks and public spaces, that receive a large amount of rainfall, can be channelled into stormwater drains, to recharge groundwater.		

Source: Compiled by CSE, 2023.

Catchment-related information

Table 1: Run-off coefficient for different types of catchments

Catchment	Type of material	Run-off coefficient
Roof	Tiles	0.8-0.9
	Metal	0.7-0.9
Paved area Driveway/courtyard, roads	Concrete	0.6-0.8
	Brick	0.5-0.6
Unpaved area garden, playground	10% sand	0.0-0.3
	Hard compact	0.2-0.5
	Lawns	0.1

Source: Centre for Science and Environment. (2013). Catch Water Where It Falls: Toolkit on Urban Rainwater Harvesting

Table 2: Run-off coefficient for different roof types in India

Roof type	Run-off coefficient
Galvanised iron sheet	0.9
Asbestos sheet	0.8
Tiled roof	0.75
Concrete roof	0.7

Source: Manual on construction and maintenance of household-based rooftop water harvesting systems, report prepared by Action for Food Production for UNICEF

Hydro-geological information

Soil

Table 3: Infiltration rate for different types of soils

Soil type	Infiltration rate(mm/hour)
Highly clayey soils	Below 2.5
Shallow soils, clay soils, soils low in organic matter	2.5 - 12.5
Sandy loams, silt loams	12.5 - 25.0
Deep sands, well aggregated soils	Above 25

Source: Centre for Science and Environment. (2013). Catch Water Where It Falls: Toolkit on Urban Rainwater Harvesting

Table 4: Permeability of soils

Type of soil	Permeability (cm/hour)
Sand	5
Sandy loam	2.5
Loam	1.3
Clay loam	0.8
Silty clay	0.25
Clay	0.05

Source: Centre for Science and Environment. (2013). Catch Water Where It Falls: Toolkit on Urban Rainwater Harvesting

Table 5: Porosity of soils

Soils	Porosity
Gravel	25 – 40%
Sand	25 – 50%
Clay	40 – 70%

Source: Centre for Science and Environment. (2013). Catch Water Where It Falls: Toolkit on Urban Rainwater Harvesting

Table 6: Soil types of India and their suitability for recharge

Type of soil	Where found	Key properties	Suitability for groundwater recharge
Red soil	Andhra Pradesh, Assam, Bihar, Goa, Parts of Kerala, Maharastra, Karnataka, Tamil Nadu and West Bengal	Red in colour. Light texture and porous	Suitable
Laterite soil	Summits of hills of Deccan Karnataka, Kerala, Madhya Pradesh, Ghat regions of Odisha, Andhra Pradesh, Maharastra, West Bengal, Tamil Nadu and Assam	Light texture and porous Yellow in colour	Suitable
Alluvial soil	Indo-Gangetic plains, Brahmaputra valley and almost all states of North and South	Sandy loam to clay loam with loose structure. Light grey colour to dark colour	Very good
Black soil	Maharastra, Madhya Pradesh, Gujarat and Tamil Nadu	Poor free drainage. Dark grey to black colour with high clay content.	Not suitable
Desert soils	Haryana, Punjab, Rajasthan	Sandy to loamy fine sand with brown to yellow brown colour	Very good

Source: Centre for Science and Environment. (2013). Catch Water Where It Falls: Toolkit on Urban Rainwater Harvesting

Table 7: Size classes of soils

Soil	cm
Fine gravel	0.2-0.6
Medium gravel	0.6-2.0
Coarse gravel	2-6
Stones 6-20	2-6
Boulders	20-60
Large boulders	60-200

Source: Centre for Science and Environment. (2013). Catch Water Where It Falls: Toolkit on Urban Rainwater Harvesting

Rock

Table 8: Infiltration characteristics of rocks

Parameter	Type of rock
Rocks that permit infiltration	Porous rocks: (Sandstone, chalk, shale) which contain pores
	Pervious rocks: (Carboniferous limestone, marble) which have cracks or joints through which water can infiltrate
Rocks that permit some infiltration	Fractured, fissured, weathered (basalt, quartzite, gneiss, slate, schist)
Rocks that permit no infiltration	Massive rocks (granite, basalt) that are impervious

Source: Centre for Science and Environment. (2013). Catch Water Where It Falls: Toolkit on Urban Rainwater Harvesting

Table 9: Porosity of rock materials

Rocks	Porosity
Limestone, dolomite:	5 –50%
Karst:	5 –50%
Sandstone:	5 –30%
Shale	:0 –10%
Crystalline rock:	0 –10%

