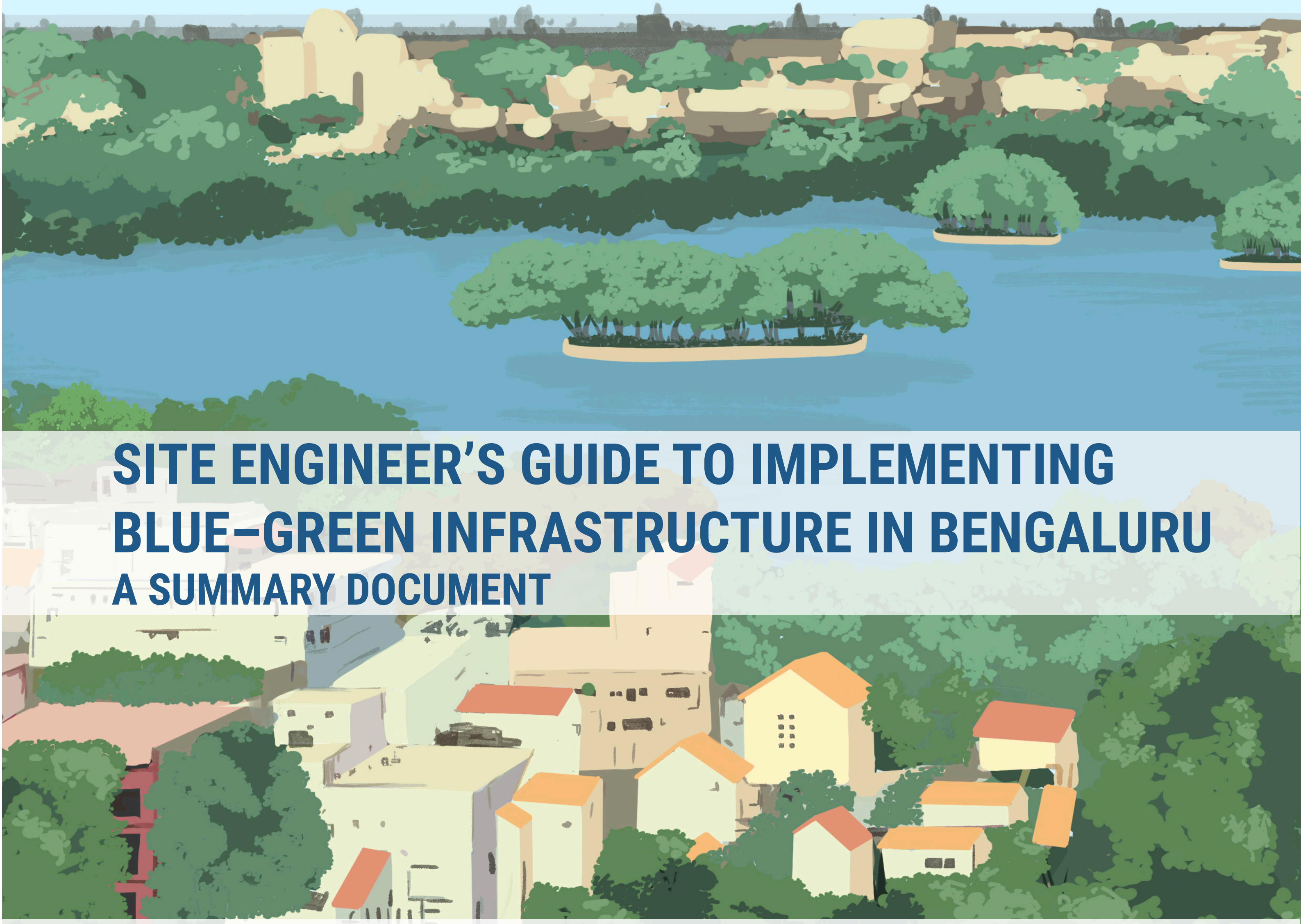

SITE ENGINEER'S GUIDE TO IMPLEMENTING BLUE–GREEN INFRASTRUCTURE IN BENGALURU

A SUMMARY DOCUMENT

Supported By:

ATREE | BIOME ENVIRONMENTAL TRUST | MOD FOUNDATION | WELL LABS | WRI INDIA

Acknowledgements

The Bengaluru Climate Action Cell acknowledges the contributions of our knowledge partners—ATREE, Biome Environmental Trust, WELL Labs, MOD Foundation and WRI India—in advancing the Blue-Green Infrastructure Network (BGIN) initiative. Their deep expertise in ecology, urban water systems and community engagement has been instrumental in shaping this document. Additionally, we extend our sincere gratitude to the local communities and civic officials whose participation has benefitted Bengaluru.

This summary document is intended to guide on-ground implementation through unified metrics, simplified illustrations and climate-resilient practices. It reflects our shared vision for a more resilient, inclusive and sustainable urban future.

Image Credits: Sanketh Shah

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Image Credits: Mahadev Ittina

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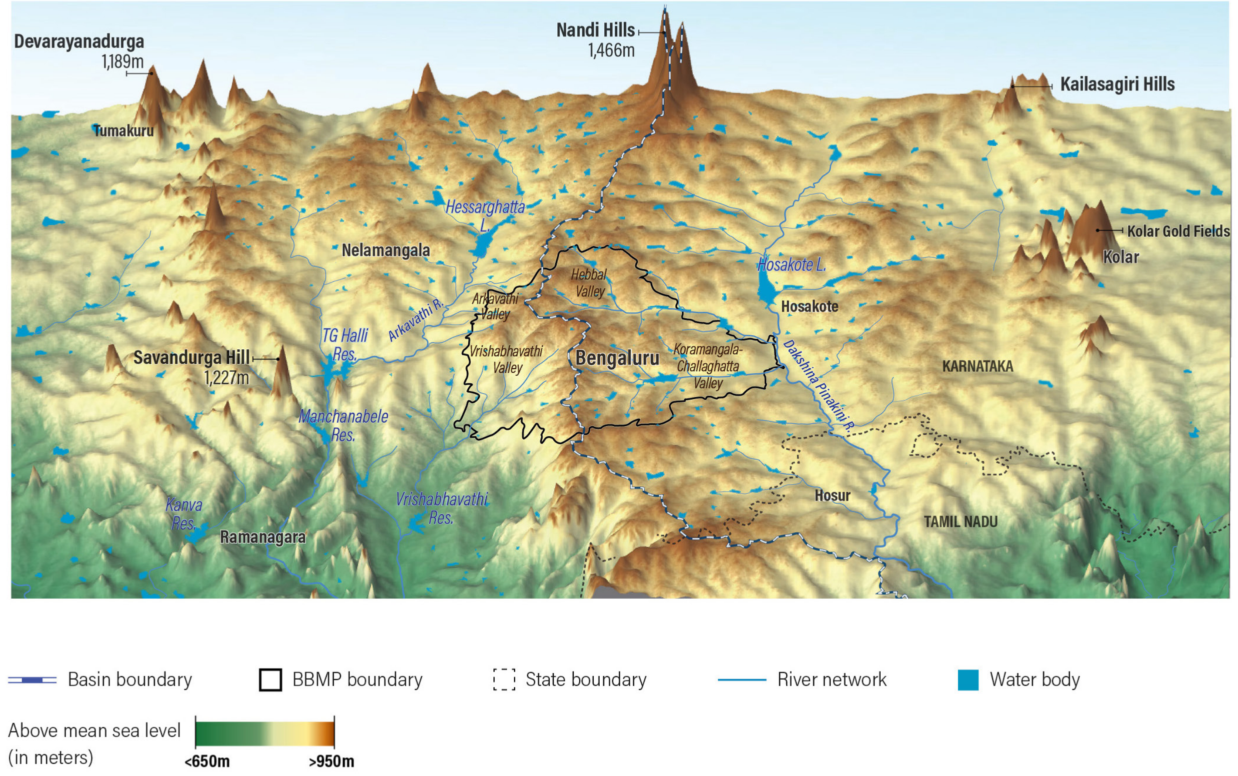
This is a short summary of the upcoming *'Site Engineer's Guide to Implementing Blue-Green Infrastructure in Bengaluru'*, 2025 and must not be construed as the full report.

All maps in this report are intended as visualisations to communicate city-wide data analysis and are not to scale.

1.0 Introduction to Bengaluru: Hydrogeological context



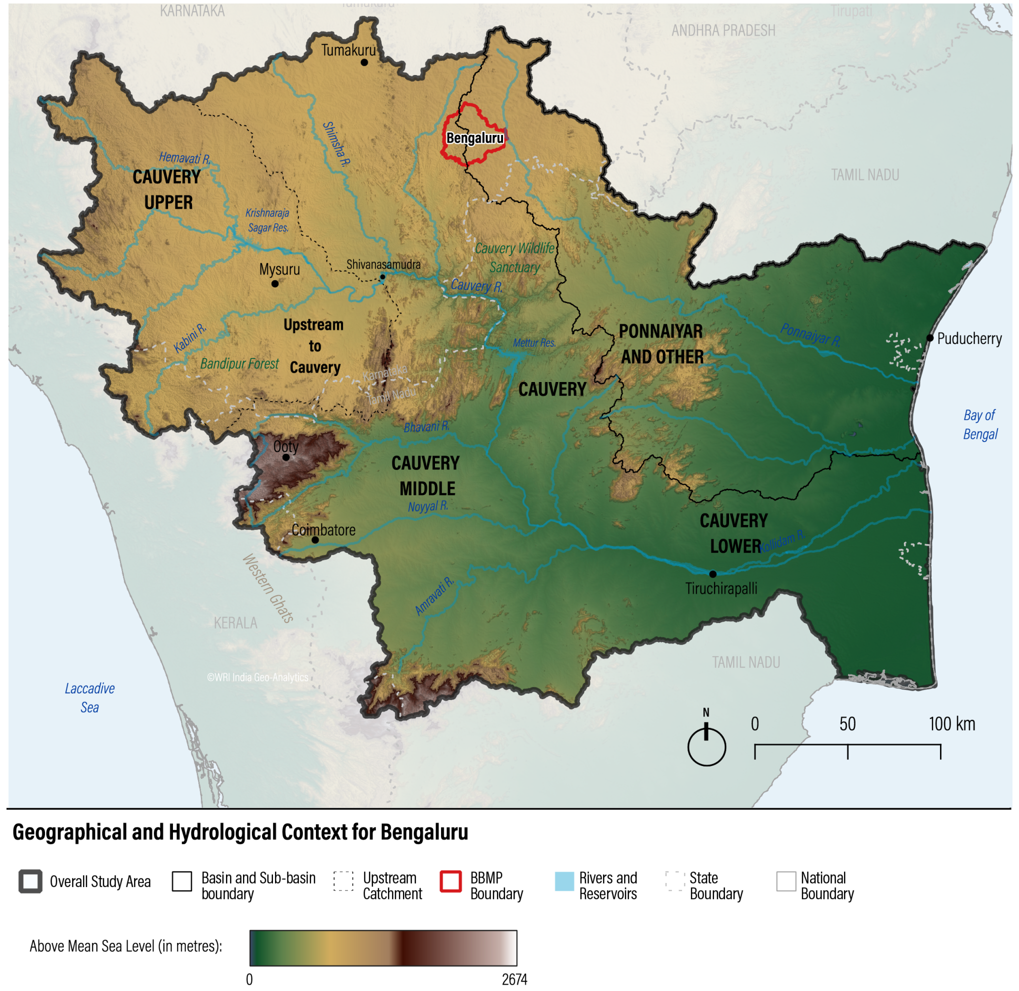
Source: Prepared for the Bengaluru Climate Action Plan. Exaggerated relief derived using Shuttle Radar Topography Mission (SRTM).

Figure 1: River valley system of Bengaluru and the adjoining region. Credits: Bengaluru Climate Action and Resilience Plan (BCAP), 2023.

Bengaluru is located in the heart of the Mysore Plateau at an elevation of 920 m above mean sea level. The city's topography can be classified as a plateau, with a central ridge spanning north to south and land sloping gently on either side. The roads have gentle to medium gradients. Bengaluru has several freshwater tanks, the largest of which are the Bellandur Lake, Varthur Lake, Nagawara Lake, Madivala tank, Hebbal Lake, Ulsoor Lake, and Sankey tank (Mundoli, Nagendra, and Premji 2018). Tanks or water bodies in the city are designed in a cascading system, from higher to lower levels; thus, they constitute a large network of drainage channels. The idea is that if one lake overflows, the excess water will flow to the subsequent lake. The naturally undulating terrain of the city facilitates the operation of this system.

The flow of water is from north to south–east as well as from north to south–west, along the natural gradient of the land (BIOME 2017).The soil is predominantly red and interspersed with rock, which facilitates quicker drainage.

The city falls within the Cauvery-Ponnaiyar River Basin, which provides a broader natural geographical context for the city. This, along with the city's elevation, determines its topography, climate and natural resources, thus rendering it a critical component in understanding the city's climatic variations.



Source: WRI India 2021, SRTM, CWC

Figure 2: Geographical and hydrological context of Bengaluru within Cauvery-Ponnaiyar Basin region. Credits: Bengaluru Climate Action and Resilience Plan (BCAP), 2023.

1.1 Urban Expansion and Environmental Risk: Profile of Bengaluru's Challenges

As one of India's fastest-growing cities, Bengaluru is confronted by significant challenges related to water management, green cover loss and ecosystem degradation. Over the past three decades, the city have experienced an increase of 170% in built-up areas, thus resluting in the depletion of water bodies and a decrease in green spaces. These developments have caused an increase in surface runoff, frequent urban flooding, the emergence of heat islands and declining biodiversity.

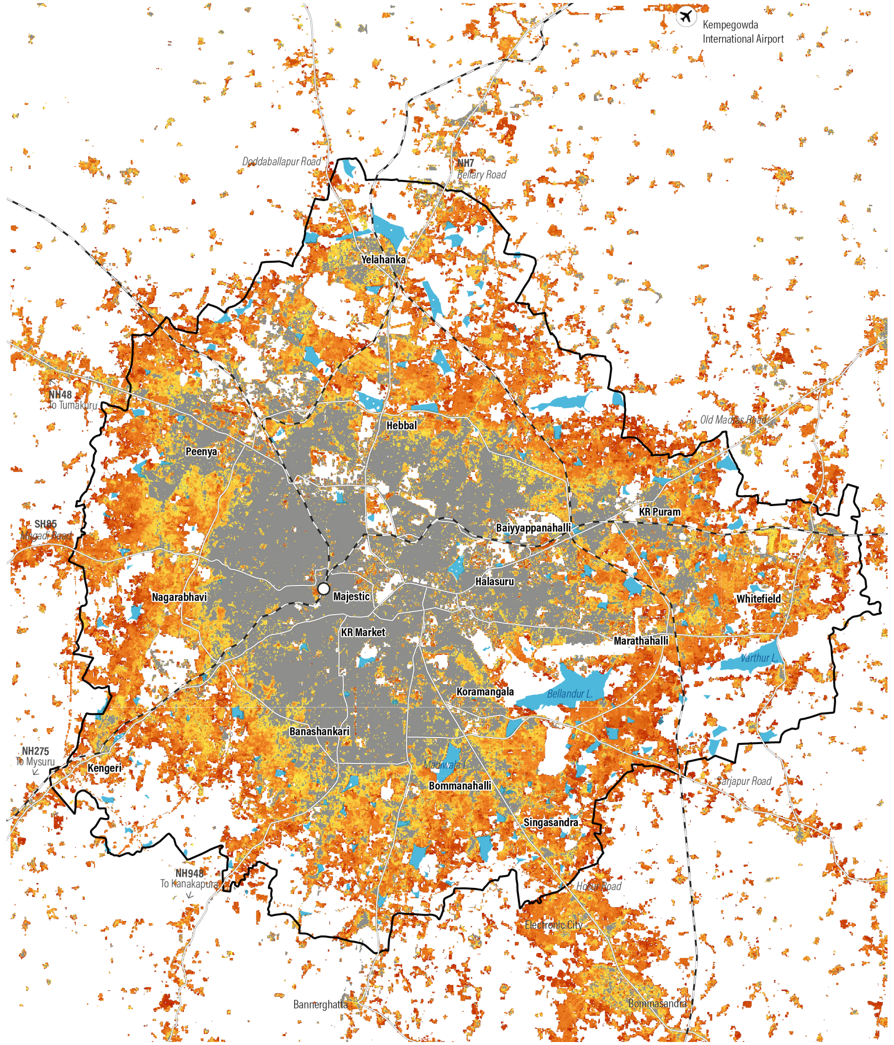


Figure 3: Built footprint evolution across Bengaluru (between 1985 and 2019). Credits: Bengaluru Climate Action and Resilience Plan (BCAP), 2023.

