HOW WATER FLOWS THROUGH BENGALURU

Urban Water Balance Report

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About WELL Labs

Water, Environment, Land and Livelihoods (WELL) Labs co-creates research and innovation for social impact in the areas of land and water sustainability. We design and curate systemic, science-based solutions using a collaborative approach to enable a high quality of human life while simultaneously nurturing the environment.

WELL Labs is based at the Institute for Financial Management and Research (IFMR) Society. Together with Krea University and other centres at IFMR, such as the Abdul Latif Jameel Poverty Action Lab (J-PAL) South Asia and Leveraging Evidence for Access and Development (LEAD), WELL Labs is part of an ecosystem of labs and research centres with a mission to help prepare for an unpredictable world.

WELL Labs started as an autonomous centre in April 2023. It began with a set of projects that the Centre for Social and Environmental Innovation (CSEI) at the Ashoka Trust for Research in Ecology and the Environment (ATREE) had initiated.

Dr Veena Srinivasan, a water expert with 20 years of experience, set up WELL Labs in 2023. She is leading the centre's mission to transform scientific research into real-world impact by designing solutions that simultaneously create livelihoods and conserve the environment.

About the Urban Water programme

The impacts of flooding and urban drought are expected to worsen as more people live in cities, more and more land is built up, and extreme climate events grow more intense and frequent.

The Urban Water programme at WELL Labs designs pathways towards water-resilient cities. We do this by addressing knowledge gaps to enable effective decision making and building coalitions between governments, market players and civil society groups.

We focus on:

- Aggregating data and drawing actionable insights
- Building an ecosystem for water resilience
- Co-creating evidence-based and user-centric solutions
- Designing market instruments and policies

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LIST OF ABBREVIATIONS

AWWA	American Water Works Association
BBMP	Bruhat Bengaluru Mahanagara Palike
BWSSB	Bangalore Water Supply and Sewerage Board
CETP	Common Effluent Treatment Plant
C&I	Commercial and Institutional
DSTP	Decentralised Sewage Treatment Plant
HSG	Hydrologic Soil Group
IMD	Indian Meteorological Department
JICA	Japan International Cooperation Agency
JRC	Joint Research Centre
KC Valley	Koramangala Challaghatta Valley
KSNDMC	Karnataka State Natural Disaster Monitoring Centre
KSPCB	Karnataka State Pollution Control Board
KL	Kilolitres
KLD	Kilolitres per day
LULC	Land Use and Land Cover
MLD	Million Litres a Day
MID	Minor Irrigation Department
NRW	Non Revenue Water
RCC	Reinforced Cement Concrete
STP	Sewage Treatment Plant

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EXECUTIVE SUMMARY

Bengaluru's water problems may seem contradictory. In the height of summer, borewells and lakes dry up and tankers supply water from afar. During the monsoon, large parts of the city face severe flooding. But these problems are interconnected.

With abundant rainfall (>900 mm annually over the last five years) and little room for recharge, wells run dry as drains overflow. Despite being allocated water from the Cauvery river, the expanding city, particularly the newer suburbs, has become increasingly dependent on a fast-depleting resource – groundwater. Moreover, even as consumption has increased, the amount of wastewater treated by centralised infrastructure remains low.

To address this crisis, we need a better understanding of Bengaluru's water system.

Local efforts are being made in response to different facets of the problem, considering the city's growth has long outpaced state infrastructure. The applicability of decentralised and low-cost technologies targeting rainwater harvesting, groundwater recharge and wastewater treatment have been demonstrated in Bengaluru time and again. Regulations for property owners to upscale rainwater harvesting are on the rise. Innovative green infrastructure systems to treat polluted water are being implemented. Examples of citizen-led efforts to locally manage wastewater are plenty. At a broader scale, campaigns to rejuvenate groundwater, restore lakes and revive drainage canals have gained traction.

The challenge that remains is that many of these efforts are being implemented in small scales and by different groups of stakeholders without an overarching strategy. Clearly, the city is in need of an integrated urban water management plan. However, some immediate questions that emerge are: where is Bengaluru's water, how much is there and in what condition?

To plan towards a city's long-term water security, a necessary starting point is to have a comprehensive view of its water system.

Essentially, urban water systems consist of complex patterns of water extraction, consumption and discharge, bound by the city's broader hydrological context.
To elaborate on the case of Bengaluru, the city relies on two main water sources extracted from within and outside its watershed. Around 1,460 million litres a day (MLD) of water from the Cauvery is transported from a reservoir 90 km away from the city. Groundwater, fed by seasonal rains through lakes and green spaces, is an important supplementary source. However, the exact amount of groundwater extracted daily is challenging to estimate due to the range of informal mechanisms through which urban activities access groundwater.

Public water supply, delivered by the Bangalore Water Supply and Sewerage Board (BWSSB), is concentrated in central areas of the city, where the population is lower than in rapidly growing suburbs. Where public infrastructure is absent, consumers, including a majority of commercial entities, have turned to groundwater accessed through private borewells, tankers and open wells.

The resultant wastewater is treated, reused and/or discharged through a variety of channels. Centralised sewage treatment plants (STPs) in Bengaluru treat only about 1239 MLD. Decentralised treatment plants supplement public infrastructure, but they are more challenging to manage and monitor. The remaining wastewater generated by the city goes untreated, often finding its way into lakes and groundwater.

The city's hydrological characteristics are crucial to how these flows occur.

For instance, water drainage patterns are influenced vastly by Bengaluru's undulating terrain. The undulations are also why Bengaluru's network of lakes and channels are pivotal to managing urban floods — the lake system was designed to manage surpluses by allowing water to cascade from one lake to another. Further, Bengaluru is divided hydrologically into three major watersheds, which are unique in their characteristics — they vary in terms of soil, topography and even groundwater recharge and storage capacities.

Lastly, seasonal fluctuations in freshwater availability is another key factor. The fluctuations are primarily driven by the concentration of rainfall between June to November. After lakes fill up as the monsoons start, even light showers can flood the city when the water has nowhere to go.

Consumption patterns fluctuate too. Green spaces and the construction industry consume more water during drier months. Domestic consumers are more likely to be dependent on water tankers when their borewells are running dry in the summer. Several interventions, such as rainwater harvesting and green infrastructure, can be planned to balance water availability between wet and dry months. However, a starting point for planning is to understand how the fluctuations look across various stages of the urban water system and how significant they are.

A City Water Balance is a summary of all flows in the urban water system.

It provides a quantified basis for urban flows; water resources feeding the city, areas of significant usage, losses, discharge and storage. The consolidated data is visualised as a 'water flow diagram' to understand how water moves through different parts of the urban water system. For example, information on Bengaluru's allocated water from the Cauvery may be easy to find. But how much water actually reaches consumers? How much groundwater is extracted to supplement the city's needs? How much is being recharged back underground? Information on the capacities and location of Bengaluru's centralised wastewater treatment plants is available. However, how much of Bengaluru's wastewater currently being treated is really being repurposed? How much wastewater goes untreated and where does it end up?

The water flow diagram accounts for all the water flows within the system, including the interdependencies. Through this process of mapping, the water flow diagram is also useful in identifying knowledge gaps. Taken a step further, the water flow diagram can be used to assess the implications of potential interventions, too. If the city was to maximise its wastewater reuse, how much would it reduce the pressure on the Cauvery? If all building roofs harvested rainwater for consumption, how would it change the city's dependence on groundwater? What area of green spaces and wetlands need to be protected or reclaimed to effectively address seasonal flooding?

Quantifying a City's Water Balance opens up many discussions.

We began this exercise of quantifying Bengaluru's water flows as a first step towards answering several conceptual questions on water management in the city.

We wanted to explore alternative pathways towards meeting Bengaluru's water demand without increasing supply from the Cauvery river. We also wanted to quantify the dual nature of the city's water crisis by investigating the difference in water availability in the wet and dry seasons.

This exercise underlined the need to develop an integrated strategy that can simultaneously leverage Bengaluru's 'three taps' besides water drawn from the Cauvery river: groundwater, rainwater and wastewater – keeping in mind the seasonal nature of the city's water issues.

Through primary data collection, analysis of secondary data sources and hydrological modelling, we drew the following key insights from the estimates:

Total demand for freshwater is ~2,632 MLD.

This is a high number compared to the city's current claims over various sources . With population growth, the city will not be able to meet its water needs with existing resources. The main consumers of water are the city's residents (72% of the total water extracted), commercial and institutional establishments (8%) and the industrial sector (17%). The construction sector consumes an additional 2% – on average.

Groundwater caters to nearly 50% of Bengaluru's water demand, the rest from the Cauvery.

In addition to 1,460 MLD of Cauvery water, Bengaluru currently consumes an estimated 1,372 MLD of groundwater. This is worrying because groundwater recharge rates remain significantly lower than extraction rates. Natural groundwater recharge through green spaces and water bodies is as low as **148 MLD**. Rapid urbanisation is eroding what's left of the city's green spaces and lakes; it is critical to maintain them to recharge shallow aquifers with rainwater during the wet season.

Recharge from anthropogenic sources, through pipeline leaks, for instance, is higher at **331 MLD**, but this is an estimate. This is relevant because the BWSSB also expends a huge amount of state funds in transporting water from the Cauvery to different parts of the city. Accounting for losses accurately is necessary to more systematically document how much of it actually recharges aquifers. Since NRW losses replenish aquifers, fixing leakages could lead to a dip in how much water percolates below. Scaling up rainwater harvesting could offset these losses.

The total wastewater produced by the city is ~1,940 MLD.

Around 63% of this wastewater is treated by centralised treatment plants, and 13% by decentralised treatment plants. 24% goes untreated. Of the total wastewater generated in the city, only a meagre 30% is reused (both within Bengaluru and beyond).

There is huge potential here to scale up wastewater treatment infrastructure in the city and promote reuse for a range of activities such as construction and greening public spaces. This would significantly ease the pressure on freshwater sources.

Run-off in the wet season (Jun-Dec) is 73% higher than that in the dry season (Jan-May).

Total rainfall in the wet and dry seasons amounts to 2,149 MLD and 1,322 MLD, respectively. However, utilisable run-offs from the total rainfall is **~982 MLD** in the wet season and **~568 MLD** in the dry season. This is a big seasonal difference and also highlights the problem of flooding in Bengaluru.

As mentioned above, green spaces can absorb a lot of the run-off; approaches such as 'sponge cities', must be considered. Cities can be planned to 'make room for the rain' and allow fallow spaces to become temporary thriving wetlands or even green recreational spaces that can hold excess flood water, while contributing to other benefits such as boosting overall livability and acting as carbon sinks. Sponge cities do exactly this.

Lakes receive and store both rainwater and wastewater and store groundwater.

The cascading lake systems of Bengaluru play an important role in draining water from the city, especially in the Hebbal and Koramangala-Challaghatta valleys, due to greater undulations in their terrain. Inlets, outlets, and stormwater drains that did exist were either broken or encroached upon by other structures. With the loss of these connections, we found that many lakes have become isolated from the system, causing them to dry out.

Flooding is another problem in many parts here since there is no path for the water to flow and reach the next lake. It is vital to explore strategies that restore the city's 'green-blue' infrastructure, i.e. green spaces and water bodies, to balance excess stormwater flows. Reuse of treated wastewater is also relevant here because, currently, lakes are full of treated wastewater and do not have the capacity to act as flood buffers.

Algal growth in the Rachenahalli lake in north Bengaluru. Credit: Shashank Palur

This exercise is based on existing available data and the simulations we carried out based on it.

We do not claim that these are accurate numbers but they do indeed serve as reasonable estimates. Through the process of quantifying the water balance, we were able to uncover the various kinds of data gaps that exist in Bengaluru's water system. Nearly all the flows were estimated based on several assumptions and projected figures from past research. We have detailed all the assumptions we operated under, as well as the data sources and estimation methods we used to quantify Bengaluru's water system.

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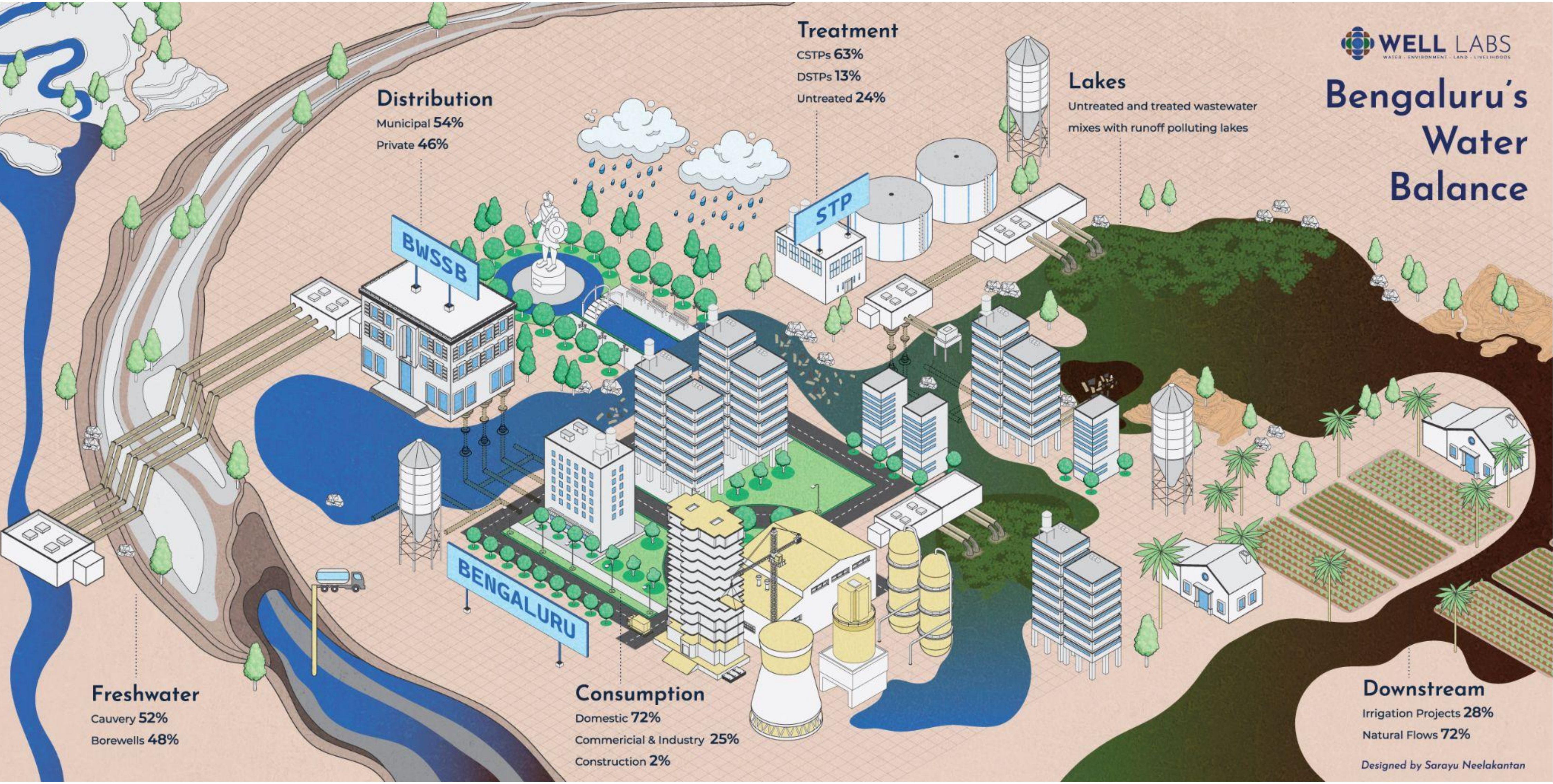
Bengaluru's Water Balance



Freshwater
Cauvery **52%**
Borewells **48%**

Distribution
Municipal **54%**
Private **46%**

Consumption
Domestic **72%**
Commericial & Industry **25%**
Construction **2%**

Treatment
CSTPs **63%**
DSTPs **13%**
Untreated **24%**

Lakes
Untreated and treated wastewater mixes with runoff polluting lakes

Downstream
Irrigation Projects **28%**
Natural Flows **72%**

Designed by Sarayu Neelakantan

1. TOWARDS WATER SECURITY

Why Bengaluru needs an urban water balance

Garbage strewn on the banks on Bellandur lake in Bengaluru. Credit: Shashank Palur

To plan towards a city's long-term water security, a necessary starting point is to have a comprehensive view of its water system. Essentially, urban water systems consist of complex patterns of water extraction, consumption and discharge, bound by the city's broader hydrological context.