Table 10: Hydro-geological conditions and type of structure

Parameter	Type/condition	Recommended structure
Nature of aquifer	Impermeable, non-porous, non-homogeneous, hard rock area	Storage
Depth of groundwater table	More than 8 metres	Recharge and storage
Nature of terrain	Hilly, rocky or undulating	Storage
	Uniform or flat, alluvial and sedimentary	Recharge and storage
Nature of soil	Alluvial, sandy, loamy soils, gravel, silty, with boulders or small stones (*kankar*)	Recharge and storage
	Clayey soil	Storage
Nature of geological formation	Massive rocks (such as the Deccan trap)	Storage
	Fractured, faulted or folded rocks, or comprises of weathered, jointed or fissured rocks	Recharge and storage
Nature of rainfall and monsoon	Number of rainy days are more, bi-modal monsoon, not intensive, uniformly distributed	Storage
	Uni-modal monsoon, rainfall available only for a few months	Recharge and storage

Physiographic information

Table 11: Suitability of rainwater harvesting structures based on physiography

Parameter	Type of terrain
Areas more suited for storage	Hilly areas are more suited for storage structures as the recharged water is likely to travel down to the valley.
	Coastal areas: Where the groundwater is shallow and saline, more suitable for storage.
	Desert areas: Low rainfall that may be absorbed by the thick sandy layer.
Areas suited for storage or recharge	Plains are suited for both recharge and storage.

Design considerations for rejuvenation of urban lakes and/or waterbodies

Urban waterbodies are a significant mitigation and adaptation measure for increased urban resilience. Yet, these waterbodies are treated as a "sink" for untreated effluents from urban centres and industries and are subjected to poor solid-waste management, exploitation of floodplains, destruction of the drainage, groundwater decline resulting fall in the water level, unplanned tourism and absence of an administrative framework further complicate the system. Waterbodies in urban and peri-urban areas are an important interface between ecology and planning, which demands long-term environmentally responsive strategies, considering issues like flooding, water pollution, and water quality with their complexities in design, engineering, planning and management. To maintain the long-term health and stability of lakes, the catchment area, shoreline and upstream need to be systematically managed over a period of time. At the same time, it is important to focus on how can a strained and disconnected community can be united around its liability and the aim should be to illustrate how rejuvenation of the neglected waterbody can act as an opportunity for these communities. Lake management process is a comprehensive and fluid process altogether.