According to the Bengaluru Climate Action Plan (BCAP) report, the city's rapid and often unregulated urban expansion has resulted in serious environmental and infrastructural issues that demand urgent on-ground action. Approximately 84% of the Cauvery–Ponnaiyar basin area is categorised under the **'very high risk'** category for drought and more than 50% of the Bangalore Metropolitan Region Development Authority (BMRDA) region including Bengaluru is classified as **'over–exploited'** in terms of groundwater extraction. With 63% of the city already developed or concreted, opportunities for **natural groundwater recharges** are **severely limited**. The situation is compounded by 85% of the city's floodplains being built upon, contributing to 1,167 reported flood events between 2013 and 2020 and the identification of 372 flood vulnerable areas.

Additonally, **heat-related risks** are increasing, with Bengaluru now experiencing an average of 60 **extreme heatwave days** annually and a decade-wise temperature increase of 0.5°C. These overlapping risks highlight the urgent necessity for coordinated implementation of **Blue-Green Infrastructure**, **nature-based solutions,** and **long-term climate resilience strategies** across departments and stakeholders.

Image credits: Umar Andrabi

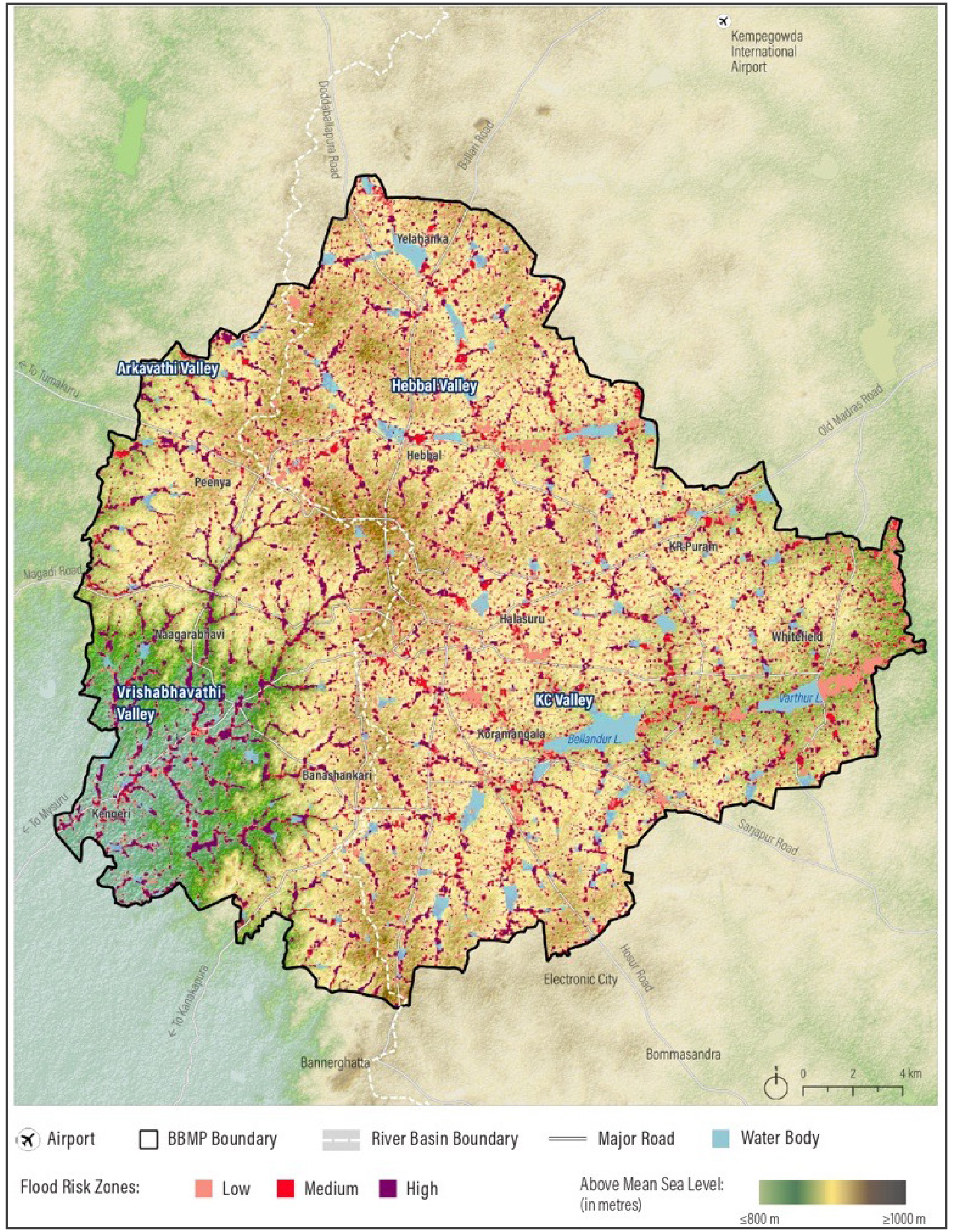


Figure 4: Map showing flood-vulnerable zones within BBMP boundaries. Credits: Bengaluru Climate Action and Resilience Plan (BCAP), 2023.

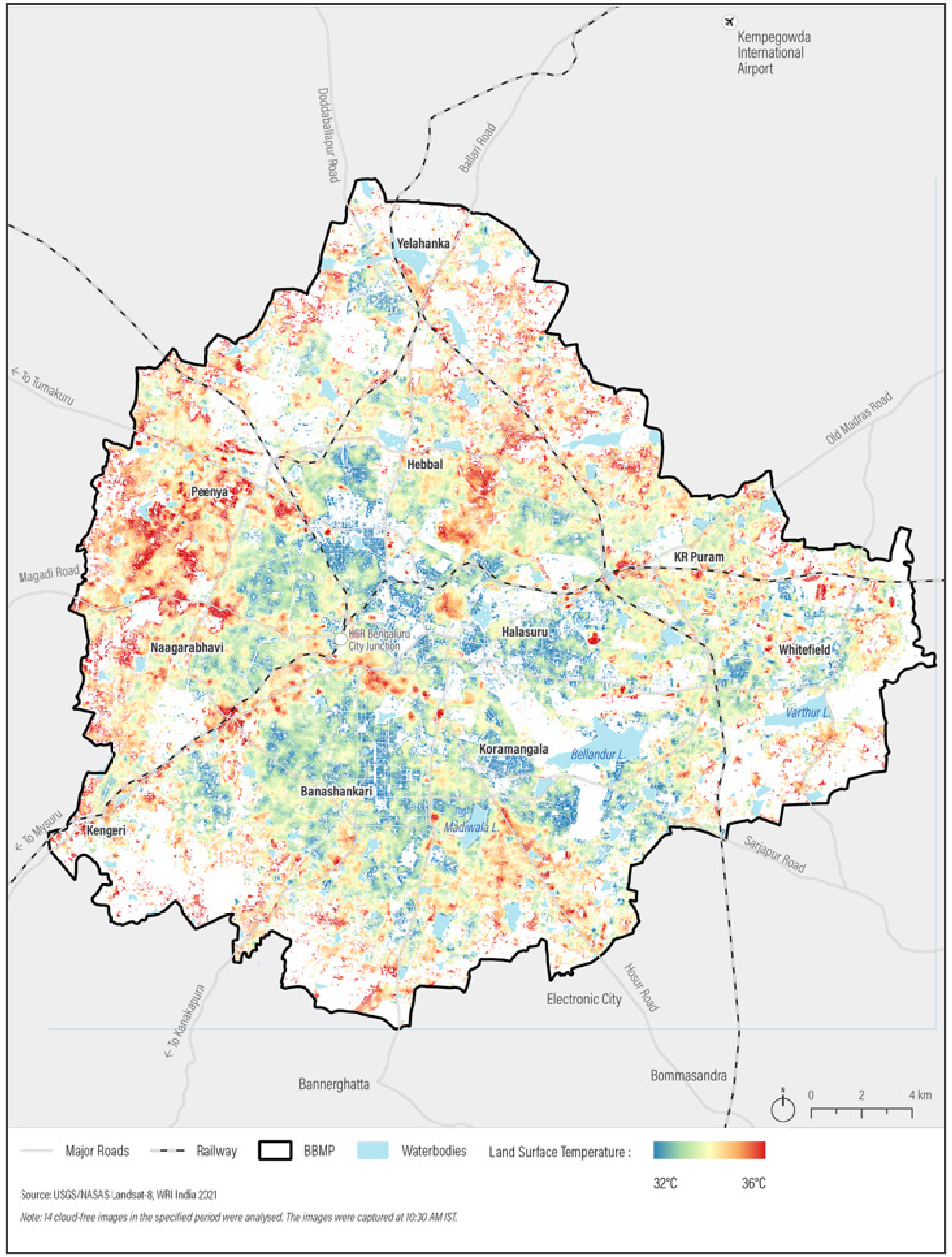


Figure 5: Average land surface temperature over built areas of the city (summer months from 2017 to 2021). Credits: Bengaluru Climate Action and Resilience Plan (BCAP), 2023.

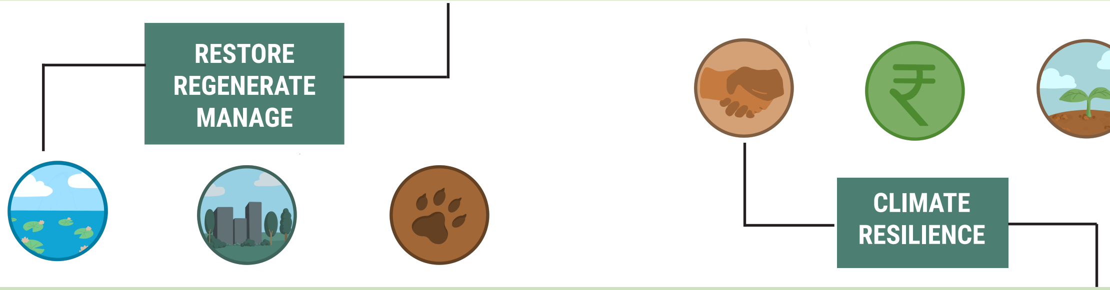
1.2 Key Questions for Building Urban Climate Resilience

Considering the scale and urgency of climate risks confronted by Bengaluru, from drought and groundwater depletion to flooding, heatwaves, and loss of ecological buffers, efforts by implementation agencies must extend beyond siloed interventions to pursue integrated, systems-based responses. As climate variability intersects with rapid urbanisation and infrastructure stress, the necessity to restore and manage urban ecosystems such as lakes, stormwater drains, green spaces, and biodiversity corridors is increasing for building long-term resilience. Thus, a critical reflection on the following key questions is warranted:

How can **urban ecosystems** such as water bodies, urban green spaces, and biodiversity be **restored, regenerated** and **managed** to **strengthen resilience** against **climate variability** and **urban shocks**?

What **approaches enable** the **ecological restoration** of lakes, stormwater drains, parks, and open spaces?

What **models** (nature-based solutions, ecosystem-based adaptation) are **best suited** for Bengaluru's climatic and urban contexts?



What **mechanisms** and **criteria** are required to prioritise, design, implement, and maintain **climate-resilient interventions** across different **spatial scales** —from site-specific actions to neighborhood networks to city-wide strategies?

What are the **current gaps** and **challenges** confronted by **implementors**?

How can **microlevel practices** on the ground be connected to city-wide knowledge systems using **data, metrics** and **scalable frameworks**?

How can Bengaluru build **climate resilience** to simultaneously **safeguard** the health, well-being, and livelihoods of its people while restoring and sustaining the city's ecosystems as foundational infrastructure for the **long-term social, economic,** and **environmental stability** of human and non-human lives?

2.0 Introduction to Blue-Green and Grey Infrastructure Network (BGIN)

The **Blue-Green and Grey Infrastructure Network (BGIN)** refers to an interconnected system of natural and semi-natural spaces, such as wetlands, lakes, parks, stormwater drains, urban forests, and green corridors, that work together to provide ecological, social, and infrastructural benefits within cities. According to Benedict and McMahon (2006), BGI is a 'natural life-support system' that sustains air and water resources, maintains biodiversity and contributes to the well-being of communities. Similarly, the European Commission frames BGI as a tool for improving environmental conditions while supporting public health, economic opportunity and climate adaptation. Rather than being limited to ecological concerns, the BGIN is inherently interdisciplinary, blending urban design with hydrology, ecology and social development.

The BGIN complements existing grey infrastructure such as roads, drains, and buildings.

Drawing from global frameworks, blue-green infrastructure (BGI) is increasingly recognised as a nature-based solution that restores hydrological functions, supports biodiversity, and enhances urban resilience to climate shocks like floods, heatwaves, and water scarcity. Unlike traditional grey infrastructure, which rely on concrete-based solutions such as pipes, culverts, and dams, BGIN emphasises the integration of blue-green elements into existing and planned grey systems. This embeddedness allows natural systems to complement the built infrastructure and delivers co-benefits, such as groundwater recharge, urban cooling, recreational spaces and improved quality of life.

Figure 6: Blue-Green and Grey Infrastructures. Image credits: WELL Labs.