The city of Bengaluru relies on two main water sources imported from outside its boundary and extracted from within.

From a reservoir 90 kilometres away and ~350 m lower than the city's elevation, a mammoth 1,460 million litres a day (MLD) of water is extracted from the Cauvery to quench the city's needs (JICA, 2017). Water from the river, the centre of a long-standing dispute between the states of Karnataka and Tamil Nadu (Ramakrishnan, 2023), amounts to ~55% of the city's freshwater needs.

A crucial point to note here is how energy-intensive this process is. The river doesn't flow through Bengaluru and the city's water utility, the Bangalore Water Supply and Sewerage Board (BWSSB) has to spend approximately Rs. 3 crore per day as electricity charges to pump the water over such long distances to fulfil just half the city's water needs (Bangalore Mirror, 2023).

The second source is groundwater, replenished by seasonal rains that percolates through the city's famed water bodies and green spaces. This amounts to 48% of the city's freshwater needs. Here too, there is a high pumping cost; it is estimated around Rs. 2.7 crore per day, almost as much as importing water from the Cauvery. This figure does not account for transportation of water by tankers.

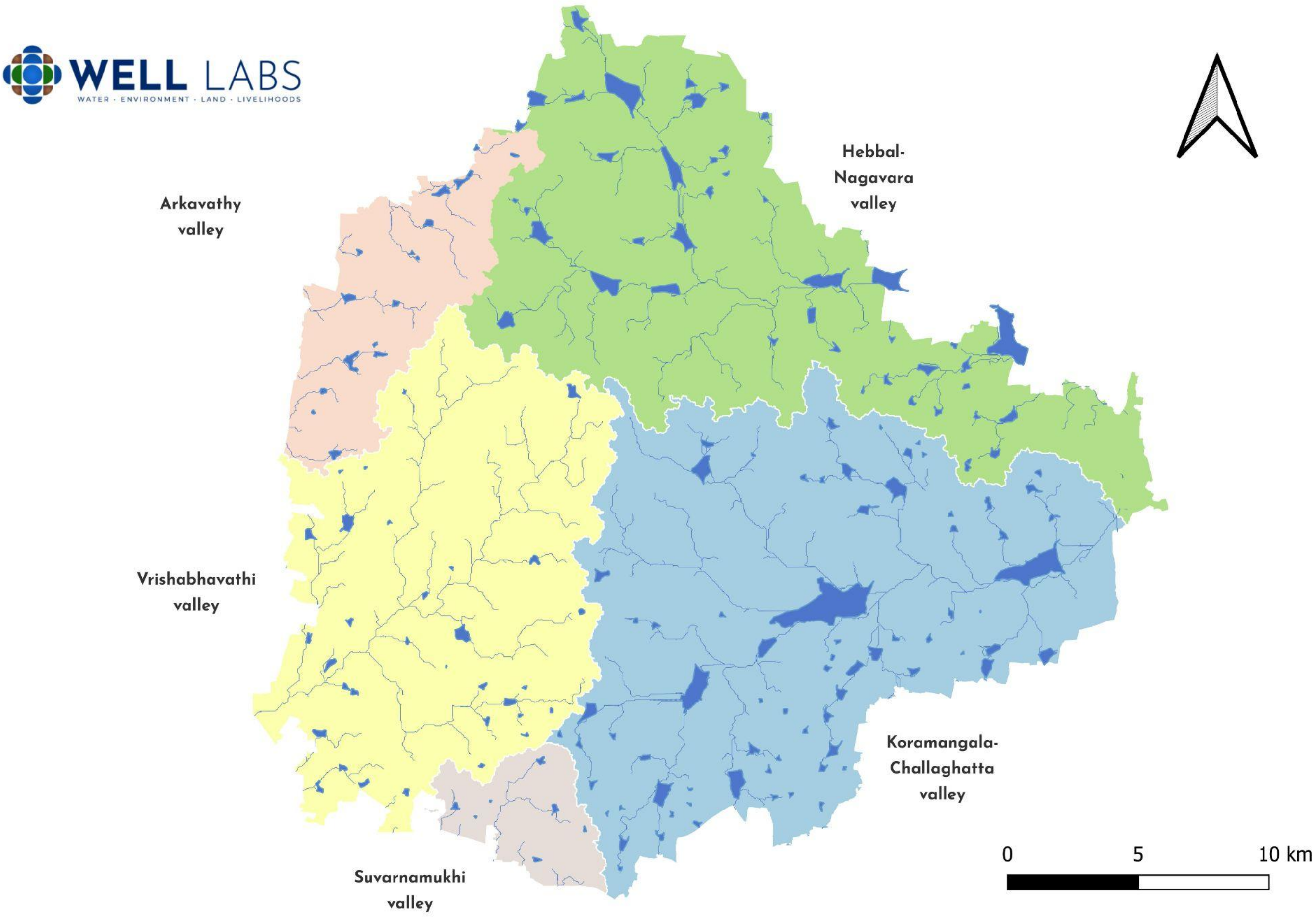
Public water supply, delivered by the BWSSB, is concentrated in central areas of the city, where the population is lower than in rapidly growing suburbs (Sharma, 2019). Where public infrastructure is absent, consumers, including a majority of commercial entities, have turned to groundwater accessed through private borewells, tankers and open wells (Apoorva et al, 2021; Sekhar et al, 2018). Although rainwater harvesting is mandatory, the vast majority of buildings harvest rainwater for recharge rather than direct use. A small but growing number of residents and institutions have invested in sub-surface or on-surface storage to enable them to use a substantial amount of rainwater for direct use .

The resultant wastewater is treated, reused or discharged through a variety of channels. Centralised sewage treatment plants (STPs) in Bengaluru treat only about 1,239 MLD which is 63% of the total wastewater generated. Decentralised treatment plants supplement public infrastructure with a capacity of around 250 MLD. But these are more challenging to manage and monitor. The remaining wastewater goes untreated, often finding its way into lakes and groundwater. Untreated wastewater amounts to at least 24% of total wastewater generated.

The city's hydrological characteristics are crucial to know how these flows occur.

For instance, water drainage patterns are influenced vastly by Bengaluru's undulating terrain (Gowda & Sridhara, 2007). The undulations are also why Bengaluru's network of lakes and channels are pivotal to managing urban floods— the lake system was designed to manage surpluses by allowing water to cascade from one lake to another.

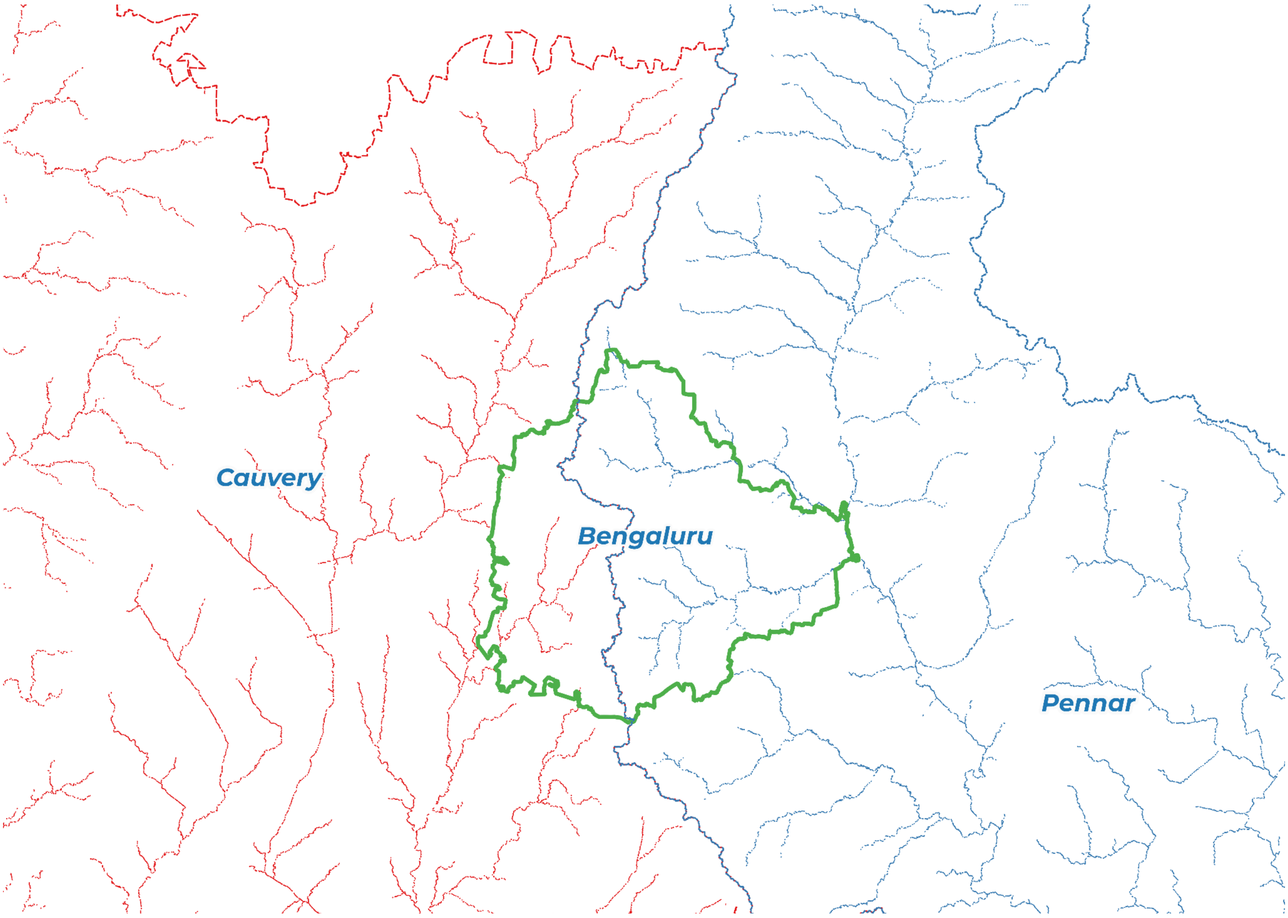
Figure 1: The major watersheds of Bengaluru



Watersheds of Bengaluru. Prepared by Rashmi Kulranjan and Shashank Palur.

Further, Bengaluru, lying on the watershed divide between the Cauvery and Dakshina Pinakini river basins, is divided hydrologically into three major watersheds (Ramachandra & Mujumdar, 2009). The Vrishabhavathi-Arkavathy valley drains into the Cauvery basin, whereas, the Hebbal and Koramangala-Challaghatta valleys drain into the Dakshina Pinakini river. The watersheds are unique in their characteristics — they vary in terms of soil, topography and even groundwater recharge and storage capacities (Srikantaiah, 2017).

Figure 2: Watershed divide between the Cauvery and Dakshina Pinakini river basins



There are two river basins that influence Bengaluru's hydrology. Prepared by Shashank Palur.

Lastly, seasonal fluctuations in freshwater availability is another key factor. The fluctuations are primarily driven by the concentration of rainfall between June to November, when the southwest monsoon sets in over the Indian subcontinent. Lakes play an important role in storing stormwater during the peak rainy season. But the problem now is that the city once renowned for over a thousand lakes is, at present, just left with a few hundred. Rapid urbanisation and the complex history of governance and stewardship for these lakes have resulted in them either being encroached upon, degraded or isolated from the cascading chain over time. This means when the city's remaining water bodies and fragmented stormwater drains fill up as the monsoons start; even light showers can flood the city when the water has nowhere to go, especially in low-lying areas.

Consumption patterns fluctuate through the year too. Green spaces and the construction industry consume more water during the drier months. Domestic consumers grow more dependent on water tankers, most of which ply water from the outskirts of the city, when their borewells run dry in the summer.

Rain clouds loom over Bengaluru city. Credit: P. Jeganathan via Wikimedia Commons

There are several interventions, such as rainwater harvesting and green infrastructure, that can be planned to balance water availability between the wet and dry months. A starting point for planning is to understand how the fluctuations look across various stages of the urban water system and how significant they are.

Understanding the urban water balance in a comprehensive manner is critical because water flows are interlinked.

For instance, leaking pipelines contribute to groundwater recharge; treated wastewater feeds the lakes which in turn recharge groundwater and so on. Plans to divert or reuse any one of these flows, would have implications on other parts of the water and wastewater system. Therefore, a comprehensive view of the urban water balance is key.

Through secondary datasets, primary data collection and hydrological modelling, we have striven to prepare an accurate picture of Bengaluru's flows and stores of water.

2. URBAN WATER BALANCE CHART

Summarising a city's flows and stores of water

A city water balance summarises all the flows of water in the urban system.

It provides a quantified basis for water flows – water resources feeding the city, areas of significant usage, losses, discharge and storage.

A number of data points are needed to develop the diagram— these include data on hydrogeology, topography, land-use and land cover, demography and consumption patterns across sectors. The consolidated data is visualised as a 'water flow diagram' to understand how water moves through different parts of the urban water system. In the case of Bengaluru, a water balance chart can visualise:

- Available freshwater sources: Cauvery river, groundwater replenished - to an extent - by rainfall
- Distribution of freshwater to consumers through private and public water supply systems
- Water losses in the supply system (unaccounted for)
- Water demand across major urban sectors (domestic, commercial, industrial) and the wastewater produced
- Total amount of untreated and treated wastewater (through centralised/decentralised systems)
- Reuse of treated wastewater
- Water discharge into lakes and rivers downstream.