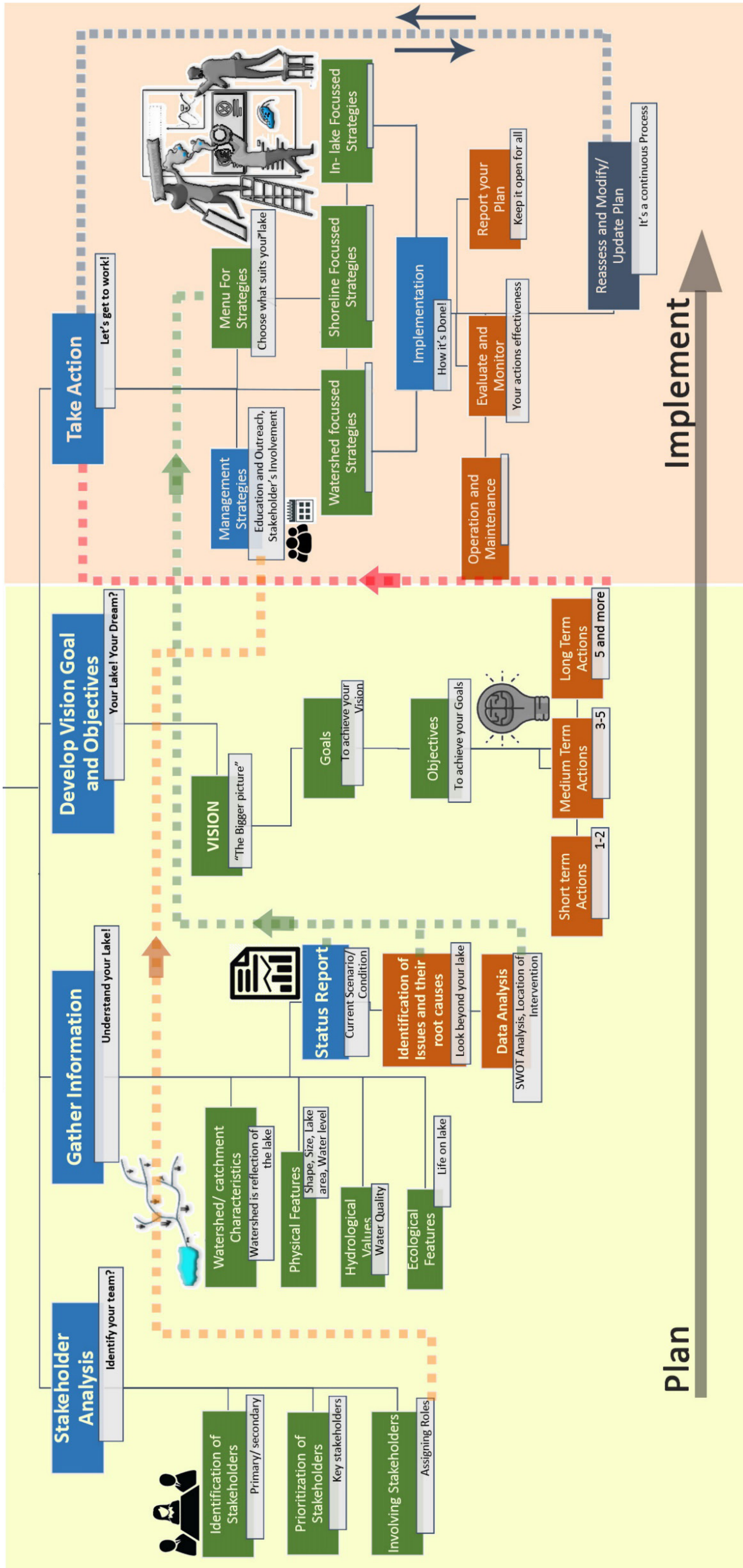
Planning considerations	Design (technology) considerations	Financing and economic considerations	Operation and maintenance considerations
▪ The quality and hydrologic regime of lakes/ waterbodies are directly dependent on the **integrity of its watershed** ▪ *Acknowledgement of Waterbodies in Master plan:* To regulate the landuse in the catchment area of lakes, including the shoreline buffer areas and contributing streams, the master plan document becomes an important tool. ▪ Catchment survey is a must ▪ To have a *systematic approach* for conservation, protection, management and restoration of an urban lake, a model framework provides step to step guidance to move forward (see Figure 1) • *Stakeholder analysis* • *Gather information and identify concerns* • *Develop vision goals and objectives* (short- medium and long term) • *Take Action* (effective for specific lake cases according to their issues and requirement for improvement) There are management strategies and technology practices focused on watershed scale, shoreline and in-lake interventions. • In-lake restoration efforts in some lakes may only result in short term improvement in the water quality • It is very crucial to emphasize on the **evaluation of effectiveness of the actions, operation and maintenance and continued monitoring** of the management implementations in order to keep up with the relative success of the plan. Urban lake management plan is a continuous process; therefore, **reassessment and modification** are an integral part.	▪ The selection of restoration techniques varies from lake to lake depending on lake and its catchment characteristics. In-lake activities caters to the symptoms and may succeed for the short term, but more often misses out on the source of these problem. ▪ When selecting a management activity, it is crucial to keep in mind that a **combination of in-lake, shoreline and water-shed-based management activities** will often be the most effective long-term strategy. ▪ *Watershed-focused strategies:* Source protection strategies and domestic wastewater pollutant control • No diversion of sewage from upstream to downstream regions • **Adopt decentralized sew-age treatment option**—only treated sewage shall enter the lake. *Decentralized solutions for treatment of pollutant at source, along the path, streams or drains and at the opening of the waterbody can be effective.* Sewage treatment through integrated constructed wetlands (similar to Jakkur Model Sec-ondary Treatment Plant (STP) + Constructed wetlands + Algae ponds, will remove nutrients, etc.); • plant vegetative buffers, put screenings along the tributary streams for natural filtration and treatment • By installing or augmenting vegetative buffers, the transport of sediment is reduced from the surrounding watershed into the lake. This technique, when paired with dredging the bottom sediments of the lake, will treat both the source and the symp-toms of the sediment problem	▪ Incorporate lake rejuvenation plans under government programmes for financing —AMRUT 2.0, Smart cities Mission etc. ▪ *Economic valuation of urban lakes:* valuation of ecosystem services is that it will con-tribute towards better deci-sion-making, ensuring that policy appraisals fully take into account the costs and benefits. • Translating ecological value into financial terms will cre-ate a compelling incentive for local communities, businesses and policymakers ▪ Single agency with the stat-utory and financial autonomy to be the custodian of natural resources [ownership, regu-lar maintenance and action against polluters (encroachers as well as those who con-taminate through untreated sewage and effluents, dump-ing of solid wastes)]. Effective judicial system for speedy disposal of conflicts related to encroachments; ▪ Urban lakes provide recre-ation and tourism oppor-tunities and also is a mode of revenue generation for government for maintaining it. Urban lakes add on to the property values and, there-fore, the local tax base. ▪ Revenue generation opportu-nities around lake: • *Water-linked livelihood* • *Increased tourism potential* • *Increased business opportu-nities, commercial ventures related to lakes* • *Increased property values* • *Employment through piscicul-ture and animal husbandry* • *Employment through tourism infrastructure maintenance and temporal activities*	▪ *Regular maintenance, monitoring and surveillance* ▪ Establishment of lake development authorities ▪ Minimum five years maintenance of the lake by an agency (who implemented rejuvenation) ▪ Regular surveillance through vigilant resident groups and a network of local education institutions ▪ Regular monitoring of treatment plant and lake water quality (physical, chemical and biological) and the dissemination of information to the public through internet ▪ Remove macrophytes (covered on the water surface) regularly to a) maintain the water spread area of lakes ▪ Minimize the instances of nutrient re- release to the lake by decay of macrophytes ▪ Allow the photosynthesis of algae and improving the trophic level performance ▪ Fountains (with music and LED) may be installed to enhance surface aeration and recreation value of the ecosystem ▪ Maintain native flora and fauna. No introduction of exotic specie of fauna (fish, etc,) ▪ Local NGOs may be identified for regular maintenance and management