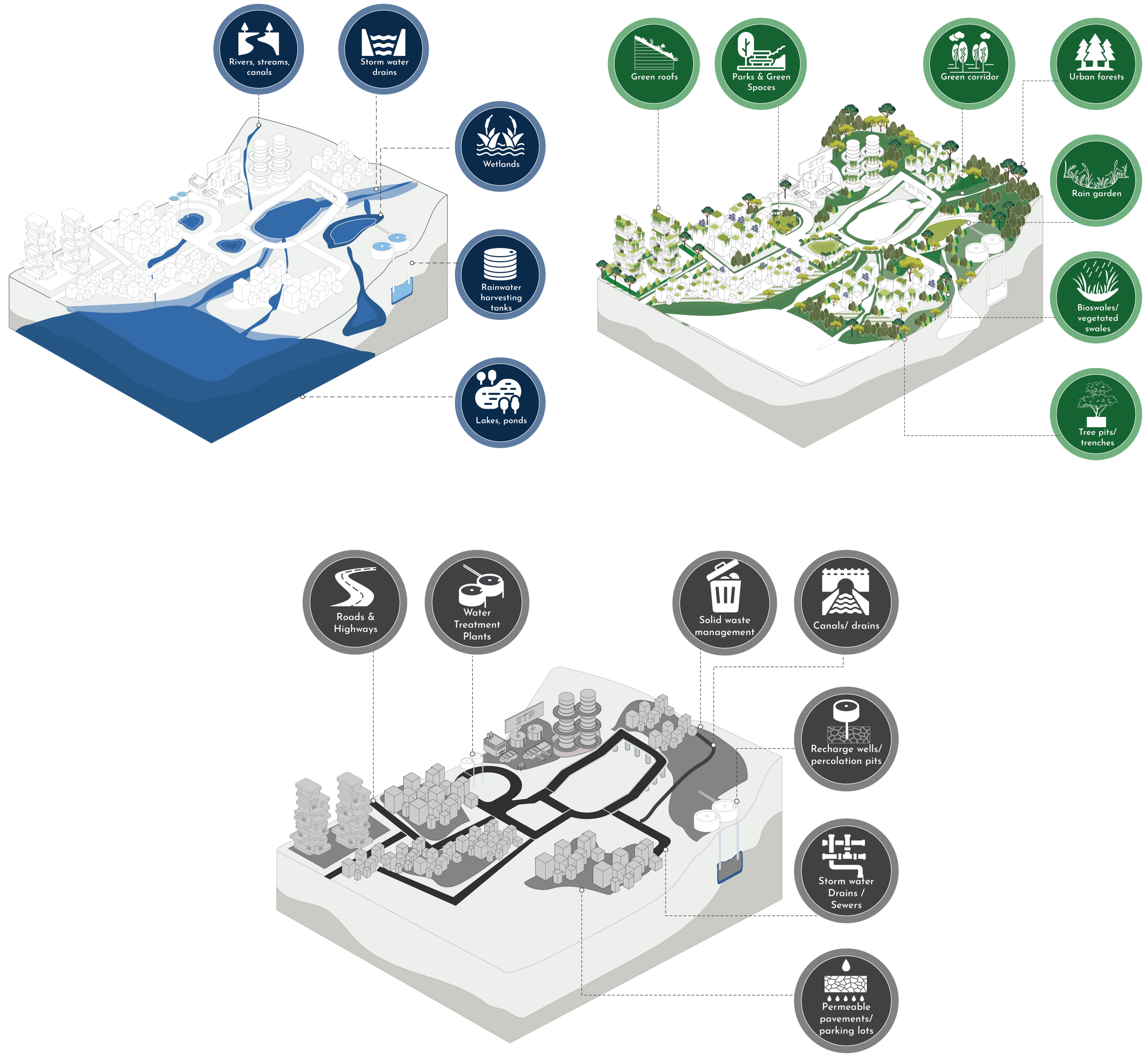


Figure 7: Blue, green and grey infrastructures in isolated layers. Image credits: WELL Labs.

2.1 Relevance of BGIN to Bengaluru

Bengaluru's urban challenges, ranging from water scarcity and extreme heat to flooding and biodiversity loss, are not abstract environmental issues; they directly affect the health, livelihoods, and well-being of the residents. However, these effects are not experienced equally. Certain groups, owing to factors like socioeconomic status, occupation, age, or gender, are more vulnerable to severe consequences. Informal gig workers, who typically work outdoors, face heightened exposure to heat stress, whereas lower-income communities in informal settlements may lack the appropriate infrastructure to cope with floods or access to clean water. Vulnerable populations such as children, the elderly and those with pre-existing health conditions are at a greater risk as well. Integrating blue–green infrastructure into the city's grey systems is vital as it transforms natural assets into practical urban solutions, thereby enhancing public health, social well-being and economic productivity. When lakes facilitate flood management, tree cover alleviates heat stress, while interconnected green spaces foster biodiversity and provide recreational opportunities; thus, the city becomes more liveable and resilient. This approach renders resilience tangible and ensures that children can walk to school safely after heavy rain, informal gig workers can perform their duties without facing heat-related illnesses, and communities have access to clean water and fresh air. By recognising blue–green systems as the core of urban resilience, we expand beyond technical solutions to a human-centered approach that addresses Bengaluru's challenges in both ecological and economic terms, while also recognising the varying vulnerabilities within the city's population and ensuring equity.

2.2 Elements of BGIN and its Function

Type of BGI	Implementation Scale	Benefits and Functions	Form
Formal green belts	City	Habitat creation Climate mitigation Sustainable species movement Outdoor recreation Buffer between built zones	Corridors
Forest and tree parks	City and neighbhourhood	Biodiversity Habitat creation Climate mitigation Economic development Well-being	Site

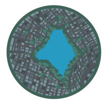
Green cycle routes	City and neighbourhood	Sustainable transport Biodiversity hotspots	Corridor Network
Infrastructure greening	City and neighbourhood	Flood mitigation Habitat creation Heat mitigation Human well-being	Network Site
Storm water drainage	City and neighbourhood	Flood mitigation Communal well-being Health and hygiene	Corridor Network
River corridors and river fronts	City and neighbourhood	Sustainable transport Biodiversity Habitat creation Climate mitigation Social interaction and play Economic development Well-being	Corridor Network
Urban parks	City and neighbourhood	Biodiversity Habitat creation Climate mitigation Microclimate moderation Social interaction and play Economic development Well-being	Site
Public gardens	City and neighbourhood	Biodiversity Habitat creation Climate mitigation Microclimate moderation Rainfall interception Social interaction and play Economic development	Site
Urban woodland	City, neighbourhood and site	Biodiversity Habitat creation Climate mitigation Social interaction and play Economic development Well-being	Site
Lakes and ponds	City and neighbourhood	Biodiversity Habitat creation Ground water recharge Flood mitigation Climate mitigation Social interaction and play Economic development Well-being	Site
Play areas	Neighbourhood and site	Social interaction and play Personal and communal well-being	Site

Avenue trees	Neighbourhood and site	Biodiversity Habitat creation Climate mitigation Microclimate moderation Rainfall interception Social interaction	Corridor
Pocket parks	Neighbourhood and site	Biodiversity Habitat creation Climate mitigation Microclimate moderation Social interaction and play Well-being	Site
Green walls and green roofs	Site	Habitat creation Climate mitigation Flood mitigation Urban cooling Reduced energy costs	Site
Recharge well and open wells	Site	Groundwater recharge Flood mitigation Water security	Site

Table 1: Elements of blue-green infrastructure and their functions.

2.3 Current Challenges in Implementing BGIN

The implementation of blue–green infrastructure (BGI) presents several challenges that must be addressed to ensure successful and sustainable outcomes:



Overcrowded Interventions in Limited Spaces
Overloading small areas with multiple blue and green elements can reduce the effectiveness and long-term sustainability of the interventions.

Inconsistent Metrics Across Sites
Varying assessment criteria complicate impact measurement and best practice standardisation across different locations.

Unsatisfactory Site Selection
A lack of data-driven site scoping results in its implementation in unsuitable locations, thereby hampering the success of BGI efforts.

Low Sapling Survival Rates
High mortality rates in young saplings are common because of inadequate post-planting care and fragile plants.

Lack of Holistic Approach
BGI projects are typically managed separately where their role in larger ecological networks is disregarded. For example, recharge wells have been regarded as standalone structures, with minimal focus on their connection to catchments or their combined benefits for flood control and groundwater recharge.

Outdated Procurement Guidelines
The guidelines must be updated to incorporate innovative BGI interventions, such as rain gardens and bioswales, which should be included in future procurement processes.

Capacity Building of Contractors
A shift from business as usual practices to more informed and specialized BGI implementation requires extensive capacity building among contractors to ensure effective execution.

2.4 BGIN Approach in Bengaluru

Our approach to BGINs begins with the understanding that a city is not merely an aggregation of infrastructure or a zone for investment. Instead it is a living, breathing system that features a unique social identity and an ecological metabolism that constantly reshapes itself in response to human and environmental stimuli. It is a network of autonomous yet interconnected units comprising people, communities, enterprises, and ecosystems. Each of these units facilitates the city's response to climate challenges. Building resilience, therefore, must begin at the individual level and scale up to the collective level across plot, neighbourhood, city and landscape levels.

To enable this, the BGIN must support **scale-based interventions** that are deeply rooted in the context of **site-level** actions, such as green roofs, private gardens, recharge wells and sustainable drainage; **neighbourhood-level** efforts such as revitalising parks, lakes or street corridors; and **city-wide** planning that connects ecological zones to protect forests and river corridors and ensures equitable access to green and blue spaces. These interventions should not be performed separately. Instead, they must function as an **aggregated system** supported by **unified and simplified metrics** that implementation agencies can use to guide responses at various levels, from site engineers to city planners. These metrics ensure that interventions are not only effective but also measurable and consistent.

Figure 8: Scale-based context: site, neighbourhood and city levels.

For instance, Figure 9 shows a map of interlinkages in the Gubbalala–Turahalli area. As shown how urban forests, lakes, stormwater drains (rajakaluves) and neighbourhood gardens form an ecological network. Our interventions should consider this systemic view. Climate resilience begins with the question, *'What can I do differently in the way I live, build, and care for the land beneath my home?'* Additionally, climate resilience intesifies when people ask, *'What can we accomplish together at the local park, lake, or school?'* Furthermore, it flourishes when institutions not only enforce regulations but also guide, enable, and inspire the stewardship of shared commons.

In this context, BGIN is not merely a collection of 'blue and green infrastructure projects.' In fact, it has become a civic and ecological movement where forests, gardens, recharge wells and rivers are not isolated entities but constitute a living urban network. Through this consciousness, rooted in family, neighbourhood and public life, we can nurture ecosystems and establish a city that is socially and ecologically resilient. We envision a city where, as we tend our gardens, we can observe the joy of a swallowtail butterfly fluttering by and hear the sweet song of a bulbul perched nearby, thus reminding us of how these seemingly minor actions create a larger, interconnected ecology. Individual gardens, parks and lakes are linked to the city's broader systems connected to the forests of Turahalli and Savandurga, thus creating a thriving, climate-resilient urban ecosystem.

Figure 9: Interconnected blue-green spaces in Gubbalala–Turahalli area.

2.5 Necessity for BGIN SoP

Support Bengaluru's Resilience Agenda

Provide an evidence-based framework to integrate BGINs into urban planning, thus addressing climate risks such as flooding, groundwater depletion, heat islands, and biodiversity loss. Emphasise scientific rigour and tested methods to ensure uniform implementation and replicable outcomes across different urban lake systems that can strengthen city-wide resilience.

Strengthen Governance and Accountability

Define clear roles, responsibilities, and governance structures for BGIN implementation. Include systems for regular ecological monitoring, outcome verification, and adaptive management to enable the long-term transparency, effectiveness and credibility of lake restoration efforts.

Promote Stakeholder Collaboration

Enable inclusive participation of communities, government agencies, non-governmental organisations (NGOs), contractors, and private partners through actionable engagement strategies. Foster shared ownership and build capacity via coordinated training programmes that align diverse actors under a common implementation approach.

Simplify On-Ground Implementation

Translate complex datasets into simple, actionable steps for field teams. Develop user-friendly metrics, toolkits, and standard operating procedures to improve on-ground execution, minimise field-level errors, and accelerate project timelines.

Avoid Maladaptive Practices

Highlight risks and recommend safeguards to prevent ineffective, exclusionary, or ecologically harmful interventions. Promote equitable, climate-responsive, and biodiversity-friendly solutions grounded in context-sensitive scientific understanding and community needs.

Create a Unified Framework

Consolidate fragmented practices and policies into a coherent, city-wide standard operating procedure (SoP) for BGINs. The shared framework will support consistent application, facilitate adaptive learning, and scale up the impact of blue-green infrastructure interventions across Bengaluru.

GREENING

3.0 Urban Greening: Cooling Cities and Connecting Corridors

Scale of intervention

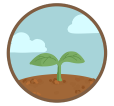
City, neighbourhood and site.

Climate focus

Urban heat mitigation, biodiversity enhancement and flood control.

Human and non-human benefits

Access to shaded public spaces, mental well-being, inclusive and equitable green infrastructure and livelihood and ecosystem services through maintenance and stewardship.



Urban greening typologies

Green roofs, private gardens, tot lots, bioswales, rain gardens, community parks, avenue planting, institutional greening, vertical greening, tree parks, reserved forests, riparian buffers, green corridors, etc.

3.1 Understanding Urban Greening Practices in Bengaluru

Urban greening refers to the integration of vegetation, such as trees, shrubs and groundcover, into urban landscapes to enhance ecological health and improve the quality of life. Despite clear frameworks and guidelines, such as those from the Karnataka Forest Department and the 2025 Bengaluru Urban Forest Manual, urban greening practices typically fail to adopt a comprehensive, scientifically informed approach. This results in isolated tree planting efforts, negligence of smaller spaces and untapped critical opportunities for holistic, adaptive interventions.

3.2 Reimagining the Greening Agenda

Urban greening aims to create a multi-layered, biodiversity-enhancing environment that supports ecosystem services such as stormwater management, urban cooling and improved air quality. By strategically incorporating trees, shrubs and groundcover, urban greening fosters local biodiversity and enhances human well-being through cleaner air, cooler temperatures and more accessible green spaces, while targeting vulnerable hotspots within urban areas to maximise environmental benefits and ensure sustainable urban development.

3.3 Urban Greening as Climate Infrastructure

Urban greening is crucial in mitigating urban climate risks. Enhancing vegetation through trees, shrubs and groundcover facilitates stormwater management, reduces flood risks by increasing soil permeability and reduces surface runoff. It combats heat stress by cooling urban environments, particularly heat islands, where dense built-up areas absorb and retain heat. Furthermore, urban greening fosters biodiversity by connecting fragmented ecosystems, supporting species migration and resilience, and providing habitats in increasingly urbanised areas.

3.4 Greening Targets from the Bengaluru Climate Action Plan (BCAP)

The BCAP outlines the following targets for the city's green infrastructure:

Compact, Mixed-Use, Walkable Neighbourhoods (by 2025): The objective is to create more pedestrian-friendly, well-connected urban areas that reduce dependence on cars, promote sustainable transport, and improve liveability.

Increase Tree Canopy Cover: Aiming for 10% by 2030 and 20% by 2040, this goal seeks to significantly expand Bengaluru's urban forest cover to combat heat islands, improve air quality and promote local biodiversity.

Integrate Climate Resilience into Spatial Plans (by 2030): This goal aims to ensure that climate resilience is embedded into urban planning processes, thus addressing risks such as heat, flooding and ecological degradation.

Expand Green and Permeable Areas (40% of the city by 2040): This target will focus on increasing the city's green spaces and permeable surfaces to improve water absorption, reduce runoff and promote biodiversity.

Implement Nature–Based Solutions (NbS) for Urban Resilience: Solutions such as urban greening, wetland restoration and green roofs, will be prioritised to enhance the city's natural infrastructure and support urban ecosystems.

Increase Public Open Space per Capita: By 2050, Bengaluru aims to increase access to public open spaces from 2.2 to 6 sqm per capita, thus enhancing the quality of life for its residents through accessible parks and recreational areas.