The water flow diagram accounts for all the water flows within the system, including the interdependencies. Through this process of mapping, the diagram can pinpoint knowledge gaps.

Taken a step further, the water flow diagram can be used to assess the implications of potential interventions too. For example, it can be used to visualise how freshwater demand will change if the city was to maximise wastewater reuse and rainwater harvesting. It can also be used to visualise how much more green spaces and wetlands the city needs to reduce the impact of seasonal floods.

The possible discussions stemming from a city water balance are many. Fundamentally, when there is a comprehensive overview of the various processes within an urban water system, it becomes easier to analyse how strategies can simultaneously address multiple dimensions of water security planning.

The Sankey diagram is an effective visual tool.

The urban water cycle is not a linear process, which is why it is important to choose a visual tool that can summarise urban water flows and their interdependencies.

Figure 3: A representation of a Sankey diagram capturing water flows in cities.

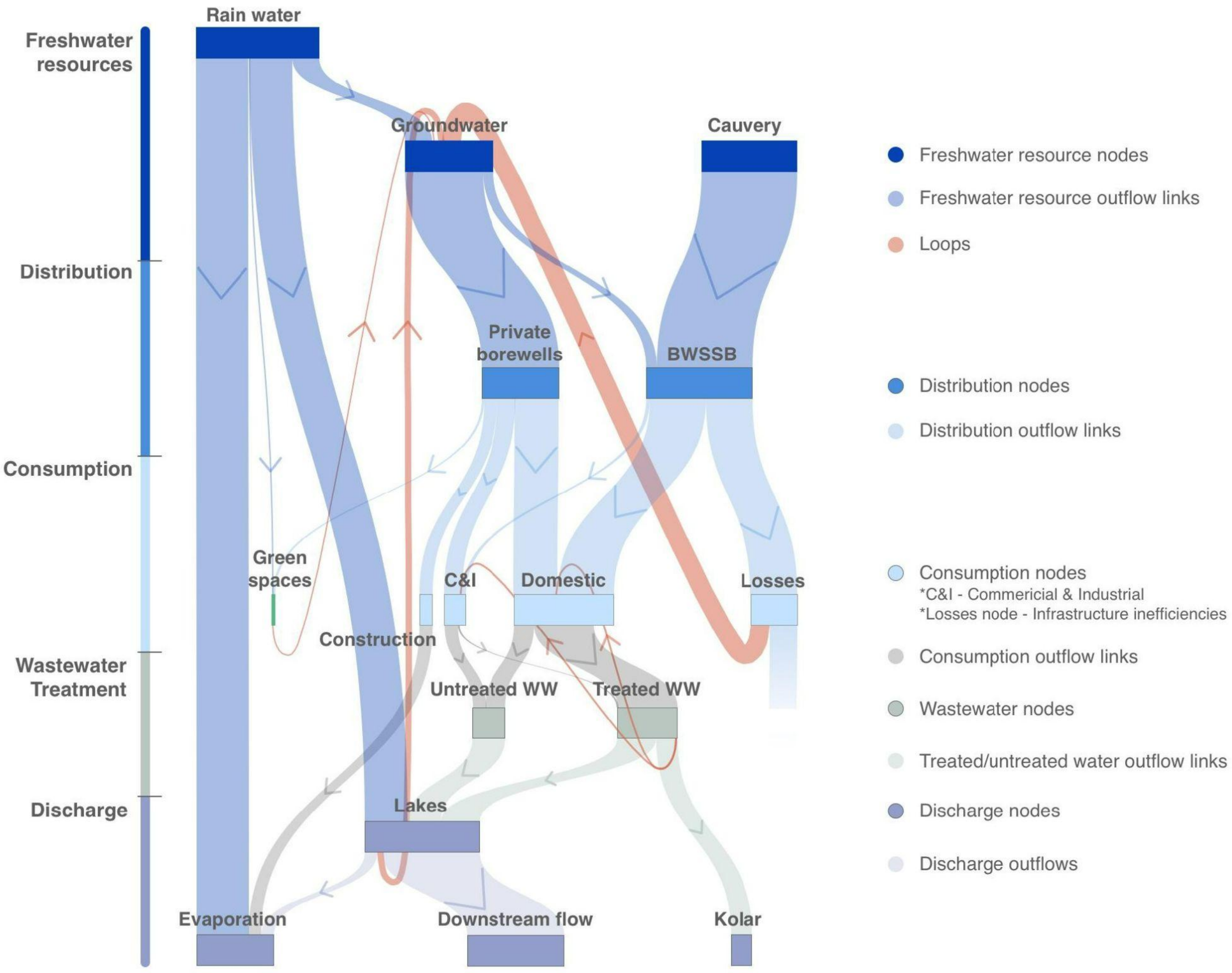


Diagram prepared on Figma by Muhil Nesi

The diagram presented above is divided into five phases of the urban water cycle. Each phase consists of nodes and links. The nodes represent important components within the system. They are connected by links that represent inflows and outflows. The widths of the nodes and links are meant to be proportionate to the actual water quantities in each phase of the water system.

The basis of the water flow diagram is the water balance equation:

Total inflow - total outflow = Change in storage + usage in the urban system

Here, 'system' refers to a defined geographical area where the flows are measured within a defined period of time. Inflows represent all the freshwater resources entering the city or extracted from within the city (rain, Cauvery river water and groundwater). Outflows are all the ways in which water leaves the urban system, such as evaporation and downstream flows (lake overflows and surface runoffs that eventually join the rivers). There are outflows at each of the five phases too. These represent the form in which water leaves the nodes in each phase of the cycle.

The water balance equation implies that the outflows from each node should be equal to the inflows in most cases. In cases where they are not equal, the difference in quantities should equal a change in water storage or usage occurring at that node.

For example, at the groundwater node at the top of Figure 3, the outflows are greater than the inflows (as seen through the total width of the inflow and outflow links). This suggests that the city's groundwater extraction is significantly greater than the amount of water being recharged. This is only possible because the city has water reserves deep underground that are rapidly being depleted. So, the difference in outflows and inflows at the groundwater node can be explained by the reduction in water storage in underlying aquifers.

A second example can be understood through the consumption nodes. At the two nodes representing domestic and commercial and industrial consumption, the amount of water consumed by the sectors is greater than the wastewater produced (again, as seen through the total width of the links). This is because some water is lost in consumption processes. For the construction sector, the loss in consumption is mainly through evaporation. But in the other sectors, consumption processes are so diverse that though the amount of wastewater produced can be roughly estimated, the specific types of losses are hard to account for.

At a broader level, this rule implies that the total quantity of freshwater resources extracted/received should be equal to the water lost through usage, evaporation, downstream flows and infrastructure inefficiencies.

Further, the movement of water within the cycle is non-linear; water doesn't simply move from one phase to the next. There are several loops in the system to be considered. For example, when it rains, water reaches lakes and green spaces, which in turn rejuvenate groundwater aquifers. (Such loops are represented by red links in Figure 3.) Identifying such loops is important to understanding interdependencies—these are key to developing strategies. Going back to the example of groundwater, the diagram illustrates that lakes and green spaces are important for aquifer recharge. So, Bengaluru's water security is dependent on the land made available for green spaces and lakes that help capture and store rainwater.

This is why governance is key. Before we dissect each stage of the city's water balance, it is important to first establish the different organisations and sectors involved in the management of Bengaluru's water resources.

A park in Bengaluru being watered with treated wastewater. It's important to understand loops in the system; water leaches through parks and lakes to recharge aquifers. Credit: Sneha Singh

3. WATER GOVERNANCE IN BENGALURU

Multiple agencies are involved in managing water

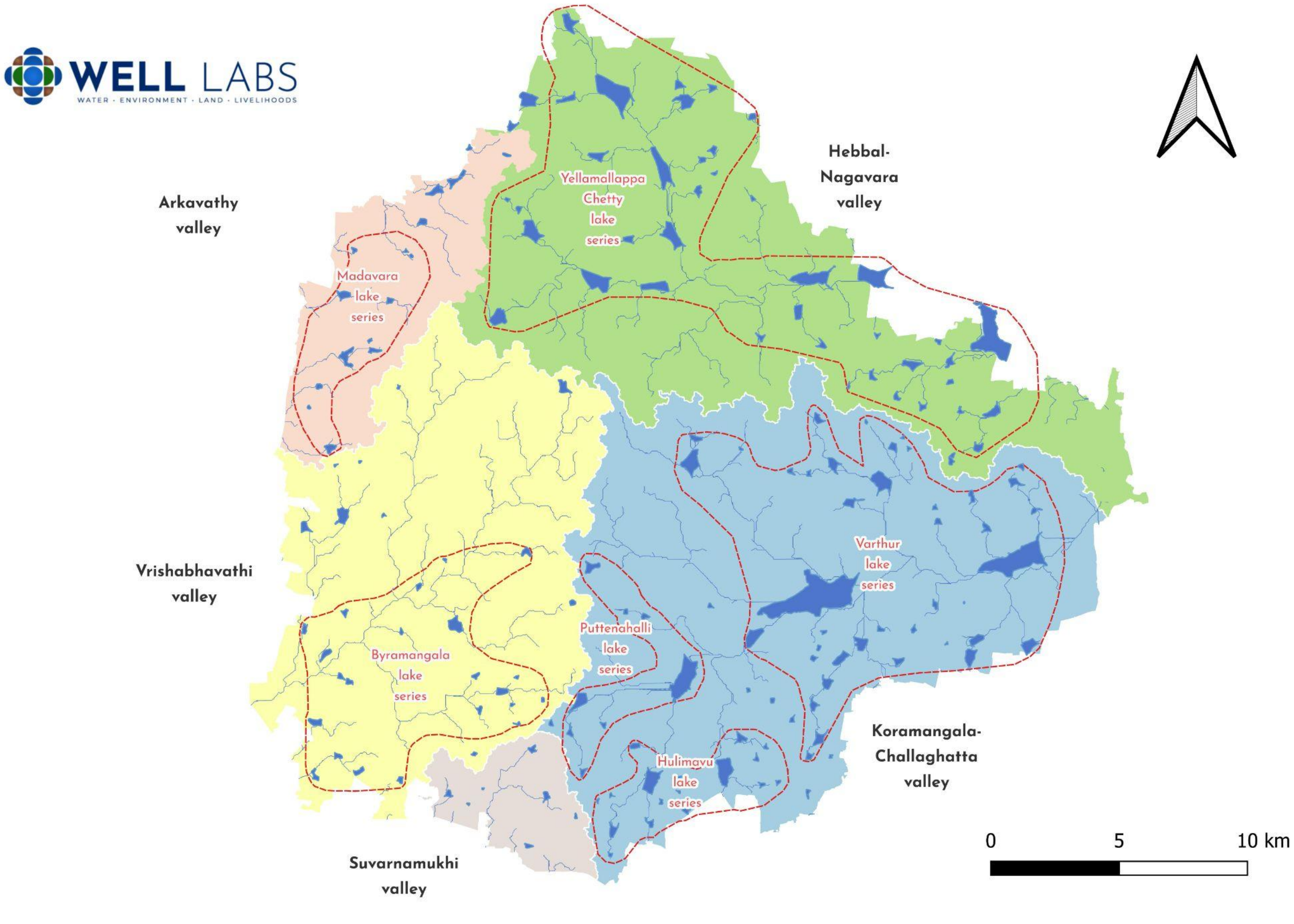
Algal growth on Rachenahalli lake. Credit: Rashmi Kulranjan

The flows of water and wastewater in the city, both current and historical, are determined by the governance of water by a myriad of agencies. Indeed, one of the main reasons for the absence of a comprehensive view of the city's water and wastewater is the fragmentation of jurisdiction. Different components of the system are governed by different agencies, some at the municipal and others at the state level.

Without a single agency to coordinate work and ensure water is managed holistically, the city suffers, apparent from the recent floods and water pollution.

Before the era of piped water supply, Bengaluru's lake system, dating back to at least the 6th century, was central to its domestic and economic growth (Sen et al., 2020). Past rulers, landowners and local chieftains invested to expand and maintain lake infrastructure (Nagendra, 2019). Most of the city's water bodies were originally 'tanks', rainwater harvesting structures constructed to serve irrigation and livestock purposes, although a few like Sankey Tank in north Bengaluru were built to serve the drinking water needs of the British cantonments. Despite centuries of effort that went into building the region's water resilience, lakes eventually began to lose their importance with the introduction of piped water supply around the 19th century. It also marked a shift in the approach to urban water governance. The lakes began to be viewed as primarily aesthetic and recreational. For purposes of this report, we will refer to the water bodies as 'lakes', regardless of their original intent.

Figure 4: Some of the larger lake systems of Bengaluru. The networks have been fragmented due to encroachment into lakes and connecting canals/rajakaluves.



Earlier, the cascading lake system required decentralised management based on traditional knowledge. These common pool resources remained crucial in water planning as livelihoods were directly dependent on them. Piped water supply brought a shift towards centralised technocratic governance.

Decision making in Bengaluru's water sector became a complex and time-consuming process, with the involvement of many governing bodies such as the Government of Mysore, city municipality, the military and the engineering department of the Government of India — and this was a century ago (Elmqvist et al, 2013).

Today, the network of government and non-government actors shaping the city's water has grown in complexity. Even so, managing water in a rapidly expanding city is no easy task.

To begin with, the city's limits are hard to define, simply because it keeps changing over time (UN Habitat, 2020). To keep up, institutions and their jurisdictional responsibilities have also needed to expand and evolve (Prasad, 2018). Several jurisdictions in and around Bengaluru have been created in order to manage urban development along with the larger region that the city depends on and influences. How different institutions (focusing on different jurisdictions) coordinate with each other is particularly important in water governance, because water moves across boundaries — be it groundwater, rivers or lake systems.

In addition to jurisdictional responsibilities, government agencies also oversee different functions or components of the urban water system.