Planning considerations	Design (technology) considerations	Financing and economic considerations	Operation and maintenance considerations
Good governance: • Protect flood plains (buffer zones) to enhance the water retention capability of the lake. Enrich floodplains with riparian vegetation so that water gets treated as it passes through riparian zones • Maintain a minimum of 75 m buffer zone in urban lake and for larger lakes the buffer zone depends on the topography and shape of the catchment; • The **uncontrolled application of reusing treated wastewater** to restore lakes may have many unfavourable effects like health hazards, salinity build-up and toxicity hazards, which can impair the quality of both lake water and soil and also the sub-surface water, especially in the long-term. **Proper guidelines for wastewater reuse and management for lake rejuvenation should be followed** to limit negative effects significantly • Autonomous status to the agency to ensure minimal interference by the local politicians • Legislators to legislate and ensure effective implementation through the executive mechanism • Efficient decentralized administration through elimination of Land, Water and Waste Mafia • Make bureaucrats and engineers of the respective para-state agencies accountable for the poor status of urban lakes • Evict encroachers with sensible rehabilitation plans. Remove the nexus of consultants, contractors and engineers. • Preparing and updating an inventory of the water bodies in the state by geo-tagging all water bodies on a web-based GIS platform ▪ **Restoration efforts should reduce pollution, improve the lake water quality and provide habitat**, which supports maximum aquatic biodiversity. **Address issues of water pollution** at source as a priority.	*Shoreline stabilization strategies:* preserving the natural shoreline, planting native vegetation, erosion and sedimentation control. • Planting native species of macrophytes in the buffer zone (riparian vegetation) as well as in select open spaces of lake catchment area • May not reuse the silt (removed from the lake) for shoreline stabilisation or for creating 'islands' as the contaminants get leached to the water, impairing the chemical integrity of an ecosystem. • Most natural shorelines have gentle, gradual slopes (2:1) or shallower. Natural materials including plants, natural stone, and biodegradeable landscaping fabric are preferred materials to use to stabilize a shoreline over time. *In-lake focused strategies* • These techniques treat the biological symptoms of lake and might ignore the root causes for these symptoms. In lake techniques are those that are conducted in the lake itself and may include, physical, chemical and biological measures for remediating water quality concerns. These actions are generally done to manage eutrophication, restore lake depth, enhance fisheries, control invasive species or increase the area of lake for recreation. • Remove all blockades at outlets as well as inlets to prevent stagnation of water and enhance aeration in the waterbody. - Stop dumping of solid waste and construction and demolition (C&D) waste in the lakebed and storm-water drain; treat C&D waste as per C&D Waste Management Rule 2016, GoI - Ensure the complete removal of silt and verification of the achieved depth through scientific survey (total station survey); - Scientific approaches in desilting; Remove all accumulated silt considering the original topographic contour	***Incentives and disincentives*** as economic instruments of controlling behaviour. ▪ All these revenue generation activities must be promoted so that it helps in revenue generation and sustaining the livelihoods of the dependents while protecting and managing these resources in an ecologically sensitive sustainable manner – for example, with some restricted areas for preservation from disruption as well as provision of certain specified area that allows for these activities to take place in a sustainable manner along with ordinances and enforceable regulations. ▪ Introducing ecotourism and concepts like community participation, collaborating research and educational programmes in lake planning and management can help maintaining the lake's ecosystem while generating income for the government as well as the locals. ▪ Some lakes without too large of a socioeconomic influence on the people nearby can be given for development of resorts or hotels around the lake area without disturbing its natural shoreline. This would help in producing revenue for the private partners as well as ensure the maintenance of the lake. ▪ Annual lake festivals, sound and light show and other public gatherings can also be conducted for annual income generation	▪ Public Participation and ownership: Decentralized management of lakes through local lake committees involving all stakeholders. Involve local stakeholders in the regular maintenance and management ▪ Online portal for all urban lakes (with the regular updation of information of water quality, photographic evidences, etc.) ▪ *Sensible policy and Implementation* • Reject the path of rejuvenation to tap off the public funds • **Ban on use of phosphates** in the manufacture of detergents: will minimise frothing and eutrophication of water bodies • **Digitization of land records** (especially common lands—lakes, open spaces, parks etc.) and availability of this geo-referenced data with query based information system to public • **Implementation of 'polluter pays'** principle as per water act 1974. Zero discharge from industries • **Restrictions on the diversion** of lake for any other purposes • **No construction activities** in lake zones