3.5 Key Steps for Implementation

This document outlines the detailed approach for implementing an urban greening project in Bengaluru, with emphasis on site selection, vegetation, implementation protocols and maintenance. Shown below is a summary of key sections:

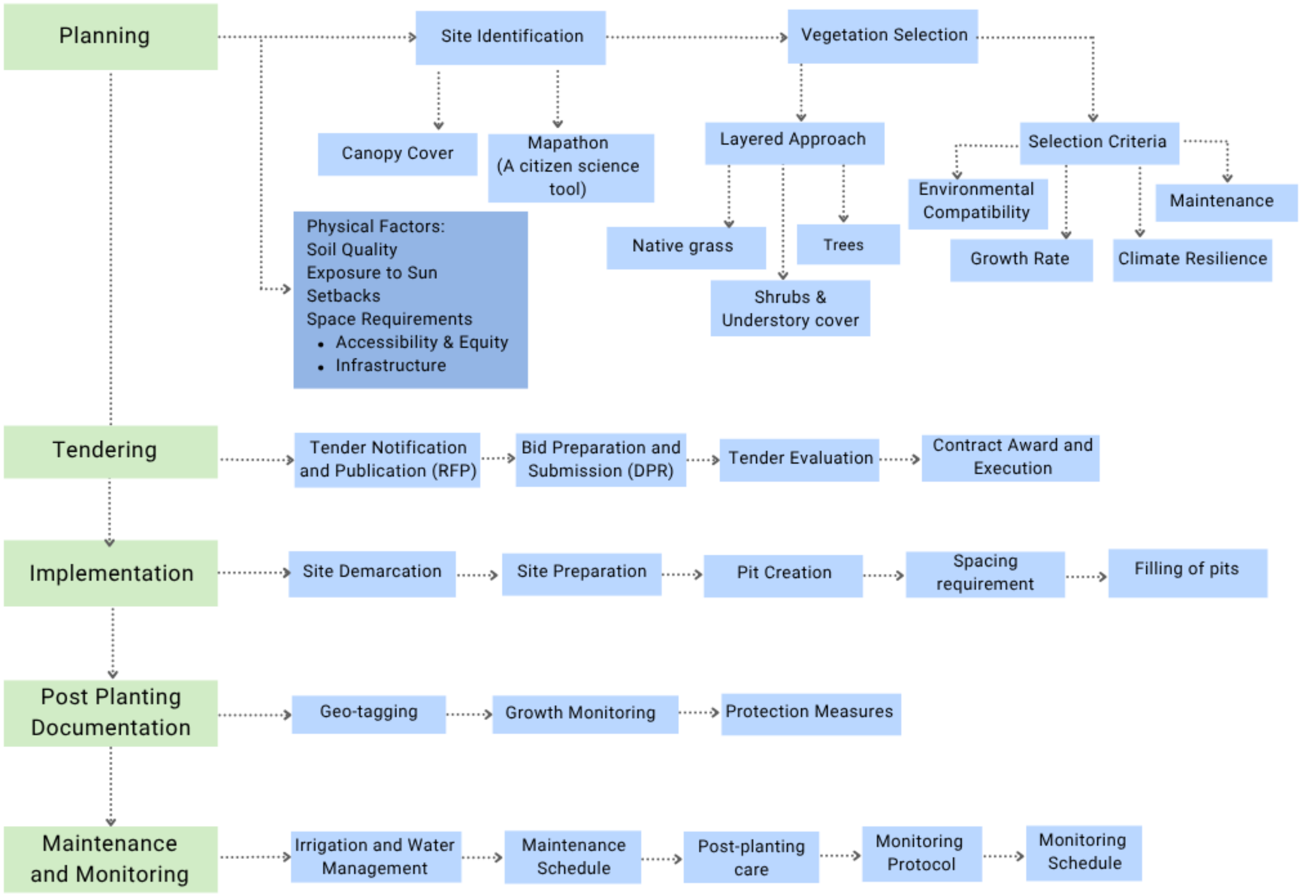


Figure 10: Key steps for implementation and maintenance.

3.6 Metrics for Planning, Design and Implementation

Parameter	Description	Metric
Canopy Density	Classification of canopy cover from existing trees	Very Low: < 10%, Low: 11%–40%, Medium: 41%–70%, High: >70%
Soil pH	Acidity/alkalinity level of soil	Ideal: 6.0–7.5
Organic Matter	Soil composition	4%–6% by weight
Drainage Rate	Water percolation rate	25mm/hour (minimum)
Soil Depth	Depth of good topsoil for planting	60 cm (minimum)
Exposure to Sunlight	Daily sunlight exposure required for plants	4–6 hours optimal; minimum 3 hours for tree crowns
Setback distance	Minimum distance from infrastructure	Foundation/compound walls/underground utilities, 1.5 m. Electrical transformer/overhead cables, 3 m, Traffic signals/road curves, 5 m
Root Space per Tree	Space required for root growth	0.6 cm^3 per tree
Spacing Between Trees	Tree spacing for different tree sizes	Small trees, 6 m; medium trees: 7–8 m, large trees: 9–10 m
Pit Dimensions for Planting	Dimensions of planting pits	Small trees, 45 cm x 45 cm x 45 cm; medium trees, 60 cm x 60 cm x 60 cm, large trees, 75 cm x 75 cm x 75 cm; avenue trees, 1 m x 1 m x 1 m. Leave 60 cm around transplanted trees.
Tree Guard Specifications	Materials and dimensions for tree guards	Bamboo: 18 bamboo strips (25 mm x 91 cm), Wood: 4 poles (2.5 m) with 12 batons (40 cm)

Table 2: Metrics for planning, design and implementation of urban greening.

3.7 Selecting Species to Support Climate resilience

The table below lists some prominent species that are resilient to extreme climate risks and facilitate in their mitigation.

Species	Scientific Name	Common Name	Kannada Name	Where it can be planted	Benefits on Climate and Biodiversity
Trees	Mangifera indica	Mango	Maavu	Open sunny spaces, parks, large yards and schools	Provides dense shade, improves air quality and offers food and habitat for birds and insects.
	Pongamia pinnata	Honge	Honge	Lake buffer zones, parks and open spaces	Drought-resistant, biofuel source, soil stabiliser and good carbon sink.
	Ficus benghalensis	Banyan	Alada Mara	Road intersections and gathering areas	Home to countless birds, insects, excellent air purifier and temperature regulation.
	Azadirachta indica	Neem	Kahibevu	Roadside avenues, parks, open spaces and dry/ degraded lands.	Medicinal pest-repellent, air purifying and shade provider.
	Phyllanthus emblica	Amla/Indian gooseberry	Nellikayi	Community gardens and home and kitchen gardens	High in Vitamin C, fruits feed wildlife, hardy and drought tolerant and faciliates carbon capture.
	Michelia Champaca	Sampige	Sampige	Avenue medians, community open spaces and lake buffer zones	Supports pollination, medicinal value, urban cooling, carbon sequestration and air purification.
	Psidium Gujava	Guava	Sībe Hannu	Agroforestry plots, urban parks and dryland horticulture zones	Serves as a host plant, fruit for wildlife, drought tolerant and improves air quality.
	Syzygium Cumini	Jamun	Nerale Hannu	Lake buffer zones, community orchards and gardens	Supports wildlife, attracts pollinators, drought and heat tolerant and soil stabilisation.
	Butea frondosa	Flame of the Forest	Muttugi Mara	Parks, avenues, and community open spaces.	Improves soil quality, drought resistant, habitat and is a food source for birds, insects and butterflies.
	Bombax malabaricium	Red Silk Cotton Tree	Buruga Mara	Avenues, roadside gardens, and parks.	Helps regulate temperature, hosts birds and butterflies, stabilises the soil with an extensive root system.
Shrubs	Crossandra infundibuliformis	Firecracker Flower	Kanakambara	Home gardens, community orchards, and terrace gardens.	Attracts pollinators, purifies air and contributes to soil protection. It is used in traditional floral decorations.
	Tephrosia purpurea	Wild indigo	Kaadu Neeli	Agroforestry plots, roadside plantations and hillside or slope areas	Important in restoration, supports soil microbes/insects, nitrogen fixing and is drought resistant.
	Hibiscus rosa-sinensis	Hibiscus	Dasavala	Home and kitchen gardens, community gardens and residential spaces	Nectar source for bees and birds, used in home gardens and promotes cooling around built-up spaces.
	Leucas aspera	Thumbe	Thumbe	Medicinal and herbal gardens and dry open grasslands	Important native nectar source for bees and small butterflies and thrives in disturbed soils.
	Lawsonia inermis	Henna	Goranti	Dryland herbal gardens, semi-arid areas and along the fencelines	Attracts bees, supports leaf eating insects and facilitates ground cover maintenance.

	Vitex negundo	Nirgundi	Nirgundi	Lake bunds, riparian zones and stormwater edges	Medicinal value, pest-repellent, drought tolerant, stabilises and improves soil and its microclimate.
	Jasminum officinale	Jasmine	Mallige Hoovu	Cultural and heritage landscapes, fences and pollinator areas	Aesthetic value, adoptable, improves soil health and promotes air purification.
	Aloe Barbadensis	Aloe vera	Alovera	Dry and arid landscapes, roadside medians and community gardens	Medicinal value, low water requirement and promotes soil stabilisation.
	Withania somnifera	Ashwagandha	Ashwagandha	Home gardens, dryland farming and agroforestry systems	Medicinal value, pollinator support, low maintenance, promotes soil enrichment and carbon sequestration.
	Plumeria obtusa	Frangi Pani	Devagudlu	Home gardens and courtyards, avenue gardens and lake promenade	Wildlife shelter, aesthetic contribution, improves air quality and controls erosion.
Grass	Chrysopogon zizanioides	Vetiver	Gouchari	Rain gardens, lake bunds, bioswales and recharge wells	Deep roots stabilise soil and support microbial life, prevents soil erosion and improves groundwater recharge.
	Cynodon dactylon	Bermuda Grass	Kambalahennu	Parks, lake buffer edges and stormwater corridors	Dense ground cover supports life, binds soil, cools the surface and filters runoff.
	Bothriochloa pertusa	Indian bluegrass	Neelahennu	Grassland patches in open parks and lake zones.	Supports soil-dwelling organisms; drought resistant and helpful in restoring degraded land.
	Panicum maximum	Guinea grass	Giniya Hannu	Reclamation zones and storm water drains	Provides ground cover and erosion control; sequesters carbon quickly and improves soil moisture.
	Ischaemum indicum	Indian murain grass	More Hullu	Wetlands, riparian zones and lake margins	Host plant for butterflies and insects, good forage grass, grows in damp areas and stabilises stream banks.
	Arundinella bengalensis	Arundinella species	Arundinella	Hillsides and urban rocky outcrops.	Supports insect life and stabilises shallow rocky soils.
	Eragrostis uniloides	Love Grass	Mudduhennu	Restoring degraded urban land patches; roadside margins	Shelter for small insects, excellent soil binder and quick coloniser on disturbed lands.
	Pennisetum pedicellatum	Desho grass	Desho Hullu	Lake buffer vegetation; erosion-prone edges	Good for fodder, pollinators, rapid growth, erosion control and adds biomass.
	Demostachya bipinnata	Darbha grass	Darbe Hullu	Sacred groves, riverbanks, and lakefronts with cultural value	Used in traditional rituals, excellent for erosion control and stabilises sandy and loose soils.
	Aristida setacea	Three-Awn Grass	Tindu Hullu	Hillocks, drylands and urban wastelands	Provides nesting materials, extremely drought resistant and stabilises low-quality soils.

Table 3: List of prominent species of trees, shrubs and grasses that support climate resilience.

STORMWATER

4.0 Stormwater drains – Rethinking Watersheds for Urban Flood Mitigation

Scale of intervention

City and neighbourhood.

Climate focus

Urban flood mitigation, ground water recharge, urban heat reduction through evaporative cooling and biodiversity enhancement.

Human and non-human benefits

Reduced damage to infrastructure, properties and lives. Access to public space for recreation and biodiversity.

Typologies of storm water drains with integrated blue and green infrastructure

Open Earth drains with vegetation, lined drains with bioswales, infiltration trenches, constructed wetlands, retention and detention ponds, treatment edges, riparian belts, recharge wells along edges, etc.

4.1 Understanding Stormwater Drains in Bengaluru

Bengaluru's stormwater network comprises approximately 842 km of *Rajakaluves*, which were historically designed to connect a series of tanks through overflow mechanisms regulated by sluice gates. This creates a hydrologically active system that enables water storage, retention and conveyance across the city. However, urban expansion, canal channelisation and watershed concretisation have altered this system significantly. These changes have accelerated stormwater runoff, which results in rapid flow into the drains and tanks, thus increasing the frequency and intensity of urban flooding. Owing to increasingly erratic and intense rainfall patterns, the city's stormwater infrastructure cannot adequlately function as intended.

4.2 Current Challenges

A significant issue presented by this network is the clogging of drains by sewage, solid waste and accumulated silt, which severely limits their capacity to transport stormwater. Routine maintenance, typically through annual contracts, results in partial desilting, broken retaining walls and unmanaged disposal sites. Furthermore, the standard approach of constructing tall retaining walls and fences minimally improves hydrological performance, flood resilience and accountability. These structures merely conceal the drains from view, without addressing the fundamental requirements of flow regulation or contextual development control. These practices compromise the stormwater drain's core function—enabling the efficient, uninterrupted movement of stormwater to the city's tanks—thus rendering the network increasingly dysfunctional and vulnerable under variable climates.

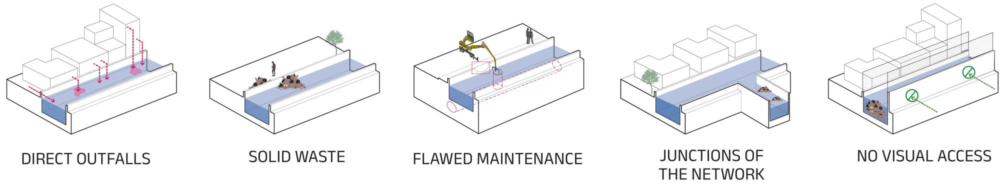


Figure 11: Key maladaptive practices include the discharge of sewage into drains, flawed desilting methods, un-reconstructed walls, negligence of drains' networked nature and infrastructure based on visibility control instead of scientific hydrological data.

4.3 Filling the Gaps: Framework Driven Approach

To enable project creation and decision-making, the framework will provide tools to streamline project creation and identify them based on hydrological and public function. Further design elements, design criteria and details specific to each performance metric are established, including flood resilience and public safety, water quality and public health, civic amenities and creation of public space.

A matrix or checklist will help prioritise areas for development as stormwater infrastructure for the city, thus facilitating the functioning of the stormwater drainage system.

Hence, the framework for stormwater drains aims to enable systematic project creation and informed decision-making for stormwater infrastructure in Bengaluru. It will address the challenges above as follows:

- **Support project identification** based on **hydrological function** (e.g. conveyance, retention, percolation, treatment) and **public function** (e.g. public space, mobility, civic amenities).
- **Provide design strategies and criteria based on typology identification**. This will be tailored to various site conditions based on the existing water volume and the available space for water.
- **Outline detailed performance-based design elements** for different intervention types.
- **Assist in departmental coordination** by clarifying responsibilities across spatial scales (catchment, zone and ward).
- **Enable data-driven prioritisation** of stormwater projects while considering urban resilience, sustainability and public use.

4.4 Valleys and Watersheds: Systems Approach to Stormwater Drainage

Projects in Bengaluru have focused on lakes in isolation by removing the storm water drain from these restoration projects. The stormwater network of the city cannot be managed in isolation. Each element is part of a larger ecological and hydrological network, which is influenced by its valley, watershed, catchment and its role in the hydrological network.

Bengaluru's topography features clear valleys, and these valleys contribute to a larger watershed which directs its waters to rivers such as the Cauvery, Dakshina Pinakini, Arkavathy, etc. These valleys exhibit distinct slope and soil characteristics, which are further determined by the role they play in their larger watershed.

To restore and enhance stormwater systems, one must integrate the natural zones of water alongside the administrative jurisdictions imposed to create projects at all levels and of all types.