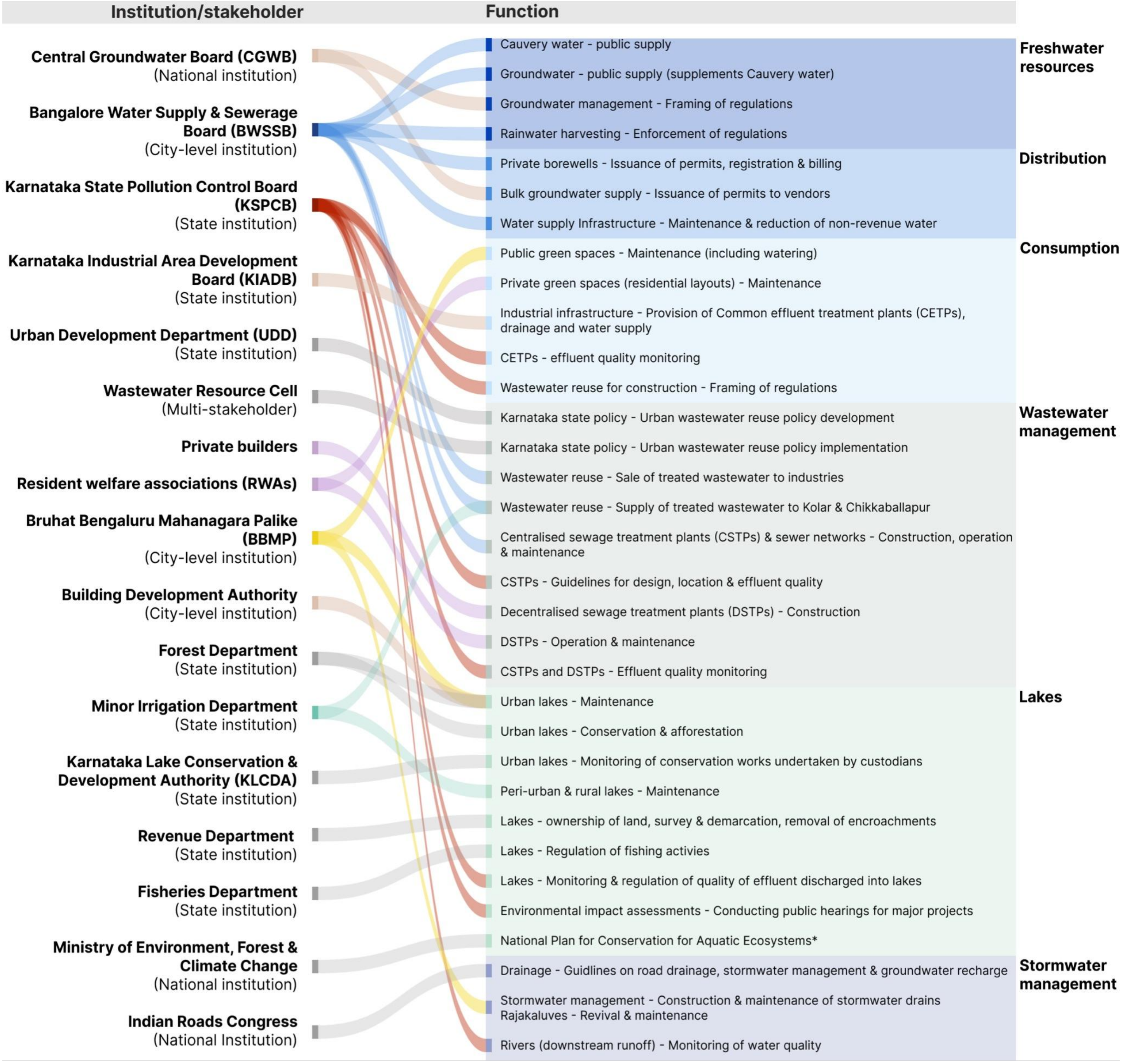
Very often, each of the functions is within the purview of local, state and national institutions. While national- and state-level institutions typically develop policies and regulatory frameworks, local bodies have a more operational role.

Take, for example, the arrangement between the Bengaluru Water Supply and Sewerage Board (BWSSB), Chikkaballapur and Kolar districts to manage wastewater. The agreement between these institutions is that treated wastewater from Bengaluru is to be used to rejuvenate lakes in Chikkaballapur and Kolar. The BWSSB is responsible for building and managing wastewater treatment plants, whereas the Minor Irrigation Department (MID) manages rural and peri-urban lakes, and the waterways that connect them, and ensures water supply for agricultural use.

Challenges arose in the project's financial management (Times of India, 2022). Should BWSSB fund the project entirely through its revenue from sewerage charges and wastewater sales to industries? Or should MID also contribute financially? BWSSB is a city-level institution and MID is a state-level institution. Which institutions should be responsible for resolving such conflicts? These are the kind of questions that arise when institutions have to work together to manage a common resource.

The figure below lists the various institutions and their functions in the water sector in Bengaluru. Despite the diversity of institutions and functions, the city suffers without a single institution bearing the responsibility of holistically managing its water.

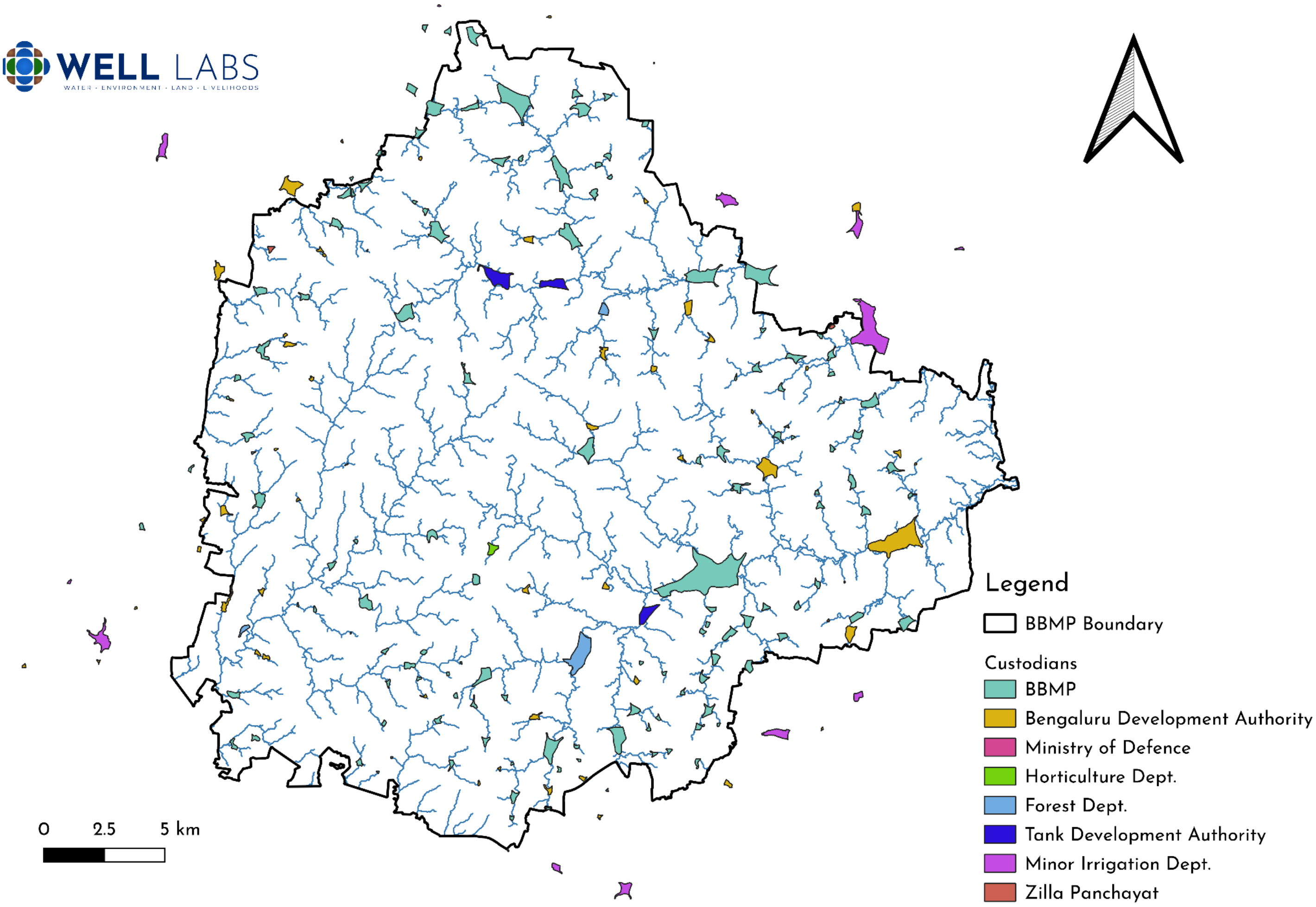
Figure 5: Institutions in Bengaluru's water management and their various functions.



Collated by Sneha Singh, Rashmi Kulranjan, Shashank Palur and Muhil Nesi

Bengaluru's lakes are a classic example of how fragmentation occurs in water governance— different agencies manage different lakes while the broader system goes ungoverned.

Figure 6: Mapping how different institutions act as 'custodians' of different lakes.



Map by Shashank Palur

4. CALCULATING URBAN WATER FLOWS

Using hydrological modelling, primary & secondary data

WELL Labs researchers take measurements of water levels in Jakkur lake. Credit: Shashank Palur

We made use of a variety of primary and secondary data sources and made reasonable assumptions in estimating the water and wastewater flows in Bengaluru's water system.

While there are uncertainties associated with these figures, we nonetheless feel that this serves as a valuable initial estimate.

4.1 Setting the scope for the water balance chart

Any water flow diagram needs to have a spatial and temporal scope. This implies that the data presented needs to be calculated based on a defined geographical area and a time period. For example, to calculate the total volume of rainfall in Bengaluru, a starting point is to decide what area of land (or jurisdictional boundary) will be used as a basis.

The geographic scope chosen for this report is the Bruhat Bengaluru Mahanagara Palike (BBMP) boundary, encompassing an area of **709 km^2**.

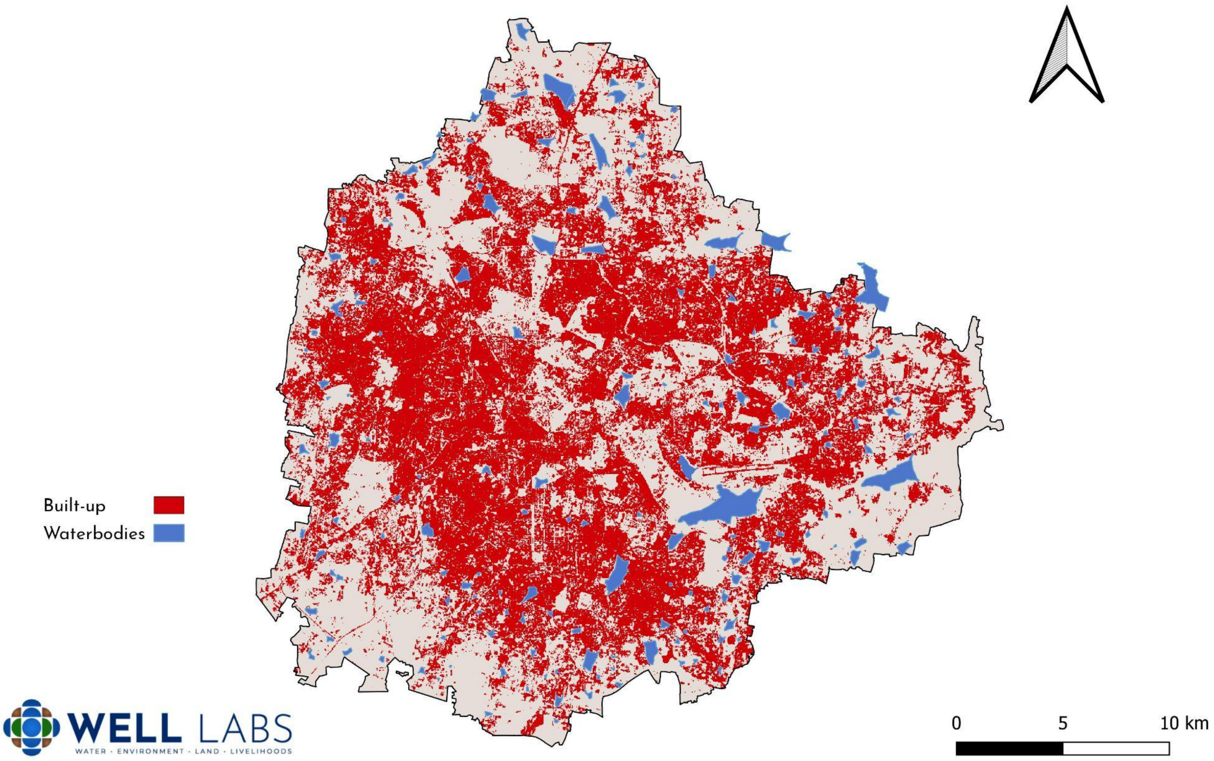
Regarding the diagram's temporal scope, because water cycles are driven by the seasons, flows are best calculated over the course of a year or specific seasons. In the case of Bengaluru, there is relevance in setting a seasonal scope. Fluctuations in rainfall, run-offs and lake storage capacity significantly influence the nature of the city's water crisis in wet and dry seasons.

Looking at Bengaluru's data between 1900 to 2000, rainfall distribution in the city has always had a bimodal pattern (Bharadwaja, 2016). The city receives rainfall both during the southwest monsoons (June to September) – which accounts for 60% of the total annual rainfall – and the retreating northeast monsoons (October to December) – when Bengaluru receives the remaining 40% of its annual rainfall. August, September and October have consistently remained the wettest months. January to May is considered the dry period, even though convective thunderstorms occur between March and May.

Hence, total volumes of each component were calculated over one year (2021), during both wet and dry seasons. We categorised these volumes into annual, wet and dry season averages – expressed as Million Litres per Day (MLD).

Secondary data found from previous years was projected for the year 2021, based on assumptions explained in the following sections.

Figure 7: Map showing urban and non-urban areas within BBMP limits



Areas in grey, i.e. not built-up or water bodies, are fallow land or green spaces. Map prepared by Rashmi Kulranjan and Shashank Palur.

4.2 Rainfall

We start by quantifying the total rainfall, followed by an analysis of how much rainfall is seen as run-offs, is harvested, lost by evaporation and recharges groundwater.

4.2.1 Rainfall volume

The BBMP area receives around 820 to 900 mm of rainfall annually (Sekhar et al. 2017). This means, on average, the rainfall received within the BBMP amounts to **1,750-1,970 MLD** (JICA, 2017). Based on data from the Karnataka State Natural Disaster Monitoring Centre (KSNDMC) for the year 2015, the daily average rainfall was found to be **1,807 MLD** (annual rainfall = 960 mm).

Rainfall in the wet season was found to be over 1.5 times – 2,149 MLD – higher than in the dry season – 1,322 MLD.

For this component, data from the year 2015 was considered acceptable as the rainfall volume falls within the normal range of **1,750-1,970 MLD**. Years 2019-2021 had received heavier rainfall than the 100-year normal and 2016 was a drought year. Further, 2015 was the most recent year with a complete data set from KSNDMC.

4.2.2 Run-off

Water from rain that flows over the land's surface is called run-off. Run-off rates are dependent on the proportion of paved and unpaved surfaces in the city. Using the curve number method (which uses a coefficient based on soil conditions, land-use and hydrological conditions including infiltration), the average annual run-off was calculated to be **811 MLD**.