Planning considerations	Design (technology) considerations	Financing and economic considerations	Operation and maintenance considerations
▪ Urban lakes are strongly associated to **religious and cultural values**. Numerous religious practices are associated with water bodies - Provision of such practices/ activity areas ▪ Any urban lake management plan to be successful depends on a lot of factors like political will, change in the colonial style of the function of bureaucracy and most importantly assertion from the citizen for the right to equality in terms of quality and quantity of water. ▪ It is important to develop climate-resilient infrastructure by **integrating blue-green infrastructure along with the grey infrastructure** to channelize runoff in the waterbody. ▪ Absent and incomplete drain work should be completed considering the recent rainfall trend and intensity should be completed. ▪ Innovative approaches like sponge cities wetland restoration, permeable roads and pavement, green roofs and harvesting systems at all scales, public spaces as flexible water retention facilities and groundwater recharge should be given priority in Indian urban areas.	• Complete removal of accumulated contaminated silt in the lake. Desiltation not only enhances storage capacity but also aid in removing contamination. Adopt latest state of the art technology; wet dredging to remove deposited sediment.		

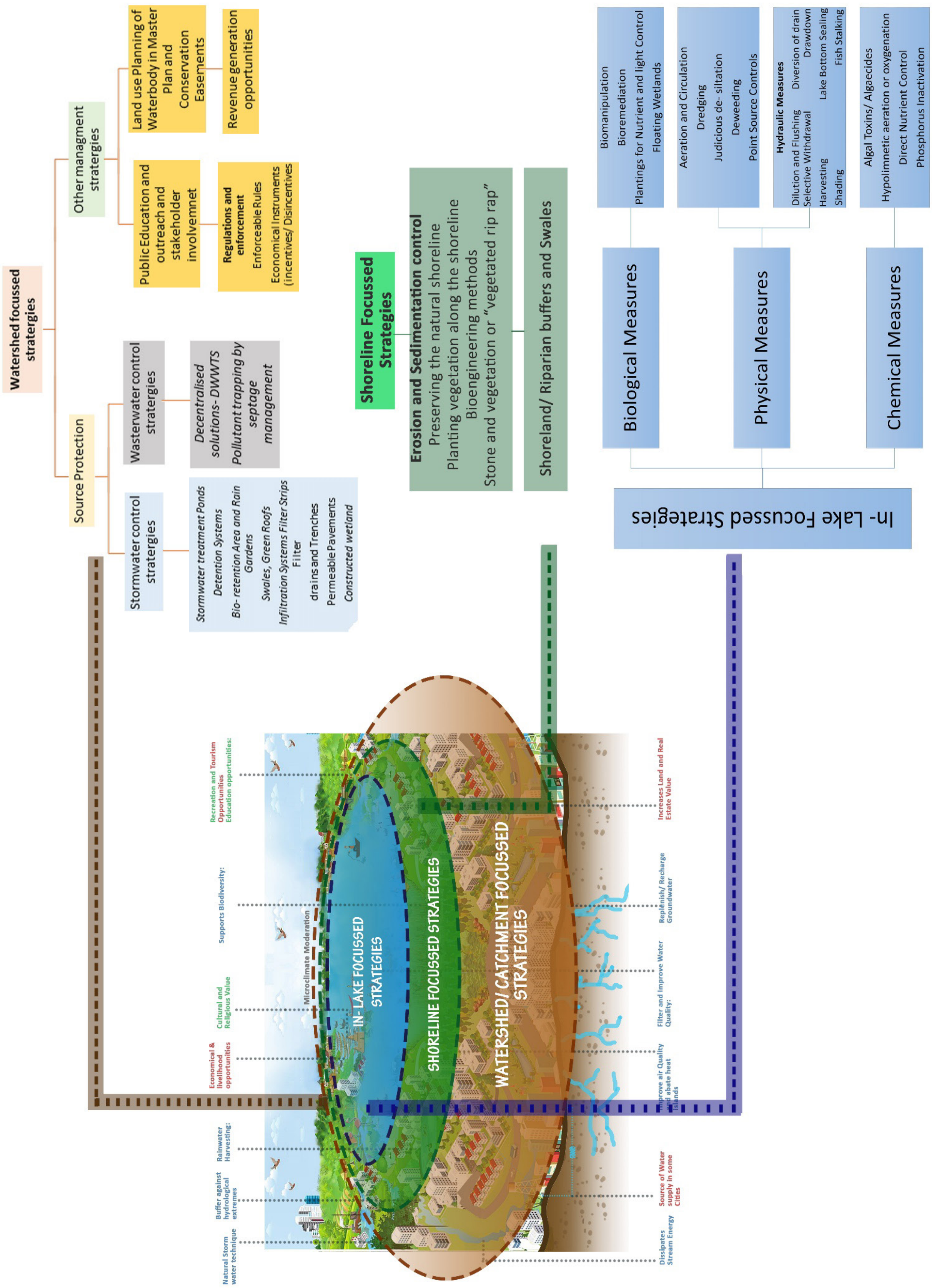
Sources: Compiled by CSE. (2023). (CSE Urban Lake Management Practitioner's guide, Ramachandra, T. V., Va, S., & Asulabha, K. S. (2020). Efficacy of rejuvenation of lakes in Bengaluru, India. Green Chemistry & Technology Letters, 6(1), 14-26.)