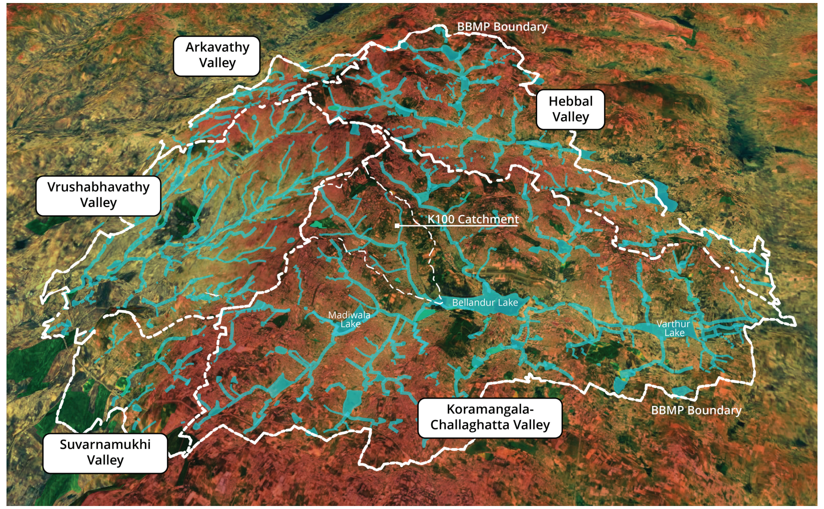


Figure 12: Bengaluru—a city featuring valleys, watersheds and catchments.

4.5 Institutional Mapping and Stakeholder Alignment

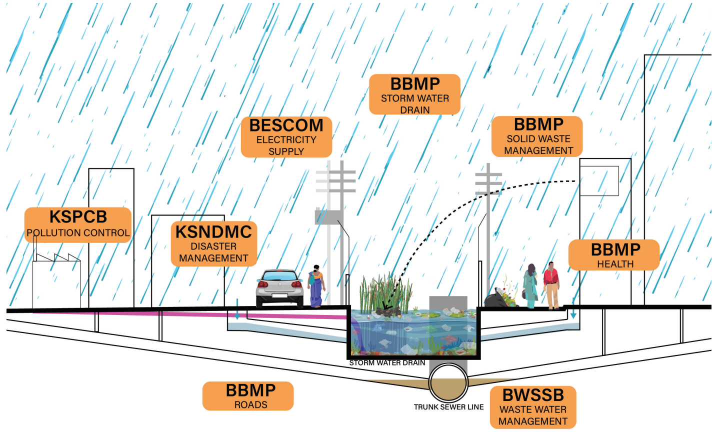


Figure 13: Stormwater drains, owing to their linear form, formed natural boundaries for administrative boundaries; trunk sewer lines of the city are built underneath, with many carrying the major power lines of the city.

4.6 Key Steps for Implementation

The K100 Citizens' Waterway was implemented by the BBMP as a pilot for redevelopment of the *rajakaluves* in the city. The project focused on changing the goals of the stormwater drain development programme into performance-based evaluation such as flood resilience, water quality, civic amenities and the creation of public ownership. The project involved multiple stakeholders collaborating to achieve the goals identified by the project.

The project focused on creating a public function to ensure accountability and ownership. Retaining walls are demolished, fences are removed, a public space is created adjacent to the drain, walking pathways are created within the drain. This was achieved through establishing catchment-level base data, including micro-watersheds, high flood levels; establishing bed levels/slopes and ground water levels; and identifying different components of the existing network.

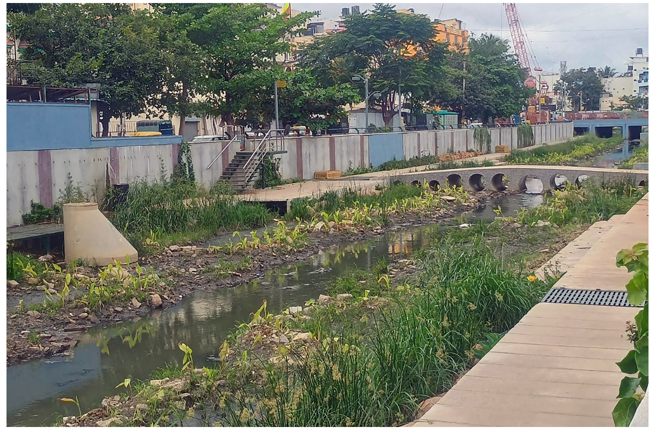


Figure 14: The K100 Rajakaluve, before and after intervention.

Key steps in the implementation process were identified to assist in further streamlining the projects. Insights from this will be adapted into the Stormwater Drain Framework.

4.6.1 Planning

- Define the scope of the project.
- Identify the project stretch, jurisdiction and land ownership to appoint a responsible government agency.
- Assess the site's location within the watershed to determine relevant hydrological and public functions.
- Categorise the project typology (e.g. conveyance corridor, retention park and treatment edge) based on existing site and drainage conditions.

4.6.2 Design metrics and parameters

- Use catchment-level data to inform the function of the stormwater.
- Incorporate design strategies that satisfy the key performance metrics such as:
  - **Flood resilience and public safety:** Peak runoff reduction, surface water retention capacity and reduced incidence of waterlogging and flooding.
  - **Water quality and public health:** Removal or treatment of greywater and effluents, reduction in solid waste accumulation and improvement in surface water quality index.
  - **Civic amenities and access to usable public spaces:** Areas of accessible public spaces created or improved; inclusion of walkways, seating, green buffers, shade; usage and footfalls in new public spaces.
- Adhere to established standards and design typologies relevant to both hydrology and urban design.

4.6.3 Stakeholder consultation

- Map all institutional stakeholders involved in the project across planning, implementation, utilities and maintenance.
- Conduct coordination meetings with departments and utilities to align roles and responsibilities.
- Engage the community early through site visits, public consultations and awareness campaigns to establish buy-ins and co-ownership.

4.6.4 Tender and onboard contractors

- Design tender documents to reflect the project type, scope and required outcomes based on hydrological and social function.
- Ensure contractor understanding of both technical and public realm objectives during pre-bid and construction stages.
- Monitor construction regularly to verify compliance with the design intent and technical standards.

4.6.5 Monitor, Evaluation and Maintenance.

- Develop a performance-monitoring framework based on predefined metrics (flooding reduction, water quality, public usage, etc.).
- Institutionalise maintenance protocols with designated departments or third-party agencies.
- Organise regular review meetings with local communities and stakeholders to sustain long-term engagement and respond to emergent issues.

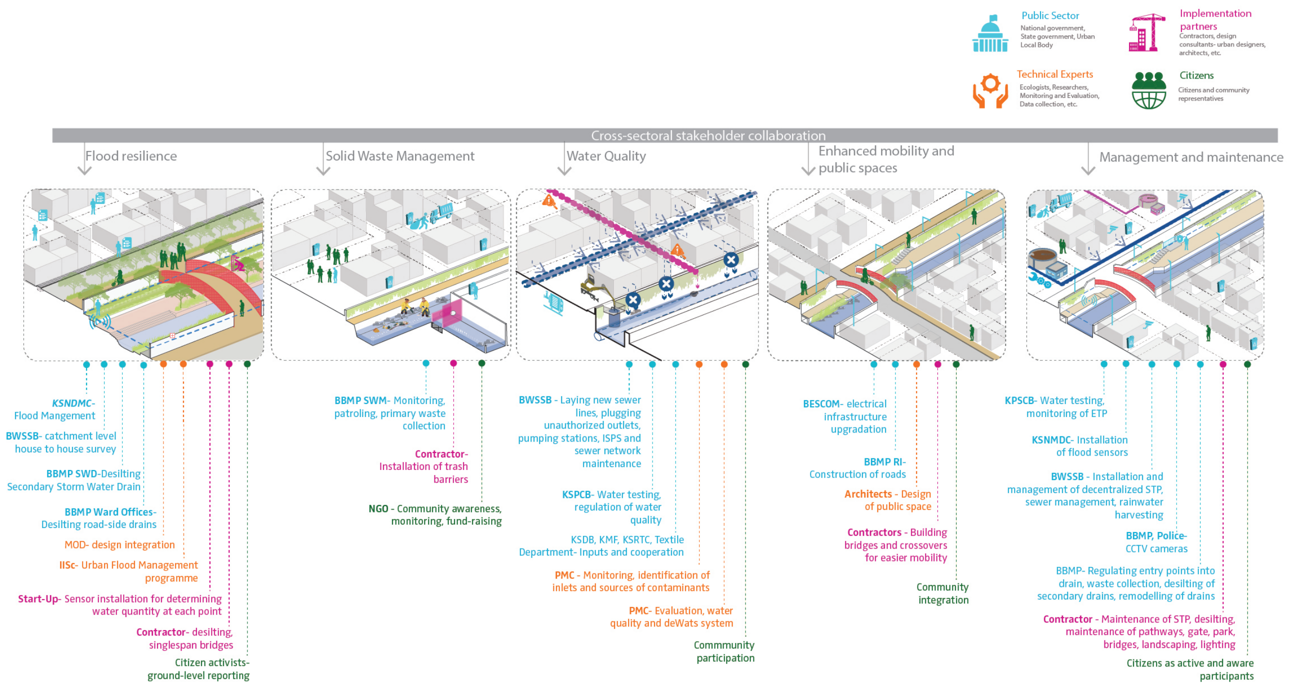


Figure 15: Co-ordinated action specific to key performance metrics as implemented in the K-100 project.

LAKES

5.0 Urban Lakes as Nature-Based Solutions: Framework for Restoration and Resilience

Scale of intervention

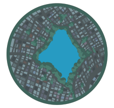
City and neighbourhood.

Climate focus

Urban flood buffering, ground water recharge, urban heat island reduction and microclimate enhancement.

Human and non-human benefits

Habitat for migratory birds, livelihood and ecosystem services.



Types of lake restoration

Desilting and deepening for increased storage capacity, constructed wetlands for filtration and biodiversity, bioremediation zones and grey-water treatment plants.

5.1 Understanding Bengaluru's Lake System

Bengaluru has approximately 183 lakes under the BBMP jurisdiction, many of which are clustered in cascading systems and linked through stormwater drains. Shaped by the city's natural topography, these lakes are distributed across three main valleys, i.e. Hebbal–Nagavara, Koramangala–Challaghatta, and Vrishabhavathi.

As a highly urbanised city, Bengaluru is confronted by increasing climate-related risks, including urban flooding, drought, biodiversity and habitat loss, and socio-cultural and livelihood disruptions. These challenges are being exacerbated by climate change and unplanned urban expansion on the periphery.

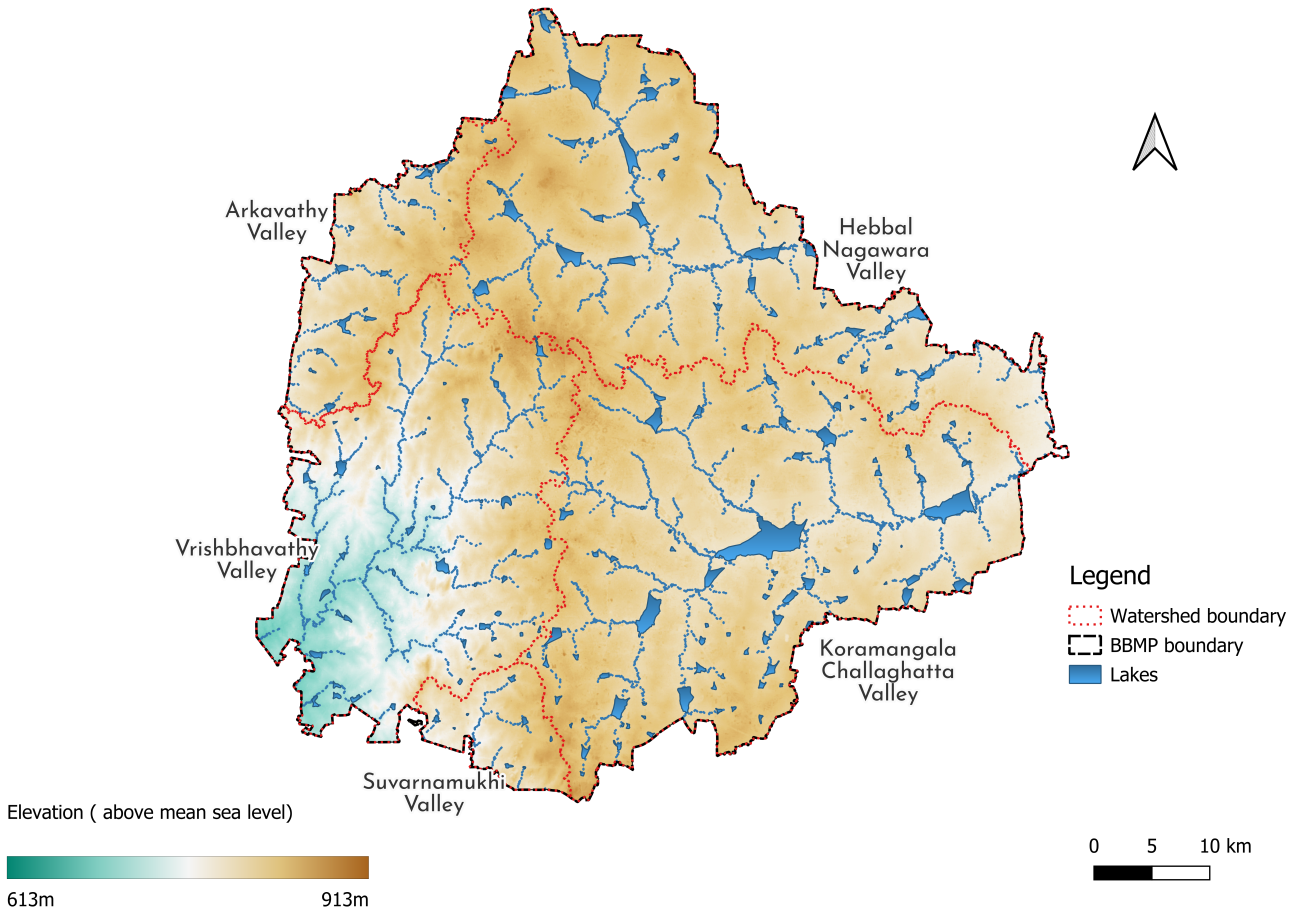


Figure 16: Lakes of Bengaluru are distributed across three main valleys, i.e. Hebbal–Nagavara, Koramangala–Challaghatta, and Vrishabhavathi.

5.2 Beyond Water Storage: Role of Lakes in Climate Resilience

Lakes, when viewed as part of a BGIN, offer a powerful, nature-based solution for building urban climate resilience. Bengaluru's lakes form a large, interconnected cascading system, capable of serving multiple functions. When restored and managed effectively, lakes can

- Mitigate urban flooding by functioning as buffers that absorb and store excess runoff.
- Recharge groundwater recharge and provide storage for indirect potable reuse.
- Support biodiversity and regulate micro-climates, thereby sustaining vital ecological functions.
- Sustain sociocultural and livelihood activities—serving as spaces for recreation, rituals, festivals, and practices such as fishing and grazing.

The extent to which a lake can perform these roles depends on its inherent characteristics and the nature of assets and interventions implemented. While some lakes may be optimised for flood mitigation, others might prioritise ecological restoration or groundwater recharge. Many can serve multiple functions simultaneously, thus rendering them critical assets in Bengaluru's climate resilience strategy.