The curve number method gave results based on the assumption that the Hydrologic Soil Group (HSG) is Type B, which is a loamy soil with moderate infiltration and run-off rates. The land-use also has an impact on the run-off; we found that 48% of the study area was built-up and 52% was unbuilt, which was considered as fallow. Run-off was calculated on a daily basis using daily rainfall data from the KSNDMC.

Further, understanding seasonal fluctuations in run-offs is particularly important to balance dry season water availability and wet season flooding. During the wet season, the average run-off per day – **982 MLD** – is about 73% more than the run-off seen during the dry season – **568 MLD**. Even during the dry season of March, April and May, Bengaluru receives summer showers, which is what we have quantified here.

4.2.3 Groundwater recharge

The city of Bengaluru is situated on a fractured hard rock aquifer. The recharge rates are dependent on land cover and soil and aquifer characteristics. Sekhar et al (2017) used the water table fluctuation method to estimate the amount of recharge in the city. Tomer et al. (2020) found that natural recharge in the city, excluding anthropogenic sources (leakage in water supply and wastewater drain), is only **183 MLD** or roughly 10% of the rainfall.

Due to a lack of information on seasonal differences in recharge rates, the rate of natural recharge is assumed to be constant throughout the year.

Natural recharge that occurs only from lakes was also estimated from the rate of recharge and the area of the lakes. In 2016, Ashoka Trust for Research in Ecology and the Environment (ATREE) conducted a water balance study of Jakkur lake to estimate the recharge rate and found it to be 0.003m/day (Palur, unpublished student thesis). This recharge rate was assumed for all lakes across the city. The European Commission’s Joint Research Centre (JRC) Data Catalogue’s yearly and seasonal datasets were used to estimate the average area of lakes, annually and during the wet and dry seasons.

The annual recharge through lakes is **35 MLD**. Since many lakes in Bengaluru are seasonal, the cumulative area changes from 7 sq km in the dry season to 15 sq km. in the wet season. Hence, the amount of water recharged varies too. In the dry season, lakes recharge **22 MLD** of water, whereas in the wet season they recharge around **45 MLD** of water.

4.2.4 Rainwater harvesting

There is no public record of the total number of properties harvesting rainwater for consumption. The Hindu reported in 2021 that only 1.27 lakh (12%) of a total of 9.85 lakh properties in the purview of the BWSSB have installed rainwater harvesting systems. This was used as the basis to calculate the total rainwater harvested in the city.

Assuming that of the total built-up area in the city (330 km^2), 20% comprises roads and pavements and 10% is informally built, the remaining area (198 km^2) can be assumed to be the total rooftop area of registered properties (RITES, 2007). If we assume the percentage of properties harvesting rainwater (12%) applies in terms of rooftop area, it can be postulated that around 24 km^2 of rooftops are being used to capture rainwater.

The capacity to harvest rainwater also depends on the sizing of storage tanks. Due to increasing intensity of rainfall, we assumed that 50% of rainfall during the wet season and 100% of rainfall during the dry season is captured from the calculated roof area.

Based on these assumptions, it was estimated that **19 MLD** of rainwater is harvested as an annual average. This would vary from about **17 MLD** in the dry season to **20 MLD** in the wet season.

4.2.5 Evapotranspiration

Of the total of 1,807 MLD of rainfall, **830 MLD** was calculated to be lost as evapotranspiration, the process by which water is transferred to the atmosphere from land and other surfaces, and through plants. This was calculated by subtracting run-off and recharge volumes from 1,807 MLD.

We did try using a remote sensing dataset called SSEBop (operational simplified surface energy balance), derived using Jaltol, an open-access water accounting tool developed by WELL Labs, to verify the 773 MLD we calculated. SSEBop data indicated an evapotranspiration rate of ~73% as an annual average for Bengaluru, amounting to 1,335 MLD. However, since this figure includes water losses from green cover, it is presumably much higher than the direct evaporation of rainfall water from land.

Evaporation from lakes: Further, we estimated the amount of evaporation that occurs only from lakes. The rate of evaporation data was obtained from IMD's evaporimeter stations. We gleaned a rate of 4 mm/day for the wet season, and a rate of 7 mm/day for the dry season. The volume of water that evaporates is dependent both on the area of lakes (7 sq km in the dry season and 15 sq km in the wet season) as well as the rate of evaporation. Thus, we estimated that in the wet season, **60 MLD** of water is lost as evaporation in the wet season and **52 MLD** in the dry season.

Table 1: Data summary: Rainfall

<table>
<tr><th>Component</th><th>Avg annual flow (MLD)</th><th>Avg wet season flow (MLD) (June-Dec)</th><th>Avg dry season flow (MLD) (Jan-May)</th></tr>
<tr><td>Rainfall volume</td><td>1,807</td><td>2,149</td><td>1,322</td></tr>
<tr><td colspan="4">Main data source (Secondary data):
- Daily data from Karnataka State Natural Disaster Monitoring Centre (KSNDMC) for the year 2015
- Data was corrected for stations that did not have data by sourcing values from the nearest station.
- BWSSB area is different from BBMP area</td></tr>
<tr><td colspan="4">Other sources used for triangulation:
- JICA report - Pg 6-15 [800-900 mm, equivalent to 1750-1970 MLD within BBMP area]
- Metabolic Urbanism and Environmental Justice: The Water Conundrum in Bangalore, India; Mehta et al, 2014 - Pg 131 [850 mm, equivalent to 1850 MLD]</td></tr>
<tr><td>Run-offs</td><td>868</td><td>1,045</td><td>617</td></tr>
<tr><td colspan="4">Calculation method (primary data): Curve number method
- Total run-off volume = (Run-off from paved area) + (run-off from unpaved area)
- Total paved area = 330 km^2; Total unpaved area = 381 km^2</td></tr>
<tr><td colspan="4">Other sources used for triangulation:
- Urban metabolism of the city: A water mass balance analysis; Paul et al, 2018 - Pg 23 [Run-off out of total rainfall = 51.3%, close to the calculated percentage (51.8%)]</td></tr>
<tr><td>Total natural groundwater recharge</td><td>148</td><td>148</td><td>148</td></tr>
<tr><td>Groundwater recharge (lakes)</td><td>35</td><td>22</td><td>45</td></tr>
<tr><td colspan="4">Main data source (Secondary data):
- A model-based estimate of the groundwater budget (Tomer et al, 2021) Tomer et al, 2018 [Natural recharge = 183 MLD]
- Based on our calculations, recharge from lakes = 44.7 MLD</td></tr>
<tr><td>Rainwater harvesting</td><td>19</td><td>20</td><td>17</td></tr>
<tr><td colspan="4">Data source & assumptions:
- The Hindu; 2021 Article [1.55 lakh properties implementing RWH]
- Amounts to 12% of built-up area (12% of total number of properties)
- Out of total built-up, 10% is slums and 20% roads
- Remaining area is roof top
- Wet season - rain captured 50%, Dry season - 100%</td></tr>
<tr><td>Evapotranspiration</td><td>773</td><td>946</td><td>528</td></tr>
<tr><td colspan="4">Method:
- Calculated as evapotranspiration = (total rainfall) - (run-off) - (GW recharge)</td></tr>
<tr><td colspan="4">Other sources for triangulation:
- SSEBop (operational simplified surface energy balance) data derived using the Jaltol tool</td></tr>
</table>

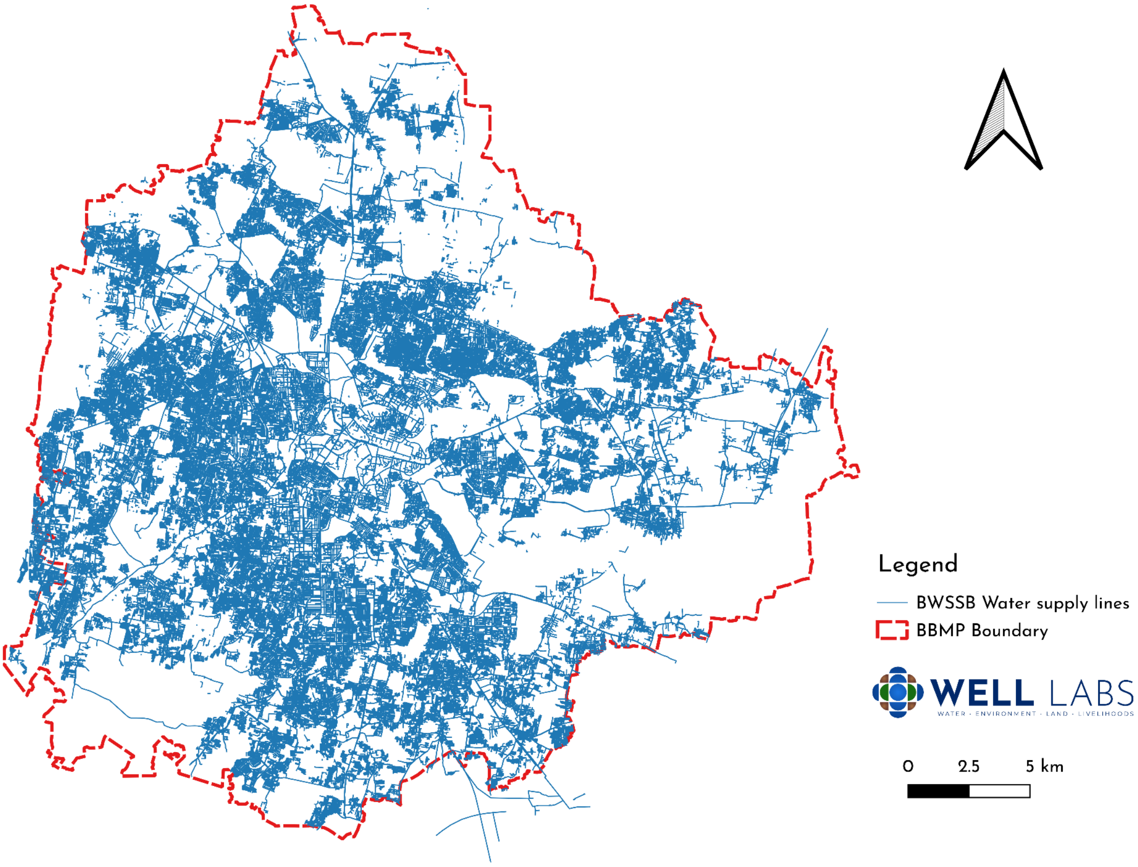
4.3 Piped water supply

In this section, we explain the quantification of freshwater sources extracted and supplied through the public piped water system. In addition to water sourced from the Cauvery river, we also cover estimates of groundwater used as a supplementary source and losses from piped networks (or non-revenue water).

4.3.1 Cauvery water

The **1,460 MLD** extracted from the Cauvery river constitutes the bulk of water supplied by the Bangalore Water Supply and Sewerage Board (BWSSB) to the Core and ULB areas alone (JICA, 2017). The four stages of the Cauvery Water Supply Scheme are used to convey water from the river to TK Halli Water Treatment Plant and on to the BBMP area through a three-stage pumping arrangement. Though there are media reports of Cauvery water supply having been increased to battle shortages in the summer (Lalitha, 2022), for the purpose of calculations, it has been assumed that this supply remains the same at 1,460 MLD.

Figure 8: Map showing BWSSB water supply lines within the BBMP limit



Water from the Cauvery river is first treated at the TK Halli water treatment plant. The pipelines traverse north to reach the Harohalli pumping station and then the Tataguni station. Prepared by Rashmi Kulranjan and Shashank Palur. Source: JICA, 2017.

4.3.2 Public borewells

Several media reports indicate that the BWSSB operates state-owned borewells to increase piped water supply beyond the 1,460 MLD of Cauvery water. However, we found it challenging to verify the exact amount of supplementary groundwater supplied by the BWSSB through secondary data sources.

A 2022 report in the Times of India indicated the presence of 12,000 borewells owned by the BWSSB and the BBMP. According to Hegde and Chandra (2012), the BWSSB was extracting around 5,000 litres per day from each borewell. Assuming that the extraction rate has remained the same and all 12,000 borewells have been operational, groundwater extraction from public borewells amounts to around **60 MLD**.

Attempts by the BWSSB to increase groundwater supply through public tankers to cater to water shortages in the summer have also been reported. For example, a 2022 report (Anjanappa, 2022) indicates a 5% rise in demand from piped supply, and in 2021, the BWSSB chief in 2021 described a rise of over 24% on peak demand days in the summer (Ramesh, 2021). This spike in demand has been attributed to lower groundwater tables and an increase in overall consumption in the summer. However, since there is no consistency in the reported increase in demand as well as public supply, the total groundwater supplied by the BWSSB is assumed to remain constant throughout the year at 60 MLD.

4.3.3 Non-revenue water (NRW)

Monitoring and maintaining Bengaluru's water supply network has many challenges. The network consists of 6,000 km of pipelines, 60 booster pumps, 84 ground-level reservoirs and over 52 overhead tanks in the city. Bengaluru was reported to have the second highest rate of non-revenue water (NRW) in 2016 among Indian cities (Saldanha, 2016). The 2017 JICA report estimated non-revenue water at 48% of Cauvery supply.

A more recent report in the Deccan Herald (2022) said that NRW in Bengaluru has been reduced to 30%, which is the percentage being considered for this water balance report. NRW at 30% of Cauvery water supply (1,460 MLD) and 16% of public water sourced from the ground (60 MLD) amounts to **448 MLD**.

Reports on NRW are ambiguous in terms of how much of the estimated NRW is 'real losses', i.e. losses caused by poor infrastructure; and how much of it is 'apparent losses', i.e. losses caused by unauthorised connections, dysfunctional water metering, etc. The American Water Works Association carries out audits of water utilities in different cities, according to which 'real losses' account for 74% of the total NRW amounting to **331 MLD** .

There are two important reasons for the need to estimate real versus apparent losses for water balance calculations. One is to estimate how much water is lost due to infrastructure inefficiencies; this would contribute to groundwater recharge. Second, even though it's called apparent losses, this is water that is still being consumed by end users, but is just not paid or accounted for.

4.3.4 Groundwater recharge from real losses from infrastructure

As explained above, despite the implied revenue loss associated with apparent losses, this water is still being consumed; and real losses replenish the city's underlying aquifers as the water that leaks from pipelines and reservoirs percolate below.

Tomer et al (2021) estimate that leakages from water supply and wastewater pipelines amounts to 791 MLD. They estimated the NRW in 2017 and assumed it at 53%. The current real losses from water supply pipelines stands at 448 MLD, which directly recharges groundwater. There is a 10% loss from the sewage network amounting to 124 MLD. Thus the total groundwater recharge from anthropogenic sources comes up to **455 MLD**.