Figure 1: Hierarchy of steps for model framework for urban lake management plan



Source: CSE, 2022

Figure 2: Menu of strategies for urban lake management plan



Source: CSE, 2022

Design considerations for decentralized wastewater treatment system (DWWTs)

Wastewater management isn't only restricted to technical solutions, it also includes other aspects such as environmental engineering, legislative, public awareness, socioeconomic and administrative considerations. A treatment system itself requires some efforts and get affected by various factors at different stages from planning to implementation to operations. These aspects decide and enable the performance and sustainability of a treatment system throughout its design period. A decentralized system could be seen as an easy to implement and affordable solution but its long run performance depends on few techno-managerial factors which are given below:

Planning/designing	Technology (treatment performance)	Financing (cost optimization)	O&M
▪ Short/long term needs and objective should be clear, a pre-feasibility study is required for proper planning of DWWTs. ▪ Site selection should be done as per attached matrix. ▪ DWWTs could be implemented in the setback areas, backyard, the primary and secondary modules can be underground. Keeping in mind the placement it should not hamper the landscape and aesthetics. The top of the primary and secondary modules can be reused as parking spaces, pathways, children's park area etc. ▪ Sizing of the system should be fixed as per designed inflow capacity, under designed/over designed system could hamper the performance and efficiency of the system. ▪ Design period of decentralized systems should not be same as centralized systems as it will lead to overdesign and system will fail to perform as required. System could be designed with considering some buffer capacity (10-20%) or a floating population of 5-10% (based on the type of land use). ▪ Inlet level of primary unit (settler) of DWWTs should be fixed with respect to invert level of outlet of simplified sewer. ▪ In case of land constraints or in densely populated area secondary-tertiary unit (PGF and polishing pond) could be replaced by Vortex and ACF/SCF.	▪ Adopt nature based treatment options as much as possible as mechanized systems require energy and skilled workers. ▪ Town typology and climate and weather should not be neglected. Variations in climate may impact bacterial and plant growth. ▪ Technology should be able to handle inflow wastewater characteristics and its efficiency should meet required output parameters (BOD, COD, TSS, TN, FC etc.). ▪ While designing different modules of DWWTs, total volume and effective volume should be kept in mind else the chambers will be over designed or under designed. ▪ Nature based systems can perform better for intermittent/irregular flow or where seasonal variations are high (like schools, colleges etc). ▪ Increasing no. of chambers in ABR up to a certain extent gives a very less increase in the efficiency. ▪ Sizes of PGF should be fixed in such a way that length is always more because travel distance through filter media is directly proportional to the treatment efficiency. ▪ Distribution chamber should always be provided at the inlet of PGF to ensure water is flowing throughout the width. ▪ Settler should be of two or three chambers and the depth should not exceed 2.0 metres. ▪ ABR depth should not exceed 1.5 m. ▪ PGF depth should not be more than 0.6 m to avoid anoxic zone formation in subsurface water flow. ▪ Upflow velocity to be maintained in the range of 0.9-1.5 m/hr. ▪ Retention time for settler, ABR, PGF and polishing pond should be two to three hours, 24 hours, 24–48 hours and 48 hours respectively. ▪ Vent pipes and free board should not be missed in any module to maintain ease of flow of gases. ▪ Black water could be treated together with the grey water after it passes through the biological treatment (ABR system). ▪ Grey water alone doesn't require anaerobic digestion, it could directly be treated in constructed wetlands kind of system after passing through sedimentation process.	▪ Nature based technology might require huge capital expenditure but operational and maintenance costs would not be so high as mechanized and packaged treatment systems. If we do the life cycle costing, the nature based systems will be cheaper compared to the electromechanical. ▪ Existing septic tank (if any) in the premises could be retrofitted into a settler to minimize the cost of construction. ▪ The land selection should be done in such a way that it should have a natural normal gradient so that the pumping can be avoided. If the land is highly undulated, the construction cost might increase and the O&M cost could also go up. ▪ If the capacity of the treatment plant is beyond 10 KLD then per KLD cost of implementing DWWTs comes around Rs 50,000–60,000. The more the capacity, the less the per KLD cost for construction.	▪ Regular removal of dead leaves and litter from PGF bed - To avoid clogging and formation of algae in filter media and to maximize efficiency. ▪ Overgrowth of plants could restrict the flow of oxygen and ultraviolet rays of the sun to enter the gravel filter. ▪ Minimum water level to be maintained in PGF to avoid mosquito breeding, foul smell and death of plants. ▪ During heavy rains, PGF outlet to be fixed at 0 degree to discharge overflow. ▪ Excess sludge to be removed from settler and ABR otherwise system will get choked and efficiency will be decreased. ▪ Plumbing fixtures to be checked to avoid any kind of leakages. ▪ The electromechanical equipment if any to be properly operated and maintained as per the manufacturer's specification