5.3 Challenges in Lake Rejuvenation and Systemic Functioning

Urban lakes in Bengaluru present a range of ecological, hydrological and governance challenges. Many are degraded due to encroachments, untreated sewage, disconnected catchments and inconsistent maintenance. While interest in rejuvenation is growing, implementation is typically prevented by structural flaws in planning, funding and monitoring. Rejuvenation efforts are hindered by a lack of shared goals. Bengaluru's lakes serve multiple purposes, thus attracting diverse stakeholders—donors, government agencies, communities and livelihoods—that often have conflicting priorities. Another key issue is the mismatch between output and outcomes. Lake rejuvenation is often treated as an infrastructure projects focusing on physical assets without assessing whether they fulfill the intended objectives. For example, flood control structures may be installed, yet flooding persists due to poor catchment management or malfunctioning assets. This stems from a limited understanding of how each asset interacts within the larger lake system. In the past, CSR-funded lake projects often prioritised cosmetic improvements over core or ecological functions.

While standards for asset design and construction exist, such as those outlined in IS codes, they are primarily meant for irrigation tanks and may not be fully tailored to urban lakes. The Central Pollution Control Board (CPCB) defines water quality criteria based on designated uses of water bodies. However, tracking incremental improvements in lake water quality is challenging because the parameters used for one designated purpose may not be included in others. Additionally, this approach does not consistently cover all relevant parameters or monitoring locations, thus causing gaps in assessment. The absence of comprehensive, lake-specific standards results in inconsistent outcomes, thus rendering it difficult to identify root causes or enforce accountability.

5.4 Approaches to Sustainable Lake Rejuvenation and Management

Successful lake rejuvenation requires more than isolated projects—it demands systems thinking and coordinated action across multiple scales. Lakes are part of a broader ecological and hydrological network, influenced by upstream and downstream lakes, stormwater drains, catchment land use and the groundwater table. Without recognising these interconnections, interventions in one section can undermine outcomes elsewhere.

- **Multiscale design approach:** Interventions must be designed and implemented across multiple levels,
  - Lake level: Focus on functional assets such as inlets, outlets and bunds.
  - Catchment level: Management of runoff, land use and waste inflows in the surrounding area.
  - Watershed level: Bengaluru's cascading lakes require coordinated planning to enhance connectivity and prevent downstream impacts.

Aligning efforts across these scales ensures more resilient and sustainable outcomes.

- **Aggregated Action:** Lake rejuvenation efforts must be aggregated instead of fragmented. Unified strategies across agencies, communities, funders and experts help avoid duplication, improve efficiency and ensure that every intervention contributes to shared goals.

- **Standardised metrics for effective monitoring and accountability**: Successful implementation hinges on the availability and use of clear, actionable metrics that address both quality and quantity aspects. Such standardisation allows for better accountability, helps track progress over time, and enables diverse stakeholders—whether donors, government, or local stakeholders—to align their efforts and measure the effectiveness of interventions in a transparent and comparable way.

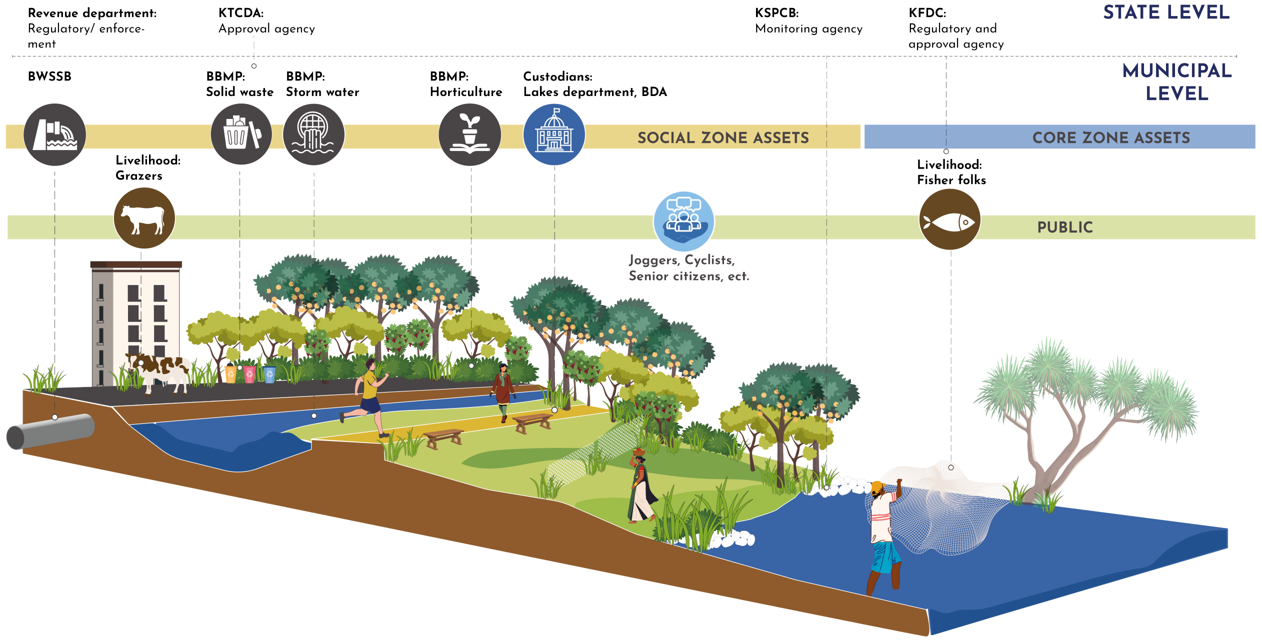


Figure 17: Stakeholders involved in planning components and management of lakes in Bengaluru.

5.5 Workflow for Lake Rejuvenation and Monitoring

WELL Labs, in collaboration with Friends of Lakes, has developed a framework for the lake rejuvenation and monitoring shallow urban and peri-urban lakes in Peninsular India. Friends of Lakes is a citizen-led collective actively managing 23 lakes in Bengaluru, with emphasis on lake rejuvenation, governance and policy. Lake rejuvenation can be approached through a five-stage process, as follows:

Stage 1

Diagnosis & Visioning: Assess risks at both the lake and catchment levels and understand the lake's inherent characteristics and incorporate community aspirations to prioritise key functions.

Stage 2

Design: Identify necessary baseline studies, map assets specific to prioritised functions, design selected assets according to standards and address gaps in existing assets to perform the functions.

Stage 3

Implementation: Conduct tests and checks to ensure that the construction and installation of assets align with design standards.

Stage 4

Operations & Maintenance: Conduct routine activities and scheduled inspections for reliable operation of assets to ensure they perform as intended.

Stage 5

Monitoring & Evaluation: Monitor progress through asset and lake health surveys, compare current and desired states across lake hydrology, ecology and water quality.

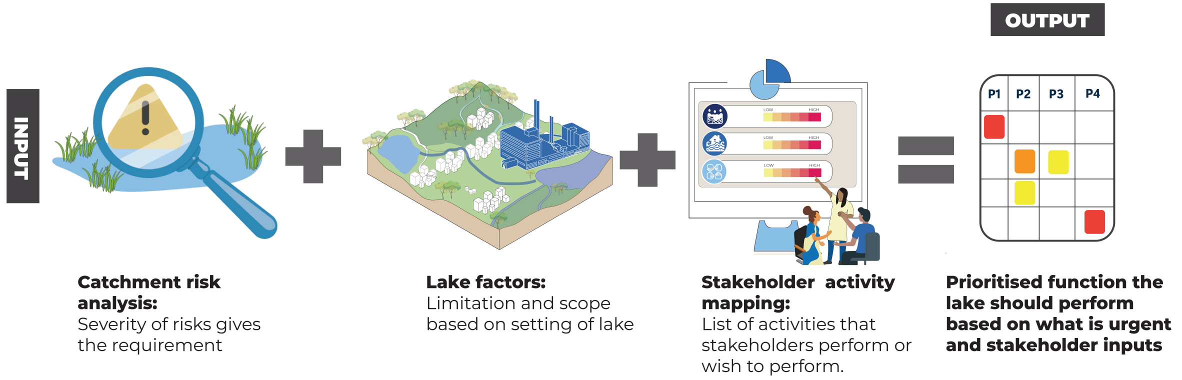
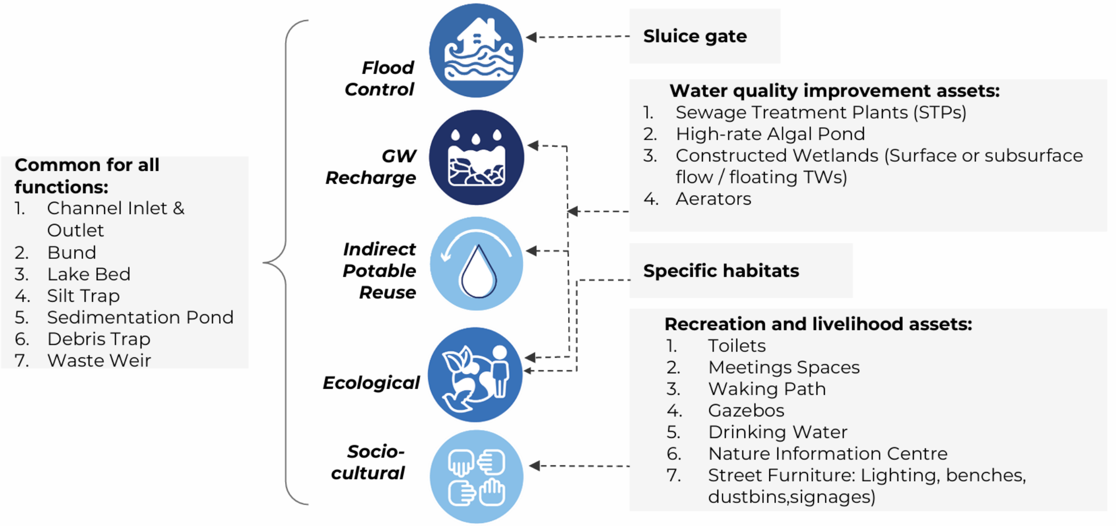


Figure 18: Step-by-step process for diagnosis and visioning.

5.6 Key Metrics and Tools for Lake Asset Design and Health Monitoring

Assetization is the process of converting resources and services related to the lake into identifiable and trackable assets (components). This approach facilitates the identification of the necessary components that enable the lake to perform various functions effectively.



The following is a list of parameters that can be used for advanced monitoring:

Lake Characteristic	Monitoring Parameters
Quantity	Peak inflow (volume of catchment runoff)
Quality	Lake water: pH, temperature, electrical conductivity (EC), total suspended solids (TSS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), nitrate (NO3), total phosphorus (TP), and fecal coliforms (FC) Lake sediment: TN, TP and total organic carbon (TOC)
Ecology	Population counts of both native and invasive flora and fauna. Habitat use by key species, including migratory birds.

Table 4: Assets required to perform different functions and metrics to track current lake condition, which is necessary for asset design.

5.7 Lake Asset Design Tool

A lake asset design tool helps one evaluate whether assets are built to fulfil their intended function. It considers key factors, such as asset location and design considerations, such as, sizing and material selection. The assessment is guided by codes set by the Bureau of Indian Standards (BIS), the Central Public Health and Environmental Engineering Organisation (CPHEEO) and other relevant national and international standards and codes of practice.

5.8 Lake Health Index

Citizens can contribute significantly to lake monitoring through observational analyses and field test kits. These tools help assess the condition of lake assets and the key characteristics of lakes including water quality, quantity and ecological health, to determine whether they are within the desired range. The **Lake Health Index**, which is a mobile application, provides a framework for evaluating lake health and can be used by citizens as an early warning diagnostic tool to monitor lakes. Additionally, ATREE has developed an online platform called **LakeRevive**, which provides scores for lake health that can be used prior to and after implementation to assess the efficiency of the implementation.

5.9 Implementation of Nature-Based Solutions for the Restoration of Blue-Green Ecosystems (Urban Lakes)

This section outlines step-by-step guidelines for performing specific tasks related to lake restoration. The tasks include water-quality monitoring, water treatment, wetland construction, wetland installation and the revival of native vegetation. Collective knowledge and experience gained by working across several lake sites in Karnataka is drawn upon.

5.9.1 Rationale, Considerations and Assumptions for Designing NbS Implementation Tool (LakeRevive)

Despite ongoing restoration efforts, many urban lakes continue to experience severe ecological issues, such as algal blooms, foul odour, poor water clarity and fish kills. These outcomes point to fundamental gaps in conventional restoration approaches. Common restoration practices such as the indiscriminate removal of in-lake and shoreline vegetation, aggressive desilting and deepening of lakebeds and the diversion of inflows, typically disrupt the natural self-regulating functions of lakes. Such interventions reduce water circulation and strip the lake of essential ecological buffers.

5.9.2 Research Insights and Ecological Rationale

Research conducted at the Water and Soil Lab, ATREE, has highlighed that lake health is determined not only by water quality but also by biodiversity and linkages to livelihoods. Achieving a good ecological status requires an integrated approach that considers all three dimensions.

For instance, conserving native vegetation along the shoreline and within the lake, while maintaining water circulation (secondary treated effluent discharge during dry season), is vital as it enhances water quality and supports aquatic biodiversity, thus preventing stagnation and ensuring adequate oxygen levels.

Although the National Green Tribunal (NGT) allows the discharge of secondary treated wastewater into urban lakes, our studies reveal that such effluents typically contain high levels of phosphorus. This promotes algal blooms that rapidly deplete oxygen, thus resulting in fish kills, bird mortality and unpleasant odours.

Urban lakes, which are increasingly viewed as multifunctional ecosystems, offer critical environmental amenities, serve as biodiversity habitats and function as flood-control structures. The implementation of NbS, which is adaptive, resilient and environmentally responsive, offers a promising way to address the multiple interconnected impacts of urbanisation and climate change.

5.9.3 Design Considerations for NbS Implementation (LakeRevive Tool)

For a lake to be ecologically healthy, two following two aspects must be considered:

- **Water Clarity:** One should be able to see clearly into the water for approximately 80 cm to 1 meter (approximately 2.5 to 3 feet).
- **Total Phosphorus (TP) Levels:** The amount of total phosphorus in the water should be low, i.e. between 0.8 and 1.0 milligrams per litre (mg/L).

The above is applicable under the following conditions:

- **Aquatic Plants:** 20%–30% of the lake's surface is covered with plants growing in the water.
- **Shoreline Plants:** The vegetation along the lake's edge is healthy.

By verifying the **total phosphorus levels,** we can identify the best NbS for restoring a lake.

5.9.4 Incorporating Self-Assimilation Capacity into Design

An important innovation of the LakeRevive tool is the integration of the self-assimilation capacity, which refers to the natural ability of a lake to absorb and process pollutants, particularly nutrients, such as phosphorus and organic matter, without compromising its ecological integrity.

By incorporating self-assimilation thresholds into the NbS design framework, we can

a) reduce infrastructure costs by leveraging the inherent capacity for nutrient uptake by the lake, and

b) optimise the intervention scale by avoiding over-engineering or unnecessary installation

The tool provides viable solutions based on the input parameters. The figure below represents the condition of urban lakes without interventions.

Figure 19 (a): Plan view of existing conditions of urban lakes.