Table 2: Data summary: Piped water supply

Component	Avg annual flow (MLD)	Avg wet season flow (MLD) (June-Dec)	Avg dry season flow (MLD) (Jan-May)
Cauvery water	1,460	1,460	1,460
Public borewell supply	60	60	60
Method & assumptions: - 12,000 public borewells according to an article from the Times of India (2022). - Extraction rate of 5000 l per day from each borewell; Hegde and Chandra (2012) - 60 MLD was arrived at assuming that all public borewells are operational			
Non-revenue water	448	448	448
Data source: - NRW in Bengaluru has been reduced to 30%, according to the Deccan Herald (2022). - Losses estimated from pipeline network that distributes 1,460 MLD of Cauvery and 60 MLD of groundwater			
Groundwater recharge from freshwater pipelines	331	331	331
Groundwater recharge from sewer lines	124	124	124

4.4 Private borewells

With little regulatory control on borewell drilling, accurately estimating the number of private borewells and the amount of water being extracted from them is challenging. As of 2019, there were 3.7 lakh private borewells that were officially registered with the BWSSB (Alva, 2019). Between 2014-2019, BWSSB only approved 40% of applications for drilling permission. Presumably, lakhs of borewells exist illegally (Kulkarni et al, 2021). Hence, estimating extraction from private borewells based on the numbers of private wells registered is not a viable option.

4.4.1 Estimating groundwater dependence from total demand

Alternatively, an approach to estimate total groundwater extraction is to calculate the city's total demand for water, and subtract the amount of public water supplied. Total demand was calculated by estimating demand across major urban sectors – domestic, industrial, institutional and commercial, and the construction industry.

Based on this method, it was estimated that the total amount of groundwater addressing the city's needs is around **1,329 MLD**.

4.4.2 Domestic demand

Domestic demand was calculated based on a projected population of 12.6 million (Directorate of Economics and Statistics, 2013) and an average per capita consumption of 150 litres per day (JICA, 2017). The total domestic demand adds up to **1,890 MLD**.

The BWSSB's metered connections provided 643 MLD in 2015 (Tomer et al, 2020). The JICA report indicated a resident population of ~9.5 million in 2016. An increase in domestic demand from the public water supply system was projected to be in proportion to the population growth. This means 58.4% of the domestic water demand is supplied by the BWSSB.

4.4.3 Industrial, commercial and institutional demand

Industrial, commercial and institutional water requirements vary significantly within the sector. A 2021 study used the coefficient-based method to determine water usage by different categories of industrial, commercial and institutional activities (Apoorva R et al, 2021). The method determines typical water usage in different activity categories within these sectors. The total consumption per category is calculated based on the number of people employed in each category.

Based on this approach, the report estimated that industrial water demand was 240 MLD in 2015. Commercial and institutional demand was estimated to be 118 MLD.

The demand in 2021 was projected assuming the ratio of demand in each sector remains the same. It was estimated that the current industrial demand for the water is **441 MLD**. Of this, the BWSSB supplies 3%, amounting to 13 MLD and the rest is obtained from groundwater. Similarly, commercial and institutional water demand is **205 MLD**, of which the BWSSB supplied 7% (158 MLD) (Apoorva R et al, 2021).
An issue with the coefficient method to calculate demand across different sectors is that water usage by informal land-use activities cannot be accounted for. Hence, the calculated figures could be an underestimate.

4.4.4 Construction sector demand

The construction industry is one of the most significant commercial consumers of freshwater. In the dry season, we estimated consumption in the sector to be **~300 MLD** and in the wet season, as low as **6 MLD**. These estimates were arrived at by focusing on the most prevalent and water-intensive activities within this industry – curing of buildings under construction, tunnel boring for metro development and road construction.

Tunnel boring

Tunnel boring for metro development is estimated to be 13.9 km (along the new pink line) (Philip, 2023). Based on reports on the status of the pink line, it was estimated that around 9.4 km of tunnel boring is planned to be completed within 1.5 years. Further, the water required to bore through one metre was found to be 6000 litres x 10 tankers, according to Tankerwala, the primary supplier of treated wastewater for metro construction. Based on these figures, tunnel boring activities consume only around **1.033 MLD**. Further, it is assumed that tunnel boring will consume the same amount of water throughout the year.

Road works

Several road development projects are currently underway and being planned in Bengaluru. These include tender SURE roads such as the Mysore road, Tumkur road and the Outer Ring Road. Proposed roads in the city include 60 kilometres of tender SURE roads and 148 km of other roads. For the sake of calculation, all proposed roads have been assumed to have a width of 25 metres.

According to literature, one square metre of road construction requires 8.7 kl of water. Assuming that the proposed roads are to be constructed over a period of three years, water consumption for this activity amounts to **1.033** MLD. It is assumed that the calculated 1.033 MLD is only consumed during the dry season.

Building construction curing

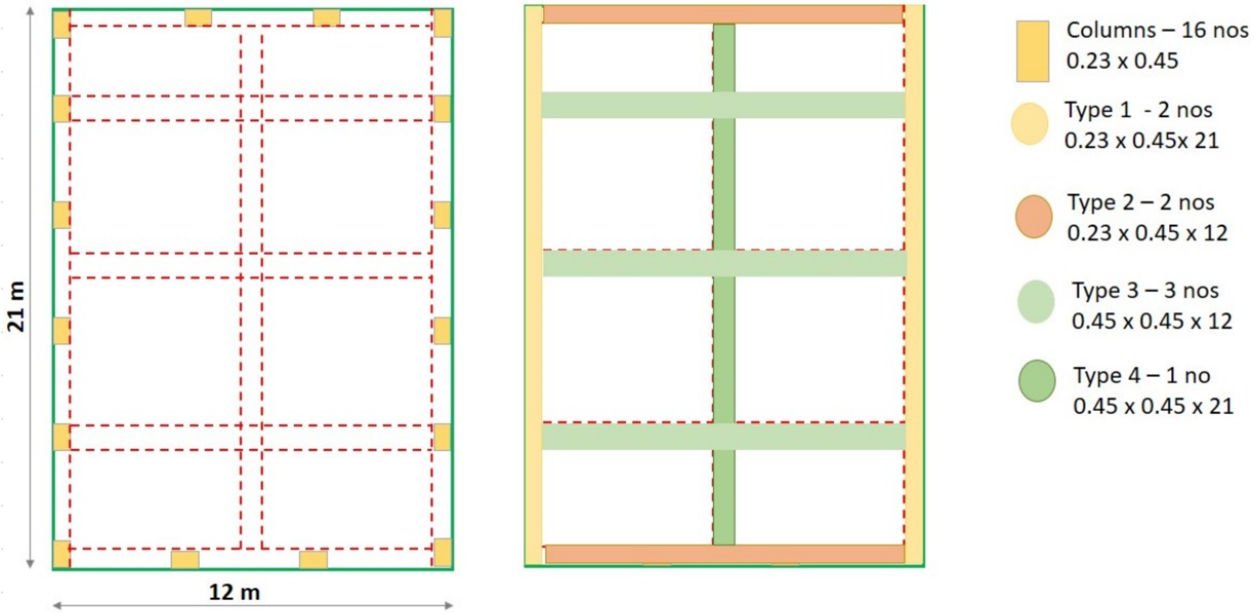
Consumption for curing in building construction is by far the most complex activity to estimate. There is no public information regarding planned construction in the city and building typologies vary significantly too.

Estimates on the amount of real estate development in residential and commercial sectors was derived from a report by Cushman & Wakefield (2023). Based on this, the different typologies of reinforced cement concrete (RCC) buildings and the areas they occupy were arrived at. Approximate figures on water consumption were calculated per unit area of each typology. The details of the calculations are in the Appendix.

The two main typologies of buildings are: i) steel framework with panelled walls and RCC slabs and, ii) RCC framework with RCC slabs and brick walls. We calculated water consumption for typical curing practices, which are the ponding method for slab curing and gunny bag method for column and beam curing. Figure 4.1. shows the typical layout of columns and beams considered for curing calculations for a four-storey structure.

Tables A1, A2 and A3 in the appendix show how estimates on consumption for curing were calculated.

Figure 9: Typical column-beam layout for a four-storey RCC structure assumed for curing calculations.



Prepared by Sneha Singh for a poster presentation at the International Water Association's conference in Chennai in January 2023.

Based on the curing estimates for slabs, columns and beams, we estimated the total water requirement for a four-storeyed fully RCC structure with the assumed framed structure. This amounted to ~9,055 kl, which translates to 8.98 kl per sq m. Similarly, a building with a steel frame and RCC slabs consumes around 1.6 kl per sq.m.

Total water consumed across all construction typologies	**12154.99 ml/year**
Total water used during construction period (dry season – assuming 3 months)	**300 MLD**

4.4.5 Green spaces demand

We also wanted to understand how much water green spaces consume. Though Bengaluru – called India's Garden City – is left with only a few pockets of parks and green areas, it is important to measure their consumption against the amount of water they help recharge.

We calculated that the BBMP uses around **24 MLD** of groundwater to maintain green spaces during the dry season (assuming each m^2 of land consumes 5 litres of water). The same extent of green spaces recharges about 2 MLD.

Table 3: Data summary - total demand & sources of freshwater

<table>
<tr><th>Component</th><th>Avg annual flow (MLD)</th><th>Avg wet season flow (MLD) (June-Dec)</th><th>Avg dry season flow (MLD) (Jan-May)</th></tr>
<tr><td>Domestic demand</td><td>1,890</td><td>1,890</td><td>1,890</td></tr>
<tr><td colspan="4">Assumptions:
- Demand calculated based on a projected population of 12.6 million; avg per capita consumption: 120 litres per day.</td></tr>
<tr><td>Domestic supply from BWSSB</td><td>1,018</td><td>1,018</td><td>1,018</td></tr>
<tr><td colspan="4">- BWSSB's metered connections provided 643 MLD in 2015 (Tomer et al, 2020)
- It was assumed that the increase in public domestic supply was proportionate to the increase in population between 2015 and 2021.
- The JICA report indicated a population of ~9.5 million in 2016.</td></tr>
<tr><td>Domestic GW extraction</td><td>872</td><td>872</td><td>872</td></tr>
<tr><td colspan="4">- Domestic groundwater demand was calculated by subtracting public domestic supply from overall demand.</td></tr>
<tr><td>Commercial & institutional (C&I) demand</td><td>205</td><td>205</td><td>205</td></tr>
<tr><td>C&I supply from BWSSB</td><td>158</td><td>158</td><td>158</td></tr>
<tr><td>C&I GW extraction</td><td>47</td><td>47</td><td>47</td></tr>
<tr><td>Industrial demand</td><td>441</td><td>441</td><td>441</td></tr>
<tr><td>Industrial supply from BWSSB</td><td>13</td><td>13</td><td>13</td></tr>
<tr><td>Industrial GW extraction</td><td>428</td><td>428</td><td>428</td></tr>
</table>

Component	Avg annual flow (MLD)	Avg wet season flow (MLD) (June-Dec)	Avg dry season flow (MLD) (Jan-May)
- C&I and industrial water demand from 2015 - (Apoorva R et al, 2021) - Assuming that the proportion of demand from industrial, C&I and domestic sectors remain the same, industrial and C&I demand was projected to 2021.			
Construction sector demand	78	6	300
Green spaces GW	24	0	24
- Tunnel boring, road works and building construction curing are assumed to be the most water intensive activities in the sector. - Real-estate development across different sectors and the projected areas: Cushman & Wakefield (2023)			

4.5 Wastewater generation and treatment

There are several layers to be understood with regard to wastewater flows. As a first step, we estimated the total amount of wastewater generated. The second step was to calculate the capacity of different kinds of treatment infrastructure in the city. In the case of Bengaluru, decentralised infrastructure has a significant presence and supplements centralised infrastructure managed by the BWSSB. The last step involved understanding what happens to the treated and untreated wastewater.

4.5.1 Wastewater generation

The total volume of wastewater produced across each sector was calculated as a percentage of total freshwater consumed. Across various sectors, portions of freshwater consumed are lost through different processes, such as manufacturing, human consumption, evaporation. In domestic, commercial and institutional sectors, about 80% of the consumed water is expelled as wastewater. In the industrial sector, about 60% of the consumed water is produced as wastewater (JICA, 2017).

The two key assumptions we worked under are: i) Water from these sectors are assumed to remain constant throughout the year and, ii) Water used in the construction industry and green spaces are assumed to be lost entirely through evaporation and is hence not reproduced as wastewater.

Based on these assumptions, the total wastewater generated in the city amounts to around **1,940 MLD**. (Refer to the data summary table for the breakdown of wastewater generated from each sector.)

4.5.2 Centralised sewage treatment

A majority of the treated wastewater produced by Bengaluru is treated through state-owned centralised infrastructure. The BWSSB manages 35 centralised sewage treatment plants with a collective capacity of **1,523 MLD**.

Based on information on STP outflows from the BWSSB's STP dashboard, centralised STPs' capacity is at 81% capacity, processing around 64% of the city's total wastewater (**~1,239 MLD**).