Matrix for site selecion

S. no.	Parameters	Maximum score	Scoring for DWWTs site
1	Ownership of land	10	▪ ULB-owned land: 10 ▪ State government land: 8 ▪ Private land: 4 ▪ Under dispute: 0
2	Availability of land	10	▪ Immediately available: 10 ▪ Available in one to three months:- 6 points ▪ Available in more than three months: 3
3	Distance from residential area/habitat (site of waste generation)	10	▪ Within 100–500 m: 10 ▪ Within 500 m–1 km : 7 ▪ > 1–5 km ▪ 1–3 km: 3 ▪ 3–5 km: 2 ▪ > 5 km 0
4	Approach road	5	▪ No approach road: 0 ▪ Narrow road: 2 ▪ Wide road: 5
5	Visibility and impact	15	▪ At prominent location and has viable reuse options: 15 At prominent location but not having viable reuse options: 10 Not a prominent location but having viable reuse possibilities: 5 Good location with reasonable impacts: 3 No impacts/no visibility: 0
6	Operations, maintenance and monitoring responsibility by any organization	15	▪ Direct under control of BNPP: 15 Partial control/stakeholder: 10 No control of BNPP: 5
7	Disposal of treated effluent under gravity or through pumping, Channelization of wastewater through gravity or pumping	5	▪ Under gravity: 5 Partial under gravity and pumping - 3; Entire pumping - 0
8	Social acceptability. Is there any chance of problem for society?	10	▪ No probability: 10 Issues may arise but their involvement can address the issue: 5 Likely chances of dispute: 0
9	Probability of flood in the area	10	▪ No history of flood: 10 No flood in recent years: 7 Occasionally flood: 5 Floodplain or flood-prone plain: 0
10	Is any waterbody adjacent to the site?	10	▪ Waterbody within 200 m: 3 100–200 m: 4 500 m–1 km: 10

Design considerations for co-treatment of septage at sewage treatment plants

Co-treatment is a process where a sewage treatment plant (STP), in addition to treating the domestic sewage transported through a sewerage city, also treats FSS emptied from various on-site sanitation systems in the city. Co-treatment is essential to achieve the goal of citywide sanitation. Since the treatment objectives for safe management of sewage are similar to those for handling faecal sludge and septage, adopting co-treatment in existing sewage treatment plants with idle capacity is a very crucial solution in our cities with non-sewered sanitation system. Co-treatment of septage in a sewage treatment plant includes several design considerations which are very crucial for planning/ designing, treatment performance, cost optimization and it's sustainability in a long run. The section below highlights a few points under each category for design considerations for co-treatment of septage at sewage treatment plants.