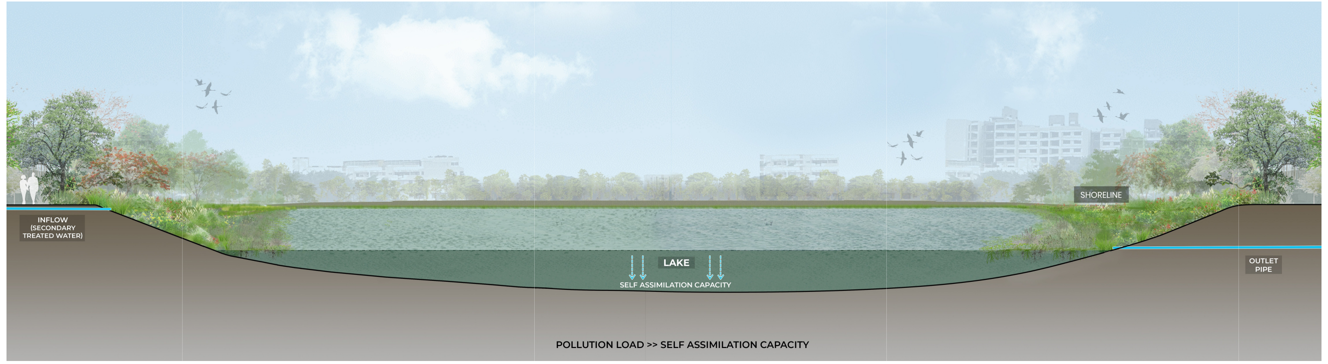


Figure 19 (b): Section view of existing conditions of urban lakes.

Scenario 1 – When sufficient area is available for implementing constructed wetland (CW)

The tool recommends CW as the sole intervention when

- sufficient area is available for CW implementation,
- CW alone can achieve the required nutrient removal, and
- the calculated area requirements for CW are below 25% of the lake area

Technical explanation: In this scenario, the nutrient removal efficiency of the CW of the available area aligns with the load removal required to achieve the desired water clarity at the lake. Subsequently, the self-assimilation capacity (natural purification capacity) of the lake is considered while estimating the area requirement for the CW. The algorithm estimates the necessary pollutant removal by determining the difference between the incoming pollutant load and the self-assimilative capacity of the lake. The output of the tool displays the area required and percentage of lake area covered by the CW.

User action: Proceed with the CW design based on the provided parameters. The manual includes detailed guidance pertaining to wetland plant selection, substrate requirements, and hydraulic considerations.

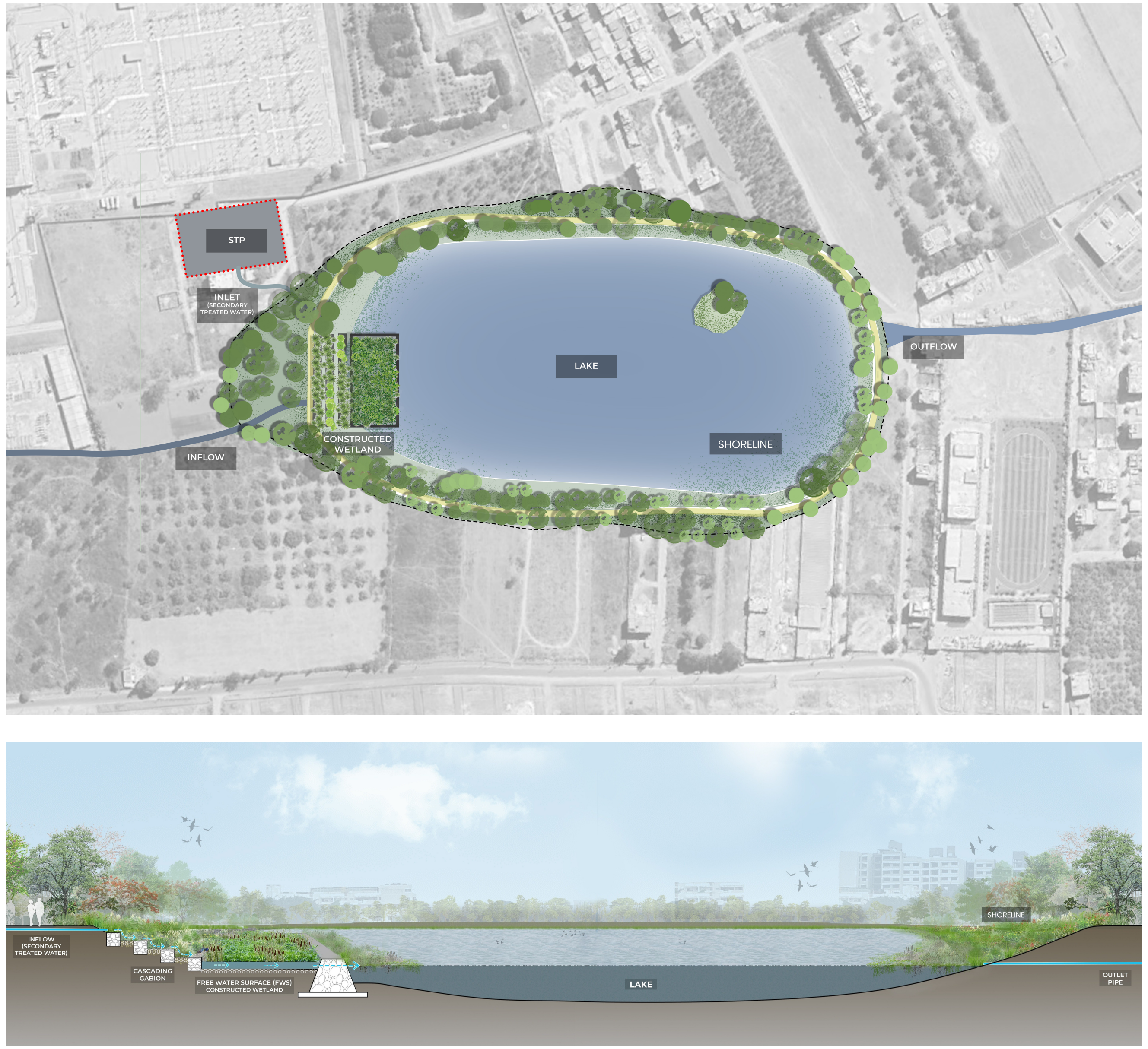


Figure 20: Plan and section views of Scenario 1.

Scenario 2 – Combination of CW and FI (where area available for CW is limited)

The tool recommends a combined approach when

- the CW alone cannot achieve the required nutrient removal,
- additional treatment is required to supplement the CW, and
- the combined area requirements are below 25% of the lake area.

Technical explanation: In this scenario, the algorithm first estimates the maximum nutrient removal efficiency of the CW, followed by estimating the residual pollutant load, which is then used to determine the area required for the deployment of FIs. The hybrid solution is estimated to achieve the desired water quality while ensuring that the net area under the NbS is below 25% of lake area.

User action: Both CW and FI are implemented based on the proportions and specifications provided. The output includes detailed design parameters for both systems and the percentage of water-spread area covered by the hybrid system.

Figure 21 (a): Plan view of Scenario 2.

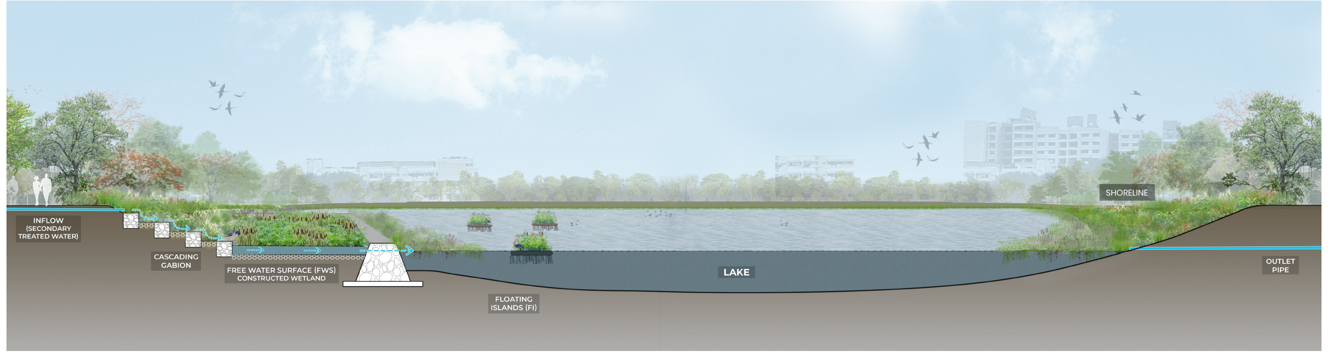


Figure 21 (b): Section view of Scenario 2.

Scenario 3: Area not available for CW but floating islands are sufficient.

Figure 22 (a): Plan view of Scenario 3.

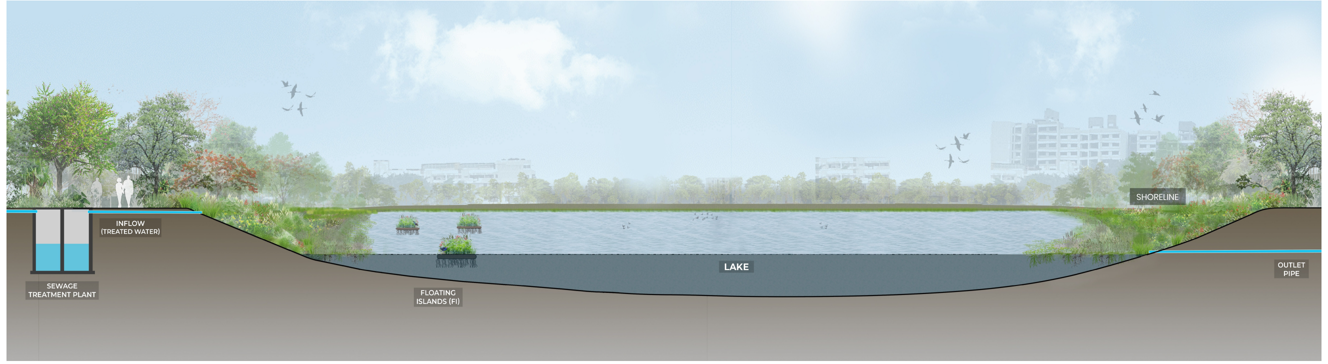


Figure 22 (b): Section view of Scenario 3.

Scenario 4: NbS is insufficient for pollution uptake; additional grey infrastructure is required

Figure 23: Plan view of situations where no area is available and additional grey infrastructure is required.

5.9.5 Types of NbS for Urban Lake Restoration

- Constructed wetlands (free water surface and subsurface flow): These are designed to reduce TP loads in secondary-treated wastewater before it enters the lake. They serve as a first-stage filter, improving water quality through plant uptake and sedimentation.

- Floating treatment wetlands (floating islands): These are ideal for scenarios where space constraints limit the construction of full-scale wetlands. They can be deployed at the outlet of constructed wetlands or directly within the lake to reduce in-lake phosphorus further and absorb residual nutrients.

- Shoreline and in-lake vegetation (native plant buffers): It serves as a nutrient filter for runoff and in-lake pollutants. It helps to stabilise the lake ecosystem by preventing algal blooms, enhancing habitat diversity and maintaining oxygen balance.

5.9.6 Monitoring, Evaluation and Adaptive Learning (Integration of Lake Health Index)

To effectively monitor the performance of restoration interventions over time, communities and stakeholders must be equipped with a tool that can reflect changes in lake health. Drawing on both primary and secondary research, ATREE has developed a Lake Health Index (LHI), which has been fully integrated into the LakeRevive tool. This index serves multiple purposes: it assesses the existing condition of the lake, supports the identification of appropriate restoration solutions, enables monitoring of intervention performance over time and guides the incorporation of new frameworks to enhance the ecological and use value of the lake. By embedding this index into the tool, it becomes a practical resource for ongoing monitoring, evaluation and adaptive learning, empowering local communities to make informed, evidence-based decisions.

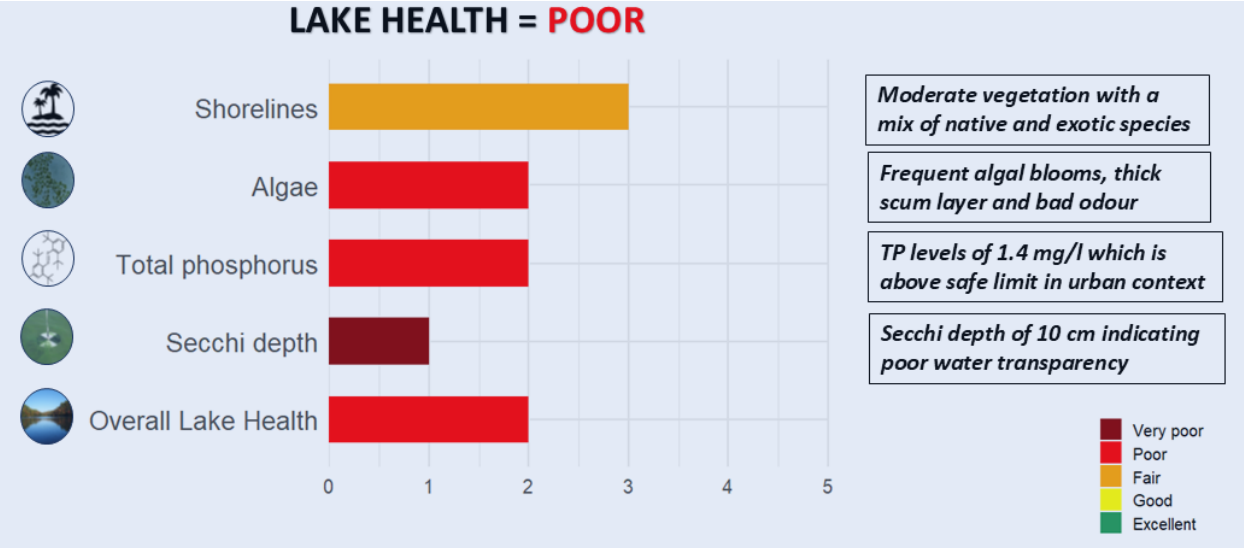


Figure 24: Output of the LHI embedded in the LakeRevive.

RECHARGE WELL

6.0 Recharge Well

Scale of intervention

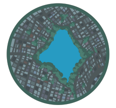
Neighbourhood and site.

Climate focus

Ground water recharge, flood mitigation, urban water security and climate adaptive water infrastructure.

Human and non-human benefits

Resilience during droughts, reduced stormwater run-off and localised flooding, reduced dependencies on external water sources and supports urban vegetation and ecosystem health.



Types of recharge structures

Percolation pits, rooftop rainwater harvesting linkages, community-managed recharge wells and recharge systems in campuses and public parks.

6.1 Reviving Shallow Aquifers and Considering Bengaluru's Open Well Legacy

A recharge well is a 'hole in the ground' that is typically 3 to 6 feet in diameter and up to 20–30 feet deep. It is dug to allow the direct percolation of rainwater into the ground, thereby replenishing the shallow aquifer. In the context of this document, recharge wells are a key blue element that enhances climate resilience by mitigating urban flooding and improving groundwater security.

Currently, 50% of Bengaluru's water comes from groundwater. Groundwater has supported the growth of the city. Historically, Bengaluru housed many open wells. Owing to the rapid growth of the city, these wells have fallen into disrepair, and the **shallow aquifer** that these wells tapped into has dried up in some places.

In this context, the 'recharge well' is a tool for Bengaluru to reinvent its open-well heritage as a form of climate resilient 'blue infrastructure' that can be both retrofit into the existing city, as well as integrated into any new development or green field projects. The primary objectives of the recharge well are **groundwater recharge** and **flood mitigation** which supports urban cooling.