(Photo of a centralised STP at Doddabommasandra in north Bengaluru. Credit: Shashank Palur)

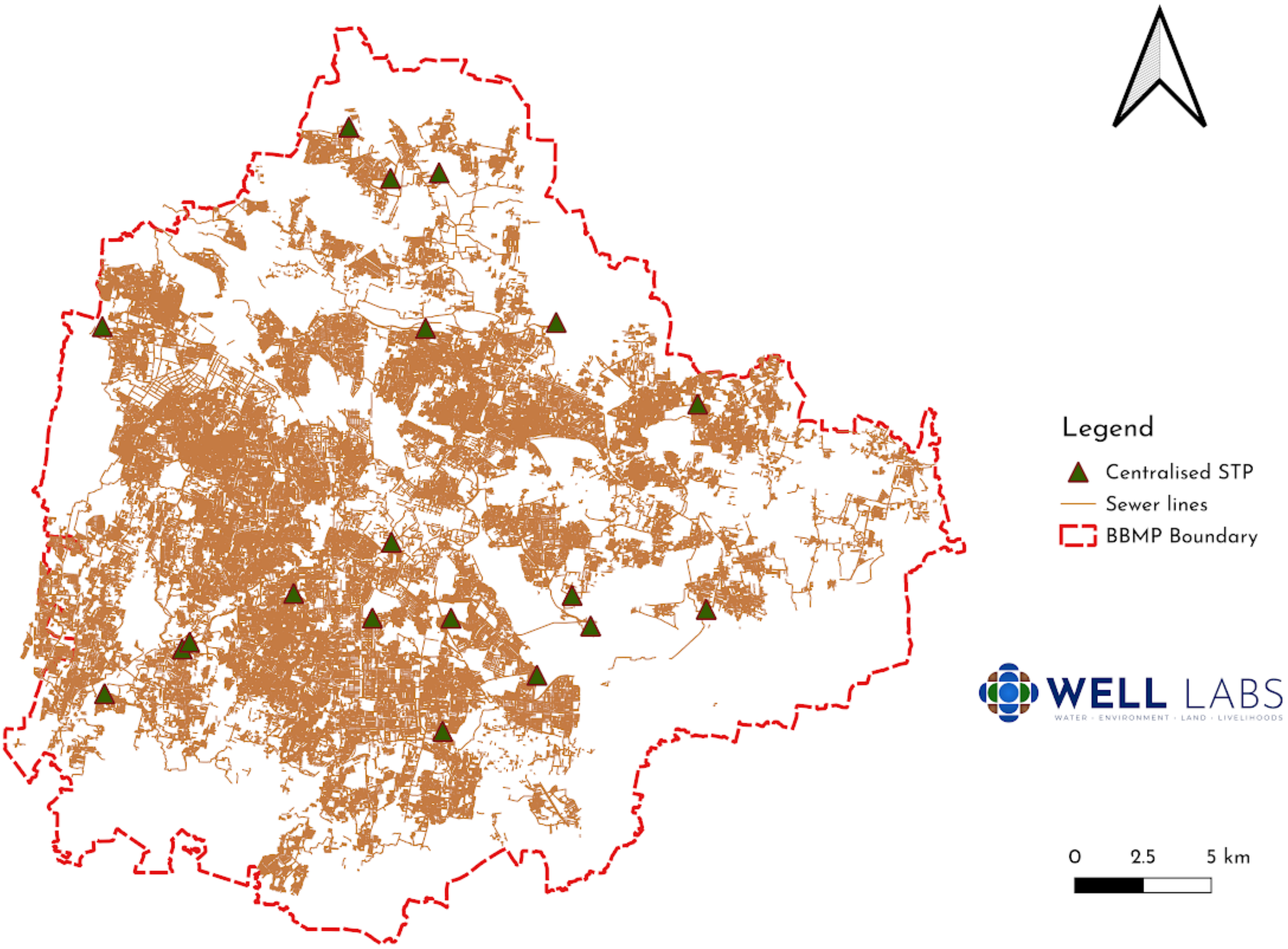
4.5.3 Decentralised sewage treatment

As a supplementary effort to increase the amount of wastewater treated in the city, the BWSSB turned to increasing privately-managed decentralised infrastructure. The regulations dictate that residential apartments, commercial complexes, educational institutions and townships over specified areas have to install on-site (decentralised) sewage treatment plants (DSTPs) and reuse 100% of the treated water within the fence (KSPCB, 2021).

The Karnataka State Pollution Control Board (KSPCB), as the monitoring authority, maintains a masterlist of the 2,644 decentralised STPs, which are classified based on their capacity (see Table A6). The collective capacity of DSTPs across the city amounts to **615 MLD**, however through anecdotal evidence (interviews with experts) we assume that only 40% of this capacity is being utilised.

The total amount of water treated in these small-scale STPs would then amount to **250 MLD**. Since there is no available information on their functionality, it has been assumed that all of them function at full capacity. In reality, reports on dysfunctional DSTPs are prevalent due to high operational costs and low awareness and capacity among resident welfare associations (RWAs) to manage these systems.

Figure 10: Map showing the sewer network within the BBMP limit



Prepared by Rashmi Kulranjan and Shashank Palur.

4.5.4 Common Effluent Treatment Plants (CETPs)

Industrial wastewater, due to its chemical composition, is treated using technology different from sewage treatment plants. The Karnataka Industrial Area Development Board (KIADB) is responsible for setting up CETPs to safely manage industrial wastewater. In Bengaluru, there are currently seven common effluent treatment plants (CETPs) with a cumulative capacity of ~7 MLD. They function at 70% of their capacity and hence treat a total of 5 MLD (CPCB, n.d.). This implies that over 98% of the estimated quantity of industrial wastewater goes untreated.

4.5.5 Wastewater reuse

Based on the above estimates, the city is currently treating around **1,494 MLD** of wastewater. However, due to operational challenges,
the quality of effluents, both from centralised and decentralised plants, varies significantly. Despite these challenges, a portion of the effluents is being reused.

The largest reuse project implemented currently is the Koramangala-Challaghatta (KC) Valley project. Around 380 MLD of secondary treated wastewater is transferred to Kolar (Lalitha, 2021) to fill up lakes and tanks as a groundwater rejuvenation measure. An additional 150 MLD treated water is supplied to Chikkaballapur district and 40 MLD to Devanahalli town in Bengaluru Rural district (Ramesh, 2023).

Wastewater reuse within Bengaluru is significantly less. The BWSSB sells treated wastewater from centralised STPs for reuse within parks, institutions and industrial establishments. As of 2019, it was supplying around 23 MLD of secondary and tertiary treated water (Sandesh, 2019).

On-site reuse occurs in establishments with DSTPs. Despite mandates on 100% reuse of treated wastewater, only ~47 MLD is reused of the total of 250 MLD being treated by DSTPs. This is primarily due to the limited amount of on-site reuse purposes for secondary treated wastewater. In residential layouts and buildings, the primary reuse purpose is for flushing. Further, many apartments are not equipped with dual plumbing facilities to enable on-site reuse for toilet flushing. In commercial and institutional buildings, treated wastewater is used for toilet/urinal flushing and for wash basins.

The break-up of calculations within each of these sectors and the assumptions made to arrive at the total reuse is explained in the tables below.

Table 4: Reuse for toilet flushing in apartment complexes

	#	**Capacity (KLD)**	**No. of apartments**	**No. of apartment flats (rounded off)**	**Total water needed for flushing @35 LPCD**	**Total reuse (MLD)**
Large STPS	353	250	463	450	63,000	22
Medium STPs	96	75	139	150	21,000	2
Local Body			0	0	0	0
Small STPs	49	50	93	100	14,000	1
Total reuse						**25 MLD**

Table 5: Estimated reuse for toilet flushing in residential layouts

	#	Capacity (KLD)	No. of apartments	No. of apartment flats (rounded off)	Total water needed for flushing @35 LPCD	Total (MLD)
Large STPS	8	250	463	450	63,000	0.50
Medium STPs	0	75	139	150	21,000	0.00
Local Body	18	500	926	1715	129630	2.33
Small STPs	0	50	93	100	14000	0.00
Total						**2.84 MLD**

Table 6: Estimated reuse in commercial and institutional establishments

	#	Capacity	Reuse per STP	Total (MLD)
Large STPS	51	250	100	5.10
Medium STPs	7	75	30	0.21
Local Body	0	500	200	0.00
Small STPs	4	50	20	0.08
Total				**5.39 MLD**

Assuming that 60% is used for sinks and urinals - 20% for wash basin, and 40% for toilets & urinals and reuse is calculated as a weighted average of the different uses.

Table 7: Estimated reuse in healthcare establishments

	#	Capacity	Reuse per STP	Total (MLD)
Large STPS	10	250	58	0.58
Medium STPs	3	75	17	0.05
LB		500	117	0.00
Small STPs	1096	50	12	12.77
Total				**13.40**

Assuming that 35% is used for sinks and urinals - 11.6% for wash basin, and 23.3% for toilets & urinals and reuse is calculated as a weighted average of the different uses.

Table 8: Estimated reuse in hospitality

	#	**Capacity**	**Reuse per STP**	**Total (MLD)**
Large STPS	9	250	50	0.45
Medium STPs	7	75	15	0.11
Local Body	0	500	100	0.00
Small STPs	4	50	10	0.04
Total				**0.60**

Assuming that 30% is used for sinks and urinals - 10% for wash basin, and 20% for toilets & urinals and reuse is calculated as a weighted average of the different uses.

Table 9: Data summary: Wastewater

Component	Avg annual flow (MLD)	Avg wet season flow (MLD) (June-Dec)	Avg dry season flow (MLD) (Jan-May)
Domestic WW produced	1512	1512	1512
C&I WW produced	164	164	164
Industrial WW produced	265	265	265
Assumptions: - Wastewater produced in each sector is calculated as a percentage of total freshwater consumed (JICA, 2017) - Domestic wastewater = 80% of freshwater consumed - Commercial & institutional (C&I) wastewater = 80% of freshwater consumed - Industrial wastewater = 60% of freshwater consumed			
Water treated in CSTPs	1239	1239	1239
GW recharge from sewered network leaks	124	124	124
Data source: - CSTP capacity and utilised capacity was accessed from the BWSSB's STP dashboard. - 10 % of wastewater produced recharges groundwater because of leakages in the sewage network; JICA, 2017			
Water treated in DSTPs	250	250	250
Data source and assumptions: - Capacities calculated from primary data (the KSPCB masterlist). - Due to a lack of data on the functionality, it was assumed that all DSTPs are functioning at full capacity			
Water treated in CETPs	5	5	5
Data source: - The 7 CETPs in the city function at 70% capacity (CPCB, n.d.)			
Untreated domestic & C&I WW	218	218	218

Component	Avg annual flow (MLD)	Avg wet season flow (MLD) (June-Dec)	Avg dry season flow (MLD) (Jan-May)
Untreated industrial WW	260	260	260

Methods:
- Quantity of untreated wastewater was calculated by subtracting treated wastewater from total wastewater produced.
- The separation of untreated wastewater from domestic and C&I was not possible since CSTPs process waste from both sectors.

Domestic reuse	28	28	28
C&I reuse	19	19	19

Methods:
- Reuse for toilet/urinal flushing and wash basins was calculated as presented in tables 1-5

Data sources:
- F-register, KSPCB 2021

Reuse beyond city	570	570	570
Reuse within city	23	23	23

Data source:
- Indian Express article, 2021

4.6 Lakes and downstream flows

Within the BBMP, there are 173 lakes spread across the three valleys forming cascading chains (Figure . These lakes receive water from both rainfall run-offs, treated and untreated wastewater that flow down the cascading systems (Kulranjan, 2022). To gauge the amount of water that enters and leaves the lakes in the city, we developed a model for the cascading lake series. The model uses the mass balance equation to estimate the closing volume of a lake for each day of the year. It accounts for all the inflows (run-off from catchment, treated and untreated sewage and upstream spills) and outflows (evaporation and recharge). By estimating the maximum storage capacity of each lake in the series, we could estimate how much excess flow to the lake would overflow and eventually end up in the downstream river.

Closing volume = Opening volume + STP inflow + combined inflows (run-off, untreated sewage, upstream spill) - outflows (evaporation, recharge, overflows)

The bottleneck for this modelling exercise was the unavailability of data on lake storage capacity. The maximum storage of a lake is typically estimated using bathymetry. Bathymetry is the process of estimating the depth of a water body at different points below sea level. Using the bathymetry data of five lakes, an area-volume relationship was arrived at. This was used as the basis to estimate the maximum storage capacity of all lakes in the city, and the areas were derived from the JRC database's yearly and seasonal datasets. The 173 lakes were then divided into three categories based on their areas (<20, 20-70, >70 hectares). Using the area-volume ratio, we estimated the volume of the lakes in each category. Further, the role of lakes in storing stormwater and wastewater varies between the three valleys. The cascading lake systems play a more prominent role in the Koramangala-Challaghatta and the Hebbal valleys. This is because the terrain in these valleys is more undulating, and excess water in the catchment can only flow downstream through the cascading systems. In Vrishabhavathi, on the other hand, due to a less undulating terrain and partly due to the loss of lakes to encroachment, lakes play less of a role in directing excess water downstream – we assume that downstream flows occur through natural gradients of land towards river valleys.

Figure 11: Terrain map and the lake systems of Bengaluru. *Prepared by Shashank Palur and Rashmi Kulranjan*

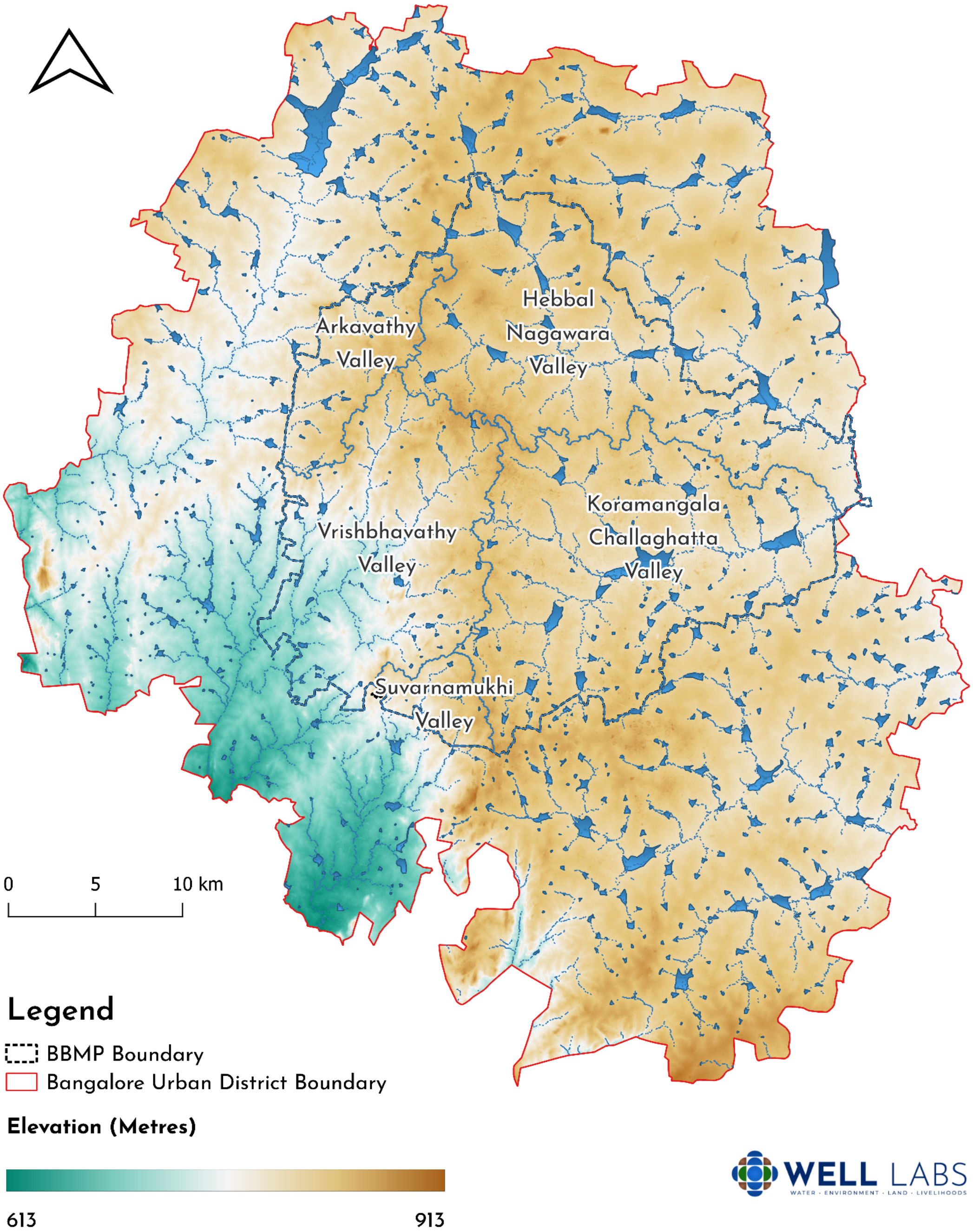


Table 10: Data summary: Downstream flows

Component	Avg annual flow (MLD)	Avg wet season flow (MLD) (June-Dec)	Avg dry season flow (MLD) (Jan-May)
Runoff into lakes	659	801	458
Wastewater into lakes	1040	1040	1040
Overflows from lakes to river	1334	1478	1128
Runoff flowing directly into rivers	209	244	159
Waste water flowing directly into rivers	472	472	472
Total downstream flows from the city	2015	2194	1760

Water exits the urban system mainly through evaporation (see section 4.2.5) and through downstream flows. The estimation of downstream flows across the seasons is dependent on total run-offs and wastewater produced as well as the lake storage capacity.