Planning/designing	Technology (treatment performance)	Financing (cost optimization)	O&M
• Short-, medium- and long-term aim and objectives should be defined for a city by preparing a city sanitation plan which will help the authorities to finalize the sanitation infrastructure for the city keeping in view the different approaches of septage management for various parts of the city depending upon the size of the city, sewerage profile and coverage of the city, sanitation infrastructure available in the formal and informal settlements - core and outskirts of the city. City extension or growth should also be considered in this plan. • Financial arrangements for capital investment and O&M of co-treatment plant. • Enabling policy and governance environment for seamless running and sustaining the co-treatment infrastructure. • Assess the existing status of sanitation system in selected town by using service level benchmarking data from ULBs or sanitation profile of cities from SMCG or any other data source. • Identify STP for co-treatment: Mapping the sewage treatment plants in the city and their location. • Gather the information about sewerage infrastructure, household connections to sewerage network. • Assess the quantity of the faecal sludge and septage generated in the city by using any of the two available method. » Sludge generation method » Sludge collection method • Cross check/ validate the data with on ground survey of the desludgers or vacuum tanker emptiers by using the numbers of tankers, capacity, number of trips, working days in a month etc. • Assessment of the quality of sludge to be treated. Quality of sludge to be treated in a co-treatment facility varies at places. Therefore a representative number of samples should be collected from various places of the city by incorporating standard operating procedure of sampling and to be analysed using standard analytical process to find out the values of total solids and organic parameters of the septage.	• Based on the analysis, Direct addition or solid liquid separation of the septage is required • Depending on the approach chosen, the co-treatment infrastructure required at the STP can vary. • Find out the road connectivity with a 5 m wide road for tankers to carry faecal sludge to dispose at STP with easy turnaround and parking facility. • For direct addition method no elaborate treatment of faecal sludge is required. A screening chamber to remove the trash and a equalization or feeding tank with a flow control valve/pump arrangement to ensure that the resultant concentrations of the inflow of septage and sewage into the STP do not exceed the design loading capacity. To handle the excess sludge generated, the STP must have excess capacity for handling the sludge. • For solid-liquid separation, screen chamber followed by solid- liquid separation unit. Technology selection for the solid liquid separation depends upon the volume of septage, desired total solids increase in the solid stream, funds availability, and minimum human contact and O&M requirements. • The supernatant (liquid fraction) from the solid-liquid separation is diverted to the headworks of the STP where it is treated along with sewage inflows. The separated solids are sent for further processing at the solid management facility in the STP.	• The existing facilities at STP, site infrastructure and manpower of the STP can be used for co-treatment and thus can eliminate the problem of engaging a new O&M operator and additional cost related to site infrastructure. • Calculation based inference about direct addition or solid-liquid separation is necessary as if the STP has the capacity to take the load for the direct addition of septage than putting in extra infrastructure for solid- liquid separation will un-necessarily increase the financial load. • In bigger cities, where more than one STP fits for accepting the septage load, should be considered for co-treatment to cater the septage loads from various parts of the city. Distance of STP for co-treatment is important for the economic feasibility.	• Funding provisions for O&M • Staff training for proper O&M of the co-treatment modules. • Agreement between ULB or STP operating agency to undertake the operations and maintenance of additional units for co-treatment through a proper agreement. • Truck arrival and disposal at the STP shall be decide keeping in view the minimum flow at the STPs. • Record of collection, transportation and disposal of faecal sludge to be maintained to avoid the industrial mixing up with the household septage. • Regular cleaning of screen chamber and grit chamber • Regular cleaning of the faecal sludge receiving area • In case of spillage, immediate cleaning and spraying of bleaching powder • Removal of settled sludge from the holding tank (once in a month) • Regulated additional of sludge from holding tank into STP, by regulating the flow through pump/valve • Regular preventive maintenance of pumps, valves and agitation equipment • Periodic removal of scum, accumulated sludge from the bottom through gravity/pumping • Feeding of sludge from holding tank, additional of coagulants and preventive maintenance of equipment

• Access the status of the sewage treatment plants: Primary survey for the actual assessment of the sewage treatment plants should be carried out to ascertain the operational/ non-operational status of the plant. Primary surveys and targeted interviews should be conducted according to the detailed checklist to collect the information regarding the capacity, utilization, designed parameters, compliance with the CPCB norms, functionality etc. Further site visits, need based assessment, interviews with locals, meetings (telephonic/via zoom/ physical) with concern authorities/departments such as Jal Nigam, ULB's officials, district development authorities and field observation should also be recorded. • The data collected for sewerage connections and septage generation will be helpful to decide the septage treatment capacity required in the city and the data collected about the sewage treatment plants will be helpful to understand the gap loading, space, economics for treating the septage in the STP. • Determine the co-treatment capacity- pre-feasibility study for co-treatment of faecal sludge should be done to find out more details of the sewage treatment plant and its co-treatment potential by using STP designed and current capacity utilization in terms of hydraulics and organic load, designed properties, gap assessment. • Space availability at the sewage treatment plant for the addition of extra units for co-treatment.	• Co-treatment unit must be commissioned only after ascertaining a few checks such as the staff required to manage and operate the co-treatment infrastructure, readiness of operations manual, training of the operators, hydraulic testing of all new modules and equipment.		

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