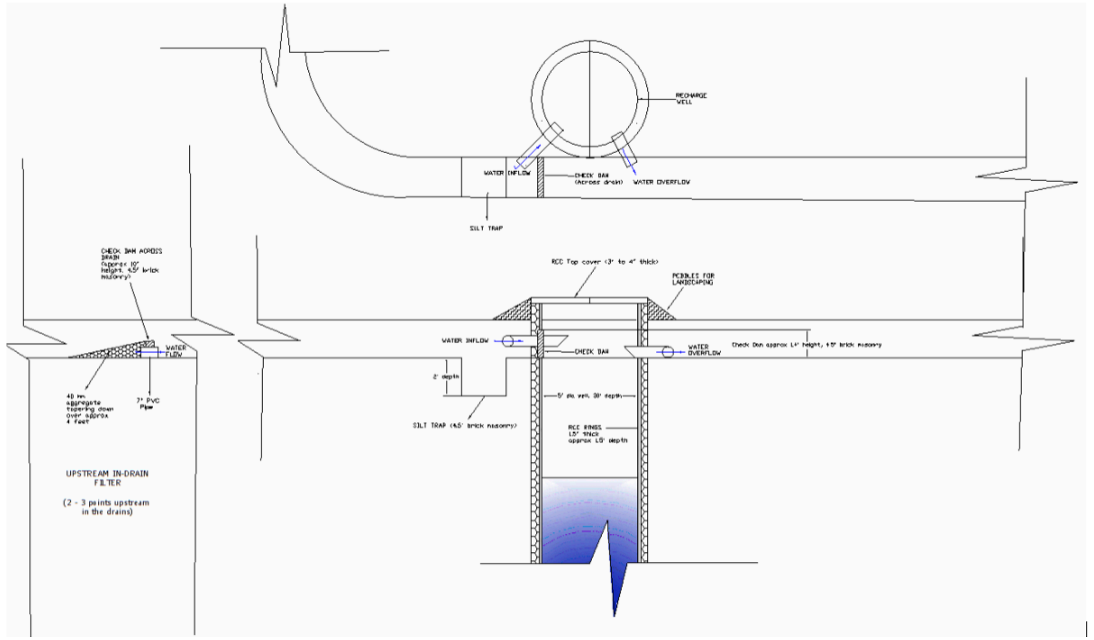


Figure 25: Technical diagram of recharge well.

The Bhovi community— an under-recognised community of well diggers— offers both skills and knowledge regarding local groundwater resources.The recharge well leverages these skills and knowledge. In the long term, the recharge well aims to revive the shallow aquifer, which is a resource underlying the heritage of the open wells of Bengaluru. Reviving and using the shallow aquifer provides an important pathway for climate resilience and mitigation for Bengaluru as it not only addresses drought and floods but also considers the fact that water from the shallow aquifer is water with the least embedded energy.

6.2 Importance in Urban Climate Context

Recharge wells offer one solution to the follwing two city problems:

- **Drought and Water Scarcity:** By recharging shallow aquifers (and the deeper aquifer through the shallow ones) with the rainwater runoff, recharge wells ensure that the 'grey infrastructure' does not cut off urban groundwater recharge.

- **Urban Flooding:** They intercept and infiltrate rainwater, particularly from rooftops and paved areas— both high-run off areas— thus reducing pressure on stormwater drains and mitigating urban flash floods resulting from rainwater runoff because of high rainfall.

The BWSSB Amendment Act 2010 provides technical guidelines for the capacity and design of rainwater harvesting for all properties in which recharge wells are an integral constituent (20 mm design). These technical guidelines were revised in 2020 based on the increasing rainfall pattern for Bengaluru (60 mm design). These guidelines therefore can be adapted based on changing rainfall patterns.

2010	RWH and specified volumes for rooftop and open area	**Rooftop (roof based):** 20 litres/sqm or more of roof area for storage and recharge **Open area (land based)**: 10 litres/sqm or more of land area
2020	Increasing the specified volumes for rooftop and open area	**Rooftop (roof based):** Not less than 60 litres/sqm of roof area for storage and recharge **Open area (land based):** Not less than 30 litres/sqm or more of land area

Table 5: Technical guidelines for capacity and design of rainwater harvesting under changing rainfall patterns.

Approximately 50% of Bengaluru's water comes from groundwater and groundwater problems have been well documented and reported in the media, particularly on the outskirts of the city. The 2023 drought in Bengaluru demonstrated that the outer wards of Bengaluru which depend exclusively on groundwater, were the most vulnerable. Case studies at the layout scale have established both the flood mitigation and groundwater recharge potential of recharge wells (urbanwaters.in). Recharge wells must be implemented and the shallow aquifer must be monitored across the city at scale.

6.3 Key Steps for Implementation

Identify the Catchment Area
Where is the rainwater coming from?

Finalise Size and Location of Recharge Wells
Based on runoff volume and size constraints

→ These two steps are critical where there are chances for maladaptations.

Call Well Diggers to Dig a Recharge Well
Based on site condition take quotation from well diggers

Well Diggers Will Buy, Transport and Place RCC Rings
Lower RCC rings individually into the pit

Well Diggers Will Fill the Gap between RCC Rings and Well Walls
Jelly stones or appropriate fillers will be used

→ The recharge well is typically filled with filter media.

Plumber Will Fix Inflow and Outflow Connections
Pipes are ensured to be connected securely and sloped correctly

Well Diggers Will Cover Well: Safety Grill, Manhole, Peephole
Accessibility and safety are ensured

Use Excavated Soil or Ask Well Diggers to Shift the Soil
For landscaping, levelling, or shifting to a legal dumping place

Figure 26: Key steps for implementing recharge wells.

- **Identifying the catchment:** The catchment of a recharge well refers to the surface area where rain falls and is then directed into the well. To ensure effective recharge, one must ensure that every recharge well has an adequate catchment. A recharge well without a sufficient catchment is a waste of money. The nature and quality of the catchment significantly effects the volume and quality of runoff water.

- **Sizing and locating recharge wells:** The recharge well(s) should be located where water flowing from the catchment can easily flow into it. Therefore, recharge wells are typically located in 'low points' of the topography that water automatically flows down to. Depending on the location and the catchment available for the recharge well, it should be appropriately sized. Given that the size of the recharge well, in the urban context rarely exceeds 5 or 6 feet in diameter and 30–40 feet deep, it is better to distribute smaller-sized recharge wells across a large catchment area instead of attempting to install one large recharge well at the lowest point. The minimum size of a recharge well in the urban context is 2–3 feet in diameter and 15–20 feet deep. Catchments can be broken into appropriately smaller sizes and recharge wells distributed across the lower points of the catchment.

- **Soil excavation:** Recharge wells are best dug manually, as skilled well diggers can manage varying soil conditions. Well diggers should ideally avoid hard rocks, although they are not necessarily predictable. If hard rocks are encountered before the target depth, then digging must be terminated as continuing further is unsafe and uneconomical. Such locations are typically not suitable for recharge owing to low infiltration. Furthermore, the diameter of the well also limits the depth. For example, a well with a diameter of 2–3 feet should not exceed 15–20 feet, as fresh air becomes scarce. Larger-diameter wells can be installed deeper more safely due to better air circulation.

- **Buying, transporting and placing RCC rings:** After digging, RCC rings are placed vertically inside the well. These rings must be 6–8 inches smaller in diameter than the well to ensure proper placement. The gaps between rings are not plastered and the bottom is left unlined to allow water to percolate.

- **Filling the gap between RCC rings and well walls:** To prevent collapse, the gap between the RCC rings and the well wall must be filled tightly with 40 mm jelly (coarse aggregates). This procedure should be done after placing every two RCC rings. Proper supervision is critical to ensure consistent packing and to prevent weak zones. If gaps are not filled correctly, the structural integrity of the well is compromised, and the walls may collapse. This step provides lateral stability and supports both the rings and the surrounding earth, thus rendering it a crucial component of a safe and long-lasting well construction.

- **Plumbing work to connect the inflow and overflow:** Proper plumbing should be provided for the inflow and overflow of rainwater into the recharge well, through the cement rings via pipes or channels. It is important to ensure that the overflow pipe/channel is below the inflow pipe/channel. Whereas well diggers typically create openings to facilitate the plumbing, a plumber connects the pipes. Both the well diggers and plumbers should be supervised to ensure the proper alignment and size for the smooth entry and exit of rainwater.

- **Covering the well with a safety grill, manhole and peephole:** The well should be securely covered using a grilled or perforated RCC slab to avoid accidents. A manhole can be installed on the slab for inspection and maintenance. Peepholes in the slab allow one to monitor water inflow and levels. In deeper wells, a safety grill placed 2–3 feet below the slab (between two RCC rings) provides additional security. This grill must have a sufficiently wide central opening to lower a rope for retrieving water samples. All these features ensure safety and accessibility while maintaining the functionality of the recharge-well system.

- **Shifting or using excavated soil:** Excavation produces a large volume of soil, whose characteristics vary by location. This soil must be responsibly managed, not indiscriminately dumped. Depending on its quality, it may be used for landscaping, leveling, or gardening. Instructions should be given to the well digger about proper disposal or reuse. Reckless dumping can block drains, reduce public space usability, or cause erosion. Responsible soil management not only meets environmental standards but also contributes to the overall sustainability and aesthetics of the project site.

Figure 27: Images representing step-wise implementation of recharge wells.

6.4 Key Design Metrics and Indicators

Catchment Area in sq.ft.	Catchment Type	Runoff Coefficient	Runoff in KL for 60 mm rain	Number of Recharge Wells			
				3' dia x 20' depth	4' dia x 25' depth	5' dia x 30' depth	6' dia x 30' depth
				4 KL	9 KL	17 KL	24 KL
1200	Rooftop	0.9	6.0	2	1		
	Paved Open Area	0.5	3.3	1			
	Landscape	0.1	0.7				
1500	Rooftop	0.9	7.5	2	1		
	Paved Open Area	0.5	4.2	1			
	Landscape	0.1	0.8				
2400	Rooftop	0.9	12.0	3	1	1	1
	Paved Open Area	0.5	6.7	2	1		
	Landscape	0.1	1.3				
3200	Rooftop	0.9	16.1	4	2	1	1
	Paved Open Area	0.5	8.9	2	1	1	
	Landscape	0.1	1.8				
4000	Rooftop	0.9	20.1	5	2	1	1
	Paved Open Area	0.5	11.1	3	1	1	
	Landscape	0.1	2.2	1			

Table 6: Key metrics and indicators for recharge-well design.

6.4.1 **Performance Metrics**

The recharge rate test is a field-based method to evaluate the permeability of the aquifer and estimate the volume of water a recharge well can absorb. It involves measuring well dimensions, verifying the lateral inflow (indicating a shallow water table), and then rapidly filling the well to ground level using tanker water. Water level drops are recorded at regular intervals: every 15 minutes for 2 hours, every hour for 8 hours, and every 4 hours thereafter until the well is almost dry. This method helps estimate recharge volume and guides site suitability and design efficiency for urban groundwater recharge.

6.4.2 **Monitoring Tools**

Regular inspection through the peephole is essential to verify that rainwater is entering and exiting the recharge well as intended. After each rainfall event, the following must be performed: (1) view through the peephole to observe the inflow behaviour and check for any clogging or unexpected stagnation, (2) observe the water level with respect to the RCC ring elevations—record which ring the water reaches (for e.g. third ring from top) and (3) maintain a simple logbook or digital spreadsheet that lists the date, time and ring number reached.

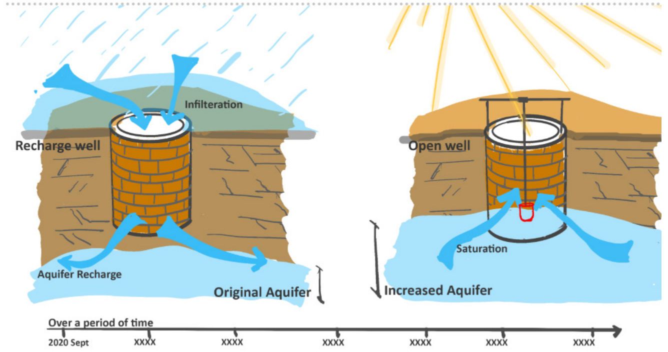


Figure 28: Recharge and open wells recharging an aquifer.

6.5 Tools and Resources

Please visit the 'urbanwaters.in' website and choose Bengaluru city. There are many relevant resources on recharge wells and other content pertaining to Bengaluru and its well diggers' directory.

- Drying borewells comic book
- Groundwater recharge case study in Bellandur
- Farm borewell recharge case study
- Technical paper on understanding Bangalore's shallow aquifer
- Wells as a solution for a layout's water seepage issue

If a recharge well is dug on your premises, upload the details to the Million Wells app. This will facilitate understanding the city's groundwater situation.

6.6 Partnership Models and Community Involvement

- Share your experience of digging a recharge well with your neighbours. Highlight the benefits you observed: reduced waterlogging, improved borewell yield, or simply the satisfaction of contributing to the environment. When the neighbours see visible changes, they are more likely to act. Talk about the simplicity of the process, the costs involved and the maintenance required. Encourage those around you to dig their own recharge wells — it's a small yet important step with long-term benefits for your house, layout, street, or apartment community.

Figure 29: Recharge well.

Figure 30: Well diggers at a recharge well.

- Well diggers offer knowledge from their experience; therefore, please listen to their suggestions and consider them. Mannu Vaddars possess generations-old knowledge about local groundwater and are generally aware of the suitability of a particular location for recharge. Their work, which is is deeply tied to their identity, blends technical skill with a profound understanding of soil, rock and their interaction with water.
- Share your data with the city and remember that the plumber, well digger and mason are your partners.

6.7 Design Considerations for Effective Implementation

- **Insufficient catchment connection** reduces the volume of water reaching the recharge well, thus limiting its effectiveness.
- **Unclean or poorly maintained catchments** lead to clogging from silt, leaves and debris, thus affecting recharge rates. Use of chemicals, soaps and detergents affect the quality of water for recharging.
- **Avoid digging recharge wells** extremely close to septic tanks or soak pits, electrical cables, house foundations and hard rocks that are extremely close to the surface.
- **Improper inlet design** can cause water stagnation or backflow; inlet pipes must be properly sloped.
- **Undersized inlet and overflow pipes** may not accomodate peak rainfall volumes — sizing should follow **National Building Code** guidelines.
- **Missing or incorrectly placed overflow pipes** can result in flooding around the well; they should be installed just below the inlet level and connected to stormwater drains.

6.8 Pathways to Scale: Institutionalising Recharge Wells for Groundwater Security

To successfully scale recharge wells across Bengaluru, several strategic actions can be implemented, as follows:

- **Strengthening Byelaws:** BBMP's recharge-well regulations should be aligned and strengthened with Bangalore Water Supply and Sewerage Board (BWSSB) byelaws to ensure a consistent implementation across the city. Compliance verifications can be incorporated into building approvals and renewals.
- **Awareness and Recognition Campaigns:** Launch city-wide campaigns featuring success stories and case studies from various land use categories (individual houses, small apartments, large apartments and layouts). Establish annual awards for best practices in groundwater recharge to motivate communities.
- **Training and Empanelment:** Regular training programmes should be conducted for plumbers, masons, and consultants to standardise design and maintenance. BBMP can empanel trained professionals, thus ensuring quality installation and service.
- **RWH Theme Park as a Hub:** The Rainwater Harvesting Theme Park can become a centre of excellence, that promotes awareness, training, and recognition programmes. It can collaborate with NGOs and knowledge partners to deliver workshops, host demonstrations, maintain a resource library and serve as a public engagement space, thus rendering water literacy accessible to all.

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SCAN AND VIEW

Webpage of Bengaluru Climate Action Cell