4.7 Data gaps and uncertainties

As we wind up this report, we want to reiterate that the water balance numbers were estimated based on assumptions and projected figures from past research. We summarise some specific clarifications here.

- **The daily rainfall data** we used in the study is for the year 2015, which was close to the average rainfall that Bengaluru receives annually (970 mm). The change in this value will have an effect on the volumes of other environmental parameters such as run-off and recharge.
- **Hourly and daily streamflow data** in the main storm water drains in the city for both the wet and dry season are not publicly available. However, these data are crucial to building accurate flood models and improving flood management in the city.
- The estimation of groundwater abstraction and recharge at a citywide scale overlooks **significant spatial variations** within the urban landscape. Given the diverse land use and cover (LULC) patterns in the region, along with varying physical and hydrological characteristics across the city, this data is crucial for effectively prioritising areas for resource management.
- We attempted to utilise satellite datasets for evapotranspiration data, but **encountered significant inaccuracies due to overestimation**. The literature-derived values we used lacked a clearly defined study area or estimation methodology, and is hence limited.

- The **precise count of rainwater harvesting units** and the volume of water they capture remains unidentified. Acquiring this data, including its spatial distribution, would enable targeted promotion of these systems in areas where they are most needed.
- The present **water demand** in the city relies on projections from older studies, encompassing population and non-domestic water use estimates. The absence of current data hinders our comprehension of the precise rate of growth in water demand across different sectors.
- Information regarding lake water quality and its natural self-purification abilities is limited across the city. Gaining insight into the **assimilation capacity of lake systems** would facilitate more informed decisions regarding the required treatment facilities for effective management.
- Despite being integral to the city's hydrological system, essential data regarding the **lakes' physical attributes** such as depth, volume, and connecting drains is currently unavailable. Acquiring this information would not only inform management decisions but also aid in identifying critical flood-prone zones and optimal recharge sites.

5. FROM DATA TO INSIGHTS

Calculating water flows can inform water security planning

A park in Bengaluru being watered using treated wastewater. Credit: Shashank Palur

Through hydrological modelling and an extensive review of secondary sources, we quantified Bengaluru's urban flows; water resources feeding the city, areas of significant usage, losses, discharge and storage.

But what do these numbers mean? In this section, we expand on five key insights and clarify the data gaps and uncertainties associated with these numbers.

The large dependence on groundwater indicates that peri-urban water security is at threat in a region underlain by a fractured hard-rock aquifer system.

Nearly 50% of Bengaluru's freshwater needs is sourced through privately-owned borewells, including those brought by tankers. This heavy dependence is most pronounced in the city's outskirts, which currently lack a formal water supply network. This pattern significantly impacts groundwater reservoirs in peri-urban areas, as many tanker-filling stations are situated on the city's peripheries.

Bengaluru and its surrounding regions rest atop a fractured aquifer system, where groundwater is held in cracks and fissures rather than in large subsurface cavities or reservoirs. This leads to pronounced fluctuations in water levels across seasons – water fills up quickly during the monsoon and depletes fast during the summer.

By harnessing open spaces like fallow land and green areas to recharge shallow aquifers with rainwater during the wet season, this variability could be countered to an extent. This is in line with the 'sponge cities' approach. Solutions that integrate blue (lakes and wetlands), green (parks and open spaces) and grey infrastructure have the potential to build more water-resilient cities.

Another way to replenish aquifers is through ***improving the state of wastewater treatment infrastructure***. If water is treated to a high quality, this water can be channelled into lakes, which serve as recharge structures. During the water-scarce summer, this would contribute to offsetting the high rates of water extraction.

Pipeline reduction schemes must be offset by additional rainwater harvesting.

The city experiences some of the highest Non-Revenue Water (NRW) losses globally. As we explained in section 4.3.3, this includes unaccounted for losses of water through pipeline leakages and unauthorised connections. Such losses serve as a primary source of groundwater recharge.

Introducing NRW reduction schemes could actually lead to a decline in groundwater recharge. To counterbalance this, the city must ***prioritise investments in rainwater harvesting***. This option proves more viable – both in terms of economics and prudent energy use – compared to importing additional surface water, especially considering the city's substantial rainfall.

There is scope to expand wastewater reuse within the city.

Currently, only one third of the city's wastewater is redirected for external reuse, which means it is taken to Kolar, Chikkaballapur and Devanahalli districts where it is used to replenish both groundwater and surface water sources. The remaining water flows into lakes and runs off land to join rivers downstream.

This means the huge quantum of wastewater generated in the city is an untapped resource. ***Once treated to the required quality, wastewater can significantly mitigate freshwater consumption*** and can be crucial in making the city water resilient during low rainfall years. There are a number of sectors that could substitute freshwater with treated wastewater – for watering the city's green spaces, the water-guzzling construction sector and, as mentioned above, to recharge aquifers.

The lakes, filled with treated and untreated wastewater, no longer have the capacity to store rainwater or act as flood buffers.

Bengaluru's lakes were initially seasonal, filling up entirely during the monsoons, serving as flood buffers during periods of heavy rainfall. Urbanisation has altered the composition of inflow into these lakes. Currently, approximately half of the water entering lakes is wastewater – both treated and untreated. As a result, most of the city's lakes remain consistently full, leaving little room for the rain that falls during the monsoon season.

For one, it is critical to carry out ***maintenance of stormwater drain***s that play an important role in managing the flow of water through the city and across the cascading series of lakes. Data is also a significant point that comes up here; we need ***real-time monitoring of water levels*** in lakes to forecast the impact of floods. Finally, ***scaling up wastewater reuse*** emerges here too as a key solution. Using wastewater to maintain green spaces and for construction would reduce the amount that fills up lakes.

A lot of pollution in lakes is due to untreated wastewater, but even where wastewater is treated the nutrients in treated wastewater flows are still high and contributing to eutrophication.

Majority of the wastewater treatment facilities in the city are only equipped to carry out a secondary level of treatment. This is not sufficient to significantly reduce the nutrient concentration in wastewater, which also contributes to eutrophication, evident from the algal blooms in lakes across the city.

Depending on the quantum of sewage, the appropriate solution would need to be employed; for smaller catchments, ***nature-based solutions*** such as floating islands and constructed wetlands can be effective.

It is also important to explore the potential of ***larger-scale solutions being implemented in other citie***s. One example is the Nesapakkam plant in Chennai, which is equipped with tertiary treatment ultra-filtration technology that treats water to a high quality.

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Appendix

Table A1: Water required for all slabs in a building with assumed layout.

Water required for curing slab : By ponding method						
Height of pond (in)	**Height of pond (m)**	**Volume of pond / floor (m3)**	**Water usage (m3/day/floor)**	**Water usage (m3/day/ building)**	**Total water usage for duration of ponding (m3/building)**	**Total water usage for duration of ponding (kl/building)**
3	0.0762	19.2024	57.6072	230.4288	3226.00	3226.00
					Water required/sq.m	**3.2004**
					Total for building	1613.0016 kl
					Total for building (per sq.m)	1.6002 kl
Number of pond refills a day = 3 Number of days of ponding = 14						

Table A2: Water required for all columns in a building with assumed layout

Water required for curing columns : By gunny bag method							
Size of the column	**length (m)**	**breadth(m)**	**room height (m)**	**surface area of column (m2)**	**No. of columns /floor**	**surface area of column(m2)/floor**	**surface area of column (m2)/building**
Type 1	0.23	0.45	3	4.08	16	65.28	261.12
Water required to cure columns @ 30% of that needed for slab (as calculated for steel building @ 1.6kl/sq.m (i.e)				0.48	per m2		
						Total water usage for duration of curing (m3/week/building)	**1754.95**
Number of days of curing = 14							

Table A3: Water required for all beams in a building with assumed layout

Water required for curing beams : By gunny bag method							
Size of the beam	**length (m)**	**Breadth (m)**	**Width of room (m)**	**surface area of column (m2)**	**No. of beams/ floor**	**Surface area of column (m2)/floor**	**surface area of column(m2)/ building**
Type 1	0.23	0.45	21	23.73	2	47.46	189.84
Type 2	0.23	0.45	12	13.56	2	27.12	108.48
Type 3	0.45	0.45	12	16.2	3	48.6	194.4
Type 4	0.45	0.45	21	28.35	1	28.35	113.4

							606.12
Water required to cure beams @ 30% of that needed for slab (as calculated for steel building @ 1.6kl/sq.m (i.e)				0.48	per m2		
						Total water usage for duration of curing (kl/week/building)	**4073.64**
Number of days of curing = 14							

Using these figures, water demand for upcoming construction was calculated as explained in table 4.4/.

Table A4: Calculation method to calculate total water demand for curing.

UPCOMING RESIDENTIAL CONSTRUCTION								
	No. of units	**Area of unit (s.ft)**	**Area of unit (sq.m)**	**Total construction area (sq.m)**	**Water consumption per sq.m**	**Total water consumption (kl/sqm)**	**Total water consumption (l/sqm)**	**Water consumed (ml/year)**
Total units launched in Q4 2019	5800							
Luxury segment - 10%	580	3000	279.59	162162.16				
Mid segment - 75%	4350	1800	167.75	729729.73				
Affordable segment - 15%	870		75	65250.00				
			Total	957141.89	8.98	8595134.19	8595134189	8595.13
					RCC construction			
UPCOMING OFFICE CONSTRUCTION								
		sft	**sq.m**		**Water consumption per sq.m**	**Total water consumed (Kl/sqm)**	**Total water consumed (l/sqm)**	**Water consumed (ml/year)**
Total new completion 4.52 msf in Q1 2020								
Total area		4520000	420074.35		5.2	2184386.62	2184386617	2184.39
					average consumption			

UPCOMING MALL CONSTRUCTION								
		sft	**sq.m**		**Water consumption per sq.m**	**Total water consumed (Kl/sqm)**	**Total water consumed (l/sqm)**	**Water consumed (ml/year)**
2.6 msf UPCOMING MALL SUPPLY (2019-2020)								
Total area		2600000	241635.69		5.2	1256505.57	1256505576	1256.51
					average consumption			
UPCOMING INDUSTRIAL CONSTRUCTION								
		sft	**sq.m**		**Water consumption per sq.m**	**Total water consumed (Kl/sqm)**	**Total water consumed (l/sqm)**	**Water consumed (ml/year)**
In 2018 about 0.8 msf was under construction in proximity to Nelamanagala								
Total area		800000	74349.44		1.6	118959.107	118959107.	118.96
					average consumption for curing slabs in steel construction			
TOTAL WATER DEMAND FOR CURING								
						Total water consumed across all construction typologies		12154.99 ml/year
						Total water used during construction period (dry season assuming 5 months)		80.5 MLD

Table A5: Centralised STPs: full and utilised capacity.

Sl No	**Name of STP/TTP**	**Division**	**Average Inflow in MLD**
1	**2**	**3**	**4**
1	218 MLD STP at K&C Valley	(STP-CV)	160.65
2	60 MLD STP at K&C Valley		61.92
3	150 MLD STP at K&C Valley		143.93
4	30 MLD STP at K&C Valley		32.38

5	20 MLD STP at K R Puram Ph-1		14.72
6	15 MLD STP at Yelemallappa Chetti Ph-2		15.26
7	4 MLD TTP at Cubbon Park		3.28
8	1.5 MLD TTP at Lalbagh		1.38
9	20 MLD STP at K R Puram (New)		15.55
	Sub Total (A) 518.5 MLD		449.06
10	90 MLD STP at Bellandur Amanikere	(STP-KV)	93.77
11	50 MLD STP at Kadabeesanahalli Ph-1		29.74
12	35 MLD STP at Agaram		23.78
13	10 MLD STP at Hulimavu		6.98
14	6 MLD STP at Kadugodi		5.20
15	5 MLD STP at Sarakki		4.61
16	2 MLD STP at Halasuru		1.85
17	5 MLD STP at Chikka Beguru		3.26
	Sub Total (B) 203 MLD		169.19
18	100 MLD STP at Hebbal	(STP-HV)	68.06
19	40 MLD STP at Rajacanal- Ph1		23.95
20	40 MLD STP at Rajacanal- Ph2		40.91
21	20 MLD STP at Horamavu Agara Ph2		22.00
22	15 MLD STP at Jakkur		15.17
23	10 MLD TTP at Yelahanka		9.15
24	1 MLD TTP at Hennur		0.30
	Sub Total (C) 226 MLD		179.54
25	20 MLD STP at Nagasandra - Ph2	(STP-AV)	9.02
26	20 MLD STP at Nagasandra Ph-1		7.14
27	5 MLD STP at Mallathahalli		4.85
28	5 MLD STP at Chikkabanavara		5.12
	Sub Total (D) 50 MLD		26.13
29	180 MLD STP at V Valley	(STP-VV)	91.52
	60 MLD TTP at V Valley		10.42
30	1 MLD WRP at Kempambudhi		0.62
31	75 MLD STP at Mailasandra Ph-1		72.19
32	60 MLD STP at Kengeri		47.24
33	40 MLD STP at Doddabele		38.79
34	20 MLD STP at Doddabele Ph2		4.56
35	150 MLD STP at V Valley		150.00

	Sub Total (E) 526 MLD		**415.34**
	Total(A+B+C+D+E) (Capacity of STP/TTP is 1523.5 MLD (except 60 MLD TTP at V Valley))		**1239.26**

Table A6: Number and capacity of decentralised STPs as listed in KSPCB's masterlist, 2021.

	Number of STPs	**Capacity (KLD)**	**Total (KLD)**	**Total (MLD)**
Large STPS	528.0	250	132000	132
Medium STPs	176.0	75	13200	13.2
STPs run by Local Bodies (LB)	18.0	500	9000	9
Small STPs	1922.0	50	96100	96.1
	2644.0			
Total				**250.3 MLD**

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